Circular Economy: Tightening the loop within demolition of existing buildings

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ABSTRACT

This project is aimed to investigate and explore the concept and applications of circular economy, specifically within the demolition of existing buildings, including the relation between this and the building products manufacturing at European level. The emphasis is on understanding the shortcomings when considering the way waste prediction and management is handled as well as the possibilities for improvements in the pre-demolition phase. Currently, there is a big focus on how BIM methods and technology can support the circularity aspect in the future, for instance, within the manufacturing and construction of new buildings, as well as their future demolition/deconstruction, but not the same level of focus is directed towards existing buildings and the waste generated by the demolition of these.

Looking into this aspect, this study aims to bring the loop closer by proposing a standardized framework for pre-demolition audits along with the structuring of data resulted for increasing the promotion and incentive for material reuse and recycling resulted from demolition of existing buildings.

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ABBREVIATIONS LIST

AEC - Architecture, Engineering, and Construction

BIM – Building Information Modeling

CE – Circular Economy

C&DW - Construction and Demolition Waste

DBMS – Database Management System

DfD – design for deconstruction

DfMA – Design for Manufacture

DfR – Design for Reuse

DXF - Drawing Interchange Format

ER – Entity – Relationship

EU – EUROPEAN UNION

GHG – Greenhouse Gas

IDEF0 - Integration Definition 0

IFC - Industry Foundation Classes

LoI – Level of Information

RDB – Relational Database

STEP - Standard for the Exchange of Product model data

UML - Unified Modelling Language

1. INTRODUCTION

According to the latest European Union (EU) statistics on waste generation by economic activities and households (EUROSTAT, 2018), the construction and manufacturing industries have clearly two of the highest waste generation percentages (*Figure 1*). That is the reason why the European Commission makes efforts towards establishing new measures and legislative proposals, in order to raise sustainable growth and help the European states go towards a more circular economy, as well as setting a role model for other states around the world (European Commission, 2021).

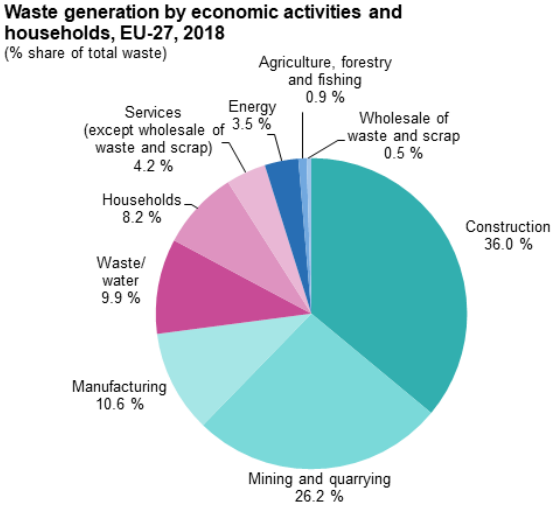


Figure 1 - Waste generation by economic activities (EUROSTAT, 2018)

According to (Lin & Wackernagel, 2020), the estimation for Earth's Overshoot Day 2020 was August 22nd , despite the fact that the world pandemic of Covid-19 has reduced substantially the emissions from fossil fuel use and the rates of logging for timber. That would mean that the Earth's potential to regenerate resources during a whole year, was demanded by the humanity in just 234 days (Lin & Wackernagel, 2020). In a regular year, the date is considerably closer to the beginning of the year: in 2019 the Earth's Overshoot Day was 29th of July (Pytel, 2019).

That is mainly the result of decades where industries have functioned based on linear economy models. This can be explained as the actions of take, make, use and dispose, model that has been and it is still used by the vast majority of industries.

One of those is the manufacturing of construction products. The greenhouse gas emissions resulted from this activity, along with material extraction, construction and renovation of buildings is estimated at 5-12% of the total GHG emission of a country. A total of approximately 80% of the emission could be saved by a bigger material efficiency (European Commission, 2020).

At Denmark's level, about 40% of the total amount of waste in the country belongs to the construction industry (this including demolition) (Miljøstyrelsen, 2020). Moreover, the total amount of waste generated from construction and demolition in Denmark has a tendency of rising over the years according to (Miljøstyrelsen, 2020) as shown in *Figure 2*. That is a strong signal that the way things are done needs to change.

Affaldsfraktioner	Ton (1.000)				
	2014	2015	2016	2017	2018
Blandet bygge- og anlægsaffald	3.121	3.210	3.307	3.184	3.932

Figure 2 - Section of the table showing the total Danish waste generation from construction related activities for both households and business (Miljøstyrelsen, 2020)

When talking about demolition, the first attempts for selective demolition in Denmark have been happening between the years 1981 – 1995 where the officialities in charge of the building industry initiated small steps towards a better selection of the materials resulted from this activity (Miljøstyrelsen, 2017). Based on the experience gained, in 1996 there has been created a first official agreement on the implementation of selective demolition as a fixed quality standard for demolition work (Miljøstyrelsen, 2017). However, this practice hasn't been very successful ever since so the officialities have reviewed it in 2012 when they have created the base for the current document (Miljøstyrelsen, 2017).

That being said, it is beyond doubt that this practice is still at a very young stage, with a possibility of great development and improvement over the years to come.

However, there is a rise in the European recycling rates and there will be an even bigger need for that as the resources of raw materials are becoming very scarce. There are and will be in the future new technological solutions meant to support a more qualitative result of recycling, and more efficient usage of raw materials (Probst et al., 2016).

1.1. Problem area

The concept *of Circular Economy* is very broad*,* but looking specifically within the construction industry this includes aspects such as focusing on how old materials can be reintroduced into the production processes, substituting part of the need for raw materials, how elements can be reused for new projects, and how generally there can be a better selection and usage of the waste resulted from construction and demolition activities, amongst many other concepts (Migliore et al., 2020) . The scope of this report is to find out the current situation, practices, incentives when it comes to the idea of circular economy within the building industry in Denmark, from different perspectives, with an emphasis on the relationship between activities such as manufacturing, demolition and the generated waste resulted from it.

As identified in the introduction, the construction industry is one of the biggest waste generators, but going closer to the root of the problem, it will be interesting to explore how exactly the demolition of existing built assets as well as the manufacturing of some of the construction products influence that status, and how could that change in the future.

It is intriguing to see that only one out of the 18 ''best practice'' businesses within the Nordic countries, when talking about a circular model, it is related to construction (Copenhagen Resource Institute et al., 2015), as well as acknowledging that many of the current circular proposals and solutions are mostly focused on the future constructions, rather than existing ones (Rose & Stegemann, 2018b).

Therefore, this report aims to further investigate and help bridge the gap between current practices and future possibilities for empowering circular thinking when it comes to demolition of existing buildings.

1.2. Problem statement

What data input/output can enable circularity within demolition of existing buildings?

- current situation of the construction industry and the different actors within it, from a point of view of circularity
- demolition and manufacturing status from the CE point of view
- possibilities for promoting the increase of re-use/ recycling of demolition waste resulted from existing buildings

1.3. Context

This paper looks into practices at EU level, with an emphasis on the Nordic countries. The focus is on data input/output for creating awareness about circularity, and the paper does not investigate in depth aspects such as economic or social.

In this context, the term ''existing buildings'' refers to buildings older than 50 years at the time the paper is written, based on the averages of a lifespan of different types of buildings (Marsh, 2017), and taking into account that the very first appearance of studies about virtual buildings or Building Information Modelling (BIM) were the years 1970's, respectively 1990's (Borrmann et al., 2018).

2. METHODOLOGY

This chapter gives an overview and description of the different methods and approaches chosen to collect data and information relevant to the project.

The report is based on three primary sources of data collection:

- Literature review
- Interviews with related industry professionals
- A survey of Danish Building Manufacturing Companies

2.1. General considerations

Based on the aim of the research, it is important that the **methods** for gaining knowledge within the subject, about existing practices but also for possible future development and identification of missing links, are suitable to the purpose of the paper.

2.2. Literature review

The initial design of the research question of this paper is based on ''snowballing '' as the main approach to identify possible practices, issues, and generally finding an initial problem to be further researched thoroughly. The process of this approach started by identifying a start set of papers, which have afterwards been included or excluded for entering the snowballing process depending on their relevance to the subject. Finally, based on the review of the relevant documents and an additional semi-structured interview, the research question has been identified.

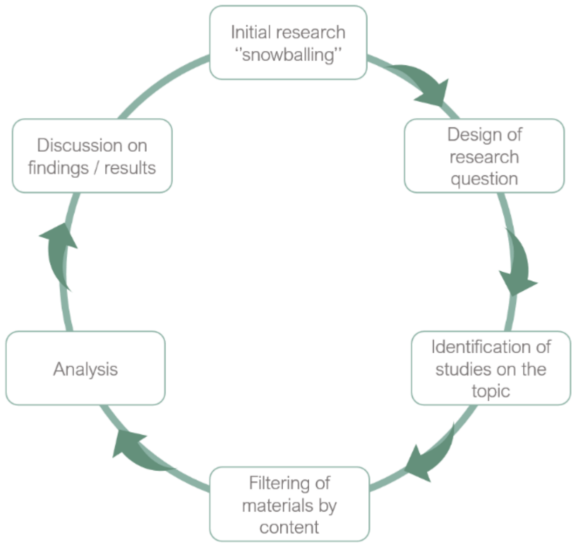


Figure 3 - Systematic literature review process - adapted according to (Denyer & Tranfield, 2009)

Further on, as illustrated in *Figure 3*, for the purpose of investigating and answering the research question, a **systematic review** has been executed. The main databases used for the research are SCOPUS, Web of Science, Science Direct, IOP Science, Google Scholar etc. The terms and inclusion/exclusion criteria used for identifying the relevant literature are detailed in *Figure 4*, as well as the steps in the process itself. However, an additional number of books, articles, conference papers, reports have been included in the overall literature review, for general definitions, methodology, standards and regulations, etc. In addition, for more accurate and relevant findings related to Denmark, a small collection of documents written in Danish have been included in the literature review.

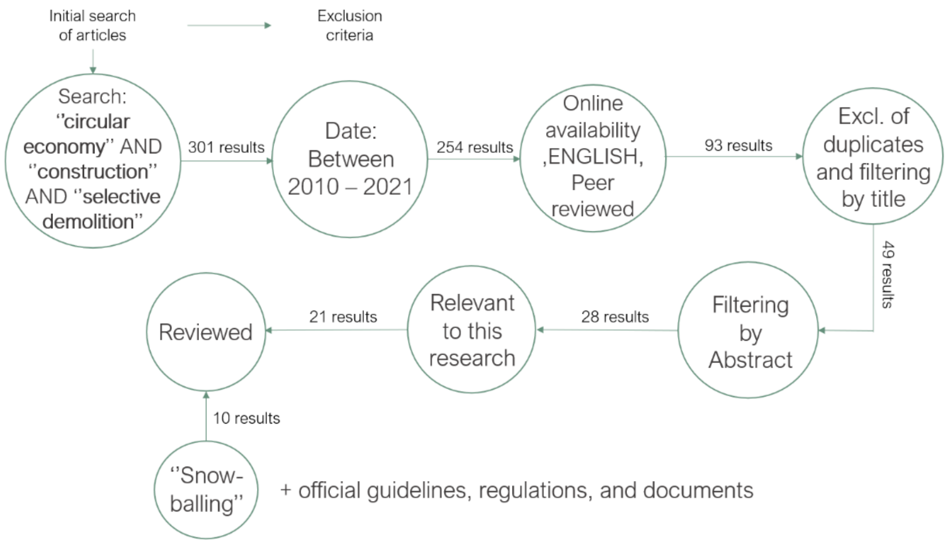


Figure 4 - Steps towards identifying the relevant papers for the systematic review (own illustration)

2.3. Research design

A combination of methods is needed in order to produce a research design for this study, as the intention is to corroborate results from existing research (secondary data) with results obtained throughout this research (primary data). Even more so, the aim is to build on findings from other methods but also looking at the research question from different angles in order to identify as many findings in relation to is as possible (Vogt et al., 2012).

This will involve collection of qualitative data obtained through the systematic literature review, as well as the collection of quantitative and qualitative data obtained through interviews and a survey. All these will give the author a possibility of analysing and drawing conclusions on existing practices regarding circularity within manufacturing and demolition of buildings, but also help identifying new possibilities, needs and future prospective.

For the purpose of developing a solution concept as a part of the answer to the problem statement, there will be used relevant methods such as Conceptual Modeling and Contextual Design.

2.4. Contextual design

A well-structured user-centered design process that helps the development of and IT system by specific methods of collection of data about users, interpretation and subsequently usage of this towards the creation of a prototype, and finally testing and refining of solution based on the users' needs (Holtzblatt & Beyer, 2014). *Figure 5* presents the two major phases within Contextual design, and the eight sub stages that support the creation of a brand new ''product'', by assuring the continuous involvement of the users and their needs.

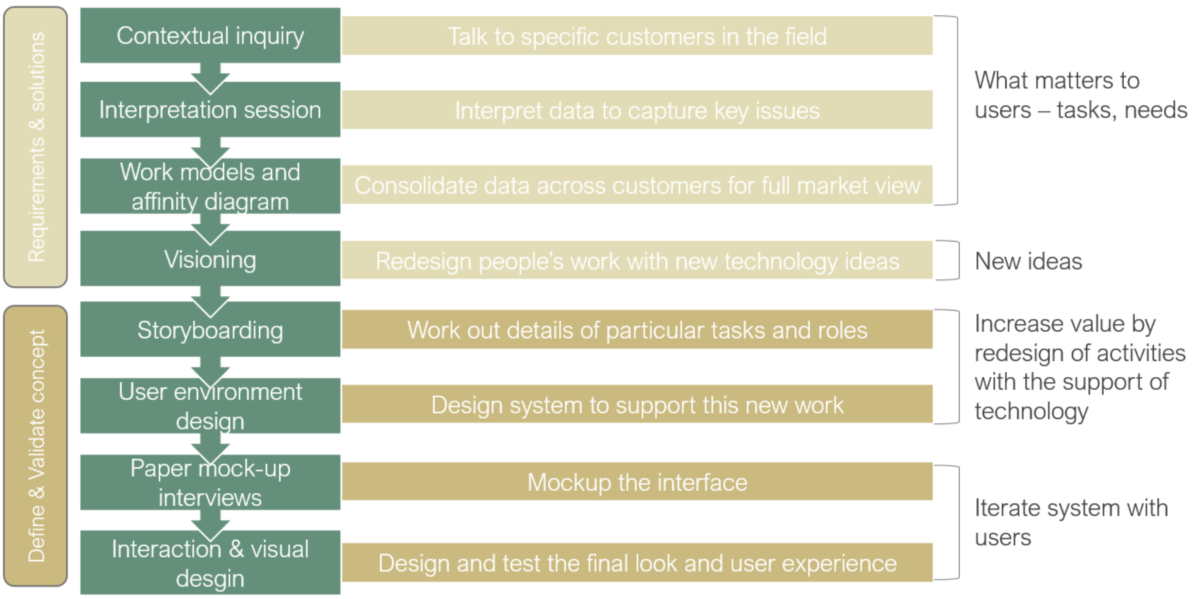


Figure 5 - Contextual Design process – own illustration according to (Holtzblatt & Beyer, 2014)

However, this paper will not cover the full development of an IT solution, therefore Chapter 5 will be based on the most relevant parts of the Contextual Design concept for the purpose of the current research, adapted for the presented proposal. The Requirements & Solutions phase is represented by the primary data collection such as interviews together with findings from literature, and the systematization of these into key issues, and out of the second phase, the Storyboarding and User Environment Design along with mock-ups will be covered up to a certain level.

2.5. Conceptual modeling

'' A conceptual model is the model of an application that the designers want users to understand '' (Johnson, 2008)

That being said, conceptual modeling is very vaguely defined in the literature (Robinson, 2008). However, there are a few aspects that it is agreed on, such as the fact that it refers to the early phases of a simulation study. That would basically mean the transition from the initial identification of a problem that could eventually be solved by the creation of an application, to the stage recognizing *what* and *how* is going to be modelled (Robinson, 2008).

A more precise way of referring to a **conceptual model** is '' a non-software specific description of the computer simulation model (that will be, is or has been developed), describing the objectives, inputs, outputs, content, assumptions and simplifications of the model '' (Robinson, 2008)

There are various methods for putting together a conceptual model such as Integration Definition 0 (IDEF0), Entity- Relationship model (ER) or Unified Modeling Language (UML), but the ER has proved to be the most suitable in the context of the proposed solution.

2.6. Primary Data collection

With the scope of collecting primary data at a certain point in time, there have been used methods such as interviews and a survey as follows.

2.6.1. Interviews

There have been conducted **semi-structured interviews** with industry professionals within Denmark, with different insights and experience within the sustainability aspect of the construction and building industry. This type of interview has been considered as most suitable for the aim of this research, as it is very versatile and flexible, and it allows the interviewer to improvise follow-up questions depending on the participant's responses (Kallio et al., 2016).

The interview guides have been created based on the principles presented by (Kallio et al., 2016) and all the specific steps are detailed in *Figure 6* .

The answers to the interviews have been analysed using the *framework method for the analysis of qualitative data* as described and structured by (Gale et al., 2013), analysis which will be detailed within Chapter 4 (for full transcripts see Appendix A,B).

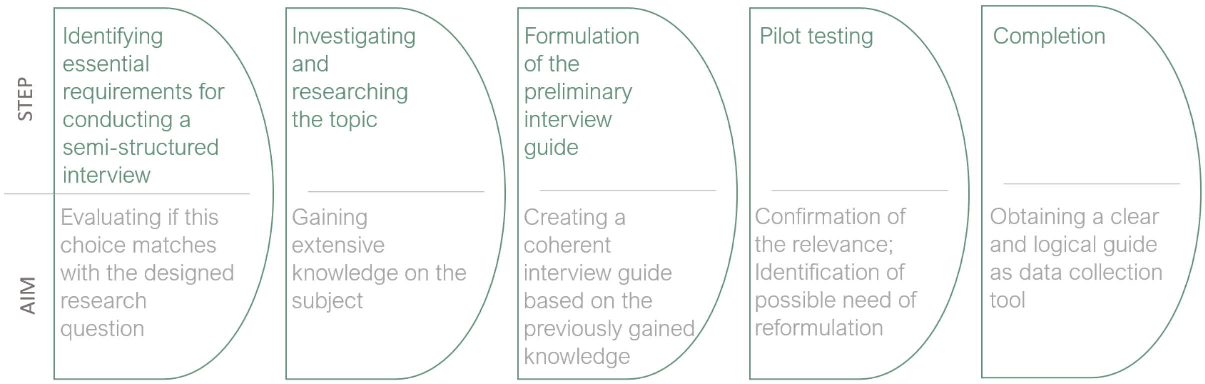


Figure 6 - A framework for the development of a qualitative semi-structured interview guide – adapted based on (Kallio et al., 2016)

2.6.2. Cross-sectional survey

A collection of **primary data** has been conducted through the means of a **cross- sectional survey,** which is meant to capture information about a specific area or subject at one point in time. The questions have been designed based on literature review about circular economy within the manufacturing industry, plus an initial **semi-structured interview** with the representant of the leading company in Denmark for selective demolition. This has been the base for creating a set of 22 different questions, designed to collect both quantitative and qualitative data points.

The language the survey has been designed in was Danish, as this feature has been expected to help generate a better feedback compared to an eventual survey designed in English.

The method chosen for selecting the participants in the survey, taking into account the purpose of this project has been the **non-probability sampling**, more precisely **purposive sampling** (Trochim, 2020). This means that the targeted respondents were selected by using the researchers' expertise, aiming for the sample that would be most useful for the purpose of the project. In the context of this paper, this was the most appropriate method due to the exploratory character of the topic chosen.

