Circular economy and BIM

"How can circular economy and BIM contribute to minimising construction demolition and waste?"

TITLE PAGE

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Preface

This report is a compulsory subject of the fourth and final semester of the Master's Degree programme "Construction Management and Building Informatics" at Aalborg University. The report has been written by Lorenzo Savallo, who will be mentioned in the entire report as "the author", under the supervision of Kjeld Svidt and Ekaterina Aleksandrova Petrova. The following report is based on the research done on the topic Construction demolition and waste, well-known and common within the construction industry, that the author will try to solve, by suggesting some solutions reckoned achievable, given the knowledge available nowadays.

The paper was written in a period of time from 1st September 2019 to 10th January 2020, where the construction demolition and waste topic and its related issues were researched and analysed, in order to find concrete and achievable solutions to apply.

Another aspect not forgotten by the author is that this report is focused on topics like the circular economy and Building Information Modelling, previously learned in the Master´s Degree programme "Construction Management and Building Informatics".

The report was written according to the IMRaD structure, which stands for Introduction, in which the question was addressed, Materials and Methods used while doing the study, which Results were found and in the end a Discussion about what the information found means.

Acknowledgments

The author of this report would like to express his appreciation to his supervisors Kjeld Svidt and Ekaterina Aleksandrova Petrova, for their professionalism, feedback and constructive guidance, which made the writing of this report. This gave the opportunity of solving real existing problems within the building industry, mostly regarding construction demolition and waste and how it might be minimised thanks to the implementation of the circular economy and Building Information Modelling (BIM).

Furthermore, the author would like to thank Aalborg University for the chance to work on such an interesting topic pertaining to the Master´s Degree course “Construction Management and Building Informatics”.

Structure of the report

This report is a research on the current and ongoing issue of construction demolition and waste and focuses on finding achievable solutions to it. The case is handled with a traditional approach, where an issue is found and the report evolves around it. In this report, the study will consist of research done by reading academic articles, browsing reliable sources on the Internet and also of personal evaluation made by the author, in which he will analyse all several possible solutions.

Using this method, information from literature is gathered and the research approach of this paper is carried out the following way: (*see figure 0*)

- An introduction, in which the main issue of the report (Construction demolition and waste) will be introduced;
- A literature review, to analyse more in depth the data collected regarding the main issue of the report, before moving on to the problem formulation. Furthermore, several solutions considered effective, given the validity of their sources, will be mentioned and explained in detail;
- The problem formulation and its related sub-questions, given what turned out in the literature review;
- Problem analysis, in which the author will evaluate the possible solutions suggested in the literature review chapter. The analysis will take place through the problem tree diagram, the problem tree diagram and PESTEL framework as well;
- Solutions analysis, in which the implementation of Building Information Modelling into the mentioned circularity-based solutions will be examined;
- Conclusion.

Figure 0 - Report structure

This approach ensures that the focus of the report stays on solving the main problem formulation.

List of abbreviations

- BIM: Building Information Modelling
- BO: Material Inventory and Analysis Tool Building One

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1. Introduction

The construction industry is a thriving sector in both developed and developing countries, responsible for more than one third of total waste generated. (Svendsen & Tang, 2018). Phenomena such as a larger and larger demand for buildings, due to urbanization caused by population growth, turned the building industry into a non-sustainable sector that, if no achievable environmental solutions are found, will lead to a point of no return. From the second World war until now, constructions have mostly been made with such building techniques able to carry execution work out as quickly as possible, in order to keep costs as low as possible.

As it can be easily understood, this way to make constructions has led to problematic situations, in which scarcity of raw materials and a too large waste/disposal caused by the need to manufacture more and more, has become the main issue to face. As a consequence, changes in conventional ways to build constructions are necessary, to reduce the quantity of raw materials extracted from nature and at the same time to minimise the amount of waste, by re-using construction materials that up to now, due to the traditional linear economic model, have ended up becoming construction waste and nothing more. The application of the linear economy model led to several challenges, among which an increase in construction demolition practises and waste generation (Svendsen & Tang, 2018). The linear economy revolves around an ongoing supply of natural resources, which resulted in the “take-make-dispose” process, based on the extraction of resources, goods and services production and their disposal after use. However, this approach is boosting pressure, due to its environmental and economic disadvantages (Het Groene Brein, 2019). The environmental disadvantages of the linear economy are that the goods production takes place at the expense of the Earth´s ecosystem. In the future, this excessive pressure put on the ecosystem might put at risk the regular provision of essential services, like water, land, air, plants and animals (Michelini, Moraes, Costa, & R. Ometto, 2017). All those steps of the so-called “take-make-dispose” manufacturing chain process influence ecosystem services in several ways. The collection of raw materials from nature causes both high water and energy consumption, emissions of poisonous substances into the atmosphere and destruction of natural environments, like lakes and forests. Moreover, when these products are disposed, hazardous substances are emitted and a considerable amount of space gets taken up from nature (Lucas & Wilting, 2018). In addition to the damages just mentioned above to the ecosystem services, economics disadvantages need to be considered as well and are mostly about fluctuating raw material prices, critical materials and increase in material demand (Het Groene Brein, 2019). Since 2006, raw material prices have continuously varied. Not only does this represent a problem for buyers of raw materials, but it also causes worse risks to the market, in which people are discouraged from investing in both material extraction and material processing and this leads to an ongoing increase in raw material prices over time. (Ramkumar, et al., 2018). Moreover, much of the production occurs with scarce resources. During their production processes, several industries, including the building industry, make intensive use of scarce resources, only available to a very limited extent. Besides being rarely available, their excessive use is another factor which might end up jeopardising the environment even more than common materials (van Berkel & Delahaye, 2019). Additionally, to the limited supply of raw materials available anyway, a significant increase in demand for materials is predicted. The number of middle-class consumers will increase worldwide by approximately three billion people by 2030, as a consequence of both population and welfare growth. In addition, since the lifespan of products has recently decreased, consumers want new products faster and therefore use their “old” products for a shorter period of time than in the past. In brief, this means that a lower quality is performed when it comes to products lifecycle, which leads to consumers desiring new products even faster. All this makes it easy to understand that a change is needed (Ramkumar, et al., 2018).

That change could be about shifting to a new economic model, which drastically differs to the linear way to make constructions, like a circular economy-based model (Svendsen & Tang, 2018). The term “circular economy” was first introduced in 1990, based on the theory that ‘’everything is an input to everything else’’, after a critical look at the traditional linear economic system was taken. That theory then led to the development of a new economic model, named “the circular economy”, to which the principles of the first and second laws of thermodynamics are applied. The first law, also known as Law of Conservation of Energy, states that “energy cannot be created or destroyed in an isolated system”, while the second one states that “the entropy of any isolated system always increases” (Rizos, Tuokko, & Behrens, 2017). The circular economy is based on system resources re-utilization, where recycling, re-using, renovating, restoring and repairing are its main characteristics, in which (Stahel, 2019):

- *Recycling*, which consists of ending the life cycle of the building or the materials used, in order to re-use them in the future life cycle of new products. In brief, it is about turning materials previously used in the building industry into new building products;
- *Re-using*, in which the original products, after minimal or no adjustments at all, get re-used for the same or similar purposes as in past activities;
- *Renovating*, linked to modifying and improving products, in order to boost their quality. Renovation is for guaranteeing that products comply with current standards and can therefore be used for tasks for an extended period of time;
- *Restoring*, in which structures are taken back to their original state;
- *Repairing*, including activities such as fixing and restoring the structure, to perpetuate its original function (Stahel, 2019).

In doing so, it is possible to reduce the manufacturing of new products through the use of raw materials taken from nature, especially when/if they cannot be restituted to the environment and would consequently get disposed, causing a drastic quick increase in waste (Sustainability for all, 2018). The advantages of such system are the following:

- An increase in the materials productivity, by manufacturing the same or more with less, in terms of material quantity;
- An increase in the materials value, both from an economic and environmental point of view;
- Understanding the links between energy and materials, how they influence each other and their consequences, where waste works as an input (Ghisellini, Ripa, & Ulgiati, 2018).

The circular economy could be the right way to achieve sustainability, given its principles. However, technology has to be the means whereby this concept of circularity can be applied (Liu, Osmani, Demian, & Baldwin, 2015). The construction industry is a sector in which there are the right conditions for technological developments and changes, given the great deal of data, details and management typical of design, planning and execution work phases, whose quality always needs to be improved. BIM (Building Information Modelling) can currently be perceived as a modelling technology and associated set of processes, which produces, communicates and analyses building models and allows all stakeholders to simulate all aspects of a construction project in a digital environment and share data on a single model (Sacks, Eastmann, Lee, & Teicholz, 2018). BIM was first developed in the 20th century and was presented as an idea of construction planning, based on attributes and parameters. However, the BIM process was developed to implement an idea into a software, but only over the last 10 years a serious implementation of building information modelling into the construction industry began (McGraw-Hill, 2012) (bips, 2014) (NBS, 2016). The National Building Specification (NBS) described BIM as tool which "*draws on information assembled collaboratively and updated at key stages of a project. Creating a digital Building Information Model enables those who interact with the building to optimize their actions, resulting in a greater whole life value for the asset*" (NBS, 2016). In addition, in order to understand how important the role played by building information modelling as a process, it is also necessary to understand what the elements of the BIM model are and this necessity is due to the need to differentiate between the process of creating the model and the model by itself. Therefore, Borrmann et alt. 2018 defined BIM as "*a comprehensive digital representation of a build facility with great information depth, which typically includes the three-dimensional geometry of the building component at a defined level of detail. In addition, it also comprises non-physical objects, such as spaces and zones, a hierarchical project structure, or schedules. Objects are typically associated with a well-defined set of semantic information's, such as the component type, materials, technical properties or costs, as well as relationship between the components and other physical or logical entities*" (Borrmann, König, Koch, & Beetz, 2018). BIM promotes efficiency and users will get several benefits, like the re-entering information into (digital) models or reduction in workload and rework. Other advantages regarding on a business level, might be like: (Rodriguez, 2019)

- Marketing: BIM opens doors to building firms, which can introduce it to new clients who do not necessarily require BIM. Companies can use it as a marketing tool, in order to gain advantage over their competitors while bidding in tenders;
- Project outcome: BIM drastically improves the quality of every aspect of a project, like design, planning, execution and work monitoring;

- Errors reduction: reduced errors and omissions in construction documents. Virtual design and construction with BIM create the potential to identify problems earlier enough in the building process (Rodriguez, 2019).

This paper aims to explain the theory of how the circular economy and some features of BIM and how their implementation might play an important role to minimise construction demolition and waste.

2. Literature review

In this section, construction demolition and waste will be analysed, in terms of current regulations, legislations and main causes. In addition, some circularity-based solutions through the application of BIM and some BIM features as well, to reduce the generation of waste, will be mentioned as well.

2.1 Current legislations

2.1.1 Waste management legislation

Waste management regulations are based on European laws and all countries which are members of the European Union or of the EEA (European Economic Area), like Iceland, Liechtenstein and Norway, adhere to the same principles and targets introduced by EU waste legislation. The Waste Framework Directive (WFD), officially stated that "*By the year 2020 the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 170504 in the European Waste Catalogue (EWC) shall be increased to a minimum of 70% by weight*". It is important to mention that the Waste Framework Directive does not include specific targets regarding individual sorts of waste which belong to the Construction demolition and waste category, but it clearly demands a target of 70% (Villoria Sáez, del Río Merino, & Porras-Amores, 2011).