The survey approached an approximate number of 100 manufacturing companies, specifically within the construction materials/elements niche, which have the manufacturing facilities within Denmark. The answers percentage was of approximately 19%, and therefore resulting in a collection of 418 quantitative and qualitative data points.

This survey was designed to help find out general information regarding types of materials used, size of the companies, annual waste generation percentages, eventual circular economy practices within the companies, economic advantages/disadvantages, barriers that hinder the implementation of the circular concept, but also professional opinions about eventual future possibilities of increasing the circularity of the business models. All these aspects will be further discussed and analysed in Chapter 4 (for full transcripts see Appendix C).

3. LITERATURE REVIEW

Presentation of the summarized and synthetized information and findings revealed by the literature review.

3.1. General considerations

This chapter will go in-depth explaining the general terms, ideas and concepts revolving around *circular economy* in the construction industry, but it will also present the results of the systematic review of literature in order to find answers and solutions for the problem statement formulated at the beginning of this paper.

3.2. Linear Economy vs. Circular Economy

3.2.1. Linear Economy

The shortest way to define the *linear economy* term would be: *'' a linear model of resource consumption that follows a 'take-make-use-dispose' pattern ''* (Ellen MacArthur Foundation, 2013). Linear model represented in *Figure 7*.

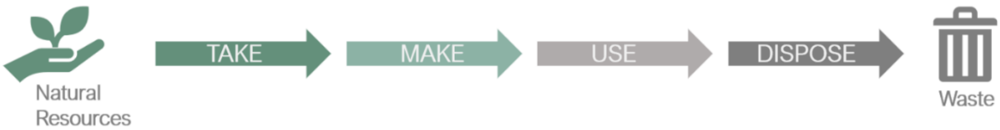


Figure 7 - Linear model (Own illustration)

It is important to understand this concept well by also understanding the effects it has had over the years on economy, raw-material sources, pollution, environmental issues, before stepping further into the concept of circular models and thinking.

Even though our industrial economy has constantly evolved and developed through the decades in many ways, the fundamental aspect, a *linear economy model,* has been unchanged ever since the very beginnings of industrialization (Ellen MacArthur Foundation, 2013). The way companies are extracting the raw materials, to then transform them into products that the consumers dispose of soon after a short-term use of those, is leading rapidly to resource scarcity and implicitly other issues (Ellen MacArthur Foundation, 2013).

The few initial downsides of the linear model as notices by different companies have been the risk of price risings for raw materials as it becomes gradually harder to extract it, and therefore supply disruptions too (Ellen MacArthur Foundation, 2013).

'' ***Over the past five decades, our global population has doubled, the extraction of materials has tripled, and gross domestic product has quadrupled. The extraction and processing of natural resources has accelerated over the last two decades, and accounts for more than 90 per cent of our biodiversity loss and water stress and approximately half of our climate change impacts. Over these last 50 years we have not once experienced a prolonged period of stabilization or a decline in global material demand.*** '' (International Resource Panel, 2019)

According to (Ellen MacArthur Foundation, 2013) the Global resource extraction was estimated to grow from 65 billion tonnes in 2010, to 82 billion tonnes in 2020, but the numbers in 2017 already, according to (International Resource Panel, 2019), were of approximately 92 billion tones, which makes more than obvious the desperate need for a change in the way the world consumes.

Looking into the area discussed within this paper, it is alarming how the construction industry has almost no consideration of the effects that construction material harvesting and processing have over the environment and society. The real thought about the fate of buildings once they have been erected and handed over is almost non-existent, as built assets are still stripped out and taken down on a regular basis, while other new ones are constructed by the use of elements made out of hardly achieved virgin materials (Cheshire, 2019).

3.2.2. Circular Economy

There is no set definition for ''circular economy '', therefore this can vary **from** being described as '' *a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. In this way, the* ***life cycle of products is extended.***

In practice, it implies ***reducing waste*** *to a minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible. These can be productively used again and again, thereby* ***creating further value****.''* (European Parliament, 2020),

TO

'' a circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital. It is based on three principles:

- *Design out waste and pollution*
- *Keep products and materials in use*
- *Regenerate natural systems ''* (Ellen MacArthur Foundation, 2021b)

However, all definitions available out there are describing the same main factors that involve the need to reduce **waste** by different means such as optimization of raw-material usage, design of better and more durable products, re-purposing, re-using, recycling, and overall a more responsible consumption behaviour.

3.2.3. Transitioning from Linear to Circular

The concept of circular economy is currently in everyone's attention: from world business leaders to policy makers, to academics or NGO's (Copenhagen Resource Institute et al., 2015). It seems like the World needs to transition towards this thinking generally, in order to help preserve nature and environment for the generations to come. This model has the potential of offering opportunities for better development, by establishing a resilient economic model that is diverse and inclusive at the same time (Ellen MacArthur Foundation, 2021a). Simultaneously, it will help tackle the global issues such as climate change, loss of biodiversity or pollution, by aiming to give form to an economy where waste is minimal and resources become regenerative by design (*Figure 8*) (Ellen MacArthur Foundation, 2021a).

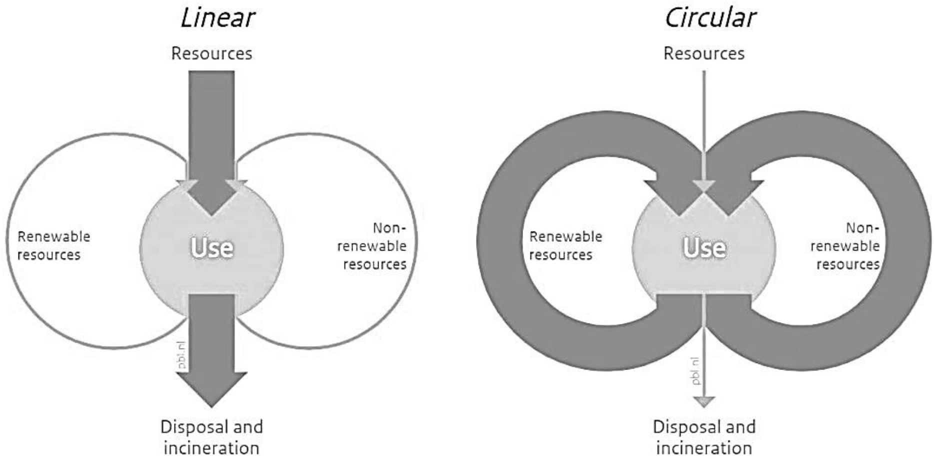


Figure 8 - Linear vs. Circular (PBL, 2021)

Currently, countries are making efforts to recover from the effects of the Covid-19 pandemic, and this can be a crucial moment for broad restructuring in the way things are done, and a very big opportunity for core changes (Ellen MacArthur Foundation, 2021a). Transitioning to circular ways involves many aspects, and not just better waste management or better recycling. This concept aims to touch on and possibly improve aspects such as economic, environmental but also social, and ultimately leading to a more stable society (Ellen MacArthur Foundation, 2021a).

(Ellen MacArthur Foundation, 2021a) proposes five complementary policy goals that could help strengthen and grow the industrial transformations, which will take the circular economy practices to a totally higher scale:

- Stimulate design for the circular economy – from fast-moving consumer goods to long-term assets;
- Manage resources to preserve value – creating tax and policies that support reparation, sharing, resale, remanufacturing to maximise asset use;
- Make the economics work – create economic incentives that will lead to circular models being the norm and not the exception;
- Invest in innovation, infrastructure and skills;
- Collaborate for system change – public -private collaboration with the aim of reducing barriers, and setting new standards;

At this point in time, the transition is happening, but at a slow pace compared to the actual need of it (Ellen MacArthur Foundation, 2021a). Many businesses across the Globe have been turning to circular ways in the last 5 years, and numbers are showing that profits can definitely exist under this business model, as many industry giants have earned considerable percentages resulted from their circular solutions (Ellen MacArthur Foundation, 2021a).

3.3. Construction and Demolition

3.3.1. Construction materials, waste generation and management in Europe

According to (European Commission, 2020) the construction sector requires a great amount of resources and it is responsible at the same time for approximately 50% of total material extraction. At European level, this industry is accountable for over 35% of the total waste generation. The level of GHG generated from all activities related to this industry is also very high and in order to be able to reduce it, there has to be a bigger focus on material efficiency, which could save up to 80% of the emissions.

In the new Circular Economy Action Plan (European Commission, 2020) there are included the main proposals for the future development of circular economy within this industry:

- Revision of the *Construction Product Regulation* which could include requirements for recycled content, while keeping in mind the performance of the products;
- Development of digital books for built assets;
- Possible integration of Life Cycle Assessment in public procurement, and better monitoring of carbon emissions;
- **Possible raise of the current requirements for material recovery targets set in EU legislation**;
- Promoting of initiatives to reduce soil sealing. (European Commission, 2020)

In practice, the **linear process** of construction begins by the extraction of land, minerals, metals, and it ends at the end-of-life of a building with a large amount of demolition waste and implicitly pollution. The general issue is that most of the building designs are focused on the current users and these are built with very little to none long term thoughts (Cheshire, 2019).

In a **circular process** of construction, the waste is repurposed into secondary resources for material production, or it is reused as elements reintroduced in the cycle of construction (*Figure 9*). At the same time, raw materials are still fulfilling the same role, only in smaller quantities and for a much longer and smarter use, through a more efficient design (Wahlström et al., 2020). The added value comes also from better product designs which will then allow for better opportunities of reuse or recycling of the main materials. Implicitly, this involves a core restructuring of firstly

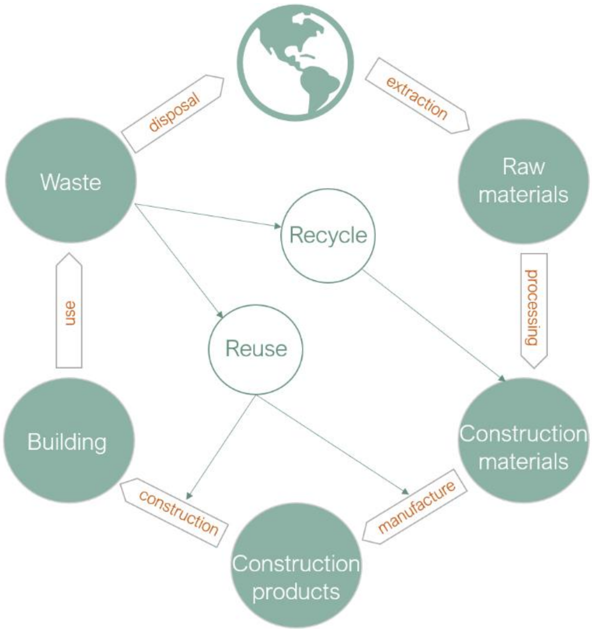


Figure 9 - Circular process of construction - own illustration adapted from (BCIT, 2021)

the way of thinking, and then value chains and business models in order to be able to achieve that (Wahlström et al., 2020).

In the context of existing buildings, where the initial construction hasn't been designed to be deconstructed, selective demolition is the main objective in order to maximize the amount of recoverable materials. However, at the time this paper is written, the potential of recycling/reusing Construction and Demolition Waste (C&DW) is under-exploited, despite the high quantitative status of it (Wahlström et al., 2020).

3.3.2. Waste hierarchy

Ever since 2008, the EU has adopted a framework waste directive, which was updated last in 2018 (Directive (EU) 2018/851, 2018), where the waste hierarchy is defined, as a very important factor within waste management in general. The biggest priority is therefore waste prevention, followed by reuse, recycling, recovery and finally disposal as shown in *Figure 10*. This sets precise targets towards reduction of waste, but also requirements for waste management and recycling, more precisely recovering targets for C&DW to have been fulfilled by 2020 (Wahlström et al., 2020). It also includes a requirement for all member countries to encourage and support selective demolition.

This directive contains criteria as well for establishing when waste can become a secondary source for products or materials. This '' end-of-waste '' criteria is currently still under development, and the specific materials investigated so far are iron, steel and aluminium scrap, glass cullet and copper scrap (Directive (EU) 2018/851, 2018).

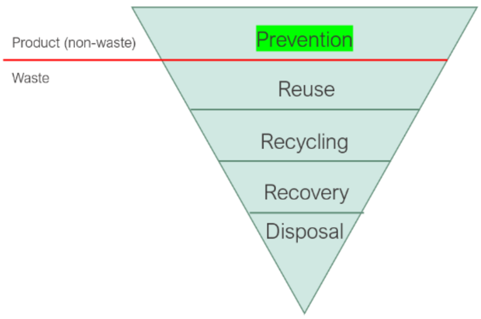


Figure 10 - Waste hierarchy - own illustration based on (Directive (EU) 2018/851, 2018)

The European Commission is requiring that all EU member states to create regional waste management plans, which should allow relevant stakeholders and general public to get involved and have a contribution in the elaboration of the plans.

These are required to be sent to the EC and be revised and updated every 6 years, and the ultimate aim is moving up the waste hierarchy.

3.3.3. Current practices in the Nordic construction sector

When it comes to the Nordic countries, the C&DW waste generation accounts for about 36% of the total yearly waste in Denmark, whereas Sweden, Norway and Finland have approximately a percentage of 30% C&DW. An example of a very common practice in these countries is that C&DW is used as the layer of gravel underneath roads, resulting this way into a high recycling percentage, but this is seen as a down-cycling process which basically implies the loss of value of these materials, and there is definitely space for improvement from that point of view. (Høibye & Sand, 2018)

The Nordic Waste Prevention Group has initiated different projects (Copenhagen Resource Institute et al., 2015) with the aim of transforming the circular-economy thinking a mainstream aspect in the Nordic countries, rather than an exception, by pushing towards a faster transition.

According to a study (Copenhagen Resource Institute et al., 2015), Nordic businesses within the construction sector suggest additions to current law and regulations such as '' **requirements on content and quality of building materials, requirements for the documentation of the use of reused building products and building products containing recycled resources in buildings and requirements for waste and demolition plans** '' (Copenhagen Resource Institute et al., 2015) which could make it more likely and simpler for different businesses to transition.

3.4. Key findings from systematic review

Table 1 presents the list of fully reviewed articles that were included in the systematic literature review, and the main topics within their content.

Because the topic researched is of big relevance nowadays, the papers were filtered to be not older than 10 years. However, the final selection, as presented in the table above, were not older than 6 years. The distribution of the articles depending on the year of publishing is presented for a better visual understanding in *Figure 11*.

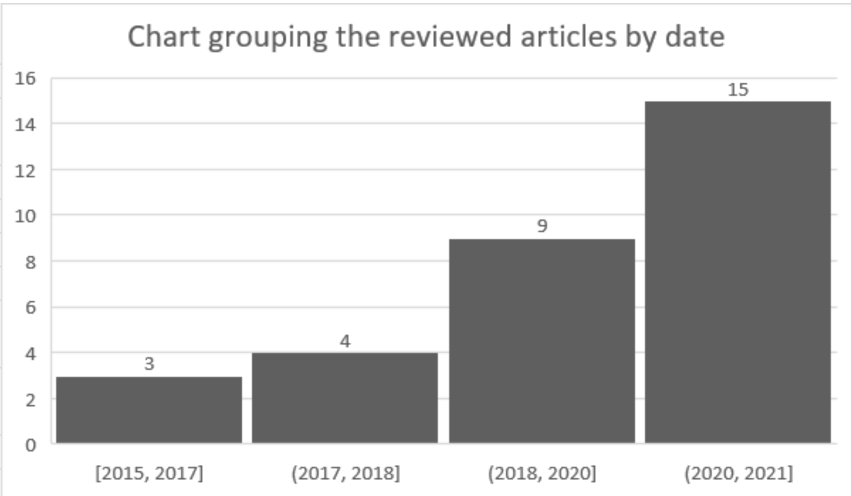


Figure 11 - Chart grouping the reviewed articles by date

No.	*Article \ Topic*	*Existing buildings*	*Remanufacturing*	*Reuse/Recycling*	*Demolition/ Waste audits*	*Design importance*	*Barriers*
1.	(Figl et al., 2019)				X		
2.	(Carvalho Machado et al., 2018)				X	X	
3.	(Ruggeri et al., 2019)				X		
4.	(Appelgren, 2019)			X			
5.	(Pavlů et al., 2019)			X			
6.	(Kozminska, 2019)			X			
7.	(Kozminska, 2020)			X			
8.	(Rakhshan et al., 2020)			X			X
9.	(Jockwer et al., 2020)					X	
10.	(Kovacic et al., 2020)			X		X	
11.	(Chen & Huang, 2020)		X				
12.	(Más-López et al., 2020)			X			
13.	(Josefsson & Thuvander, 2020)			X		X	X
14.	(Rose & Stegemann, 2018a)			X	X		X
15.	(Bertino et al., 2021)			X	X		
16.	(van den Berg et al., 2020a)				X		
17.	(Iacovidou & Purnell, 2016)			X		X	X
18.	(van den Berg et al., 2020b)				X		
19.	(Kancheva & Zaharieva, 2020)		X	X			
20.	(Brütting et al., 2019)			X			
21.	(Teijón-López-Zuazo et al., 2020)			X			
22.	(Sfakianaki & Moutsatsou, 2015)	X			X		
23.	(Hradil, Wahlström, Bergmans, et al., 2019)				X		
24.	(Rose & Stegemann, 2018b)	X		X			X
25.	(Rašković et al., 2020)	X			X		
26.	(Kyrö, 2020)	X					
27.	(Ehlert et al., 2019)			X	X		
28.	(Hradil, Wahlström, Teittinen, et al., 2019)	X			X		
29.	(Probst et al., 2016)			X			X
30.	(Adams et al., 2017)			X			X
31.	(Bertino et al., 2021)				X	X	

Table 1 - Literature included in the systematic review and the main areas of study

The systematic review of relevant articles offers a better understanding of where the industry stands from the perspective of the topic researched.

''The talk'' about circular economy is spreading rapidly, however, when it comes to the construction industry, many of the circular solutions are intended to be transitioned to in the future. Therefore this paper aims to find out more about the existing buildings, those that do not necessarily come with 3D models, or data sets attached to it, those which haven't been designed in the technology era and therefore do not come with a lot of information when their end of life comes.

Many papers and studies (European Commission, 2020; Ellen MacArthur Foundation, 2021a); Høibye & Sand, 2018; Cheshire, 2019) look into how circular thinking and practices can be achieved in the near future, by setting goals, rules, by structuring these into clear aims and procedures.

But when it comes to the relationship between building manufacturing and demolition, there are many suggestions as to which direction the industry should go towards. There have been efforts put into adapting the general suggestions for moving towards a general circular economy (Ellen MacArthur Foundation, 2013;European Commission, 2020) into guidelines with the same purpose, but applied specifically to the construction industry (Cheshire, 2019; Arup, 2016; Høibye & Sand, 2018) .

The idea of looking at buildings as *material banks* by ensuring that the materials going into these are valuable and will still be valuable at the end-of-life of a construction (BAMB, n.d.) it is undoubtably very good, same as creating something such as a *material passport* in order to control and monitor data about specific materials (BAMB, n.d.), however, all these have the biggest focus on transformations taking place from now on, without looking too much into the situation of existing built assets. The future developments, or the developments **for** the future, are without a doubt the way to go in order to create a shift in the construction industry and ultimately leading this to a circular model (BAMB, n.d.). But just as important on the list should be solving the puzzle of old buildings and the upcoming waste resulted from those, because in the days we live it is fairly simple to create theoretical policies and promote circular ideas with regards to the way things could be done in the future, with the support of technology, but there is still a pressuring issue when it comes to waste management resulted from the demolition of existing buildings and there is a need for better theoretical refinement of CE within this specific field (Kyrö, 2020).

The transition to CE it is a very complex process and it will definitely not happen overnight, but Ellen McArthur Foundation has created a framework called RESOLVE, which includes a set of steps towards business transition to circularity: Regenerate, Share, Optimise, Loop, Virtualise, Exchange (Ellen MacArthur Foundation, 2015). However, according to the research of (Kyrö, 2020), only a few of these steps are relevant to the case of existing built assets and those are:

SHARE – shared spaces, co-location synergies;

OPTIMISE – preserving and adapting materials and components;

VIRTUALISE – emerged into sharing;

EXCHANGE – or rethink;

The most relevant to the subject investigated by this paper is ''**Optimise**'' as this includes the concept of adaptive reuse of materials and components (Kyrö, 2020). Unfortunately, the first records of materials in an existing building take shape only when they are entered into a waste report, at the end of life of a building, as records for these built assets have the tendency to be very poor or non-existent (Rose & Stegemann, 2018b). In this way, the potential high-value components and the opportunity of those being reused is basically skipped.

Current practices and regulations

A system that would allow materials and components to be assessed by professionals long ahead of a demolition project could help identify the potential for upcycling or reuse, as well as recycling (Rose & Stegemann, 2018b). A variety of studies show that currently, the demolition contractors have a very subjective way of dealing with waste management (van den Berg et al., 2020b), as there are not enough assessment tools for the evaluation of materials and components in the buildings they are having to tear down, as well as lack of standardized techniques. In addition to that, it is still difficult to reclaim components from demolition, and the prices for the materials are still very low compared to the labour price of carefully taking them down (Rose & Stegemann, 2018a). These contractors usually are responsible with deciding the fate of the materials, guided by uncertainty in regard to their usefulness, fear of extra costs, and fear of possible risks generated by the eventual reuse or repurposing of those (Rose & Stegemann, 2018b).

However, the EU is making efforts within establishing guidelines for well managed demolition and renovation projects (European Comission, 2018), and one of the focuses is on the good-functioning of the pre-demolition **waste audits**.

A waste audit represents the practice of assessing a building prior to demolition or renovation, in order to identify waste streams (European Comission, 2018). It is very important that a total or partial demolition project is well planned ahead of time, in order to minimize the environmental impact resulted from this action, by identifying potential hazardous materials, reusable or recyclable materials (European Comission, 2018). Even though the steps outlined within the official document ''Guidelines for the waste audits before demolition and renovation works of buildings '' are very clear, the practice still differs greatly from a country or region to another, and there is a lack of consistency to it (European Comission, 2018).

As for actual possibilities of reuse for building materials, this is an ongoing research, but many studies have shown different potential rates of the most common materials found in constructions (Iacovidou & Purnell, 2016). A **high potential**, as far as the current knowledge goes, is for reuse of clay bricks (lime-based mortar), structural timber, structural steel, concrete building blocks, concrete paving slabs, clay or concrete roof tiles, stone paving, stone walling (Iacovidou & Purnell, 2016; Brütting et al., 2019; Más-López et al., 2020), but also smaller items and components from inside buildings such as appliances, fixtures etc (Appelgren, 2019). With a **medium potential** at this time, but still having a possibility for reuse would be steel cladding, sections, pipes, precast concrete, slate tiles or timber floorboards (Iacovidou & Purnell, 2016). There are also **low potential** materials that in the right circumstances can become valuable such as mineral wool, gypsum wallboard, steel rebars, timber trusses, concrete elements or glass components (Iacovidou & Purnell, 2016).

However, a successful implementation of material and component reuse is based mainly on the technical attributes of these such as durability or minimum performance requirements set by regulations, as well as the will and capability of the organizations engaged in a specific project (Rakhshan et al., 2020). In order for this approach to become popular and efficient there is a big need of interdisciplinary collaboration (Rakhshan et al., 2020). There are a few vital elements that could contribute massively at the development of this area, and these are inventory, classification and analysis of the materials and elements (Josefsson & Thuvander, 2020). As mentioned before, the waste audit can cover most of these aspects if the auditor has, as required, very good knowledge about current and historical materials and products, as well as building techniques and legal requirements, but also demolition practices, waste treatment and eventually local markets, in order to realize a correct assessment (European Comission, 2018; Hradil, Wahlström, Teittinen, et al., 2019). Moreover, existing research such as (Bertino et al., 2021) can represent a very good base for both audits and demolition contractors towards improvement of assessment and choice of methods and strategies for achieving the most balanced and efficient process of demolition, in order to be able to increase waste prevention and maximize the valorisation of the materials resulted from a project.

Economic circumstances

The economical aspect within transition to CE is one of the biggest challenges, as the financial case is still very unclear (Adams et al., 2017) the cost benefit is not understood by every party involved, and there is uncertainty and fear that CE won't bring profits the same way as a linear business (Adams et al., 2017).

At a more technical level, as long as manufacturing costs when using waste as input (recycling) are higher than extracting raw materials, there is not much incentive for businesses to change their linear ways, unless eventual taxes on virgin materials, or shortages on material extraction will take place and that way creating motivation for a change (Wahlström et al., 2020).

When talking about *reuse,* studies (Rakhshan et al., 2020) show that this is a more preferred way of reducing waste, as there is potential for financial savings when using recovered building elements for new constructions (Rakhshan et al., 2020), shortly said making new buildings cheaper. Once awareness increases about prices of reused building components being attractive, there is a potential for growth of this way of circular practice.

However, there are barriers hindering the mass adoption of this procedure, as it is believed to be more labour intensive, as deconstruction is more time consuming than demolition, therefore more expensive to recover the materials, than the actual profit generated by the re-selling of those (Iacovidou & Purnell, 2016). Another economic barrier of reuse is the increased price of design incorporating recovered building materials: this has to stay flexible, relying on the chance of finding the right elements for the desired designs (Rakhshan et al., 2020), and other economic aspects hindering this process are costs of component testing, costs of adjustments, or lack of an recognised market for reused components (Rakhshan et al., 2020).

Transitioning

In order to change the core of the way the construction industry works and not only, the base should be set by educating the professionals in this field as early as possible, to have a circular thinking, before they actually reach their first jobs in the field (Josefsson & Thuvander, 2020). That, and a bigger effort for '' *promoting research, development, tests, demonstration project and market maturity of circular solutions and technologies* '' (Høibye & Sand, 2018) should have a big impact into pushing a more rapid transition to a CE in the construction field, where still many businesses are basing themselves on old practices.

Reuse and Recycling potential of construction materials

The limited knowledge on demolition comes from the low volume of this in comparison to the construction of new buildings (Sfakianaki & Moutsatsou, 2015). And the decision of tearing down a building or not is purely managerial, mostly dependent on the owner, even though this can have effects on social, environmental and financial aspects (Sfakianaki & Moutsatsou, 2015). There is still a general ongoing dispute in Europe in regards to the best environmental solution for ageing built assets, and whether demolition followed by new construction or an extension of life cycle is the way to go (Sfakianaki & Moutsatsou, 2015).

However, building materials and components don't include only structural elements and doors or windows, and a good representation of this is contained by (BIM7AA, 2017) as shown in *Figure 12*. Built assets contain many complex components such as the equipment used to service the building or interior fittings etc (Cheshire, 2019). All these are made of a vast variety of materials, some toxic and some not, therefore it is very important to work towards empowering the customers and public buyers, which the EU plans to do by setting new policies involving requirements for correct and trustworthy information on products when they land on the market (European Commission, 2020). It is a crucial factor for ordinary people or businesses to receive the right information in regards to a product's lifespan, repair possibilities, spare parts or correct disposal (European Commission, 2020), in order to be able to make use of those in the most optimal way.

Figure 12 - Categories of different building elements and materials as presented by (BIM7AA,2017)

Drivers and actions for promoting circular practices

Currently, aspects such as price fluctuations and resource scarcity are driving a general interest for circular ways, as well as the goal of sustainable businesses, and EU regulations pushing for a better waste management are creating bigger demand for high quality recycled materials and reuse (Probst et al., 2016). There are still barriers such as the export of waste which discourage local investments for optimal recycling or the actual organization of waste collection that does not necessarily support the efficiency of recycling (Probst et al., 2016), but these can be directly tackled in order to minimize their downsides.

There are many suggested interventions for promoting circularity in the construction industry such as adaptive reuse, deconstruction, Design for Deconstruction (DfD), Design for Reuse (DfR), Design for Manufacture (DfMA) (Iacovidou & Purnell, 2016), however, most of them refer to the buildings designed from now on, with the help of technology.

For the end of life of built assets, with focus on ageing ones, the main CE aspects are deconstruction, selective demolition, reuse of products and components, closed loop – recycling or open-loop recycling, which go hand in hand with one very important CE aspect within building product manufacturing, which is the use of secondary materials for production (Adams et al., 2017). This can be one of the potential benefits of selective demolition and a better assessment prior to this activity from a CE point of view.

Existing buildings

Taking materials from previous constructions and reusing it for a new purpose is not a new concept from a historical point of view (Bertino et al., 2021), but along with the industrial revolution, and the rapid increase in the number of new buildings, the focus has been on economic growth and not so much on the environmental benefits, therefore destructive demolition has been the way to go for the industry (Bertino et al., 2021).

As underlined by (Kozminska, 2019), the reuse of materials is still hindered by the fact that there is not enough data about their availability, the quantity or quality of these, as well as guidelines to ways of finding or processing them. Designers are a big factor in this picture, as their lack of education specifically within designing for reuse affects implicitly the demand of used materials for new projects (Kozminska, 2019).

Generally, the recycling and reuse potentials are still largely unexploited. There are indications that for example European countries only replace as little as 2% of concrete aggregates in production, with recycled material, when the potential of this ratio can go up to 45% (Schiller et al., 2019). And this can change if one of the main barriers, which is the lack of information, won't hinder anymore the optimal and effective implementation of circularity in the construction sector (Schiller et al., 2019).

Existing buildings are a prime example where lack of information hinders efficient waste management and potential for reuse ,recycling or recovery as their as-built records tend to be poor (Rose & Stegemann, 2018b). In order to achieve a better prevention of the content of the existing built stock from becoming waste, there is a general need for an increased level of information, that can improve the current situation (Rose & Stegemann, 2018b).

4. ANALYSIS

This chapter presents, as the title implies, the analysis of primary data obtained taking into consideration the findings resulted from literature review

4.1. Interviews

Date	Name	Discipline	Company	Field
18.12.2020	Hans	Head of Marketing and Sustainability growth	Titan Nedbrydning	Best practice in selective demolition - DK
15.02.2021	Johan	Head of Sustainability and Technical department	Xella DK	Best practice in circular manufacturing – in the Nordic countries

Figure 13 - Conducted Interviews

As part of the empirical process of the project, two interviews (*Figure 13*) have been conducted in order to gain insights from different perspectives within the construction industry. The analysis of the interviews has been realised by following and adapting the main ideas presented by (Gale et al., 2013), as summarized in *Figure 14*.

1. **Transcription** – refers to a word for word transcription of an audio recording of the interview;
2. **Familiarization with the interview** – while transcription is realized, it is almost natural that the interviewer will also familiarize with the content of the interview;
3. **Coding** – this is the step where the interviewer applies a paraphrase or label to mark important ideas in a specific paragraph;
4. **Development of a Framework** – categorizing and grouping all the previously identified ideas;
5. **Applying the analytical framework** – indexing subsequent transcripts;
6. **Charting data into the framework matrix** – summarizing data by category;
7. **Interpreting the data ;** (Gale et al., 2013)

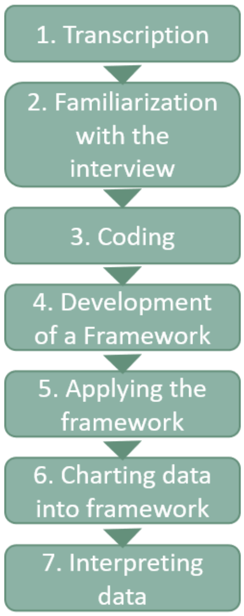


Figure 14 - Main steps in analysis of qualitative data according to (Gale et al., 2013)

The initial research for this paper has been directed towards the main ideas surrounding circular economy in construction generally, then looking deeper into building demolition and building manufacturing practices. Based on that, there has been developed a semi-structured interview created to identify current practices in the *selective demolition* area, how do these actors currently function in developed countries such as Denmark. The interview (see Appendix A) has been conducted with the Head of Marketing and Sustainability growth from the leading company within this specific area in Denmark. The idea behind this has been to find out what is the level of ''circularity'' in a company that can be considered as ''best practice'' in selective demolition at national level.

Company presentation – demolition contractor

Titan Nedbrygning A/S is an only 4 years old Danish building demolishing company, leading this market at country's level in regard to the circular thinking and practices. They make great efforts towards a transition to a more circular way of dealing with materials and components resulted at the end of life of a building. (*Titan Nedbrydning A/S*, n.d.)

Subsequent to that, and based on the already gained knowledge from the previous interview, there has been conducted an interview with the Head of Sustainability and Technical department of Xella Group DK, which is the only building-related company showing up in the best circular economy practice examples in the Nordic countries (Copenhagen Resource Institute et al., 2015).

Company presentation – manufacturing

Xella Denmark is a part of the international group *Xella Group*, and they are manufacturing Autoclaved Aerated Concrete blocks (AAC) and a few other building elements, led by circular practices, so from the raw material extraction, throughout the use phase of the products, and finally to those becoming waste, sustainability is the main factor guiding the business (Copenhagen Resource Institute et al., 2015).

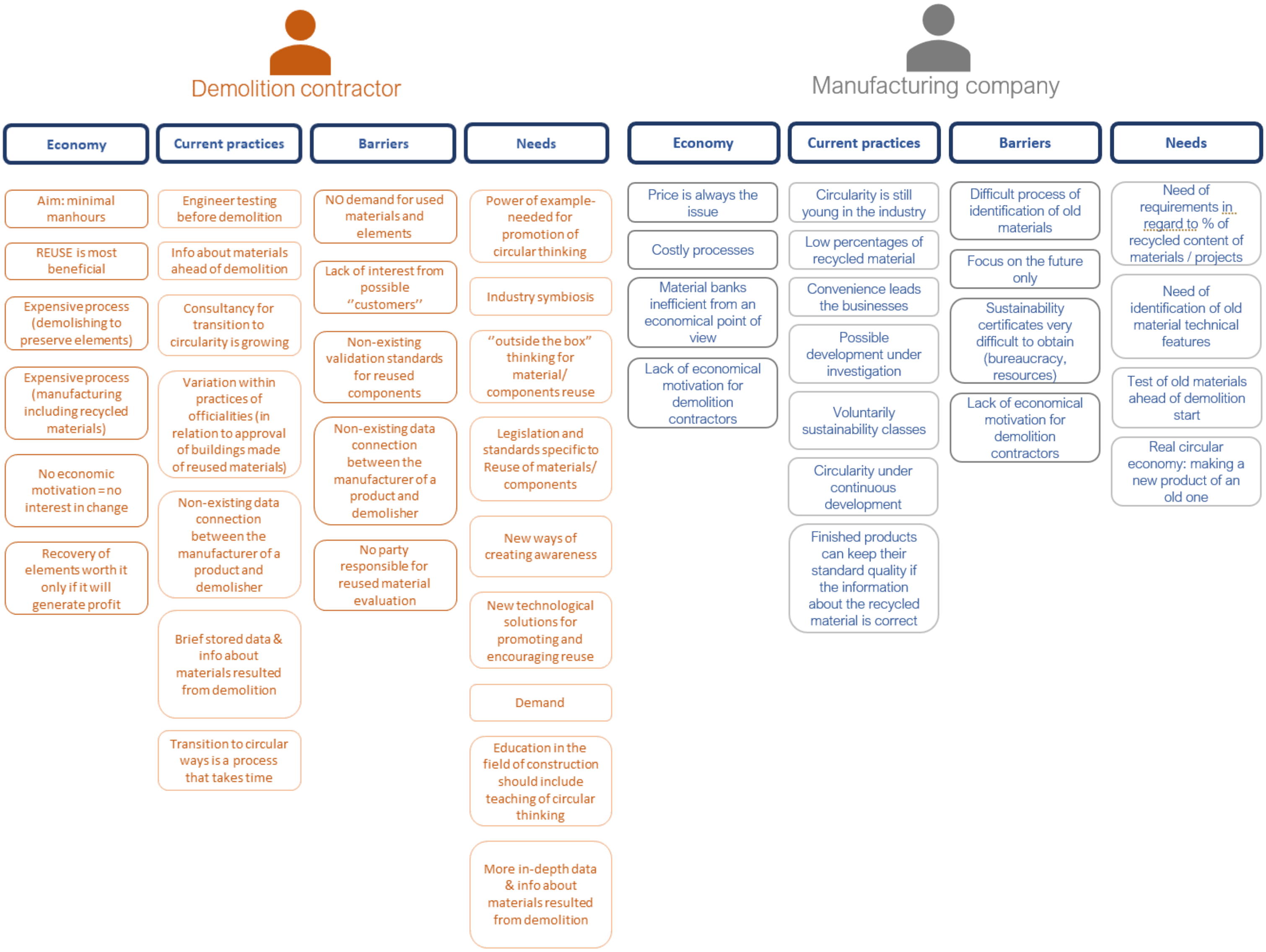


Figure 15 - Charting of data obtained from interview with demolition contractor and manufacturing company

The charting of data resulted from the interviews (*Figure 15*) with the demolition contractor and the manufacturing company has helped identify four main aspects in regard to the circular model practices: economy, current practices, barriers and needs.

As a summary, it looks like the economical aspect still plays the most vital role in any possible changes, developments, or encouragement for transitioning to a circular economy, as the manhours are still much more expensive than the profits generated by demolishing, processing and recycling old materials. The decisions about the sorting of the materials still belongs to each and every different contractor that takes over a project, and unless their knowledge can help determine whether a material is '' worth it '' or not from an economical point of view, these will most probably end up as waste.

However, it is highlighted that reuse of materials or components has the potential to be the most convenient for the purpose of creating circularity, as the processing is less complicated compared to recycling. Unfortunately, that goes into contradiction almost with the fact that there are still no standardized rules, or bodies that are responsible with assessing if for instance an old building element still fulfils the requirements for being reused into a new project (strength, condition, quality etc.). At the same time, there is still not enough awareness within the public, so there is no demand for reused/recycled materials and components. It will take a bigger effort to spread and promote the circular thinking and the ways every single person and not only companies can help towards that change.

The selective demolition is still a very young practice in the construction industry in the Nordic countries, and even though the circular economy approaches are growing nowadays within the construction industry overall, there is still a long way to go, and this can only be done by taking one step at the time. There is a lot of focus on finding solutions to better identify materials and their content, so when the end-of -life of a building comes, a demolition contractor will be able to perform their job better than they can do today. Unfortunately, all these solutions such as *material banks*, *material passports* are features that only starting to be implemented now, so the results will be seen in the future. It is a huge step, but there is still a huge amount of old buildings with very little data-set attached to, which will soon enough need to be either demolished or renovated, and there isn't much talk happening on that subject in matters of solutions for waste management, recycling or reuse possibilities.

In our days, the very first information about materials contained by old buildings is found out only when those reach the waste status, so implicitly there is very little time to actually try to manage that towards circularity. Therefore, there is a need of standardization of the way things are done, which could begin with in depth testing of materials long before an actual demolition job starts, in order to allow the other parties involved to find the best ways of waste management.

An ''outside-the-box '' approach has to be applied to these projects in order for them to become of use, and not just waste, but that goes against the current legislation and rules that only allow EU certified building products to be used for new construction. That leads then to a need in the change of laws and regulations in regards to material and components reuse, in order to facilitate these processes and not hinder them, and implicitly discourage the few companies out there that are really trying to find alternatives but hit their head into rejected applications and uncertainty.

4.2. Survey Results

The multitude of qualitative and quantitative data points resulted from the conducted survey represent a way of understanding the manufacturing businesses' position in the big picture of CE within the construction industry, and identifying the aspects that relate directly to the demolition waste and how this can be up-cycled rather than down-cycled.