2.1.2 Waste management policy

Environmental policies should be based on precautionary principles. According to the European Union, "*The waste producer is required to consider the environmental impacts and possible risks occurred during his activity, in collaboration with the other parties involved (producers, distributors, consumers, disposal and recycling companies, as well as government offices). The producer should develop a system which minimizes the adverse environmental impacts and maximizes the recovery of resources (recycling, reuse)*". For that reason, to facilitate this practice of waste management even more, not only does this policy include economic instruments like taxes on landfill, but also legal measures, such as demolishing obligation, voluntary agreements and responsibilities. In doing so, already during the work execution phase, there is the attempt to reach effective and environmentally compatible avoidance and recovery of waste. Therefore, both manufacturers and distributors should design their products such a way to minimise the amount of waste produced, also to facilitate the removal of waste which cannot be reused. (Villoria Sáez, del Río Merino, & Porras-Amores, 2011)

2.1.3 Landfilling regulations

A stricter control of landfilling, especially regarding certain types of construction waste, represents a driving reason for better management. For example, in Denmark disposing in landfills the waste destinated to incineration is forbidden, as well as the disposal of waste destinated to recycling. In addition, Denmark has a landfill disposal tax and a voluntary agreement, with good practices and environmental management systems for demolition activities. The implementation of a voluntary commitment of the building industry targets a reduction of up to 50% of the amount of construction demolition and waste landfilled. (Villoria Sáez, del Río Merino, & Porras-Amores, 2011).

- **Landfill tax**

The implementation of a waste taxing system has succeeded in discouraging the practises of construction demolition and waste generation across European countries. This initiative consisting of taxing waste was introduced in Denmark in 1987 and played a key role when it came to reducing the amount of waste in landfill and incineration (The Danish Environmental Protection Agency, 2019).

The waste tax was introduced as a European tax, even if both Denmark and the Netherlands were the first two countries which decided to implement it into their system. The tax is for incentivising countries and companies to efficiently manage their waste and work on recycling and a direct re-use of materials. In Denmark, the tax initially consisted of a taxing system of 40 Danish Crowns per ton and then rose to 475 Danish Crowns per ton as of nowadays (Fischer, 2011).

However, despite the initiative taken by the European Union so far, through all European laws and legislations passed, as well as the landfills fees introduced, construction demolition and waste and their related issues mentioned below, such as noise and hazardous substances getting released, still represent an ongoing phenomenon, which does not seem to stop, to reach the ambitious sustainability goals set.

The cement industry is still the second largest producer of CO_2 in the world, contributing to 8% of this gas emissions globally, in which 60% of them are caused by chemical processes and 40% by burning fuel (World business council for sustainable development, 2002) (Lehne & Preston, 2018). The CO_2 emissions caused by the concrete production are proportioned to the cement content used in the concrete mix and estimates found that 900 Kg of CO_2 resulted in being emitted during the manufacturing of 1 ton of cement, corresponding to approximately 88% of the total emissions associated with the total concrete production (Mahasenan, Smith, Humphreys, & Kaya, 2003) (Nisbet, Marceau, & VanGeem, 2002). The concrete manufacturing drastically leads to an increase in greenhouse gases directly through the production of CO_2, when for example calcium carbonate gets decomposed during the production of lime and carbon dioxide and also indirectly, through the use of energy, during the combustion of fossil fuels (U.S. energy information administration, 2011). This is due to the presence of aggregates, plasticisers and water, used in the concrete production, which are to some extent plentiful and are easily commercially available, meaning that transportation represents 7% of the total energy consumption of concrete, while the concrete production represents 70% (Building green, 2015), with a percentage of fly ash not higher than 20%. It was estimated that if only 1% of cement were replaced by fly ash, there would be a reduction in energy consumption of 7% (Nisbet, Marceau, & VanGeem, 2002). The environmental impact of concrete and its production are quite complex. Some effects are harmful, others are not. Cement is one of the major components of concrete, which has its environmental and social impacts and also contributes to those of concrete (World business council for sustainable development, 2002).

Concrete dust released while performing construction demolition activities is still a sort of hazardous air pollution, since the presence of some substances in concrete, like additives, cause health-related issues, due to their radioactivity and toxicity (Centers for Disease Control and Prevention, 2019). Wet concrete is also alkaline and must be handled by wearing some protective equipment.

In addition, construction demolition activities require specialised equipment and heavy vehicles, like sorting conveyors, loading and unloading trucks and crushing machineries, which might cause high levels of noise and ground vibration too on waste recovery facilities, as well as on demolition sites (Bruckman, 2013). People who live nearby local construction demolition sites or waste management areas are affected by their impact. In addition, the transportation of construction demolition materials by heavy vehicles can also contribute to increasing noise and dust related issues. But the same happens while performing recovery activities, including tasks such as sorting, crushing and grinding. The impacts of dust, heavy noise and vibration can lead to air pollution (Bruckman, 2013).

Hazardous substances generated by construction demolition and waste, like asbestos and PCB, possible to find in roofing plates, floor tiles, exterior concrete walls and insulation elements are still a relevant issue (Bruckman, 2013). Asbestos consists of six naturally occurring fibrous minerals composed of thin fibres and exposure to them causes several cancers and diseases, including mesothelioma and asbestosis, since fibres become soaring and consequently get carried around environments located nearby. Its exposure takes place during:

- Hand demolition of building materials containing asbestos;
- Demolition of asbestos-containing buildings, through machines such as a wreck ball-equipped machine causing dust;
- Renovation of buildings, where asbestos-containing materials demolished;
- The handling, move and dumping of asbestos-containing debris and waste as well (Western Environmental Solutions, 2018).

PCB, a group of man-made chemicals commercially produced world-wide on a large scale, given their great chemical stability and resistance to heat, are massively used in the building industry as components for electrical and hydraulic equipment and lubricants too; they "travel" into materials like concrete, contaminating other nearby materials (European commission, 2019). Both substances like asbestos and PCBs are highly toxic and cause ground contamination and crucial human health diseases by inhalation or skin contact (Bruckman, 2013).

In chapter 2.2 below, the main categories of the origins that according to Won et alt. 2017 cause construction waste will be listed and explained.

2.2 Causes of construction waste

Won et alt. 2017 identified the potential categories of the origins of such large quantities of construction waste are the following:

- Poor procurement;
- Poor design management;
- Double material handling;
- Inadequate construction waste management on site;
- Poor participation in construction waste management (Won & Cheng, 2017).

2.2.1 Poor procurement

Procurement consists of buying and delivering products and services and its causes could be many. One of the first mistakes made, which causes poor procurement, is the wrong quantification of the construction materials necessary to perform on-site activities (Poon, Yu, & Jaillon, Reducing building waste at construction sites in Hong Kong, 2004) (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). Another reason why it occurs might be the choice of low-quality materials and products, due to unclear specifications from the client or imprecise estimates, which both lead to incorrect purchase. In addition, what may cause incorrect goods deliveries is project time schedules not being taken into account (Bossink & Brouwers, Construction waste: quantification and source evaluation, 1996).

2.2.2 Poor design management

Poor design management is another cause of construction waste generation (Poon, Reducing construction waste, 2007) (Yeheyis, Hewage, Alam, Eskicioglu, & Sadiq, 2013). The main causes could be due to detailing errors, lack of information or specifications present in drawings, which might make the drawings “reading” more complex. In addition, “last minute” design changes are another causes of poor design management, could run the risk of affecting the execution phase (Osmani & Glass, 2007) (Gavilan & Bernold, 1994). In the building industry, “last minute” design changes occurring right before the beginning of work execution should be eliminated, because if not, they might be responsible for an increase of up to 33% in construction waste volume. In some projects, poor design management leads to an increase in mechanical, electrical and plumbing engineering systems costs. Moreover, design needs to be improved in order to reduce poor procurement (Poon, Yu, & Jaillon, Reducing building waste at construction sites in Hong Kong, 2004) (Weisheng & Hongping, 2010) (V. Saez, del Río Merino, San-Antonio González, & Porras-Amores, 2013) (Wang, Li, & Tam, Critical factors in effective construction waste minimization at the design stage: A Shenzhen case study, China, 2014) (Faniran & CABAN, 1998) (Ekanayake & Ofori, 2004).

Poor design management includes inaccurate dimensions of components, like in prefabrication. Prefabrication is one of the most recommended solutions to minimise on-site concrete waste and despite its positive impact on the reduction in construction waste, it still encounters issues. The issues can be about lack of accurate dimensions of building elements in the design phase (Meibodi, Kew, & Haroglu, 2014). Construction waste can be generated when differences appear in the drawings; even if error-free sets of drawings are rare in building projects, despite many quality control methods conducted (Weisheng & Hongping, 2010) (V. Saez, del Río Merino, San-Antonio González, & Porras-Amores, 2013).

2.2.4 Double material handling

Another cause to take into consideration is double material handling. Even if remarkable improvements have been achieved, the reduction in incorrect material handling is still challenging in the building industry (Weisheng & Hongping, 2010) (Del Río Merino, Izquierdo, & Weis, 2009) (Faniran & CABAN, 1998) (Audus, Charles, & Evans, 2010). Double handling manly refers to "*when a material first gets transferred or unloaded to the wrong place or wrong position on site*", which means that it will have to be moved to the correct location afterwards. When a resource is delivered, stored and then moved again to another area of the same building site, double handling takes place. The reasons why it is disadvantageous are many, since it increases the likelihood to damage materials, as well as on-site workers´ health might being affected, since continuous handling and moving might cause collision between workers and materials. Moreover, double handling is time consuming, because assets need to be transported twice. However, sometimes it is difficult to avoid it, since accurate storage on the first try not subject to any future changes results in being complex (Eliasy, 2018).

2.2.5 Inadequate on-site construction waste management

Several causes were found in relation to inadequate on-site construction waste management processes, such as lack of proper tracking of construction waste moves, incorrect space planning and material storage, as well as delayed on-site waste sorting (Gangolells, Casals, Forcada, & Macarulla, 2014) (Weisheng & Hongping, 2010) (Poon, Reducing construction waste, 2007) (Faniran & CABAN, 1998). Another cause of this category includes lack of or limited presence of containers, useful to successfully perform waste collections, in order to sort, recycle and reuse (Weisheng & Hongping, 2010) (V. Saez, del Río Merino, San-Antonio González, & Porras-Amores, 2013) (Audus, Charles, & Evans, 2010).

2.2.6 Poor participation in construction waste management

The causes pertaining to this category are:

- Lack of coordination, while planning waste management;
- Passive participation of all stakeholders in construction waste management and minimization plan;
- Lack of communication among project participants;
- Lack of coordination and review meetings and insufficient waste management planning (Gangolells, Casals, Forcada, & Macarulla, 2014) (Lu & Yuan, 2011).

2.3 Circular economy-based solutions

After a brief introduction on what the European Union aims to achieve, in terms of circularity, Materials Passports, deconstruction and Design for Deconstruction will be introduced as circular economy-based concepts.

In 2019, a document on the development of the best practices in the Extractive Waste Management Plans regarding the Circular Economy Action was published (European commission, 2019). The analysis was for assessing to what extent European policy tools support circular and sustainable products, in order to "*protect the environment* *and human health by manufacturing products such a way so they become more energy and resource efficient and empower consumers to choose better products*".

So far, The Commission has committed to (European commission, 2019):

- Taking the initiative to ensure a more efficient recovery of valuable resources and also perform proper waste management practises while doing construction and demolition works;
- Developing pre-demolition guidelines recycling protocols, in order to boost recycling in the building sector, which aim to improve quality of recycled materials;
- Proposing stricter legislations, to guarantee better sorting of construction and demolition waste (European commission, 2019).

Still according to the European union, the circular economy, also in a sector like the building industry, would encourage to achieve more and more ambitious sustainability goals and would boost competitiveness as well, thinking long term. Some of the benefits would be the following (European commission, 2019):

- Preserving resources, especially the scarce ones, more likely subject to price fluctuations;
- Reduction in costs of new buildings, due to re-use of materials and components;
- New business opportunities;
- Building innovative, resource-efficient businesses;
- Create local high-skilled jobs (European commission, 2019).

Cradle to Cradle is a design philosophy, in which products are part of a biological or technical circuit, which aims to create value for the environment, the economy and people as well (Vugge til Vugge, 2012). The core principles of Cradle to cradle is developed by saving resources, in order to minimise the negative impact of waste on the environment. Cradle to Cradle consists of the vision of a world whose production and consumption must have positive impacts on the economy, the environment and people, without reducing consumption and welfare. Products are designed such a way that all materials are beneficial to the environment and can therefore be part of a repeating circle, since no waste gets produced anymore and everything gets recycled and consequently becomes a resource for the manufacturing of something new. Materials Passports and deconstruction are two circularity concepts based on Cradle to cradle (Vugge til Vugge, 2012).

2.3.1 Materials Passports (MP)

Materials Passports (MP) "*aim to create ways to increase the value of building materials, because dynamically and flexibly designed buildings can be integrated into a circular economy, where materials in buildings sustain their value*". This will cause a decrease in both waste/disposal and use of virgin resources as well (EPEA GmbH, 2019). The way Materials Passports can be expressed is circular design, whose idea comes directly from the concept of the circular economy, meaning that circularity also affects the way business is done, not only how building components are designed or used (Aguiar, Vonk, & Kamp, 2019). Right now, circular design represents one of the most doable sustainable solutions to think of and work with, to achieve circular economy-related goals. The basic principles of such design type consists of valuing materials and elements at the end-of their life cycle, since demolition works do not result in being environmentally friendly and resources which have great potential for re-use get discarded (Aguiar, Vonk, & Kamp, 2019).

Two achievable examples of Materials Passports, named "Old roofs new façades" and "Circrete", will be introduced below.

- **Old Roofs New Façades** (*see figure 1*)

The concept of "Old façades" is based on the use of old roof elements as façade cladding, as they get hung as shingles and aims to combine a façade concept for re-using roof tiles, to promote the benefits of sustainable solutions. The materials used for the "Old Façade concept" are mostly local and the mounting system will be performed globally. It is important to mention that, since the materials will mostly be local, once again for environmental purposes, the manufacturing and organisation of this concept will change from country to country, depending on the materials available. This is done to discourage as much as possible both the importation of materials from other areas and resource scarcity as well (Vandkunsten AM, 2018).

Circular solution: the concept can be reckoned a circular solution for many aspects: the laying (on top of each other) and disassembling of pantiles would be performed the same way, by untying the ties and then piling the tiles (Vandkunsten AM, 2018). Clay roof tiles are designed on purpose such a way to be disassembled many times with no risk of damage and can be dismounted by cutting the metal ties and connect them to the roof structure (Vandkunsten AM, 2018).

Waste reduction: As regards the type of waste getting, this concept decreases the waste of clay tiles, which would be used as filling for roads. The waste fraction being reduced mostly depends on the product availability (Vandkunsten AM, 2018).

BIM use: regarding this solution, BIM could be relevant, since the facades mounting will be monitored through a programme able to digitally perform the mounting before it gets carried out and estimates the costs of this work (Vandkunsten AM, 2018).

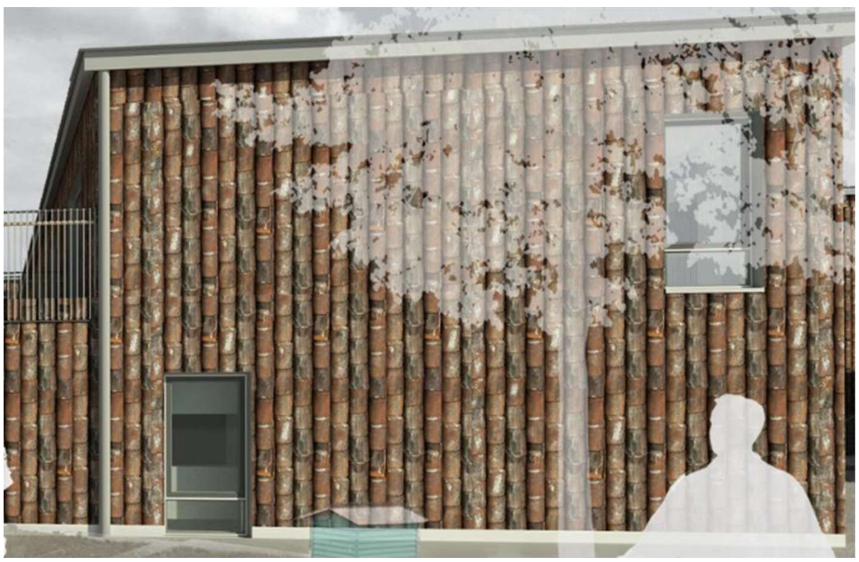

Figure 1 - "Old roof new Facade" concept

- **Circrete**

The concept of "Circrete" ("circular" + "concrete") came up after having looked at waste in the construction industry, since concrete is that material which distinguishes, both in terms of mass and incorporated energy. Worldwide, concrete has been the material used the most in the building industry, in rising and established economies too. Even though circular construction methods in the future are likely going to rethink the use of building materials, concrete currently represents and will continue representing one of the most common driving causes of waste. When a building gets demolished, the concrete gets broken into smaller pieces and used as filling in road construction or degraded and discarded, while reinforcement bars get recycled. Starting from its production phase, every cubic meter of concrete releases of 402 kg of CO_2, which not only represents an economic loss, but also an environmental damage. Circrete would drastically change the perception of deconstruction concrete structures and would play a relevant role in the manufacturing of specified circular products for clients. Furthermore, Circrete can also be produced with materials from dismantled buildings, without having to necessarily re-use them in the same nearby location and this will turn Circrete into a low or no cost composite materials and will introduce it to a scale of products to be sold (Nørlund, 2018).

2.3.2 Deconstruction

As already mentioned, the construction industry has significantly contributed to the amount of waste produced so far, also caused by demolition activities (Macozoma, 2001). In the past, the invention of machine-made and mass-produced materials, besides the low oil costs, discouraged deconstruction practises from coming into common use in the industry. But now, some changes seem to start occurring, since:

- The prices of concrete, steel and transportation have increased;
- Landfill fees continuously increase;
- Opening new landfills is getting more and more problematic, not only for environmental reasons, but also due to space limitations;
- Some building materials have become scarcer or worse in terms of quality (Guy, 2017).

The construction industry has recently realised how important environmental changes are and has tried to adopt effective solutions, which consist of both activities and processes which aim to minimise negative environmental impacts. Therefore, building deconstruction can be relevant to solve environmental-related issues. Deconstruction is a building method based upon the demounting of construction components, to facilitate the rescue of materials, through recycling and reuse. Deconstruction contributes to minimising the quantity of waste destinated to landfills and therefore saves landfill spaces. What gets recovered can be transformed into secondary materials and represents a new source of resources for the building sector, since it diminishes the amount of virgin materials and it encourages the preserving of natural resources. In addition, the utilisation of secondary materials will conserve the embodied energy present in and drives down the need for more energy consumption, which usually occurs while performing the extraction of virgin material, production and supply as well. Moreover, another factor which motivates deconstruction techniques is the increasing number of used building materials stores (Macozoma, 2001).

- **Design for Deconstruction**

Design for Deconstruction (DfD) refers to the design of buildings, performed such a way to run their end-of-life more efficiently (Fraunhofer-IRB, 2019). The process is for guaranteeing easy disassembly/deconstruction, which aims to maximise the recovery of building components and materials as well for recycling and reuse, to reduce waste. Design for Deconstruction has to include building resource management and its practice is increasing worldwide, because thanks to this method, there would be a re-utilisation of already in use materials and components, instead of disposing the waste generated by the demolition works of existing buildings and having to extract new virgin materials (Fraunhofer-IRB, 2019).

What characterises the longevity of buildings depends on how well their structural integrity can last over time. The structural integrity is influenced by the durability of materials (mostly determined by their quality). An important principle of Design for Deconstruction is the so-called "Theory of building layers", according to which "Building components can be decomposed into packages, based on the same or similar life expectance, so that an entire package could be removed from the building to get replaced, recycled and eventually reused". This theory gives designers the chance to add flexibility to building design, which allows a building to be easily disassembled into components (Fraunhofer-IRB, 2019). Flexibility of design is useful, since it enables buildings to evolve and still get efficiently used, even if some changes in operational requirements occur, contrarily to inflexible buildings, which could run the risk of getting obsolete (Designing Buildings Wiki, 2017).

2.4 BIM application to the five categories of construction waste

In this section, several BIM features will be mentioned, to explain how and why Building Information Modelling is useful, in order to achievable solutions to the main categories of construction waste previously described.

2.4.1 4D coordination

Thanks to the 4D coordination, three of the five main categories of waste causes like double material handling, inadequate on-site construction waste management and poor participation in construction waste can be solved. The reason why it can be the right solution is because BIM technology can methodically extract information on construction materials from BIM models and integrate it with the project schedule, by combining building elements and each construction activities, which successfully reduces the likelihood of generating on-site waste (Ahankoob, Meysam Khoshnava, Rostami, & Preece, 2016). Furthermore, a 4D coordination encourages effective planning, estimates and displays construction sequences and space requirements as well on site, besides being able to identify workspace-related issues (Jongeling, Jonghoon, Fischer, Mourgues, & Olofsson, 2008). By combining construction materials quantities (which are possible to extract from BIM models) and the project time schedules, the amount of construction materials required at specific work execution stages or while performing specific activities can be measured faster and more efficiently. In addition, more precise scheduling through BIM enables “Just-in-Time” deliveries of materials and equipment. Consequently, time-based quantity take-off using BIM can prevent long periods of on-site storage (Tommelein & Yi Li, 1999).

- **Site utilisation planning**

Categories like double material handling, inadequate on-site construction waste management and poor participation in construction waste management can benefit from site utilisation planning, as part of BIM feature 4D coordination. The reason why Site utilisation planning is useful is because it is able to analyse site layouts, when moving from one work execution phase to another, but it also identifies potential and critical space and time conflicts, by extracting from BIM models information on project time schedule, equipment and facility specifications (Wang, Zhang, Chau, & Anson, 2004).

Regarding double material handling, it creates the basis which leads to efficient space management, which consequently facilitate the movement of materials present on site and reduces the likelihood of unnecessary double handling, through the analysis of appropriate on-site locations, based on the material sizes. This aims to avoid long-periods of storage and prevents material wastage unexpectedly produced on site.

Moreover, communication among participants might benefit from the use of Site utilisation plan (Huang, Kong, Guo, Baldwin, & Li, 2007). In addition, site utilisation planning turns out to be useful to run on-site safety-related planning, since a 4D coordination would give the chance to visualise safety arrangements across the building site at every work execution stage of the project (Sulankivi, Mäkelä, & Kiviniemi, 2009).

2.4.2 Quantity take-off

BIM-based feature quantity take-off successfully addresses poor procurement management and this is possible through fast and accurate extractions of quantities information of building materials from BIM models and then it integrates it with waste indexes and costs, including transportation and labour costs, but also disposal fees (Monteiro & Poças Martins, 2013).

BIM-based quantity take-off can also perform waste estimates as well, which addresses the waste produced during all construction phases. Furthermore, information on size, area and volume of construction materials and components can be efficiently calculated, thanks to quantity information extracted from BIM models, which has to include lengths, areas, volumes and any sort of necessary data of building components and materials, in order to minimise the amount of construction waste, since quantity take off considers the specification, rates of loss while performing cutting etc (Charette & Marshall, 1999).