Following the guidance of (Saldaña, 2013) for analysing qualitative data, and in addition creating a picture of the quantitative data results, the complete analysis of the survey is presented in this subchapter.

General

There were 19 responses to the survey (Appendix C). The responders work in companies that manufacture and distribute building products based on a variety of main materials such as concrete (6) , plastic(1), wood (5) , metal (1), mineral wool (1), paper wool (1), gypsum (1) and clay (1) or a mix of these (2). The countries targeted were the Nordic ones, however, for practical reasons and for a bigger chance of feedback, the survey has been designed in Danish.

Materials used for production

This set of questions (3,4,5,6) were designed to help find out what kind of materials are used in the manufacturing process, and what is the balance of raw material to recycled material usage.

Most of the raw materials for production for the businesses comes from within Europe, but the sources extend all the way to China, Russia or Japan, so that implicitly involves a very ample logistic process.

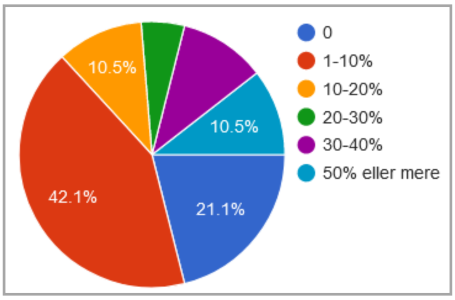


Figure 16 - Percentages of recycled material used in the production

14 (73.7%) of the companies are using recycled materials in their production, however, the predominant average of percentage is only 1-10% (see *Figure 16*), and the second biggest percentage goes for value 0. This creates the image of companies starting to adopt circular practices, but the percentages of recycled materials are still very low generally, and there is still a big part of companies that do not include recycled materials at all in their production.

Even though it would look like quite a few of the companies have tried to adapt recycled materials into the production the situation is totally different when talking about materials resulted from demolition. Only one of the companies uses that regularly, and another 4 of them use them to some extent (*Figure 17*), which proves one more time the very limited existence of demolition waste reuse/recycling in the industry, considering this is the status in a developed country where a variety of technology and knowledge are available.

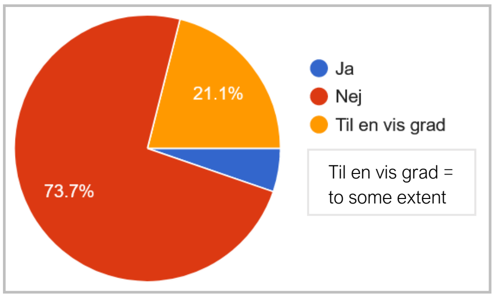


Figure 17 - Usage of recycled material resulted from demolition

Barriers and ideas for improvement

Questions 7,8,9,10 were meant to give an insight about barriers encountered in the possible intention of recycling materials into production.

The answers underlined the fact that lack of quality is a very big factor hindering the usage of these, and there is a general big interest into finding new methods of using recycled materials. Some of the suggestions are the creation of specific production lines for recycled material or creation of a separate set of standards for products resulted from the use of recycled content, as well as possible new customer requirements.

As for the major elements that could help close the loop the answers are focused on need of requirements and support from officialities for new ways of thinking, standardized systems of recycling/reuse, need of more information on materials/elements available for reuse, as well as establishing a responsible body for assessment, and willingness to change.

Circular Economy

The questions from 11 to 19 were intended to identify general aspects about the concept of CE within the companies, more precisely how familiar the concept is, and some practices in regard to this.

The first two questions show that all companies have at least basic knowledge about the concept of CE, but only 12 (63.2%) of them actually have elements based on it within their business strategy. Some of the companies have always been guided by circular thinking, some other have made transitioning changes in the last 5 years, and others do not consider yet this transformation.

When it comes to the most difficult elements encountered when trying to transition to CE, the answers show that **lack of demand** (9 answers) of recycled/reused materials is the most popular one, followed by the **economic disadvantage** (7 answers) and **lack of knowledge** (7 answers), and the third most popular one is the **resistance to change** (6 answers).

From a different perspective, the most popular element in the value chain that companies would first change in order to move towards a more circular way of doing business is the **technology resources** (9 answers). Some of the most valuable statements when it comes to what would create an economic incentive for these companies to use recycled material, would be the **need of methods** for ensuring a sufficient quality of the finished product made from these.

The last two questions in this section helped underline the fact that businesses are more inclined to take small progressive steps towards changing their business strategy to a circular one, rather than making radical changes at once.

Generated waste and industrial symbiosis

The last section of questions aimed to find out if the companies are aware of the waste they generate through production. However, some of the answers were invalid. The valid answers paint the picture where only less than half (37,5) of the companies generate over 50% recyclable waste, and half of the companies that answered to this question generate a percentage of 25%-40% of bury waste. These aspects show that there is considerable place for improvements when it comes to the way materials are used in the production and the waste created by those.

Industrial symbiosis is recognized and confirmed as a current practice within the company by approximately half of the participants (9), whereas the rest (10) either still aren't involved in any kind of activities related to it or do not have knowledge on this matter. This underlines again the unexplored opportunities that can bring building manufacturing companies closer to CE.

The professionals who filled in the survey have functions such as: technical manager, engineer, civil engineer, development manager, product manager, quality and development manager and others.

4.3. Initiatives in the area

To further investigate the topic of waste resulted from demolition of existing buildings and eventual existing solutions out there, a number of relevant initiatives trying to tighten the loop within the building industry, by promoting circularity and recycling/re-use of building materials and elements have been selected, explored and summarized.

Genbyg (Denmark) - https://genbyg.dk/

Denmark's largest construction market of used building materials. Privately owned, this company specializes in purchasing and reselling of used building materials, of a somewhat small scale: doors, windows, floors, timber etc. All materials are posted on the web shop which gives access to both private and professionals to access them. (Genbyg, n.d.)

Material Mapper (Norway) – https://materialmapper.com/

At the time this paper is written, Material Mapper is a private start-up aiming to help property developers and municipalities find and predict reusable materials in specific locations. Founded in Oslo, Norway, this has as base Artificial Intelligence and Machine Learning resulting into a powered search and forecasting tool platform is mostly dedicated to facilitate easy project planning and re-use of building materials. In order to access the information, there is a significant subscription fee. However, this project is still taking shape and the functionality of it is still unknown at this time. (Material Mapper, 2020)

Materiaalitori (Finland) - https://materiaalitori.fi/

This is a waste and by-product data base managed by a Finnish state-owned company, with the purpose of exchange, sale and purchase of waste materials, side streams and left overs. It is under the form of an internet platform intended solely for professional exchange of waste (companies and organizations). It is free of charge, but a company has to register in order to use the system. They can subsequently make entries in the platform with eventual upcoming material streams, accompanied by specific description, containing details such as characteristics, quantities or pictures. This acts as a connecting bridge between the ones offering and the ones looking for recycled materials, creating industrial symbiosis. (Materiaalitori, n.d.)

Opalis (Belgium) - https://opalis.eu/

It is a project that aims to facilitate the use of re-used materials in construction and renovation projects. The online platform mainly revolves around promoting professional operators that sell construction materials resulting from the dismantling of old installations and buildings. It also contains documents on material specifics and characteristics, as well as inspiration to use old materials. This platform works across Belgium and France. (Opalis, n.d.)

	Access	Price	Targeted Users	Main goal	Privately/Public owned
Genbyg	Open to anyone	Webshop	Private and professional	Purchasing and reselling small-scale building materials	Private
Material Mapper	Restricted only to the subscribed members	Paid	Property developers and municipalities	Forecast of materials streams at big scale	Private
Materiaalitori	Possibility of registration	Free	professional	Connexion between those offering and those needing used materials; industrial symbiosis	Public - municipality
Opalis	Open to anyone	Free	Private and professional	Promoting the professionals selling reuse materials from building dismantling and demolition	Private

Table 2 - Comparison between the four related initiatives

The selected examples above are relevant to this paper, as they present similar but at the same time very different approaches to solution-oriented tools for a better circularity in the area of potential waste resulted from demolishing of existing buildings.

Table 2 summarizes the main features of these and compares them. ''Access'' refers to how accessible the tool is from a point of view of the variety of users, then ''price'' implies eventual fees that are required for the access to these, ''targeted users'' represents the target group these platforms are intended for, and finally if these are privately or publicly owned as well as their core goals. This brief comparison will help formulate an improved proposal in the following chapter of this study.

4.4. Identifying the gaps

Based on the findings resulted from the literature review, the primary data analysis, and the existing initiatives in the area, this chapter will summarize all the main ideas and identify the missing links, which will be further tackled in Chapter 5 of this report.

There is a continuous research and investigation towards finding solutions for minimizing waste resulted from the construction industry and maximizing product efficiency, but when it comes to existing buildings, older than the digital era, there is a very little amount of initiatives and research on how to minimize the waste resulted from their demolition. This paper looked into a demolition contractor's view on the matter, and later on a building product manufacturer's view on how do they see this issue, accompanied by a survey trying to identify the practices within the general building products manufacturing, on how big the interest is in circularity and implicitly an eventual use of demolition waste as a secondary source for production.

The main ideas concluded were that there is not enough awareness from the large public (including companies) when it comes to the availability of reusable materials, there haven't been many official requirements imposing major recovery percentages into new projects or production, and there is a general lack of knowledge when it comes to the management of the waste resulted from demolitions, leading to uncertainty and ultimately disposal of materials that would still have a potential for re-use or recycling, losing therefore valuable resources.

In practice, there are initiatives in different European countries (as explored in Chapter 4.3) on different tools promoting the circularity, but these solutions are still very varied and only implemented at local levels.

With the latest proposals from the European Commission, the rates of reusability and recycling will have to increase considerably, and therefore there is a significant need for standardization.

4.4.1. Key issues

The following key issues have been identified throughout this research, and will be tackled in the following chapter:

- Lack of research and standardization of solutions for waste resulted from existing buildings (poor in complex documentation about their construction);
- Lack of pre-demolition planning and testing, therefore in-depth data & info about materials resulted from demolition of existing buildings;
- Lack of general awareness and interest about building products re-use and recycling at a big scale (private and professionals);
- Lack of demand for used materials and elements;
- Lack of interest in industrial symbiosis;

5. PROPOSED SOLUTION

This chapter presents the proposed solution of this research paper, based on all the previous findings.

5.1. General considerations

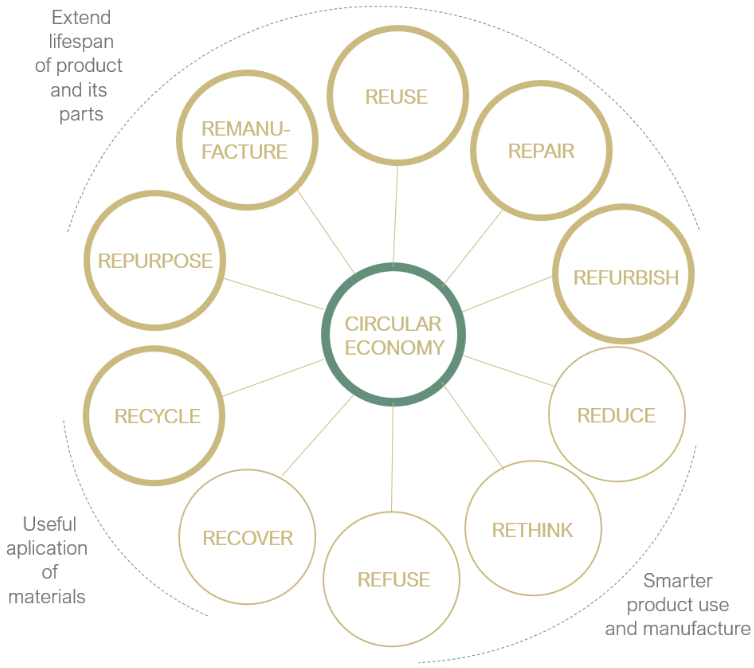


Figure 18 - All R's: own illustration adapted according to (Potting et al., 2017)

Based on the literature review and the primary data collection, this paper aims to create the fundament for the concept of a web platform, intended to tackle the issue of waste management resulted from demolition of existing buildings, and the lack of information available.

In regard to this, it is important to analyze all the elements that will give shape to this system. It is vital to identify the possible users that could benefit from the development of such a tool, as well as needed functions, requirements and so on.

According to (Potting et al., 2017) and as presented in *Figure 18*, there are 10 R's describing the general strategy for transitioning to a circular economy. However, only 6 of these are relevant to the use of the materials and components obtained from the demolition of existing buildings, and these can be summarized into two main sections: REUSE and RECYCLE. This will be the base of the proposed solution in this current chapter.

5.2. Stakeholders

In order to achieve a systematic understanding of the needs that have to be fulfilled, it is critical to identify and analyse the potential stakeholders involved in this process (*Figure 19*). As resulted from the primary and secondary data, these will be as follows:

Municipality – it is the party responsible with the approvals for new construction/demolition, therefore data about future demolition projects is held by them; furthermore, specific built assets are owned by these, implicitly data about these;

Building Owner – this could be a possible private owner of one or more buildings, with the power of decision over the property, and also interested in keeping expenses as low as possible; holds information about property;

Demolition contractor – decision power over the general approach and the materials resulted from demolition; interested in making profit and selective demolition; holds information in regard to the materials;

Engineer /waste auditor – responsible for testing of materials and estimations before demolition project starts; no involvement or interest in other aspects of the process;

All the above mentioned can represent administrational users of the proposed application, and they have the role of providing data input into the system.

End User – the end user refers to the actual user of the proposed application; these can be grouped into four categories:

- Administrational user: this user can be for instance a demolition contractor that will be able to update and/or manually enter data into the system, and will need a different interface than all the other end users;
- Private person – interested in buying relatively cheap building materials/components of small scale; e.g.: cabinets, appliances, wood boards, tiles, etc.; at any given time;
- Designer/ Architect – interested in finding big scale elements that can be incorporated into new construction design, ahead of time; e.g. structural beams, windows etc;
- Manufacturing Company – possibly interested into recycling mass material resulted from demolition into new products; e.g. concrete, plastic etc.; ahead of time;
- Material restaurator company – possibly interested into buying, refurbishing and reselling materials and components;

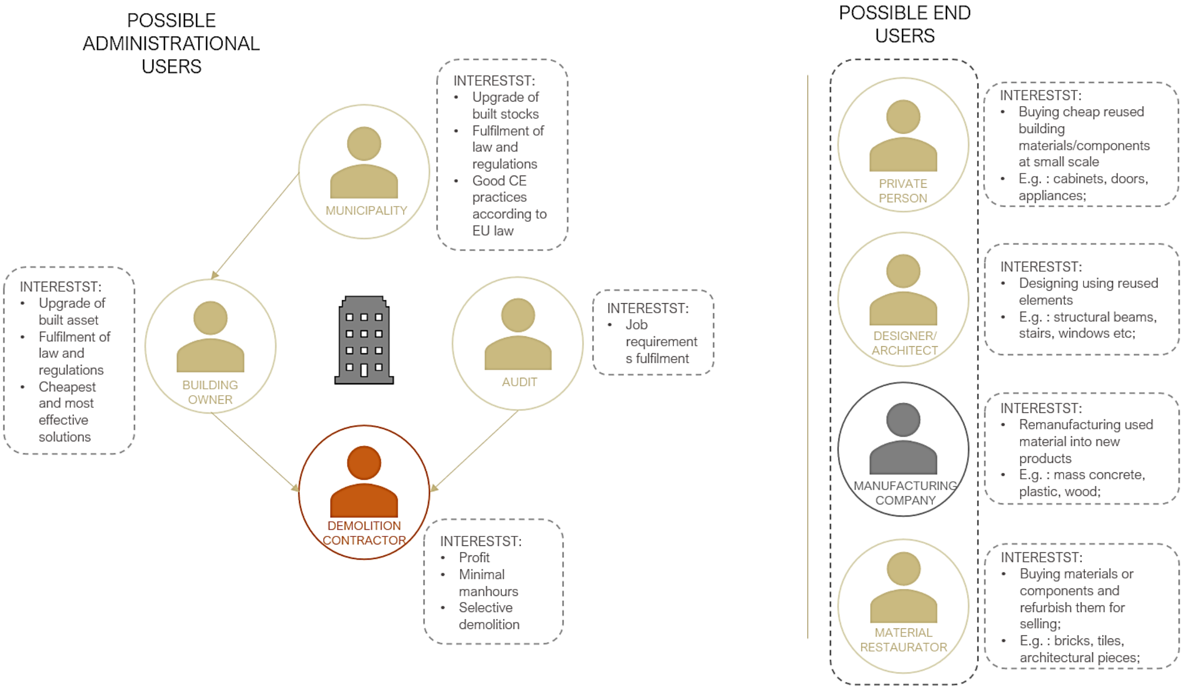


Figure 19 - Identification of possible stakeholders - own illustration

Furthermore, the recommended general process and stages within a demolition and waste management process is represented into *Figure 20*, for a visual representation of the timeline of how every step takes place: after the municipality notices the building owner there has to be action taken about the specific building, and the decision of renovating or demolishing it is taken, the building owner is responsible to inform themselves as well as possible in regards with the further proceedings, to make sure the solution is the most suitable and efficient. This will notice an audit, which will further get involved into the process. The team for the Waste Audit should investigate, sample and test the building, and hand over a full report on this to the building owner. The latter will make an invitation to tender and along with the waste audit report should call for bids from different demolition contractors. These will estimate the cost and will get back to the building owner with an offer. In parallel, a permit request is asked for from the municipality, in order to proceed with the demolition. Once this is approved and the building owner accepts an offer from a contractor, the planning starts, followed by the preparation of the site and then the practical work can start. The demolition itself is handled by the contractor, and most of the decisions about waste management are in practice made by this.

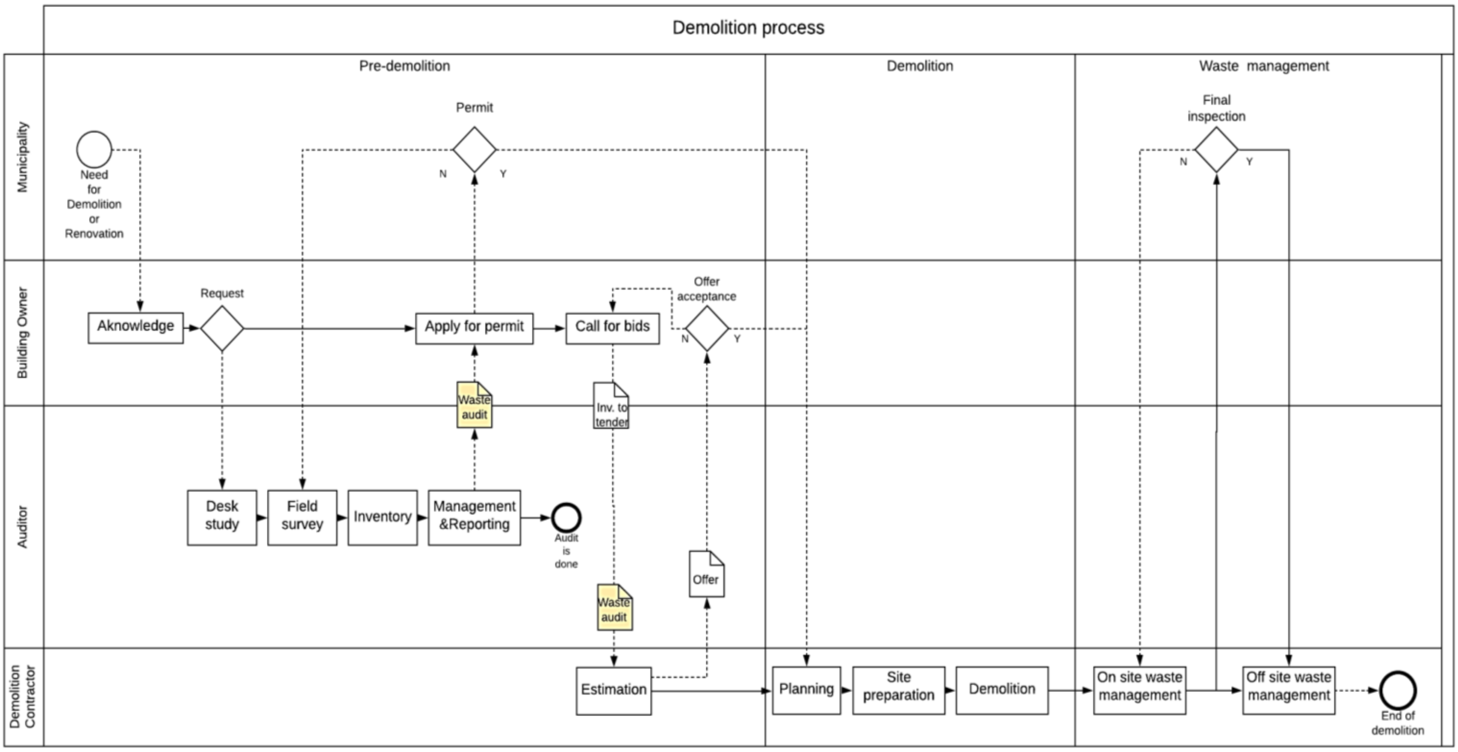


Figure 20 - Overall process of demolition - own illustration

5.3. Waste audit - Existing practice in Denmark

To be able to propose a new standard for the practice and content of a waste audit, it is important to establish how things are currently done in real practice, in this case, at Denmark's level. The official regulations (Retsinformation, 2020) with relation to waste resulted from renovation and demolition works only require that the client has the duty to screen and eventually map for the hazardous substances, prior to demolition activity, in order to make sure to dispose of the materials containing them accordingly to regulations, and the biggest focus has been on buildings built or renovated in the period 1950-1977.

However, there are guides (Værdibyg, 2020; Miljøstyrelsen, 2018) for a better practice within this area, suggesting a better planning and a more insightful information, promoting recycling and reuse of renovation and demolition waste, called ''resource mapping''. Even so, at practice level, the adoption of any of these guides or parts of them is almost non-existent due to uncertainty and lack of expertise, as well as economic reasons (example in Appendix D).

Even more so, not even the minimum requirements are always respected, as the law and regulations still leave considerable room for different interpretations (Lærke, 2019), and the ''easiest'', cheapest solutions are very often chosen in practice, over the most environmental suitable.

5.4. Storyboard

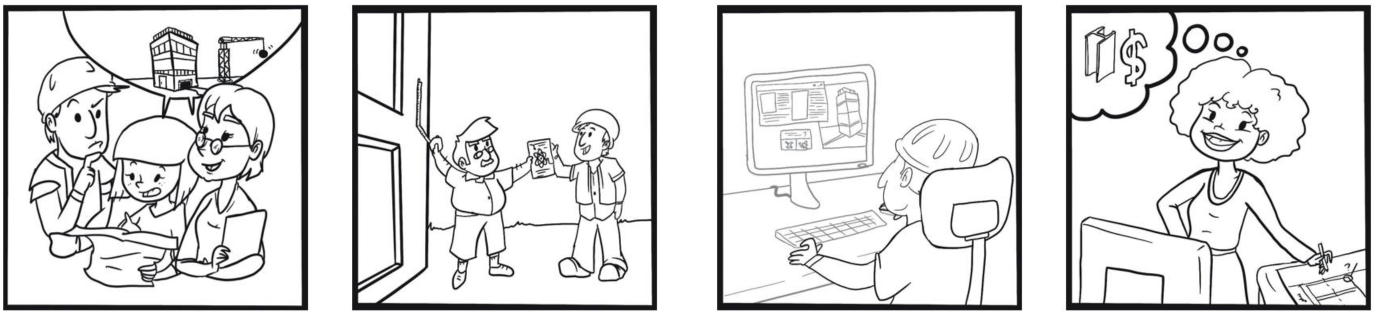
With the purpose of defining a better picture of the actors' interaction in the way the demolition process is taking place at the moment, and how this could be improved by the proposed system, this has been represented in the storyboards (*Figure 21, Figure 22*).

Demolition contractor being requested to take a building down by municipality & building owner | Demolition contractor uncertain of the waste management knowledge and practices | Demolition Waste ending up on landfills

Figure 21 - Existing practices (own illustration)

Based on the findings of the literature review (Chapter 3) and the analysis of primary data (Chapter 4) the existing practices when it comes to renovation and demolition projects are still very varied and uncertainty about correct and sustainable waste management is still an issue. The building to be demolished isn't investigated enough in order to identify the amounts and categories of materials/elements that will be resulting from this activity, therefore very often the demolition contractor will have to decide the faith of the waste.

To develop a solution that will help close the loop within demolition of existing buildings and the waste resulted from it, there is a need of a more extensive sampling, testing and investigating the building that is to be renovated or fully demolished, and use the data resulted for creating a connection with the possible parties interested in the recovery of the materials and elements resulted.



Demolition contractor being requested to take a building down by municipality & building owner | Audit handing waste audit report to demolition contractor | Demolition contractor entering data into IT system | Happy designer/architect finding reusable building elements for a good price on a web platform

Figure 22 - Workflow for proposed solution (own illustration)

5.5. Proposed format for waste audit report

In order for existing data to become valuable, this has to be put to use. In this context, the existence of a **pre-demolition waste audit** can have a crucial contribution into raising awareness about available reusable/recyclable materials and components at an early stage ahead of the practical demolition activity.

A **waste audit** is recommended (European Comission, 2018) to consist of specific steps, as shown in *Figure 23*. However, because it is not an official requirement, there are still big variances when it comes to real life practice, where not everything is done ''by the book '', and pre-demolition audits are still at a very low level of implementation (European Comission, 2018; Rose & Stegemann, 2018b; Ehlert et al., 2019). If officially demanded and standardized, this report can have a huge value as it would contain specific information and estimations about the materials and components within the building that is about to be fully or partially demolished (European Comission, 2018). The **waste holder**, which is the building owner, unless this has passed the ownership to the demolition contractor (Hradil, Wahlström, Teittinen, et al., 2019), has the obligation to find out as much information as possible about the potential waste resulted from the demolition, and to find the best solutions for sorting and disposal (European Comission, 2018). Despite of that, in the current practices in developed countries such as Denmark, the pre-demolition sampling is done strictly in relation to the identification of hazardous materials and the handling of these (*Titan Nedbrydning A/S*, n.d.) (DGE, n.d.) (See Appendix D).

This chapter suggests therefore an improved and standardized approach to the pre-demolition waste audit and the data contained by it, in order to facilitate the circularity promotion and practices in the context of existing built assets.

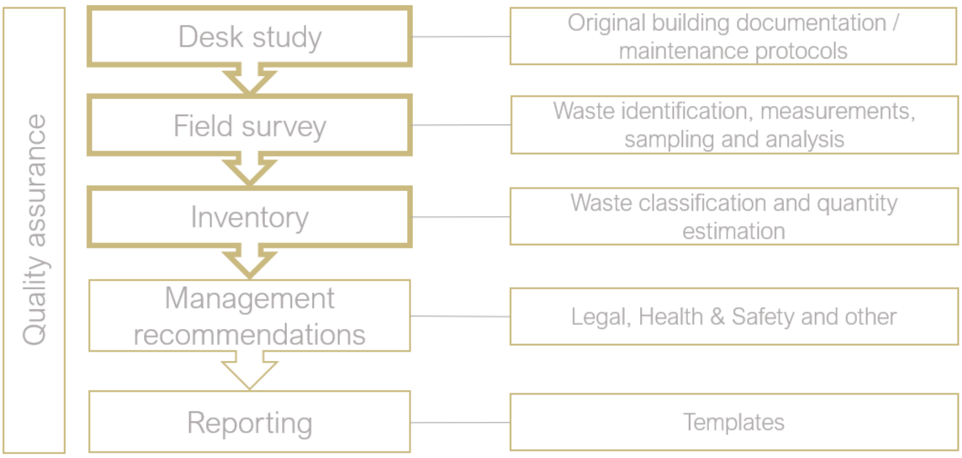


Figure 23 - Waste audit general steps – own illustration adapted from (European Commission, 2018)

The collection of data resulted from the desk study, field study and inventory (*Figure 24, 25, 26*) of the building to be renovated or taken down is very valuable and has the potential of promoting circularity if used in the right context.

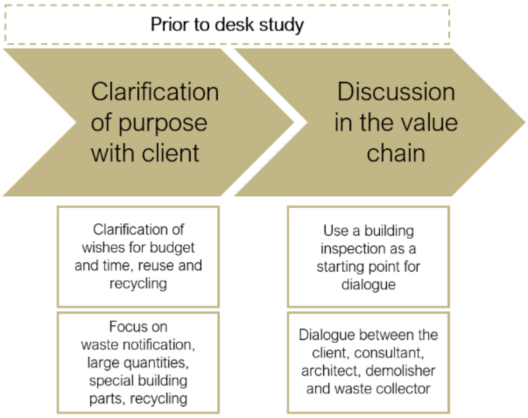


Figure 24 -Steps prior to Desk study - own illustration based on (Miljøstyrelsen, 2018)

Desk study (or preliminary research) – in this stage, the audit collects as much as possible of the already available data on the specific building, such as original building documents, information in regards to significant activities that took place in the service life of this built asset (maintenance, extraordinary events); this information is used for an initial draft estimating the types of materials used for the construction, but also for the planning of an appropriate site visit where the draft will be updated according to the conditions at the site. All these will be attached to the final waste audit report (Rašković et al., 2020).

Field study: in this stage, the previous study is used as the base and subsequently completed by further tests, measurements, sampling, observations made at the actual building site. This is when potential hazardous materials are identified and a plan for demolition is developed, as well as recommendations for on-site waste handling (Rašković et al., 2020).

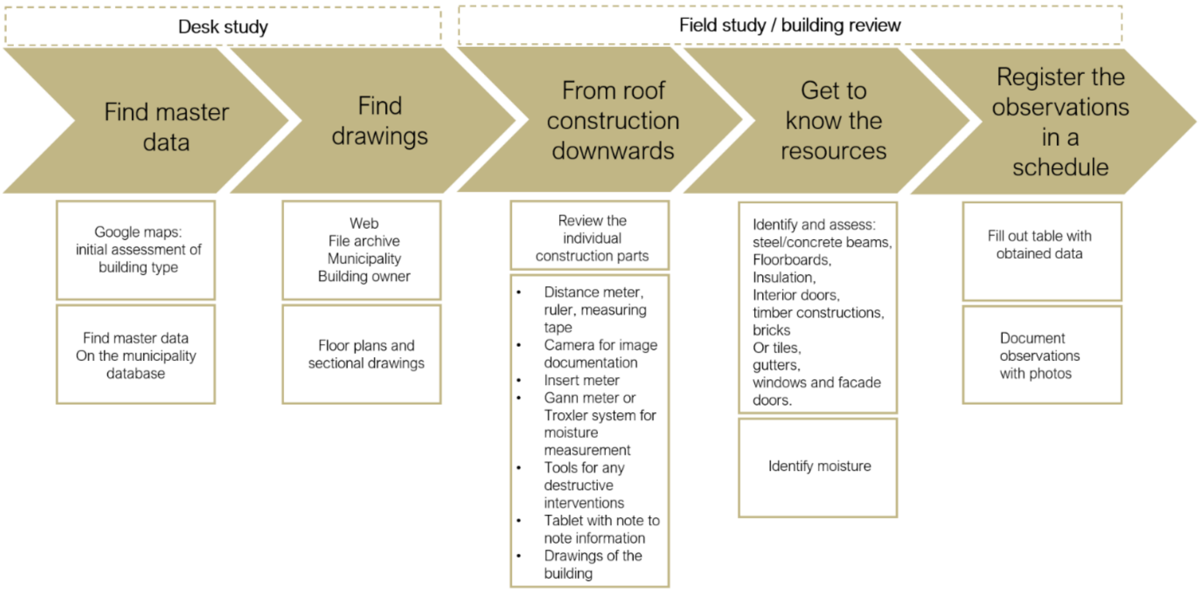


Figure 25 - Detailed steps within Desk study and Field study – own illustration based on (Miljøstyrelsen, 2018)

Inventory: this stage should not only ensure there is an estimation of the total waste resulting from the demolition, but also a classification of constructive and non-constructive element, as well as the different types of materials. On top of that, it is recommended that this should include separation of waste source by building levels, feasibility of separation, and inclusion of pictures showing details. The material assessment should take into account the easiness of recovery for each element. All these should help make the future work of the demolition contractor more efficient. (European Comission, 2018)

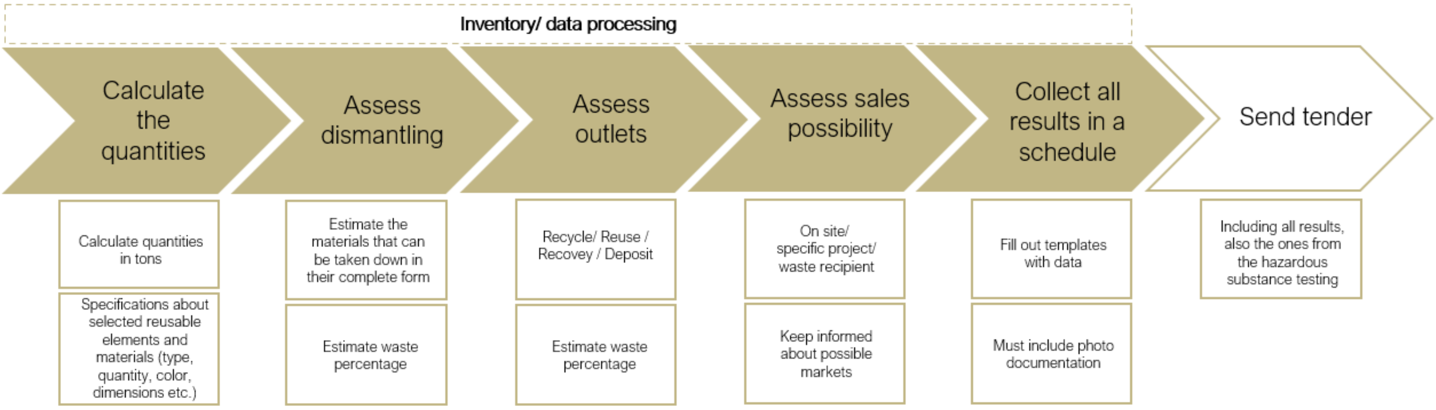


Figure 26 - Detailed steps within Inventory phase - own illustration based on (Miljøstyrelsen, 2018)

The information about the **building** gained throughout the waste audit process will contain: the unique land register number, the location of it, age, records of major maintenance activity or extraordinary events, design documents such as plans, and possibly tender specifications or as-built documentation of the construction or renovation works (European Comission, 2018) (Miljøstyrelsen, 2018).

Finally, the proposal to a standardized minimum content for an early assessment of a built asset that needs to be renovated or demolished, translated into a **pre-demolition waste audit,** is summarized for a better understanding of what kind of information this should contain as a result of the steps presented earlier, and based on findings from Chapter 3 and Chapter 4 and (European Comission, 2018; Rose & Stegemann, 2018b; Hradil, Wahlström, Teittinen, et al., 2019) (Appendix D) , in *Figure 28*.

All this information can be achieved within the first three stages of a waste audit described previously in this chapter. After the collection and analysis of original documents of the building within the **desk study**, a clearer process of the proposed **field study** is showcased in *Figure 27*. When the sampling and assessment is over, there will be specific recommendations for specific materials or elements, such as: reusable, recyclable, backfilling, energy recovery or landfill. And all these should show up in the final report.

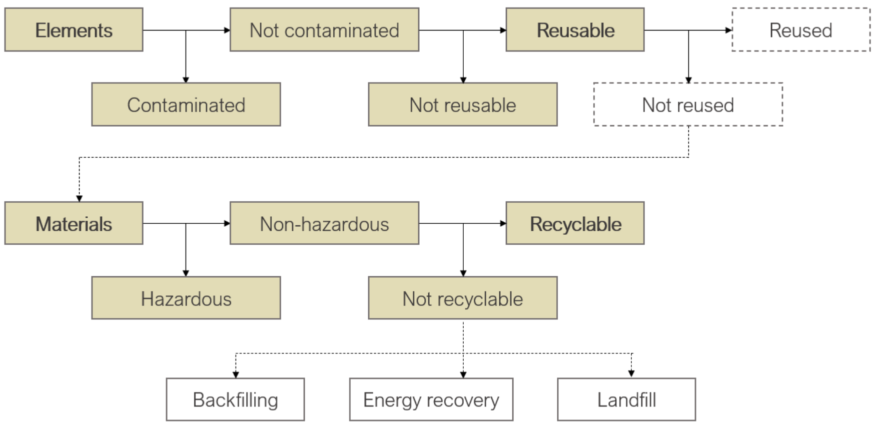


Figure 27 - Classification of elements and materials during field study

	Content in current practice	Minimal additional proposed content	Future additional possibilities
About the building	• Land register number • Historic use • Location, age • Owner, auditor, contractor Documents: • Maintenance activity • Design documents • As-built documentation	• Semi-automated laser scan when as-built drawings are missing – for 2D drawings generation; • Review and measurements of the building parts by using a variety of tools;	• Semi-automated laser scan • Photogrammetry • 3D point clouds • Automated scan-to-BIM, or existing model *to be used especially when 2D drawings are completely missing;
Hazardous substances	• Identification of hazardous substances and filtering of materials and elements containing them		Additional sampling for main materials composition;
Reusable components		Uncontaminated: • Elements identification and classification • inventory of all recoverable ones • Identification of all possible outlets • price suggestions • other CE specific notes based on audit's expertise	Additional testing in relation to functionality attributes;
Potential waste materials	• Hazardous and non-hazardous • Classified according to European Waste Code	For non-hazardous: • Estimated quantities • Recoverability of materials • Price suggestions	
Photo documentation		Photos for each potential recoverable element or material	

Figure 28 – Proposed standardized content for early pre-demolition audit – own illustration

Based on all the findings, analysis, and professional assessment of the audit in these first three steps, the resulted data should cover the proposed structure (*Table 3*).

BUILDING	Example	ELEMENT	Example	MATERIAL	Example
Building ID - Land register number*	360433	**Building ID**	360433	**Building ID**	360433
Type	Residential	**Element ID (BIM7AA typecode*)**	213	**Element ID**	213
Location	Østerbro 72, 9000 Aalborg	Name	Exterior wall	**Material ID - Waste Code (EWC*)**	170102
Year of construction	1929	Available On-site from	Jul-21	Name	Bricks
Date for significant alterations/renovations	2013	Age (years)	92	Available On-site from	Jul-21
Total Area (m2)	599	Possible Outlet*	Reuse/RecyclingRecovery	Age (years)	92
Additional Documents	e.g.:.dwg/ .pdf / .xlsx	Recommended Outlet*	Reuse	Lifespan (years)	>100
Photo documentation	e.g.:.png/ .jpg / .pdf	Maintenance Activity Date	2013	Possible Outlet	Reuse/Recycling
Additional data can occur due to variance of document availability		Structural	No	Recommended Outlet	Reuse
		Unit (m2/ m3 / pcs.)	x	Unit	piece
		Total Quantity	x	Total Quantity	3500
		Unit Recommended Price (kr.)	x	Unit Recommended Price (kr)	10
		On Site Until	Sep-21	On Site Until	31/08/2021
		Stored At	x	Stored at	Nålemagervej 4, 9000 Aalborg
		Stored at After	x	Stored at After	01/09/2021
		Stored Until	x	Stored Until	31/12/2021
		Photo documentation (.png/ .jpg)	façade.jpg	Photo documentation (.png/ .jpg)	brick.jpg
		Additional Documents (.dwg/ .pdf)	x	Other Characteristics	Dimensions - 215 x 102.5 x
		Other Characteristics	x	Notes	
		Notes	the brick façade has been professionally cleaned in 2015		

General information | Identification | CE indicators

Quantities | Availability | Additional information

Table 3 - Systematic presentation of proposed content for waste audit report

*Land register number – unique identification based on municipal registration – (in Denmark - https://bbr.dk)

*BIM7AA typecode – building elements classification (BIM7AA, 2017)

*European Waste Catalogue - EUR-Lex - 32014D0955 - EN - EUR-Lex (europa.eu)

*Possible Outlet – Reuse/Recycle/Recovery/Backfill

*Recommended outlet - must be identified taking into account the hierarchy of waste treatment and the potential possibilities in the proximity of the jobsite;

Characteristics for the different materials or elements will vary at the phase of pre-demolition, depending on access possibilities, and context, therefore this will be under variable text format.