2.4.3 Design review

The BIM-based feature design review is useful when it comes to estimating reusability rates of materials, optimise design, reduce the likelihood of too large amounts of materials orders caused by poor procurement, caused in turn by incorrect design. Design review turns out to be effective since it diminishes the number of last minute design changes, thanks to the possibility to visualise design changes and adding comments to existing drawings and models and this consequently drives the amount of construction waste down (Olsen & Taylor, 2017).

Compared to tradition 2D reviews, one of the most significant advantages of BIM design review is that technical drawings available in both horizontal and vertical sections are extracted from the model and are therefore compatible with each other. In addition, conflicts present in different disciplines (like architecture and engineering) can be easily detected and corrected by clash detection at early design phases. Furthermore, design review is able to check whether the entire model can fulfil standards and regulations. Finally, the model data can be used to make accurate very quantity take-off estimates, fundamental step to reliable cost estimations and higher accuracy in the tendering documents (Borrmann, König, Koch, & Beetz, 2018).

2.5 BIM in circular economy-based solutions

In the sections below, the application of Building Information Modelling to the circular economy-based solutions (Materials Passports and Design for Deconstruction) will be explained, based on what mentioned above, in order to show how BIM can turn the concept of circularity into something feasible.

BIM is a tool which can be used in several situations for different purposes, like establishing requirements, validating designs, estimating costs or in logistics and planning and asset management as well. BIM results in playing a relevant role, when it comes to building with low failure costs, but also to make sure construction for future deconstruction will take place based upon reliable information (Aguiar, Vonk, & Kamp, 2019).

2.5.1 BIM for Materials Passports

There is already a fully functional BIM model, which contains a lot of information and a database, in which data gets managed and linked. BIM stimulates circular design and motivates circularity with reliable graphical information, which drastically reduces the waste of time while searching for elements in the database and their related information (Aguiar, Vonk, & Kamp, 2019). Deconstruction, one of the key concepts of Materials Passports and its BIM-related tool, will be explained right below.

- **BIM-supported Materials Passports**

A BIM-supported tool for Materials Passports is necessary, to give the opportunity to carry out assessments regarding the recycling potential and environmental impacts as well of building materials and components. The purpose of this tool is to boost the information sharing pertaining to the materials life cycle assessment, in order to increase as much as possible the quality of building materials and components, but also their re-usability rates (Durmisevic, 2019). To create a BIM-based Materials Passports, it is necessary to combine two digital tools: a BIM software for modelling and a Material Inventory and Analysis Tool Building One (BO) for data management with bidirectional connection, which contains information is present on building elements and materials and their properties, like recyclability, re-usability and their environmental impact. BO results in being useful to perform Materials Passports assessments, only after having got data from the BIM model (Honic, Kovacic, & Rechberger, 2019) and can be described as a digital platform or digital book with a large amount of data among which recyclability and re-usability properties and has direct access to the BIM model (OneTools, 2019). To sum up, the BIM software contains basic data on walls, doors and windows and needs BO and its properties inventory for external data management, to perform life cycle assessments (Alwan, Jones, & Holgate, 2016). Life cycle assessments are conducted to every building element and material of the building, in order to have an overall documentation of the building´s composition, recyclability and waste rates, estimated by the BO (Honic, Kovacic, & Rechberger, 2019).

2.5.2 BIM for deconstruction

- **Disassembly and Deconstruction Analytics System (D-DAS)**

Akinade et alt. 2015 elaborated a disassembly and deconstruction analytics system (D-DAS) which needs to be integrated as a plug-in into BIM software Autodesk Revit to provide an assessment of end-of-lifecycle of buildings, starting from design phases (Akinade, et al., 2015). This tool aims to facilitate decision-making in relation to sustainable building end-of-life performance, to make sure that that the right materials get chosen, in order to minimise the waste generation and discourage demolition practises (Douglas, Ekehorn, & Lockwood, 2016). There are the key functionalities featuring in this tool:

- Building Whole Life Performance Analytics,
- Building Element Deconstruction Analytics
- Design for Deconstruction Advisor (Akanbi, et al., 2018).

1. Building Whole Life Performance Analytics

It considers all aspects which might have an impact on both building materials and components, to ensure that their functionality during the entire life cycle of buildings does not get altered. This means that if materials and components do not perform as expected, they will simply be removed, to be reused or recycled. The performance of buildings can be expressed through the equation below, in relation to time:

$$P = RU + RC + ɣ.$$

P indicates the *performance of the building over time*, while RU and RC respectively stand for *Reusable factor* and *Recycling factor*. ɣ is referred to the “performance” factor, which leads the disposal of materials in landfills (Geissdoerfer, Savaget, Bocken, & Hultink, 2016).

2. Building Element Deconstruction Analytics

Building Element Deconstruction Analytics is useful to discover whether a building is more suitable for deconstruction over demolition, once its lifecycle has reached the end. The aspects taken into account by this key functionality are the building element type, presence of prefabrication at design stages and its related specification, type of connections, but also other relevant factors, like reusability and recyclability properties of each material and component and eventual use of toxic substances and which materials have been used as finishes (Akinade, et al., 2015).

3. Design for Deconstruction Advisor

Its purpose is the analyse the current design of the building examined, in order to specify which of the building elements and materials have to be changed or somehow improved or check whether they match, to reduce the generation of waste. In addition, this key functionality has to ensure that the best design and construction practises have been adopted, to minimise waste in both construction and deconstruction phases. Furthermore, it has to encourage as much as possible design for deconstruction, to tackle the above-mentioned waste-related issues (Yakub, et al., 2019).

3. Problem statement

Construction demolition and waste, despite all regulations, standards and new requirements, still represents an ongoing serious problem. As regards the linear economic model and its disadvantages, some information on how the price of raw materials keep on fluctuating was found, not to mention impacts on the environment, whose ecosystem constantly gets jeopardised (Het Groene Brein, 2019).

The information found, pertaining to both European and Danish laws, was for discovering how much has been done so far and also how governments have tried to tackle or limit the problem. What emerged was that the European Union aims by 2020 to recycle and re-use at least 70% of the total weight of what does not get utilised during construction execution works (Villoria Sáez, del Río Merino, & Porras-Amores, 2011). However, according to the regulations, it is not mandatory for producers to make re-use and recycling plans, since they "*should develop a system which minimizes the adverse environmental impacts and maximizes the recovery of resources (recycling, reuse)*" (Villoria Sáez, del Río Merino, & Porras-Amores, 2011).

Both data and information mentioned in the literature review showed that since manufacturers are not obliged by law to make effective re-use and recycling plans, but they are just "advised" to, the problem will not get properly solved and the "70% goal" regarding re-using and recycling will not get achieved. This was possible to notice by looking at the current regulations and also at the current unsatisfying achievements, given the amount of waste still getting produced. In order to achieve such an ambitious goal, other solutions must be suggested and put into practice, which is the purpose of this report.

After getting some input from the information collected about the construction demolition and waste issue, the following problem statement could be formulated:

"How can the circular economy and BIM contribute to minimising construction demolition and waste?''.

In addition, some sub-questions are formulated, to support even more what stated by the main problem formulation:

- How can the circular economy be applied to the construction industry and to which aspects?
- Which BIM features contribute to reducing construction demolition and waste?

4. Research method

The main purpose of this chapter is to provide the reader with the understanding of how the author did his research design, to have an overview of all steps taken to find valid and reliable answers to the main problem formulation. The research tools used, when it came to collecting and analysing of data, are mentioned as well.

4.1 Methodology

Methodology consists of the procedure and how the report was developed and describes how the data to be re-elaborated was collected, analysed and how the reliability of the results was determined. The methodology has great influence on the outcome of this report, since different methodologies will provide different research methods and consequently different results (Lune & Berg, 2009). Therefore, it is important to determine the methodology used before the report work is started. The methodology of this report will be briefly explained in the following sub-chapters.

4.1.1. Research design

Research design is defined as a framework of methods and techniques chosen by a researcher, in order to combine all different components of the research in a logical way, so that the research problem gets efficiently handled. It provides insights about how to conduct research using a particular methodology. Furthermore, in this report, the research design type is a descriptive research design, in which there is interest in describing the situation or case under the research study, based on gathering, analysing and presenting collected data (Bhat, 2019).

The research design of this paper is a *descriptive research design*, since it gives the chance to describe a current issue under the research study, in which the author will gather, analyse and present the data collected. Moreover, the author will evaluate himself the solutions suggested.

In this type of research design, it is important to plan and design the study such a way to highlight what is relevant to the problem statement, in order to collect relevant data. In addition, there are no strict rules regarding the data collection in a descriptive research design, contrarily to, for example, a scientific report (Bhat, 2019). This report aims to make sure that both the problems and solutions found are valid, as well as investigating the validity of the results will help understand whether it is possible to apply the solutions to similar cases. This research is important and the type of research chosen will influence the result of the paper. The use of deductive and inductive research approaches might give the possibility to use both qualitative and quantitative research strategies when working on a study (Saunders, Lewis, & Thornhill, 2009).

However, given the limited amount of time available, the sort of approach used by the author in this report is a deductive approach. The meaning of both approaches will be explained below.

4.1.2 Deductive approach

The deductive approach (or deductive reasoning) is for testing or evaluating in a different way already existing theory. In this report a deductive approach is adopted, since this paper focuses on existing problems and not on new phenomena (Bradford, 2017). The reasons for using the deductive approach are the following:

- It gives the possibility to explain causal relationships between concepts and variables;
- It measures concepts *qualitatively* (Research methodology, 2019), *see figure 2*.

In this report, the deductive approach was used to analyse the literature review, found in research and studies done, in order to evaluate the main issue regarding construction demolition and waste and suggest achievable solutions, based on already existing theory. This means that the author will not elaborate himself any new hypothesis.

	Deductive approach preferred	**Inductive approach preferred**
Wealth of literature	Abundance of sources	Scarcity of sources
Time availability	Short time available to complete the study	There is no shortage of time to compete the study
Risk	To avoid risk	Risk is accepted, no theory may emerge at all

Figure 2 - Deductive and inductive approach

4.1.3 Data collection methods

Data is collected in many ways and its collection is fundamental to the quality of any research, since it provides a stable overview, supported by facts and results which are from reliable sources. There are basically two ways to collect data: primary and secondary data (Kabir, 2016). The reasons for collecting any data is to answer one or more research questions. Data collection provides a great deal of information and it is important to limit the amount of data collected to only what can be considered useful to the research done (Kabir, 2016). Based on this concept, the strategy used to do this study is a secondary data collection, based on qualitative methods, *see figure 3*.

- **Secondary data collection**

Secondary data is the data previously collected by other sources, which are cheaper and more quickly obtainable than primary data (Foley, 2018). Secondary data consist of documentation and drawings from a case, but also theoretical data of books and articles and results in being fundamental because they provide this report with the necessary theoretical support. Their advantages are the following:

- They are economic;
- They save efforts and expenses;
- They are time saving.
- The problem understanding gets drastically improved (Foley, 2018).

Secondary data analysis consists of using the information already gathered by someone else for the researcher´s purposes. Researchers have to maximise the use of secondary data analysis in order to answer a new research question, or eventually to examine an alternative to the original question of a previous study. Primary data is original data collected directly by researchers, through interviews for a specific purpose, when they want to information for example on a specific topic or a specific firm.

In this paper the data collection is performed through the literature review, in which relevant data and information regarding construction demolition and waste, its main aspects and consequences were exposed, in order to elaborate the main problem statement.