In addition to the content of the Waste Audit, general information about the demolition contractor will be used in the data management process.

5.6. Data management

5.6.1. General flow of data

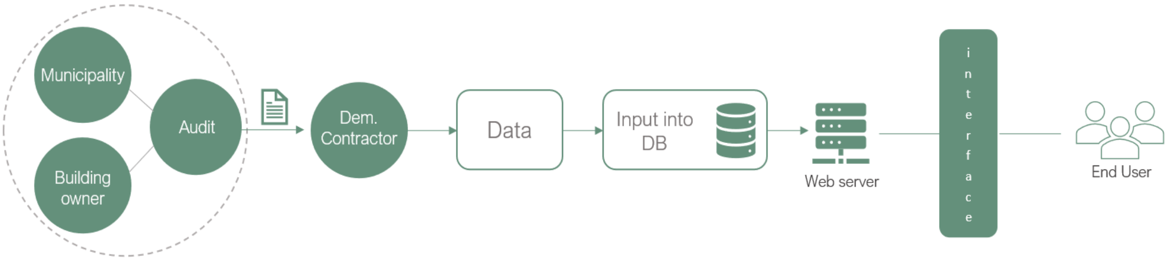


Figure 29 - General flow of data in the proposed solution – own illustration

Based on the knowledge about the available data, a general workflow of the proposed system can be identified as shown in *Figure 29*. The collection of data from municipality, building owner and audit ends up into the demolition contractor's hands under the form of, most commonly, a report, which can then become the input for the main database of the system, and with the help of a web server and an end user's interface will make possible the access to all the information.

5.6.2. Data types

As defined by (BSI, 2013), in the context of Architecture, Engineering & Construction (AEC) industry, when a building is handed over, the amount of data collected throughout the Project Stages (Project Information Model) is consisting of three major types of data: **Grapical data**, **Non-Graphical** data and **Documents,** and these will be detailed and explained within this subchapter. However, this does not always apply to existing buildings, as sometimes documents from time of construction are missing or are incomplete as they are most likely in the ownership of municipalities, and very often the attempt to access them can be unsuccessful (Rose & Stegemann, 2018b). Moreover, as-built digital models are very unlikely to exist for the majority of these (Rose & Stegemann, 2018b), but various technologies such as semi-automated laser scanning, photogrammetry and 3D point clouds generation (Macher et al., 2017; El-Din Fawzy, 2019; Macher et al., 2017) can help create BIM models of these buildings. Even so, these practices are not very popular as they involve even bigger expenses.

Table 4 summarizes the three main different types of data in the context of built assets.

	Graphical Data	Non-graphical Data	Documents
General	• Can be 2D (plans and drawings) or 3D (as-built model) • The 3D ''object'' acts as a ''container'' for some of the non-graphical data • Examples of 2D data formats: DWG; DXF; PLN; • Examples of 3D data formats: DXF; STEP; IFC	• This can be represented by the digital attributes to the elements within the 3D ''object'' • This is defined in (BSI, 2013) as Level of Information (LOI) and the requirements for the depth of it depending on the stage of the project;	• From drawings, to specifications, to product manuals etc; • Usually delivered in static formats • Examples: pdf; xlsx; • Most relevant form in the context of existing buildings, designed before the ''digital'' era;

In the context of existing buildings	Most common: • 2D drawings; Other possibilities: • Possibility to generate as-built models through semi-automated laser scanning, photogrammetry, 3D point clouds; • Automated scan-to-BIM process still in infancy;	• Information about building elements, systems, products, materials • E.g.: specifications, dimensions, operational information, attributes, properties etc, related or non-related to a 3D model;	• The most usual form of information storage; • E.g.: specifications, reports, contracts, planning, surveys, tender documentation etc.;

Table 4 - Types of data in the context of existing buildings- based on (El-Din Fawzy, 2019) (Macher et al., 2017) (Montague, 2016) (BSI, 2013)

5.6.3. Stages for data management - database design

In order to manage this significant amount of data, and optimise it so it could be used to extract useful information in an efficient way, this can be systemized into a database (Ramakrishnan & Gehrke, 2003). But in order to achieve that, there are specific steps to go through, and according to (Ramakrishnan & Gehrke, 2003) designing a database contains six main ones *Figure 30*.

Figure 30 - 6 steps into DB design (Ramakrishnan & Gehrke, 2003)

Requirements Analysis – is the phase where it is identified what the database will be used for (Ramakrishnan & Gehrke, 2003): in this paper, this has been discussed throughout Chapter 4, and Chapter 5. The stakeholders, possible users and desired functions have been clarified.

Conceptual Design & Logical Design – represents the steps where Entity-Relationship (ER) modelling is used in order to identify relevant *entities* and the relationships between them, resulting into an *ER diagram* (Ramakrishnan & Gehrke, 2003). This phase will be further discussed and analysed within this subchapter, including identification of data types and needs for storage, ER modelling and diagrams.

Schema Refinement & Physical Design & Application & Security Design – these steps involve the effective use of the database after the base structure has been shaped, and it involves mathematical analysis, technical decisions, and interfacing with applications and security (Ramakrishnan & Gehrke, 2003). However, these are not the focus of this paper, therefore only a draft of the physical data model is presented in this chapter.

5.6.4. Conceptual, Logical and Physical Design

In order to start designing the database, it is important to firstly identify the entities, the elements about which data should be stored, and their attributes (Harrington, 2016). The purpose of this step into the design is to enable the possibility of data retrieval at a later time (Harrington, 2016). By creating data models such as conceptual, logical and physical, the data begins to be organized and consolidate the blueprint for the further physical development of a database. In this context, the base for the Conceptual data model has been represented by Table 3, and further translated into a simple ER diagram (*Figure 31*) where the main *entities*, *attributes* and *relationships* have been shown from a ''real-world'' point of view. In this case, the main three entities identified based on the available data and the needs of the system users are *buildings*, *elements* and *materials.* These and the relationships between them are further consolidated and represented into the next steps.

Conceptual data model

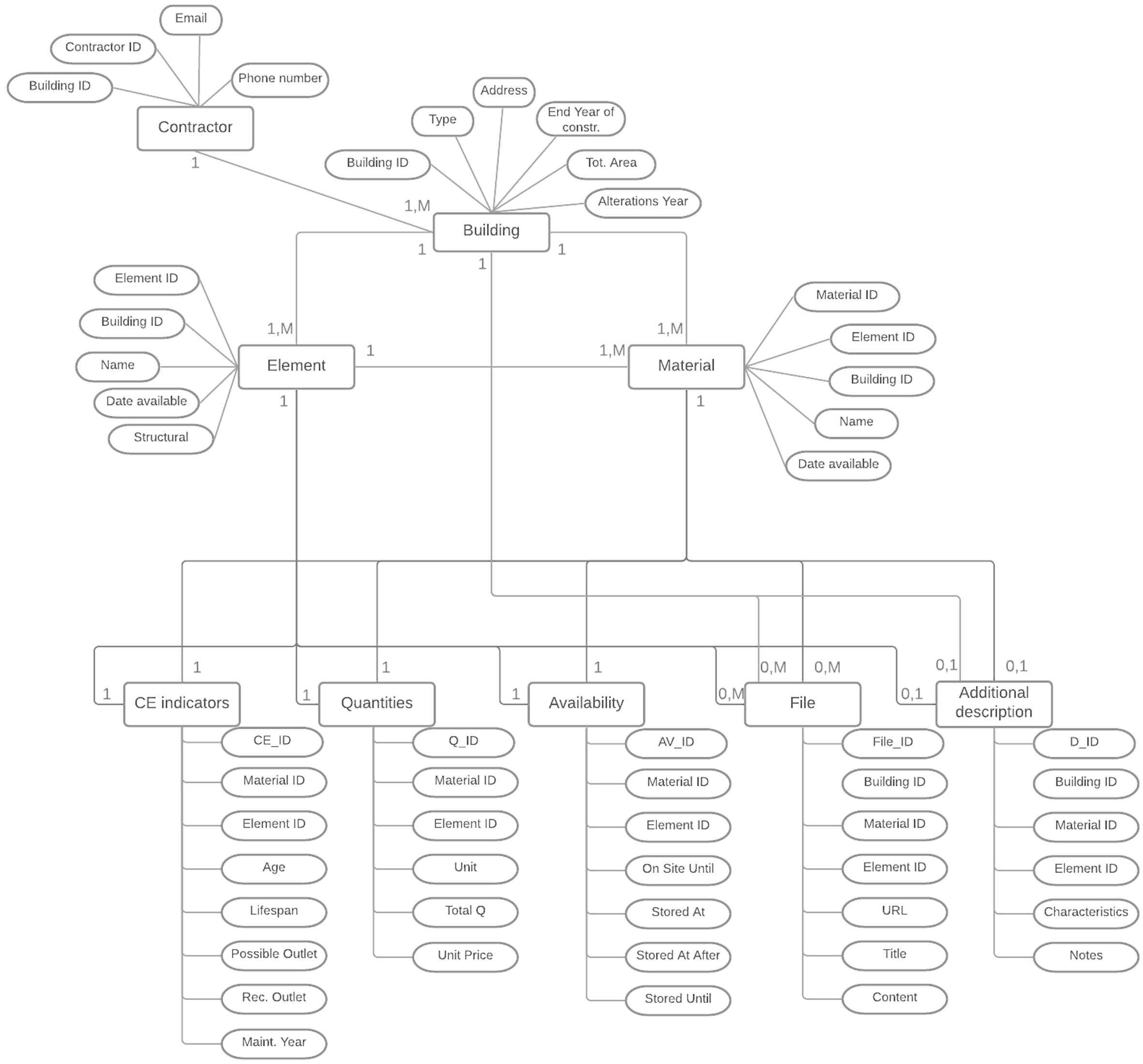


Figure 31 – Conceptual data model – own illustration

Logical data model

The logical data model is important for understanding the details of the data, and this is built on top of the initial established requirements. It implies more details, but it is still easily readable and understandable by any of the stakeholders involved, and it represents the first step towards building out the fundament of a database (Sherman, 2014). Definitions of the primary keys, foreign keys are included in this phase (*Figure 32*).

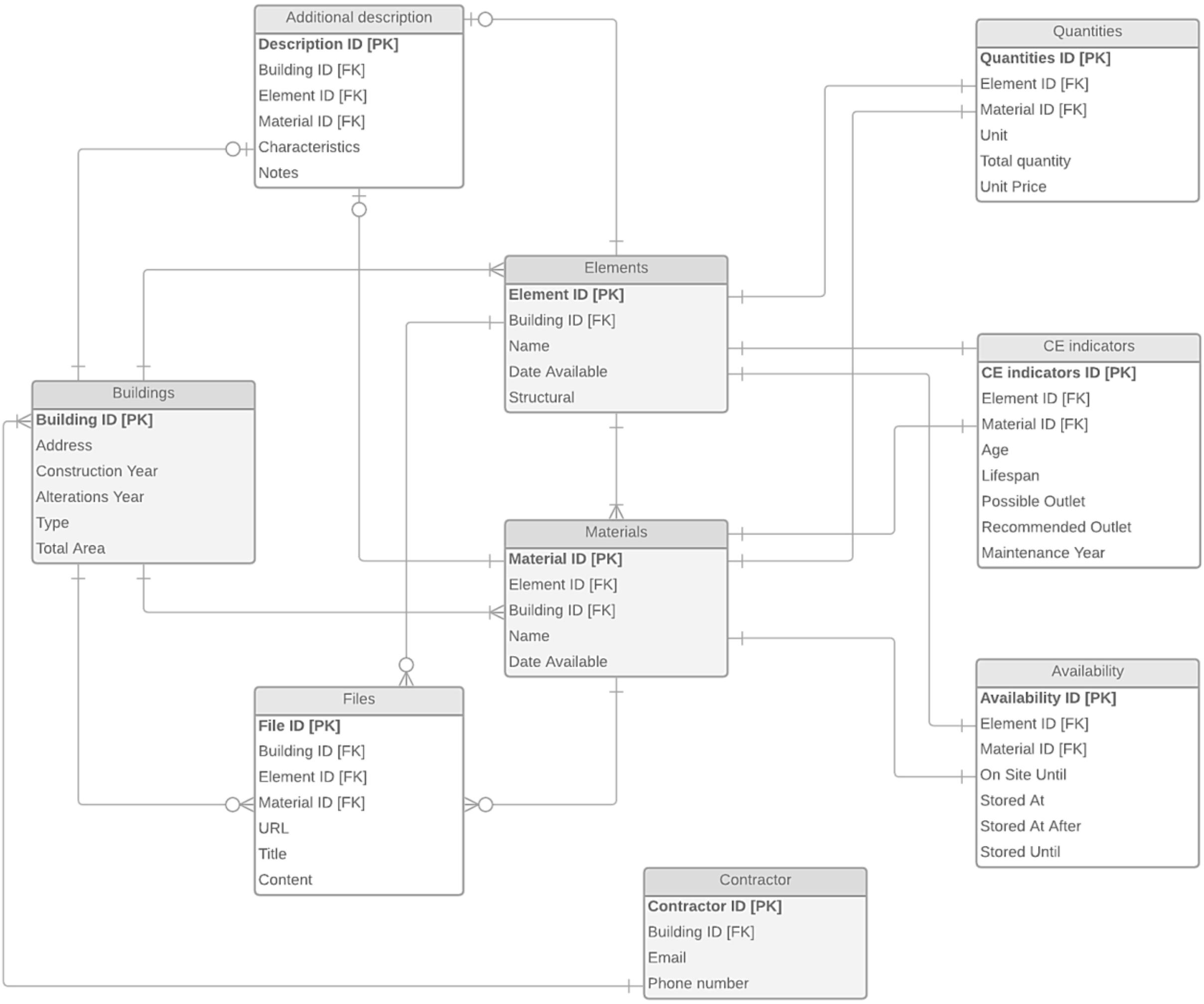


Figure 32 - Logical data model

Physical data model

The physical data model is intended to develop even more the structuring of data, by generally representing the logical model in a database schema (Sherman, 2014). In this subchapter, a draft of the physical data model is presented, and this has the potential of being adapted to varied types of databases. It is important to mention that in the representation (*Figure 33*) performance requirements of the future database are not considered, as it is part of a more technical level which is not the focus of this study.

Based on the proposed data models, it is most likely that a Relational Database (RDB) would be the best fit for further development, this being used for later retrieval of data. The study does not intend to focus on the further technical phase of implementation and testing, and it does not suggest a specific type of database the models should be used for, but it presents a general scenario.

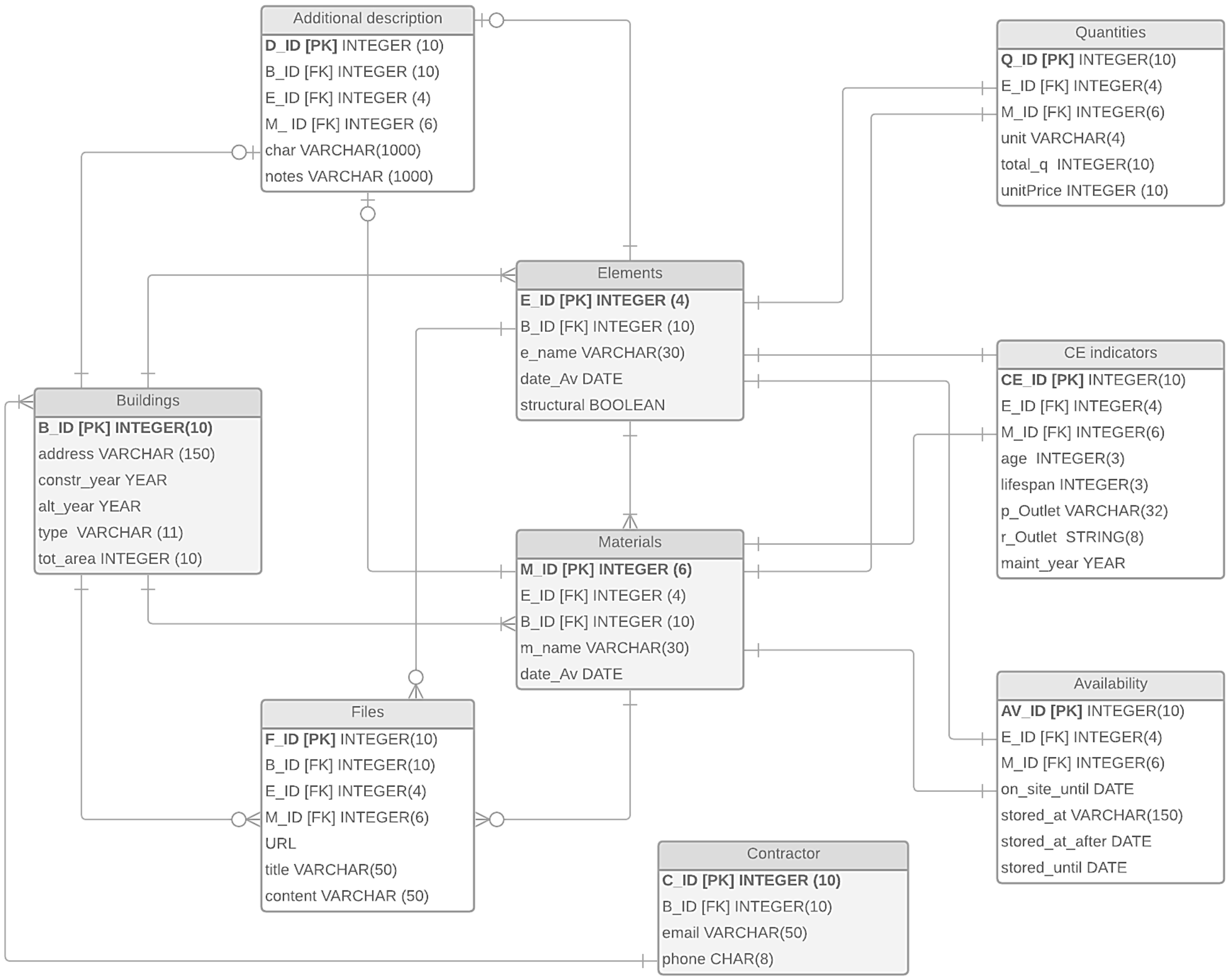


Figure 33 - Physical data model

Database Query

As the ultimate purpose of structuring data is to simplify the management of it and extract valuable information in a time efficient manner (Ramakrishnan & Gehrke, 2003), so in this case, the data structured previously, is suggested to serve as base for the implementation of a database, which then will be the fundament of a web-platform with the aim of increasing awareness about circularity within demolition of buildings, by providing information about buildings, elements, materials that will be available for reuse, recycling, recovery etc. in the near future.