- **Qualitative method**

Qualitative research mostly consists of exploratory work, not presented in the form of numbers and consequently it is not measurable (De Franzo, 2011). It is gathered through observations and interviews used to have an understanding of the reasons, causes, opinions, and motivations. It gives an insight of the problem and helps to suggest ideas or hypotheses, in order to do quantitative research.

Qualitative research is for uncovering trends and for diving deeper into problems as well. Qualitative data collection methods vary, depending on unstructured or semi-structured techniques. Some common methods include group-focused methods (or group discussions), individual interviews, and observations. The size is usually small and respondents are selected to fulfil a given quota (De Franzo, 2011).

QUALITATIVE METHOD	QUANTITATIVE METHOD	MIXED METHOD
• Example: observation data or interview data; • Exploring and understanding the underlaying reasons and opinions.	• Example: statistical data or performance data; • Testing variables that can be measured according to theory.	• Mix between quantitative and qualitative research methods; • Example: statistical data combined with a text analysis of interviews.

Figure 3 – Data collection method

4.1.4 Research Tools

In order to provide the reader with valid solutions to the problem formulation, the author had to carry out specific types of analysis.

The information collected has to be reliable as well as valid, meaning that the literature collected was assessed securing that It includes only information proven to be true. As already mentioned above, the sort of research design is a mixed method, which allowed the author to collect both qualitative and quantitative data.

By carrying out a variety of analysis, the author will get a better and clearer understanding of which solutions must be practically adopted, in order to try to solve the main problem. The first type of analysis consisted of investigating what construction demolition and waste is about, to highlight its main causes. The research tool, to have a more effective analysis, is the PESTEL analysis.

The reasons for using this type of research tool is because it provides a simple but effective structure, useful when it comes to processing a great deal of data and information (Woodruff, 2019). Moreover, it helps to identify potential threats and reduce their impact, not to mention how effective it becomes when it comes to a strategic thinking mindset and also to creating the right conditions to exploit new opportunities. Last but not least, it helps to evaluate which impact choices might have, before they get implemented, by taking into account their pros and cons (Woodruff, 2019).

- **The PESTEL analysis**

The PESTEL analysis (*see figure 4*) is a tool used to evaluate all aspects of business, by examining its political, economic, social, technological, legal, and environmental factors. These advantages help with phases like the idea, product development and product launching, to increase the likelihood of success (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014). The advantages of the PESTLE analysis are about cost effectiveness, which provides a deeper and better understanding of business and how to exploit opportunities (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014). The term “PESTEL” stands for:

- Political;
- Economic;
- Social;
- Technological;
- Environmental;
- Legal (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014).

Political Factors

Political factors consist of how and to what degree governments intervene in the economy, in terms of foreign, trade policy and tax policies, political stability or instability, labour and environmental laws and trade restrictions (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014). Political factors often have an impact on the launch of new ideas and how to introduce them to the market (Marketing theories – PESTEL analysis, 2017).

Economic Factors

Economic factors have a significant impact on how a firm does business and also how profitable its ideas could be. These factors might include economic growth, interest rates, exchange rates and inflation (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014).

Social Factors

Social, or socio-cultural factors are about the attitudes of the population, such as population growth, health consciousness and career attitudes. They have a severe impact on how marketers understand customers and what drives them (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014).

Technological Factors

It is about how the technological landscape changes and shapes both markets and products (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014). Technological factors affect marketing and the management as well in three ways:

- New ways to manufacture goods and services;
- New ways to distribute goods and services;
- New ways to communicate with target markets (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014).

Environmental Factors

Environmental factors need to be taken into account, given due to the ongoing increase in raw materials scarcity, pollution rates, in order to do business in both ethical and sustainable ways, by for example targeting CO_2 emissions, an example of both political and environmental factors at the same time (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014).

Legal Factors

Legal factors include - health and safety and product safety (Johnson, Whittington, Scholes, Angwin, & Regnér, 2014).

Figure 4 - The PESTEL analysis

4.1.5 Reflections on validity and reliability

- **Validity**

A study is valid, when the data presented supports the conclusion and the conclusion made confirms itself what has been mentioned all over the research. While dealing with both qualitative and quantitative investigations, which this paper is an example of, the question becomes whether the data collection and analysis match the purpose of the investigation. Based on this, the validity of any research is based on the trustworthiness and establishing confidence in the data (Golafshan, 2003) .

- **Reliability**

In a qualitative study, such as this, reliability and validity are viewed collectively. The reliability of this report will determine whether the results are compatible (Golafshan, 2003). It is also a matter of whether the conclusion of this paper can be reckoned reliable or not. Furthermore, in this report, the reliability of the results will be determined based on the dependability and trustworthiness.

5. Problem analysis

This chapter aims to find describe what mentioned about construction demolition and waste, which emerged in the literature review. In addition, the PESTEL analysis will be used to analyse the literature review and the problem tree diagram and better understand what the current situation is.

5.1 Problem tree diagram

The purpose of the problem tree diagram (see *figure 5* below) is to highlight the causes of the focal problem, being an increase in construction demolition practises and waste generation and its consequences (effects) as well. The effectiveness of this diagram consists of easily determining and addressing the current causes of the focal problem, but it also gives the chance to quickly visualise a good overview of the focal problem. Moreover, this type of diagram helps to find possible solutions at early phases, to eventually prevent the problem and its effects from occurring by focusing on its causes.

As displayed by the problem tree diagram, the roots of the main causes of construction demolition and waste are essentially: incorrect design (which consequently leads to poor procurement), lack of awareness of demolition and waste and lack of strict European laws which force stakeholders in the building industry to adopt sustainable solutions and digitalisation. Those initial causes lead to not enough investments being made to tackle the problem, which contribute neither to improving design to achieve sustainability (Materials Passports and Design for Deconstruction) nor to boosting demolition and waste planning.

Consequently, demolition works would still be preferred over deconstruction practises and this causes an increase in construction waste. The effects of the focal problem might be catastrophic: the generation of more waste will require more landfills to be built, besides enhancing raw materials prices and running the risk of causing materials scarcity.

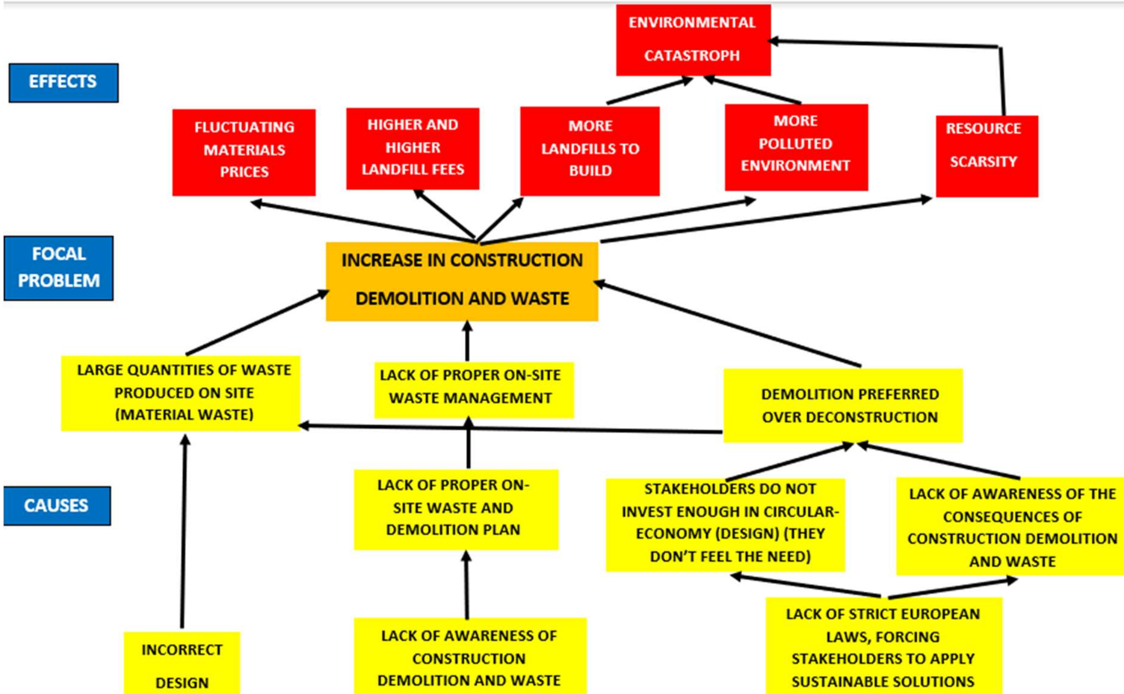

Figure 5 - Problem tree diagram

After the analysis carried out through the problem tree diagram, the PESTEL framework will be used as already mentioned in chapter four, to provide a deeper examination of the many aspects present in the introduction and literature review as well.

5.2 PESTEL analysis

The PESTEL analysis was chosen because it represents a successful strategic planning method, which takes into account the Political, Economic, Social, Technological, Legal, and Environmental factors, in order to better examine and understand the possible threats and scenarios, besides providing an explanation of the solutions benefits listed in the literature review.

P – Political

The political aspect indicates to which extent governments or the European Union itself as well have intervened, as regards construction demolition and waste.

So far, the European Union has passed some laws and legislations which could somehow limit or reduce the practise of construction demolition works and waste generated. In fact, there is a legislation which states that through "*The year 2020, the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 170504 in the European Waste Catalogue (EWC) shall be increased to a minimum of 70% by weight*". However, despite mentioning that the re-use and recycling of waste should correspond to at least 70% of the waste weight produced, this legislation does not state anything about targets regarding individual sorts of waste, belonging to the construction demolition and waste category, but it only limits to specify a target of 70%. The same goes for the European environmental policy, which states that "*The waste producer is required to consider the environmental impacts and possible risks occurred during his activity, in collaboration with the other parties involved (producers, distributors, consumers, disposal and recycling companies, as well as government offices). The producer should develop a system which minimizes the adverse environmental impacts and maximizes the recovery of resources (recycling, reuse)*".

As regards the legislation, it is worth mentioning that it aims to achieve an ambitious target of re-use and recycling of at least 70% of the weight of the waste produced on site, but it does not specify in detail how and what building companies are mandatory to do by law to achieve that goal.

The positive aspect is that it seems that little awareness started getting raised among stakeholders, but still much, in order to tackle the issue represented by construction demolition and waste, has to be done. Regarding stakeholders, lack of awareness prevents clients and companies from making effective demolition and waste planning, which to some extent might lead to fines and improper on-site space management too. Furthermore, lack of knowledge and awareness among the population are mentioned. If people were more informed and aware of the issue, they could start demanding circularity-based solutions for their own private projects, such as the construction of a property. If that happened, importance of sustainable circularity solutions would be spread way better and faster. Therefore, what lacks right now is the presence of effective strict laws and legislations which force (not just advise) all stakeholders in the construction industry to adopt some measures to reduce the problem of waste and demolition. To sum up, if not enough knowledge gets spread, issues such as impact on the environment and the economy of the focal problem might end up being underestimated.

Another of example of what just mentioned above is the European environmental legislation, which indicates that producers have to consider the environmental consequences of their work and should develop effective solutions to reduce the environmental impact of their actions. Since they only “should”, it is not mandatory by law for them to do so and can therefore decide whether environmental impacts could be or not matter of concern for their business. Too often, in capitalist societies, companies tend to act based on their economic interest (mostly their profitability), which is often in contrast with environmental solutions, which might result in being costly and therefore reduce profits. In conclusion, if the European Union really wants to concretely solve demolition and waste related issues, proper laws and legislations, leading businesses the right direction to achieve sustainability, must be passed and do not have to give businesses the freedom to neglect environmental consequences if they interfere with their primary economic interests.

E – Economic

Building components, given the linear economic model through which they are manufactured which contributes to construction waste generation, have a significant impact on the economy, in relation to the fluctuation of prices of many raw materials, which might also depend on their scarcity.

Poor procurement can be considered an economic issue, since too large quantities of materials ordered will represent a waste of money, due to unutilised resources. In addition, an excess of materials and then (incorrectly) stored on site, might cause their double handling with all its consequences (see the consequences of “double material handling” below in this section). Poor procurement is also examined as environmental factor (see poor procurement in “environmental” below).

Poor design management may not end up being accurate and leads to an increase in resources to utilise, as a consequence of re-work to be performed due to differences between design and right technical work to carry out, given the current building regulations and standards. In addition, re-work can be performed due to incongruencies among sets of drawings.

Double material handling might represent an economic issue as well, since materials which get moved several times all over the construction site run the risk of being damaged and would therefore not be suitable for use for any on-site activity. Consequently, three factors will enhance projects costs: ordering new materials (new procurement costs), new deliveries (and their costs) and longer project duration, caused by postponed activities, until new deliveries take place. Postponing work and often the handing-over as well might lead to fines to pay, an additional cost to take into account. Category of waste origin “Double material handling“ can also be analysed as a legal aspect (see double material handling in “legal” below).

Poor participation in on-site construction waste management, as well as inadequate on-site construction waste management could result in being an economic issue for building contractors and sub-contractors too, because of fines to pay due to poor participation or ineffective action taken to reduce or manage waste management according to the authorities. Fines could end up being high and might affect project costs. Inadequate on-site construction waste management is also analysed as a social factor (see inadequate on-site construction waste management in “social” below).

As regards circularity-based solutions, they can only give a positive contribute to achieve sustainable goals, through the recycling and re-use of building materials and components. In addition, the use of second-hand materials reduces project costs and this represents a useful aspect to start with.

Building Information Modelling has proven over the last decade that its implementation in the construction industry will bring benefits, also from an economic point of view, due to accuracy of calculations and estimates, useful when it comes to quantity take-off, design, reduction in design errors, operational costs, better communication, reduction in waste generated and site space management. Moreover, transitioning over to a more digital approach still represents an obstacle and it is a step not everyone might be willing to take. Design errors can occur due to poor and/or lack of proper communication among the parties involved, such us the client and the main contractor, besides technical errors while performing design. Improper communication impedes good cooperation among team members and project stakeholders and this, besides not leading to find effective solutions to design errors, does not favour information sharing, which slows work down and worsens the atmosphere at workplaces. Furthermore, design errors lead to wrong quantity take-off and poor procurement, which both cause generation of waste. In addition, design errors might lead to poor on-site quality performance, which causes rework, resulting in generating even larger quantities of waste and in being expensive, besides postponing the project handing-over.

S – Social

Inadequate on-site construction waste management represents a social aspect to take into account, for two reasons. The first one is that if on-site waste does not get sorted and stored the right way, workers might run the risk of colliding it and get injured. Injuries at work can also represent a social aspect. The second reason is about construction waste getting disposed in landfills, which might represent a social problem as well, since the higher the amount of waste generated is and the more landfills are necessary to be built, which could deprive society of space destinated for other purposes, besides representing a social cost, since landfills are mostly state-funded. This issue is also analysed in “legal” section below.

The circular economy also involves another aspect, which has been forgotten or somehow “overshadowed”, which makes people worldwide aware of one important thing: recycling and re-using are possible also in the building industry. In the early 1990, the idea of recycling and re-using materials and building components previously used for other projects began to catch on, given the environmental damages caused by many sectors among which the building industry. The circular economy aims to replace the linear economic model, based on the “Take-manufacture-use and dispose” concept that society has been used to for decades. With a circular economic model instead, things would drastically change, since it aims to reduce the quantity of raw materials extracted (“take”), manufacture, use and then rather than disposing, building materials and components can be recycled.

T – Technological

Both circular economy and Building Information Modelling represent a challenge and could end up changing and shaping new markets and types of

products.

As already mentioned, the circular economy brought a new way to perceive not only the economy, but sustainability as well; as regards the economy, a new way to manufacture products, not only to be recycled or re-used, has been found. This means that this new way to produce might represent the opportunity to start a new market.

The presence of technology, in this case referred to Building Information Modelling, might improve the general current demolition and waste situation, since BIM tools not only aim to better manage the amount of waste generated, but also to design and then consequently manufacture differently, in comparison to the past. The reason why BIM plays such an important role is because a great deal of information, data and factors need to be taken into account, while choosing the most sustainable and effective deconstruction materials and strategies. Strategies comprise logistics costs, energy use and costs associated with recycling processes, design of components for re-use through design for deconstruction, as well as disassembly and re-assembly works costs. Moreover, buildings are made of several thousands of components with different characteristics that affect their re-usability and recyclability rates.

E – Environmental

Construction demolition and waste lead to several environmental consequences, such as a more polluted near-by environment and more landfills to build, given the ongoing increasing quantities of waste and resource scarcity.

Procurement consists of buying goods and services. If not done properly, due to poor quantity take-off, lack of experience or without taking into account times schedules, poor procurement leads to larger amounts of wasted generated, caused by resources not fully utilised, which are going to be accumulated on-site as waste and then disposed at landfills, which increases pollution in the near-by environment. It can also be considered an economic aspect (see the “economic” part of the Pestel analysis above)

As regards a more polluted near-by environment, demolition and waste often end up contaminating the soil located right underneath or close to building areas and this represents a risk, since aquifer would be affected by unused or waste materials, causing death of many animals species living underground, which means a damage to the general-ecosystem whose balance would be altered and not always possible to reverse. In addition, the construction of new landfills, besides increasing public costs, will also contribute to lessening space, which might be destinated to other types of facilities or purposes. The higher the number of landfills present is and the higher the risk of giving rise to environmental pollution becomes, since ground and space meant for landfills construction might not be properly isolated from the rest of the soil, which would get filled with disposed waste. As it can be easily understood, the consequences of virgin materials scarcity on the ecosystem combined with the presence of more and more landfills, due to waste generation, might lead to an irreversible environmental catastrophe.

L – Legal

The legal factor consists of laws and legislations which affect and influence too the way business is done.

There is clear lack of effective laws and regulations, to safeguard workers’ lives in the construction industry, besides promoting and encouraging the use of circular economy-based solutions and their application to real building projects through the implementation of Building Information Modelling. So, effective policies and regulations still have to be developed not only in relation to sustainability, but also in terms of health and safety.

Inadequate on-site construction waste management could also represent a legal risk for companies. The reason is that if on-site waste does not get properly managed, the contractor/contractors who failed to comply with on-site waste requirements could run the risk of being fined, since improper on-site waste management might jeopardise and affect on-site workers´ health (as already mentioned in “social” section of this analysis). This category of waste origin was mentioned under “legal” section of the PESTEL analysis, which includes health and safety, both of workers and products, as its main aspects.

Double material handling can be also examined from a legal point of view. As already mentioned above, health and safety play an important role in the legal factor of PESTEL. The reason why double material handling can be included in the legal factor is because double and/or unnecessary moving of stored materials, especially if not planned and monitored the right way, may increase the likelihood of collisions between on-site workers and the materials being moved across the site. This will jeopardise workers´ lives.

In conclusion, this chapter emphasises awareness that waste and demolition activities represent a problem, not only for the construction industry itself, but also for the environment and health as well. Despite all, great progress has been made to tackle the issue over the last decade, through the discovering of some circular economy-based solutions, as well as Building Information Modelling. However, still a lot needs to be done, which is what will be explained in detail in the next chapter.

6. Solutions analysis

This chapter aims to analyse how the building industry could benefit from circular-economy-based solutions and their application through Building Information Modelling. In addition, some observations on the advantages of such solutions are made, as well as their disadvantages and what still needs to be done in the discussion of chapter 6.5.

The analysis is based in relation to the solutions found and their benefits, but the main contribution will consist of explaining what still needs to be done, to improve the already existing solutions, both in terms of sustainability and digitalisation, as well as what has not been done at all, but needs to be taken into account and implemented as soon as possible.

6.1 Objective tree diagram

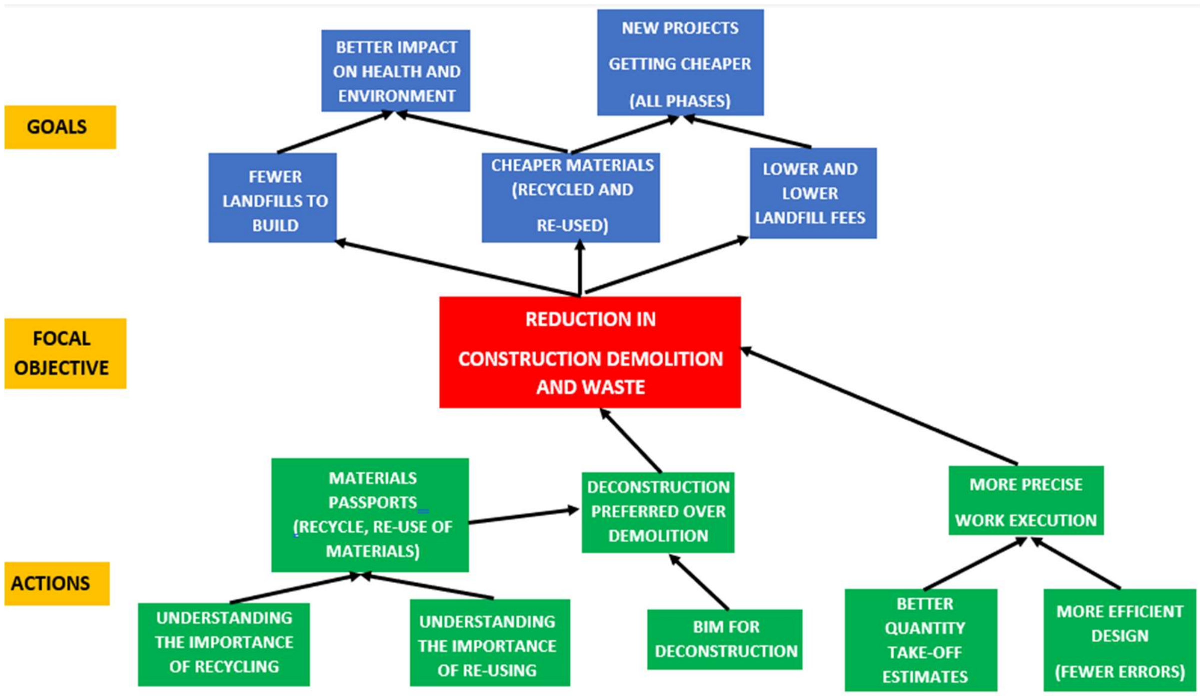

Figure 6 - Objective tree diagram

The problem tree diagram in the previous chapter clearly highlights both the current causes and effects of the focal problem, consisting of construction demolition and waste, which are of different types.

The objective tree diagram (see *figure 6*) on the contrary, aims to display which actions need to be taken, like Materials Passports and deconstruction, in order to achieve the focal objective. However, the circularity-based solutions are possible to apply if the implementation of Building Information Modelling takes place, to perform better design through the analysis of re-usability and recyclability rates.