With the scope of proving the later functionality of such data structure, for the context provided, examples of possible queries are presented below, considering the use of an SQL Database Management System (DBMS) as the application allowing data retrieval, for purely exemplification reasons.

```
SELECT * FROM elements WHERE date_av >= '2021-08-01';
```

The above query would fetch any existing element that will be available after 1/08/2021, and the results could look like this:

213 – 360433 – Concrete stairs – 2021-09-01 – False

The following query would retrieve all the names and dates available of the elements that have 'reuse' as the recommended outlet.

```
SELECT elements.e_name, date_av
FROM elements
JOIN ce_indicators ON elements.e_id=ce_indicators.e_id
WHERE ce_indicators.r_outlet="reuse";
```

The results to such a query would look like the example below, considering only 3 elements were found to have 'reuse' as recommended outlet:

Concrete stair – 2021-09-01
Wood beam – 2022-01-01
Window – 2021-08-15

Such a query would be used for example to create a filter for the user interface, where they could choose to list all the reusable elements available. The query can be extended to retrieve the building these elements are part of, the address of it, or for instance the place they will eventually be stored at after on-site management.

However, these are only two simple examples of the functionality of the database, which has as foundation the proposed model, but the queries can get a lot more complex depending on the needs of retrieval.

5.7. System design

As mentioned before, the aim of creating a database with the above proposed content, is to ultimately use this as a base for creating a web-based system where the end users will be able to retrieve the data, and become more aware of the existence of available reusable/recyclable building elements and materials. With that scope, this chapter briefly suggests how this platform would work, and what is the final output of the overall proposal of this paper.

5.7.1. General workflow of proposed system

The general workflow of the proposed solution (*Figure 34*) explains the elements that have to come together in order to create a functioning system. This is important for understanding the communication between the system components and all the stakeholders.

Based on the findings in the paper, it is considered that the most relevant administrational user would be

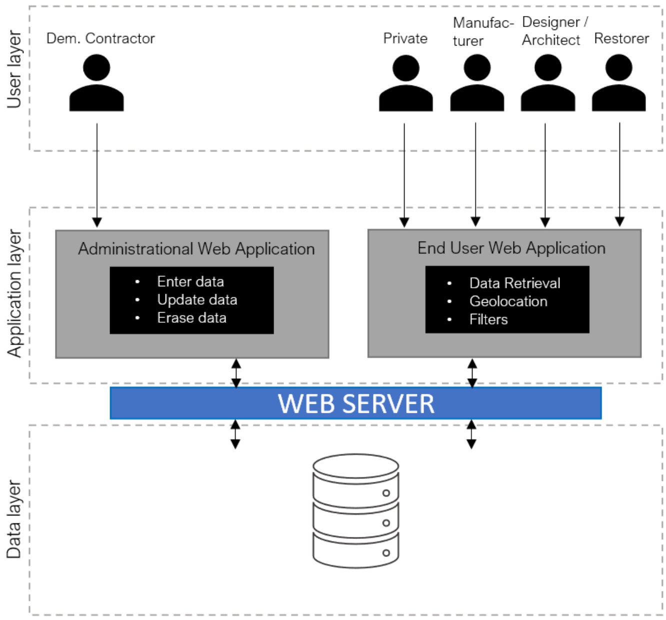


Figure 34 - General workflow of the proposed system

represented by the demolition contractors, as it is most common they receive the ownership of the waste, which means eventual earnings from material reselling would represent the main incentive for trying to make this system work. In addition to that, the final state of the materials will be known by this stakeholder, and how successful the actual retrieval of those has proved to be after the actual demolition activity, which might lead to a need of updating the estimation and inventory previously done in the waste audit report.

On the other hand, the targeted end -users will use a different web application for retrieving data, which could have a geolocation function for easier identification of address of the building being demolished, as well as filters for easier navigation and browsing of relevant needed information.

5.7.2. Mock-up design

For a better understanding of the output the proposed solution would have, a mock-up design is presented in this subchapter. The pictures, names and details within the examples are used for purely exemplification purposes.

Example Scenario 1

One of the possible users will be as described in this solution chapter, a private person who would like to be able to buy used building elements of small scale. The landing page (Figure 35) will give the option to pick between elements or materials. In this example, someone is looking for available furniture and equipment after the date of 10/08/2021, in Aalborg (Figure 36). The filters have returned 3 results (Figure 37), and the person has further clicked on the kitchen furniture to see all available details (Figure 38).

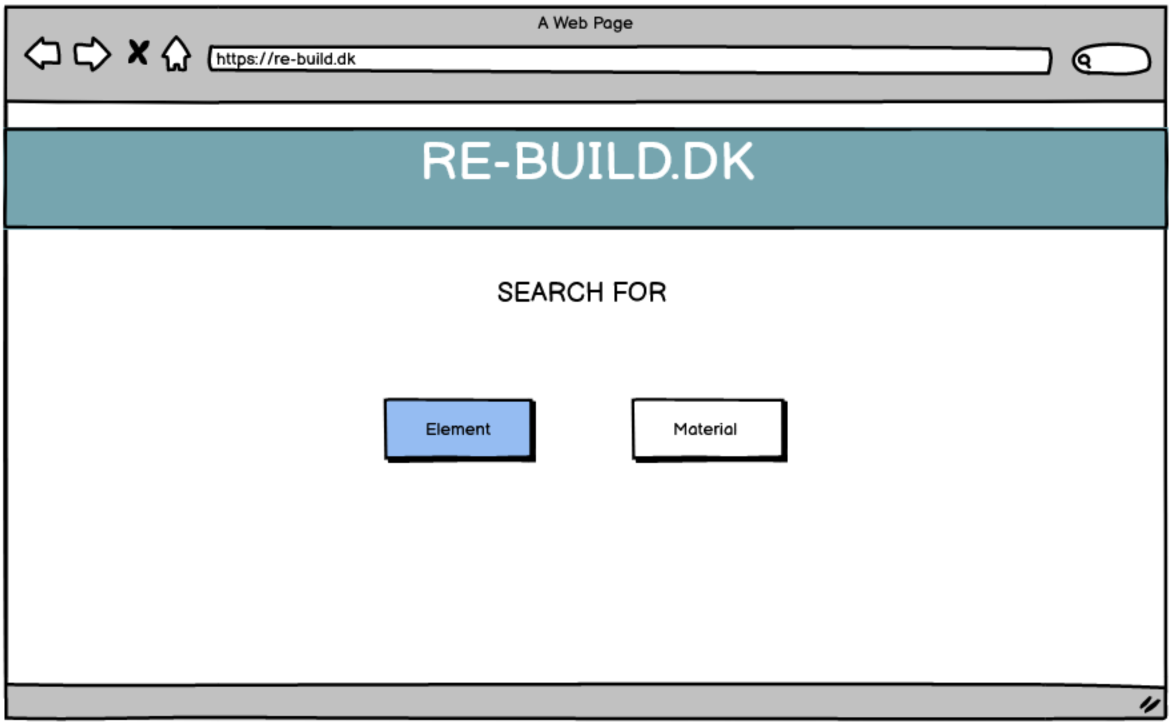


Figure 35 – Landing page

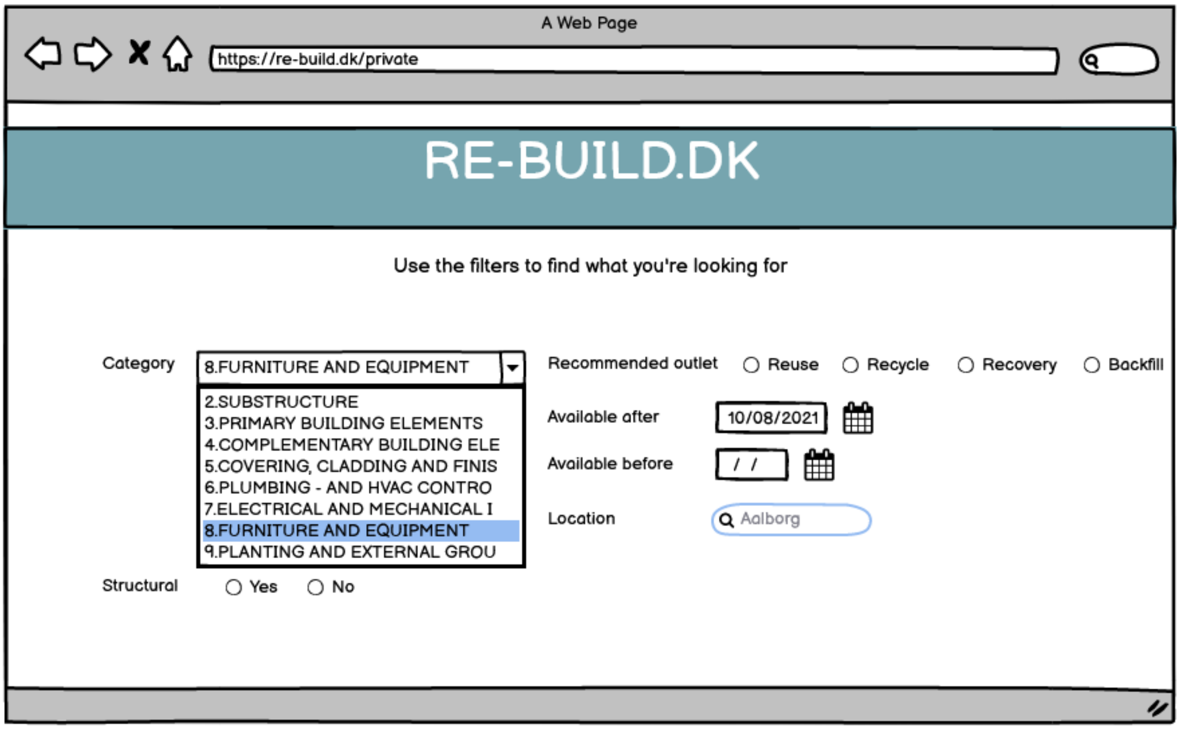


Figure 36 – Element Filter page

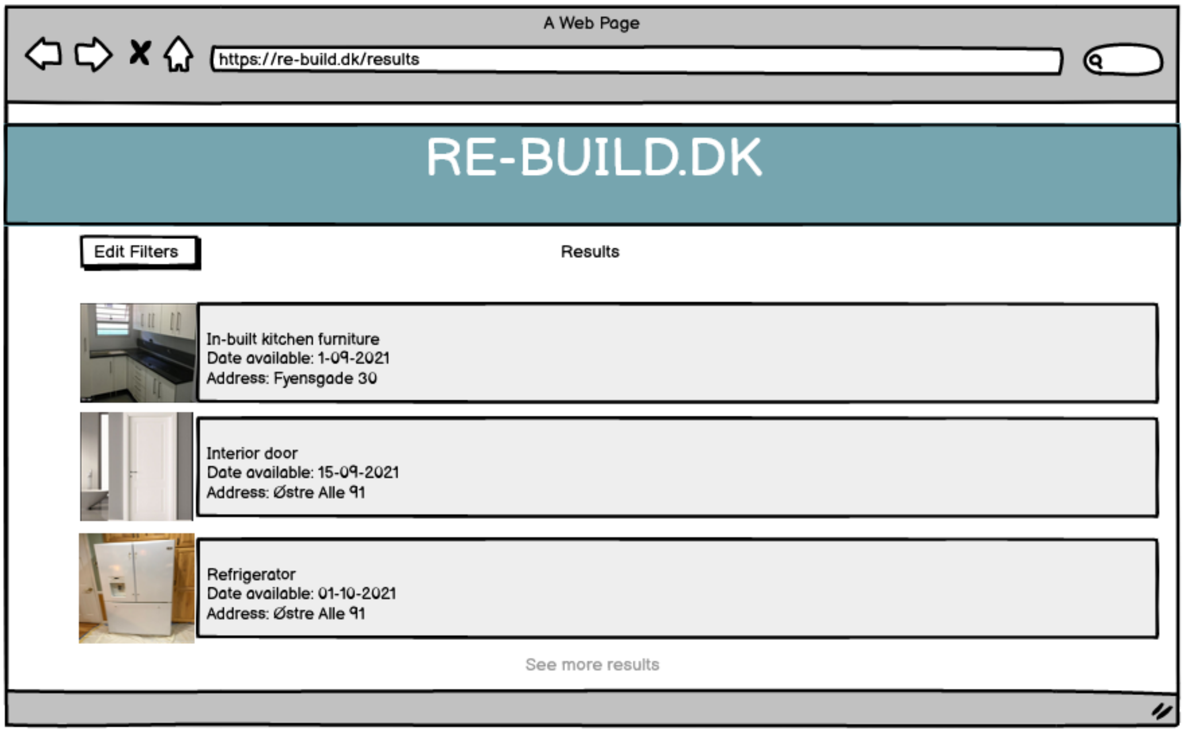


Figure 37 - Results of the filter applied

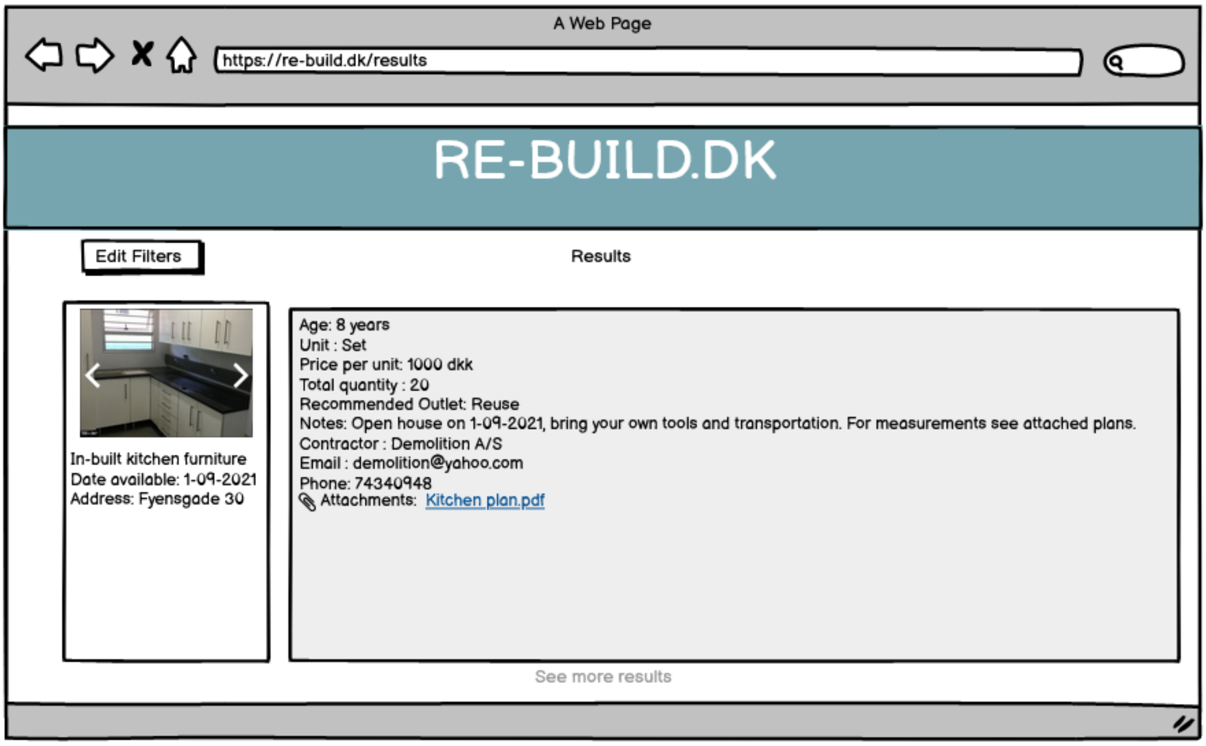


Figure 38 - Selected item page

The selling of this type of small-scale materials and elements would represent the most efficient, cheapest, and environmentally friendly way to dispense of these, and by the possibility of people using own tools and transportation there is no expense that has to be supported by the contractor.

Once the persons found the item they are interested in, they have the possibility to get in direct contact with the contractor and discuss eventual further details. Otherwise they can show up for the open house and pick up the items needed.

Example Scenario 2

The second scenario represents either a manufacturer that could be interested about the availability for possible aggregates for their production, or a recycler company looking for big quantities of materials. On the main page the user selects ''Material'' as the category and ''Recycle'' as the recommended outlet (Figure 39, 40). The results return 3 options available (Figure 41), and the user selects bricks (Figure 42). Now they can get in contact with the contractor for further details and planning.