As regards the circular economy, Materials Passports and deconstruction are the most effective solutions. However, in order to properly apply those sustainable solutions, design efficiency and more accurate quantities estimates are crucial factors and constant attention needs to be paid to them. Therefore, the use of some BIM features is necessary, since they enable to perform deconstruction at the end of the building life cycle, not only to solve design-related issues which hinder deconstruction practises, but also to address quantity take-off, planning, scheduling and on-site-space-related concerns. A reduction in construction waste will lead to a lower use of virgin materials for new manufacturing and the likelihood to face resource scarcity would be decreased. This means better availability on the market of raw materials which would become cheaper, on the same demand. However, the main purpose of the circular economy is not only to decrease raw materials prices, but also to promote sustainability.

6.2 BIM for Materials Passports

The purpose of Materials Passports is to generate value by outlining the potential for re-use and recycling of construction products and materials (EPEA GmbH, 2019), which need to have the right characteristics and properties to be recycled.

The reason why this BIM-supported tool is effective in relation to Materials Passports, is because it contains detailed knowledge on materials properties, which enables to estimate recyclability and re-usability rates, a relevant aspect for design decision-making that takes place at early design stages. Therefore, given the great deal of data to manage, in order to perform efficient design, a BIM software like Autodesk Revit or Autodesk ArchiCAD is not enough and needs to be backed up by another, named Analysis Tool Building One (BO) (see *figure 7*).

Thanks to Autodesk Revit or Autodesk ArchiCAD software, which performs as a drawing platform and knowledge tool for geometry, the basis of the analysis will be set through the creation of building components. But, what makes a difference in relation to Materials Passports, without which assessments would not be possible to conduct, is the Analysis Tool Building One (BO). BO is important to carry out materials properties assessments and their recycling potentials, to fulfil the requirements of project clients, developers, architects, engineering firms and building regulations. In addition, Materials Passports assessments are going to be accurate and possible to review at any time, since bidirectional connection allows ongoing data exchange between the two BIM tools.

However, despite the importance of BO, the first step to take to perform successful assessments consists of drawing up components and classify them the right way, before exporting them into BO for further analysis, to ensure that they will easily match the same elements (and their respective properties) present in BO, meaning that elements geometry and volume in the BIM model are allocated to their properties in BO.

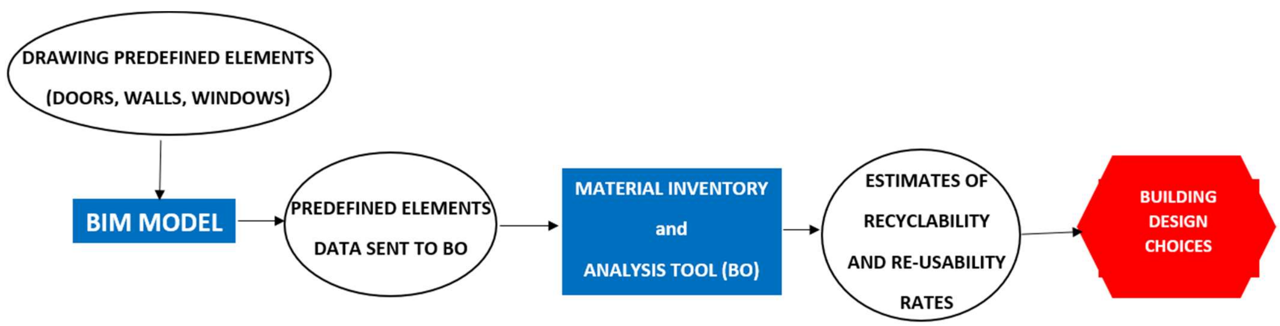

Figure 7 - BIM for Materials Passports

Despite the advantages of such digital tool, there are also some challenges and disadvantages which are worth considering, mostly due to incorrect drawing or classification and data management.

Incorrect drawing or classification of building components into the BIM model might lead to misleading data, that if transferred into the BO software, will cause incorrect calculations and assessments. Consequently, the quality of materials destinated to be re-used or recycled might be lower than expected.

In addition, data management into BO represents another remarkable issue not to neglect. The presence of a great deal of databases, besides resulting in being time-consuming, causes lack of consistency and therefore incorrect or unreliable results and solutions. To prevent this from occurring, working with only one database per time could be an initial solution, because it reduces the likelihood of incongruencies and wrong assessments too, but at the same time, the use of only one database could limit the amount of data being analysed, causing restrained assessments which may influence the final design, affecting the quality of the materials manufactured. In order to solve both issues of drawing/classification and data management, expertise through qualified personnel is required, but it may represent another obstacle, since many building companies, especially the small ones, might not be willing to incur such expenses due to more qualified personnel.

6.3 BIM for Design for Deconstruction

Deconstruction gets properly carried out only if correct design has been previously performed. If *Disassembly and Deconstruction Analytics System* (also known as "D-DAS", see *figure 8*) gets utilised, deconstruction at the end of the building life cycle can be successfully performed. Deconstruction practises will be achievable thanks to a complete analysis conducted by the thee key functionalities of the BIM system, which take into account four fundamental factors, like:

- The building life cycle performance;
- Recyclability rates;
- Deconstructability rates;
- Possible hazards occurring while performing deconstruction activities.

As a result of the first key functionality, named "Building Whole Life Performance Analytics", it will be possible to discover how the initial building life cycle gets affected by the materials chosen at design stages. This key functionality also helps to provide an insight into recyclability or disposal rates.

Through the second one, named "Building Element Deconstruction Analytics", it will be possible to determine whether the building will be more suitable for demolition or deconstruction at the end of its lifecycle, given the design and material choices previously made.

Finally, the third key functionality named "Design for Deconstruction Advisor", will detect potential risks while deconstruction activities are conducted, given the current building design.

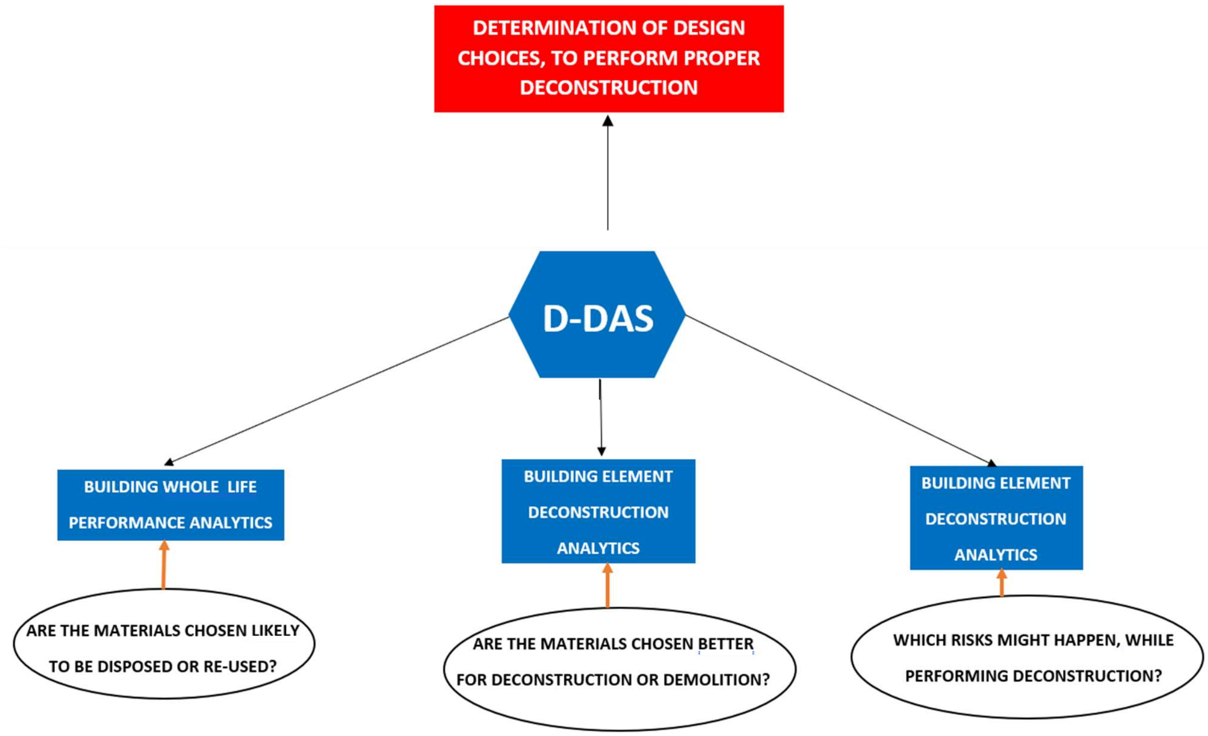

Figure 8 - Disassembly and Deconstruction Analytics System ("D-DAS")

6.4 BIM for the main categories of construction waste

In the literature review, it clearly turned out that the main categories which lead to the generation of construction waste are mostly about poor procurement, poor design and site layout-related issues (such as double material handling, inadequate on-site construction waste and poor participation in construction waste management).

The reason why they occur is because many estimates are made based upon the personal experience of managers, which does not have the same accuracy as BIM software. *Figure* 9 below helps to summarise why BIM tools and features can effectively solve or minimise the five main categories of construction waste.

CATEGORY OF WASTE CAUSE	BIM SOLUTION
Poor procurement	Quantity take-off
Poor design management	Design review
Double material handling	4D simulation/coordination
Inadequate on-site construction waste management	4D simulation/coordination
Poor participation in construction waste management	4D simulation/coordination

Figure 9 - BIM solutions to the main causes of waste

Procurement planning consist of buying goods and services and in the construction industry its poor management mostly occurs when quantity take-off estimates are not made with high accuracy. The BIM software which can help minimise their occurrence can be Autodesk Revit, Vico Office or Autodesk Navisworks, given their ability to link individual building elements to the materials they corresponds to in the model (Olsen & Taylor, 2017). The reason why those tools are effective is because they facilitate quantity take-off estimates and increases their accuracy; consequently, more accurate estimates will lead to better and more efficient procurement, which is going to reduce the likelihood of too large orders, which cause on-site excessive storage and more waste generated.

Regarding design, the main issues are mostly about last-minute changes and technical design errors. These issues can be solved by BIM software Solibri Model Checker, that thanks to its features, will facilitate the detection of errors which can get fixed at early design phases and eliminate incongruencies (Sacks, Eastmann, Lee, & Teicholz, 2018). The design review feature enables the detection of technical errors and incongruencies at early design stages. The sooner eventual errors and incongruencies are found and the cheaper and the more efficiently they will be corrected, since a too late detection right before the beginning of on-site activities, might be stressful to run and could force managers to postpone the work execution planned. Moreover, since design review gives the possibility to optimise design quality, there will be a reduction in construction waste generation due to poor procurement, caused by inaccurate quantity take-off, caused by poor design. Better design also lowers the likelihood of rework due to technical errors while performing on-site work execution.

Double material handling consists of moving several times the materials already stored on site and its occurrence is often caused by lack of experience of the managers in charge of storage or incorrect use of on-site storage space. Changes in on-site layout often occur because of unexpected events and can be resolved by BIM software like Vico Office, Synchro Software and Autodesk Navisworks (Elgohari, 2015). Those software result in being effective thanks to their 4D coordination feature, which examines the building site space in 3D and combines it with scheduling data to enable visual planning, for safer and more organised storage, also in relation to where on-site activities are or will be taking place. Furthermore, it might lower the likelihood of additional orders, due to materials damages caused by unnecessary moving.

Inadequate management of on-site construction waste represents a relevant issue, since once waste has been generated, it must be temporarily stored before getting disposed in landfills and its presence might be in “conflict” with the presence of machines or materials stored. Therefore, planning where to place the waste generated and ensure that it hinders neither work execution nor damage stored materials could be a bit challenging and risky. One of the risks could regard safety, since workers might get injured if any collisions occurred between them and waste being stored too close to working areas. However, if BIM feature 4D coordination gets employed to perform site utilisation planning, given its ability to analyse on-site space and create layouts, inadequate management of on-site waste might be properly resolved. In addition, a 4D coordination can also help to find out where waste containers need to be placed on-site, but also where and when they can be moved in relation to time schedules of on-site activities. Therefore, the use of containers, would drastically eliminate the chances of injuries caused by collisions, as well as fines due to its poor management.