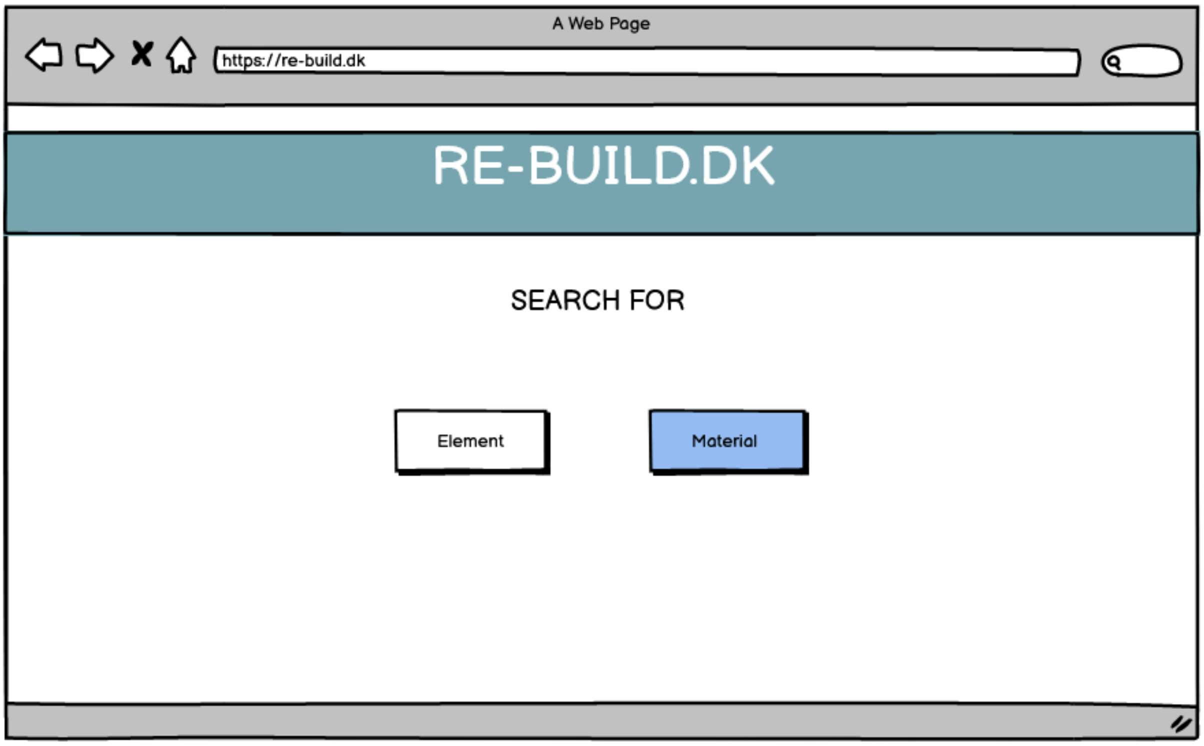


Figure 39 – Landing page

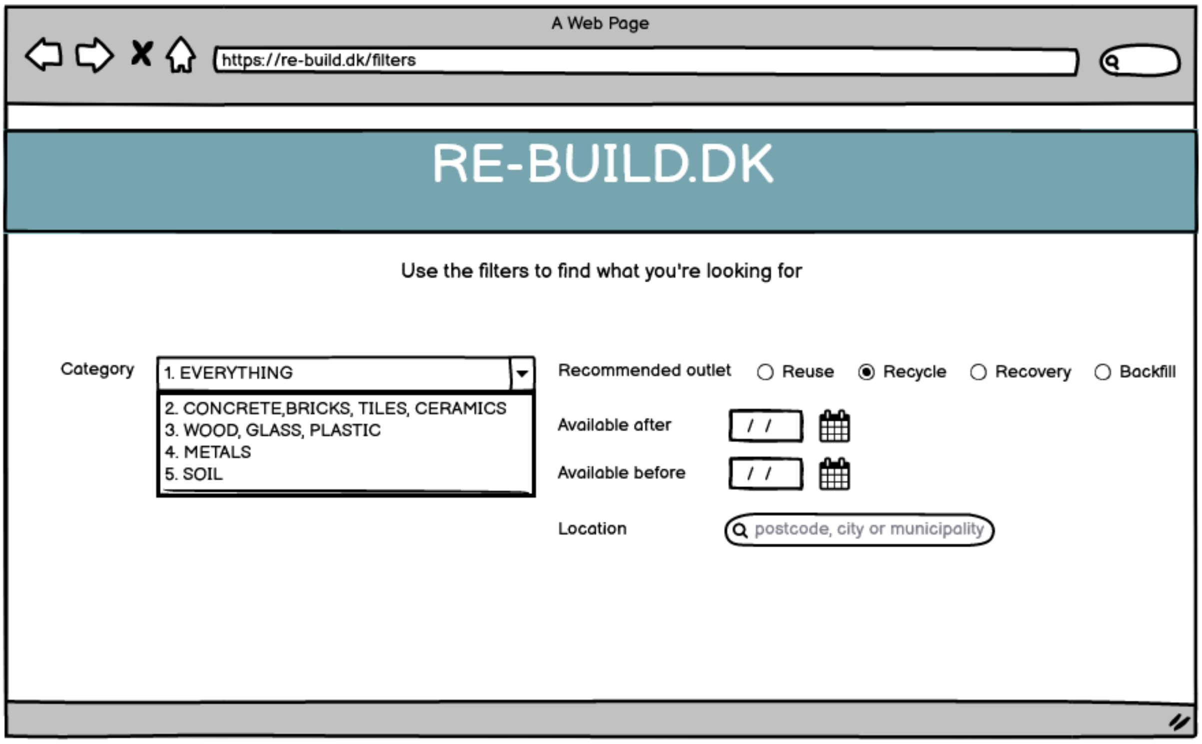


Figure 40 – Filters page

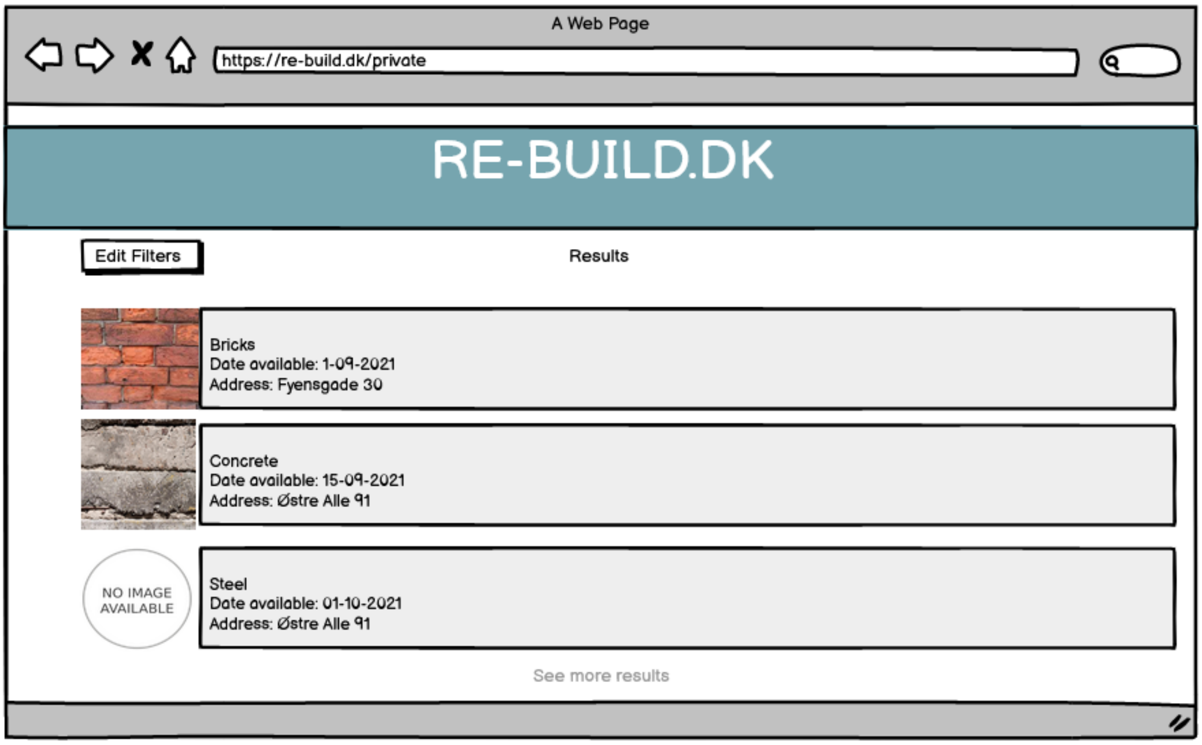


Figure 41 – Filter results

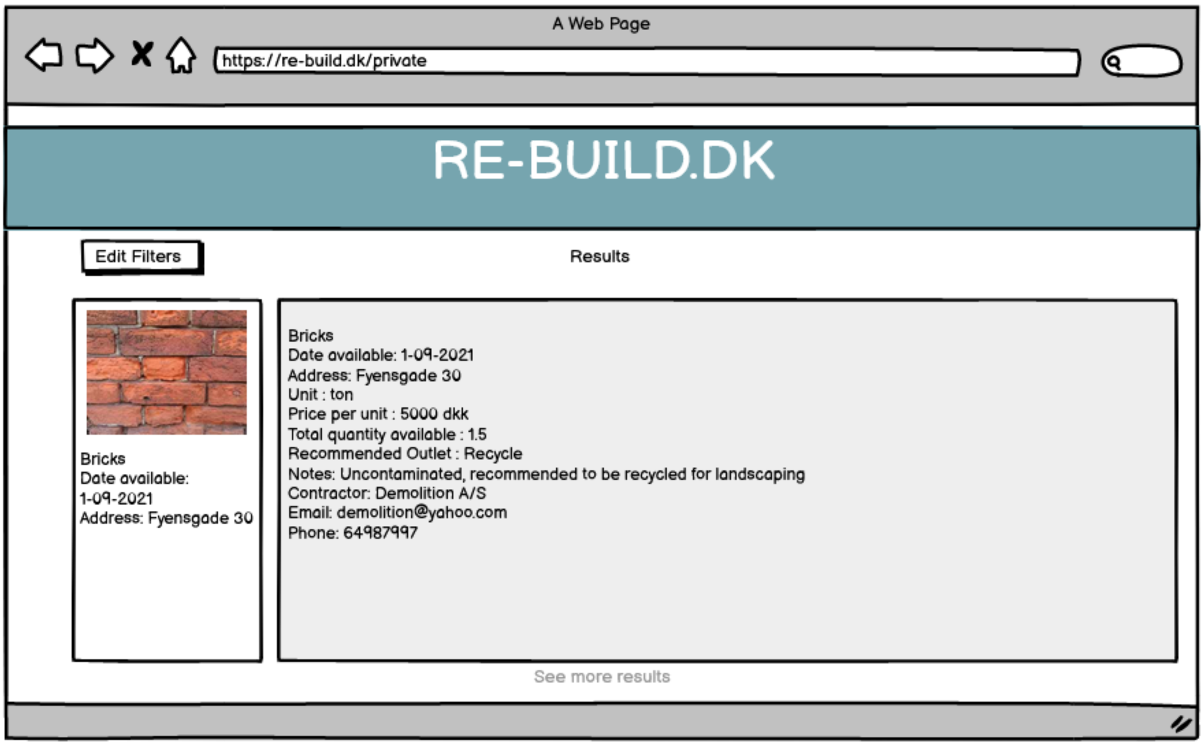


Figure 42 – Selected item page

As mentioned previously, these are only two examples of the many possibilities and scenarios that could represent the output of this paper's proposed solution. Future possibilities for development will be briefly discussed in the next chapter.

6. DISCUSSION AND FUTURE PERSPECTIVES

6.1. Discussion

Based on all the findings presented in this paper, there are still many factors hindering a mass-adoption of circular principles within the construction industry, therefore this still is a big waste generator and raw resource consumer. One of the many issues present in the industry is the big scale C&DW generation, as a result of the linear economic model of take, make, use, dispose that has been used as a core practice for a long time now. A more efficient use of raw material and a better waste management is greatly needed for a shift in the way this industry works, more than ever before.

The demolition of built assets and the manufacturing of building products hasn't been in close relation throughout the development of this industry, but this has started to slowly change as the pressure, from risks of price fluctuation for raw materials are occurring often due to scarcity of resources, is pushing towards a bigger interest in circularity and ways of efficient reuse, recycling and recovery for the purpose of reducing raw material usage and minimization of waste generation. However, the biggest focus nowadays has been directed towards future buildings, based on BIM technology, which have the potential to be designed from the start to be circular.

These initiatives are very much needed, but the results of it will only be achieved in at least 50-100 years from now, when the buildings designed now will have to come to their end of life.

From a different perspective, there is still an area that isn't as popular within research, and that is represented by the ageing buildings, the historical ones, or generally the ones raised over 50 years ago, which in a matter of years, for various reasons will need in-depth renovations or total demolition. Because these tend to lack in information, as-built documentation, and generally having inconsistent records, more efforts are needed towards better assessment prior to demolition activities, in order to ensure an optimal process, and the highest possible rates of reuse, recycling and recovery of the materials contained by these.

The literature has shown that very often the first records of the materials contained by a building are the waste reports, and this circumstance categorically hinders the maximization of materials lifespan, by allowing these to become waste before assessing if they could still have potential for any of the circular concepts.

The conducted interviews have shown that there is generally a big lack of demand, awareness and initiative when it comes to creating circularity within demolition of existing buildings, which results into lack of interest for material recovery from a building product manufacturer's point of view. The barriers and proposals for the bettering of the situation have been described in a very similar way from both sides, and besides the economic issues and uncertainty, the lack of information was underlined in both discussions.

The results of the survey have shown how materials resulted from demolition of buildings are not at all the first choice for recycling into production, and how there is still great room for improvements and developments with the aim of achieving greater circularity in this field. The analysis underlined the need for promotion of CE ideas and methods, as well as need for incentives.

Based on all the results, this paper proposed a concept that would help tackle some of the main issues encountered in the context.

6.1.1. Waste audit

Everything has led to identifying the lack of information regarding existing buildings, and the minimal assessment practices prior to demolition, which finally leads to a very increased volume of waste, that could be prevented if more information would be made available in direct regards to all elements and materials contained by buildings needing demolishing works.

Therefore, the study proposes a more in-depth and standardized waste audit process, where in addition to the existing minimal requirements of material testing for hazardous content, there would be more focus on identifying the potential of reuse/recycling/recovery of the elements and materials contained by a built asset, in order to collect this data, structure it, and make it publicly available, as early in the process as possible, before the actual demolition activity will commence.

The aim of this, is tackling the general lack of information, awareness and contributing to the promotion of circular thinking, by including and giving access to all types of potential users into the proposed solution. The similar existing initiatives explored in the paper are either excluding private users, either charging fees, or restricting general access by requiring subscriptions and user accounts, which hinders in one way or another a mass-adoption of the initiative.

The idea this study is based on, is that first step into creating circularity would be making people know this exists, and in this specific situation lack of information about availability of reusable materials is the main concern.

6.1.2. Data management

Based on the proposed content for the waste audit, the paper presents further an initiative for the data management, with the scope of making the information within the report useful. The conceptual, logical and physical model presented can represent a fundament for a fully working system.

The proposal is created to represent the minimum information needed for such a solution to work in real life, but this can be taken to a higher level of detail depending on the depth of information the waste audit will be able to provide as newer technologies are continuously emerging and will help testing and estimations be more clear than they are nowadays.

At the same time, the data models are designed based on logic and functionality purposes, with less focus on actual performance and efficiency matters.

6.1.3. System design

As a third step in the proposed solution, and with the aim of showcasing the final output of the data management, a brief description of a possible system design is presented suggesting the development of a web based platform that will enable this valuable data to contribute to raising awareness about circularity and tackle the issue of lack of information about material availability and easiness of finding those.

It is important to identify how all the proposed elements will come together to provide easily accessible information, available to any possible interested end-user.

6.2. Future perspectives

All in all, the results of the research have shown that there is great potential for improved pre-demolition assessment from a technical point of view, and there is available technology that can facilitate this, however, the same studies have also shown there are many other barriers hindering this from actually happening. One of the most important aspect is the economical one, where there is still great confusion in regards to what party should be supporting the expenses of in-depth testing and assessment of buildings, as well as the perception of the process not being worth as the prices received from selling used materials remains low. These are very complex aspects which this paper does not investigate, despite the fact that the implementation of a system as the one proposed by the author highly depends on this topic.

Another shortcoming of this paper is the reduced primary data collection the analysis is based on, and as mentioned in the methodology, this does not allow a generalization of the findings. The results are interpreted and analysed in balance with the findings from the secondary data collection.

Moreover, the standardization of a framework as the one presented, implies very sharp practices at the auditor's end, as the way data is collected throughout the waste audit process needs to be done in a standard manner, in order to enable a good functionality of a system as the one proposed and for eventual further developments. However, the proposed content does not focus on the technical tools, solutions and methods for obtaining the data, and the study does not imply specific technical, physical, and chemical characteristics of the materials, as this is a different objective than the current one.

Future possibilities in relation to this aspect would involve identification of methods and tools for data collection at the auditor's end, and possibilities for automation and digitalization of the way this is done, as the ultimate aim is to be able to input data straight into a system that will then connect right away with the proposed database, instead of having to manually enter data into different tools, platforms etc. This will increase efficiency and reduce manhours, therefore resulting into a more productive process.

Research shows that there are available solutions for the digitalization of existing buildings, which starts by the generation of as-built documentation and models. There are various methods (El-Din Fawzy, 2019; Macher et al., 2017; Benarab et al., 2018) such as semi-automated laser scan, photogrammetry, generation of point clouds in order to achieve the ultimate goal of 3D BIM models which can empower the interoperability in the context of these existing building assets. This type of procedures can represent the base for a potential future development of the solution presented in this paper, in order to obtain a fully automated and digitalized way of data collection.

Looking at the data management, the paper does not specify a precise type of database that should be used for the development of the system, due to the fact that even though a Relational Database would suit best the current proposed data model, and this type has proven to be the most common one in the context of web applications systems, the industry is generally making efforts to move towards more efficient data storage, such as Resource Description Framework

(RDF), where data is not stored in tables but in ''triples'', and this has the potential to improve significantly the access to information, by making it more interconnected. Therefore, this can represent a possible future possibility for the proposed solution, however this will only be realizable if the data collection will be achieved through a unified standardized way.

The system design is also an important factor and has great potential for future improvements as the aim is to attract and make as many users as possible happy, and this can be achieved by good quality data and great functionality of the applications. The design presented in the solution is based on the main idea of the proposal, the easy retrieval of data, and uncomplicated features. However, this can be further developed by eventually separating the content available to private persons and companies, which can be done by creating authentication layers, a mobile application would also increase the popularity of the tool, better filtering such as categories of elements materials based on their ID, or names, or geolocation giving the possibility of searching by radius from the user's current position.

Moreover, looking at the bigger picture in the industry, a solution like this could have the potential to later on merge with the current systems proposed for the construction of new buildings, based on BIM, material passports and generally available data about in-use stocks.

All these and more, can represent future possibilities for this paper's proposal for a digitalized and efficient way of increasing circularity in the context of demolition of existing buildings.

7. CONCLUSION

As the building sector still requires big efforts in order to become more environmentally friendly, and this contains a very extensive amount of different areas that need to be improved, this research aimed to identify what data input/output can enable circularity within demolition of existing buildings. To be able to find an answer to this, the main research objectives presented in the introduction have guided the overall research.

Construction industry remains one of the most significant waste generators, as this includes waste resulted from building products manufacturing, from construction activities, maintenance, renovations, and most importantly demolition, which throughout the industrial revolution has continuously increased the negative impact on the environment.

As the dominant way of business in this industry has been the linear model of take, make, use , dispose, manufacturing of new building products and demolition of built assets have not been in a close relationship, and even nowadays, the low demand from the manufacturing companies of adopting recycling within their production reflects in the poor procedures when it comes to pre-demolition assessment and planning, as there is no interest in sorting and prevention of waste generation from a waste holder's point of view, which most often is represented by the demolition contractors.

From a technical point of view, research shows that there are possibilities for material recovery from demolition of existing buildings, and as technology evolves rapidly, the future prospects look even better within this matter. The adoption of procedures for obtaining more in-depth information prior to demolition about existing buildings, which are generally poor in records and documentation, would help a better identification of elements and materials, and prevent as many of these from becoming waste.

Based on the results from the available literature and the analysis of primary data, this study proposes a three-step solution in this area. First element within the proposal is the standardized minimum required content for a pre-demolition audit report, as the current practices even in technological developed countries are very poor and inconsistent, resulting into a very low level of information and planning prior to demolition activities. Ultimately, this hinders the identification of possible recoverable building materials, and a high waste generation. The proposed solution is needed as an official requirement in order to obtain a standardized procedure and consistent practice.

The second element within the proposed solution is the management of the data obtained through the waste audit process. In order to make use of the report, the data contained by it has to be managed and structured in order to allow later retrieval in a time efficient matter. The paper presents a three-step development of a data model, which captures, in a structured manner, the relevant data contained by the pre-demolition audit report. This model represents the fundament for a database development, in this context a Relational Database. The implementation of this offers the further possibility of creating a system that can allow access to the stored data.

This is also the final step of the proposal, where the presentation of the system design shows the output obtained from the development of the solution, where the end-users can be represented by private persons, designers, architects, restaurateur companies, and even manufacturers. The solution is presented as a web-platform that can facilitate the access to information about the material availability, ahead of the actual demolition activity, in order to allow planning and further decisions of both the demolition contractor and the eventual end-user, without having the lack of time as the main factor hindering the process.

The overall purpose of this solution is to maximize the power of information, in order to promote circularity, and offer a chance to any interested party to get involved, without limiting the access to it. This can have the potential to increase at the same time the general public awareness about circular ways, availability, and contribute to the education of newer generations, even at an academical level.

The transition to a circular economy involves many complex aspects, but this will only happen if small steps will be taken in the right direction, because change starts from every single individual, which has the power to share and promote these ideas, in order to achieve a mass circular thinking, which will hopefully become the norm, and not something out of the ordinary.

A bigger effort has to be invested in clarification of procedures, guidelines and economical aspects of transitioning to CE, in order to diminish uncertainty and lack of initiative, as well as adaptation and creation of specific law and regulations for recoverable construction materials, that will be more permissive for ''out-of-the-box'' thinking.

The current studies and initiatives for the digitalized way of building will have without a doubt a great effect on the future constructions, and their end of life, from a CE point of view, but from a different perspective, the already built stock is very generous and needs just as much focus, as well as a solution oriented approach.

In conclusion, this study's proposal only tackles a very small area of this complex concept called Circular Economy, but it offers a base for bridging the existing gap within demolition of existing buildings in current practice, by offering a proposal of standardization for pre-demolition assessment, as well as a foundation for the management of data collected through that process, leading ultimately to a tool that could help raise awareness and encourage circularity.

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