Poor participation in construction waste management is mostly caused by poor communication among contractors, who carry their own activities out on site without always being aware of one another´s activities, as well as by lack of proper waste planning regarding each contractor´s activities. Therefore, to increase the likelihood of better participation in order to reduce waste, BIM feature 4D coordination results once again in being relevant. The reason is that if it were adopted by all contractors, one another´s time schedules would be shared and awareness about all different sub-contracting activities would be raised. Therefore, it would be possible to make common and more effective waste planning, due to better participation and awareness one another´s activities. Effective participation in waste management will also diminish the likelihood of waste-related fines.

6.5 Discussion

Nonetheless, despite the effectiveness proven so far of circularity-based solutions through the implementation of Building Information Modelling, as well as Building Information Modelling alone to solve the five categories of waste origins, some considerations need to be made.

6.5.1 Circular economy

There is no doubt that the circular economy will increase employment, as found by the European Commission, which has estimated an increase in jobs of at least 700.000 units by 2030, only thanks to the adoption of more sustainable and "circular" economic models, due to a higher demand for labour intensive recycling, reduction in demand for primary sectors and increase in economic efficiency (European commission, 2019).

However, such employment changes come at a cost. Despite the advantages of the circular economy, that will benefit the environment and some categories of jobs too, there is one stakeholder in the construction industry and one sector as well that will not profit from it: manufacturers and the mining industry. Regarding manufacturers, the reason is that the circular economy promotes recyclability and re-usability concepts and therefore it discourages the manufacturing of new finished products from virgin materials. Consequently, this would represent a "threat" to manufacturers´ profits, since there would be a lower demand for new finished building elements in the market. About the mining industry, the reason why this sector will likely be negatively affected is because in an economic model like the circular one, which aims to rely less and less on virgin materials, fewer extraction activities will be performed causing a decline to the industry.

By the same token, neither clients nor developers might always find the circular economic model a good initiative, since designing and manufacturing products such a way that they can be recycled results in being expensive, because of high initial costs. High initial costs are due to both the high-quality virgin materials and highly qualified personnel, responsible for carrying out recyclability and re-usability assessments through Building Information Modelling. Consequently, the first construction project "circular" building components are used for as brand-new elements is going to be more expensive, and only in the future, when they are utilised as second-hand elements, projects will be cheaper. Higher upfront costs, as a more expensive initial investment to benefit from in the future which will drive projects costs down, are therefore not costs all developers are willing to incur.

In addition, nowadays it is still very difficult to trade second-hand building materials, due to the lack of a market which enables purchases and sales of such products. Before being put for sale, building elements must be tested, in order to check whether after their first use, the main properties (like load-bearing capacity, tension and compression) still make them suitable for re-use for the same type of construction project as in the past. If they did not, they can be re-used for other types of building projects, whose standards and regulations to fulfil are lower than the previous project elements were used for. To solve this issue, a state-run entity should be appointed, to carry proper testing out. The entity must be public, to ensure that public interest like safety is always prioritised over the private one, whose main goal could mostly be profitability.

6.5.2 Building Information Modelling

Regarding Building Information Modelling, there is no doubt that it contributes to more accurate quantity take-off estimates, as well as better design management and more efficient site layout-related issues solving. However, there are some risks associated with digitalisation and some considerations are worth being made again.

If "Just-in-time" deliveries took place, the risk of excessive storage would be eliminated or somehow drastically minimised and issues like double material handling would be avoided. On the other hand, just-in-time deliveries result in being risky, because their practise would lead to almost no on-site storage and if for any reason they took place later than expected, all upcoming activities will be delayed and this could postpone the entire project duration.

Another concern could be about digital interoperability, which can be described as "*a characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, in either implementation or access, without any restrictions*" (Xia, 2016) or "*the ability of computer systems or software to exchange and make use of information*" (HIMSS, 2020). Due to interoperability, editing or working on data on one software, which was previously elaborated by another, might be a bit challenging, due to different formats. In the construction industry, this may represent a problem too, because the project teams consist of employees from different companies in charge of different tasks often managed by different software. This means that when contractors share or work on data and documents with one another, the different software formats could make the use of digitalisation a bit challenging.

In addition, one of the driving reasons why BIM is still not fully utilised in the building industry is because of the time needed to train employees, as well as costs to upgrade hardware and costs of software, which represent costs not all companies might be willing to bear.

6.5.3 Politics

Concerning politics, some changes need to be made. Chapter 5 highlighted how the lack of strict laws and regulations, to force construction stakeholders to implement such sustainable solutions like the circular economy, limits the solving of the current problem. As already mentioned, the main goal to achieve by year 2020 consists of re-using and recycling at least 70% of the waste produced on site.

However, the European Union only limited to indicate which goals it aimed to achieve, without stating through which means and the increase in landfill fees was the only solution mentioned. But, as it is easy to understand, the enhance in such fees is still not enough to tackle the problem which does not seem to stop occurring and no proper guidance was provided about the circular economy and Building Information Modelling. To sum up, if it were mandatory for architects, engineers and building contractors to apply such effective solutions, construction demolition and waste issues would be drastically solved or limited. But, since stakeholders are still given the opportunity to choose what to opt for, they will most likely continue adopting the same design solutions and demolition practises too, because they give more guarantees since they have been applied for decades, result in being cheaper and fast. The reason why this happens is because the adoption of more sustainable solutions and digitalisation still seems too risky and expensive.

A way to encourage such sustainable solutions might exist: for example, all public European building projects must include the circular economy and BIM as main awarding requirements. In alternative, all building companies, no matter their size or annual revenue, should be required to perform a certain percentage of all their annual projects by applying circularity-based solutions and digital modelling as well. Otherwise, construction firms might be required to comply with such requirements in all tenders (public or private) they take part in, whose budget is higher than a certain amount to be set by public authorities.

7. Conclusion

This main goal of this report is to solve the current issues pertaining to construction demolition and waste, thanks to the present circular economy based and Building Information Modelling solutions. The analysis of the main issue is carried out both in the introduction and in the first part of the literature review, where the economic and environmental impacts were examined, as well as the current situation in the European Union, in terms of laws and legislations passed, in order to tackle the issue. In the second part of the literature review, the categories of the origins of construction waste are mentioned, as well as some achievable sustainable solutions, based upon the concept of circularity and digitalisation too.

The contrast of information included in the first two chapters, represented the premise of this report that leads to the main problem formulation being the following:

"How can the circular economy and BIM contribute to minimising construction demolition and waste?''.

In chapter five, through both the problem tree diagram and the PESTEL framework, it is possible to have a clear understanding of what has been done so far, once awareness of construction demolition and waste being a current issue is raised. The problem tree diagram helps to examine the focal problem, its causes and its occurrence through its effects, while the PESTEL framework provides a detailed analysis from several points of view (like politics, economy, society, technology, environment and law). Still in this chapter, it turns out that awareness started to get raised, since there are some European laws and regulations which aim to minimise the generation of waste, but still much has to be done, given the presence of large amounts of waste produced. In addition, the European Union clearly mentions what goals it aims to achieve, without specifying through which means, like for example circularity based and Building Information Modelling solutions. Furthermore, the current laws and regulations are not stating that it is mandatory by law for stakeholders in the construction industry, to generate less waste or carry out demolition works as little as possible, since they only state that all different parties involved in building projects *should* consider a reduction in waste and demolition works. This means they are given freedom to choose between the new sustainable solutions and the current practices, in terms of both design and on-site work execution, which are currently responsible for such large quantities of waste generated and therefore not suitable to reach such ambitious goals of sustainability. This is due to the lack of knowledge being spread not only among contractors, but among the population as well, unaware of the benefits to the environment and the economy as well of the circular economy and Building Information Modelling.

The main economic benefits of such solutions would lead to a reduction in building costs, due to the use of second-hand building materials and components which discourage the use of virgin raw materials extracted from nature and this would prevent resource scarcity from occurring and their consequent sky-high prices. Switching to more digital methods could still take time, since steps into digitalisation represent a risk not everyone wants to run. The social aspect highlighted how important making the planet more sustainable is, in order to leave a better world to the future generations.

Chapter six starts with the objective tree diagram, whose purpose is to display the benefits of circular-based solutions and the implementation of Building Information Modelling. What turns out regarding the “actions” is that the use of Building Information Modelling would lead to more accurate design, more accurate quantity take-off and better on-site space management that would only benefit any aspect of projects. In addition, besides being used to perform more accurate estimates or better run the building site layout, Building Information Modelling can be helpful to replace demolition works through design for deconstruction. As regards the circular economy, it is possible to understand how important recycling and re-use practises are, rather than disposing. If the Materials Passports and design for deconstruction solutions are adopted, as well as more effective quantity take-off and design thanks to BIM, there will be a reduction in demolition activities and in construction waste, being the focal objective to achieve.

Furthermore, a reduction in demolition activities and lower quantities of waste would bring numerous advantages, like fewer landfills to build and landfill fees will drop and recycling will make building materials and components cheaper. The circular economy can contribute to decreasing the production of brand-new prefabricated elements and consequently the price of virgin materials prices would diminish, due to lower extractions and phenomenon like materials scarcity will have a lower probability to occur. Lower landfill fees reduce building projects costs and will benefit the environment and economy.

As regards design for deconstruction, the BIM-based tool Disassembly and Deconstruction Analytics System “D-DAS” helps to conduct assessments of end-of-life cycle of buildings and examines the building materials characteristics, to determine their re-utilisation, recyclability or disposal rates, as well as possible risks while performing deconstruction once the building life cycle has reached the end. This will have a great influence on design decision-making.

Nonetheless, despite all the advantages of both circular economy and Building Information Modelling, some observations are made.

As regards the circular economy, it is still not possible to sell or buy second-hand building materials and components, since there is no such market which allows it. Moreover, there is currently lack of an entity which carry proper engineering tests out, to check whether the building materials disassembled are still suitable for re-use. If such an entity existed, it would represent a great opportunity to create a market of second-hand construction materials and new jobs as well.

However, the circular economy may not be a great opportunity for everyone, since manufacturers and the mining industry too would be the parties that do not benefit from it. Manufacturers would not profit from the circular economy, since it aims to promote recyclability and not the production of brand-new building components through raw materials, causing a lower demand in the manufacturing sector. There will be a negative impact on the mining industry as well, since the circular economic model aims to reduce the number of extractions for the production of new finished products, which will cause a decline to the industry. In some cases, the circular economy might not always benefit developers and client, since the performance of deconstruction practises is only possible if high-quality building components are manufactured and this represents a higher upfront cost. Higher initial costs will increase the costs of the first building project circular building components are used for. Therefore, investing in circular components will only benefits clients and developers decades later, once the first lifecycle of the building reaches its end. For that reason, higher initial costs for later economic benefits could not represent a cost developers want to bear.

Regarding BIM, it has been noted that just-in-time deliveries represent a risk, since they consist of almost no on-time storage by delivering what is only necessary for the upcoming activities. If they occurred later than expected, they will postpone work execution with the risk of extending the project duration, which may also lead to fines.

Interoperability might be another possible issue, since working and sharing files and documents into different software formats could be a bit challenging. In addition, switching to a BIM work approach requires time to train employees, upgrade hardware and software and these three aspects a cost not all companies, especially the small ones, might be willing to sustain.

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