CIRCULAR DEMOLITION PROCESS

Enhancing the reuse potential of components and materials in the building industry

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M.Sc. Thesis

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Graduation thesis

University: Delft University of Technology

Faculty: Civil Engineering and Geoscience

Master: Construction Management and Engineering

Date: 30 November 2018

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Preface

This thesis is the result of my graduation research on circular demolition process. I conducted this research as the final part of the Master Construction Management and Engineering at the TU Delft.

This thesis would not have been possible without the help of my graduation committee. I would like to thank first my supervisor Ad Straub, who always made time to help me when I needed it. He helped me to find the focus of my research, he always read my work and gave me valuable feedback. I would like to thank my second supervisor Francesco Di Maio for sharing his knowledge in this field and helped me to shape my research even further. Next, I would like to thank my professor Tillmann Klein for his constructive feedback during the meetings that helped me to define my research better.

Furthermore, I would like to thank all the interviewees that participate in this research and took the time from their day to share their valuable experience and knowledge with me. It was nice to discuss the concept of circular demolition and the reuse of materials with you and grasp the excitement that you have on that topic. Many ideas were mentioned that shows that people want to change the situation in order to deliver a better environment for the next generations.

Finally, I would like to thank my family and friends who supported me through the process of completing my graduation project.

Polina Michael

Delft, November 2018

Summary

The construction industry uses a lot of raw materials and produces a huge amount of waste each year. This causes a lot of environmental problems such as the excessive extraction of raw materials, the produced CO_2 emissions and the waste that end up in landfills. This is mainly caused due to the linear economic model that the construction sector uses. In this model when a building comes to the end of its lifetime, the materials are disposed of. Instead of that, the circular economic model should be used where the components and materials should be reused after the end life of a building.

In the demolition phase, a lot of waste is produced that end up in landfills, or they are recycled. In the Netherlands, 95% of the demolition materials are recycled. However, there are counties in EU that have very low recycling rate. Even with recycling, the materials lose some of their value. To recycle them a lot of energy is needed and CO_2 emissions are produced. The best option is to reuse components and materials. In the Netherlands, only 3-4% of the materials being used in the building industry are secondary materials, which shows that the building industry is not circular. To change that, more materials need to become available for reuse. However, the current demolition process doesn't allow the retrieval of materials and components that can be reused. Most of the components are destroyed in the process, and they end up together in the same streams without proper separation. The demolition contractors don't realise the value of circular demolition and reuse of materials.

The objective of this research is to develop a new demolition process flowchart and provide recommendations to the actors involved that will enhance the reuse potential of the components and materials. In order to achieve that the following research question is formulated as:

"How could the demolition process in the building industry be adjusted in order to enhance the reuse potential of the building components and materials?"

Methodology

To answer this research question the relevant available literature needed to be reviewed, and input from the industry was necessary. In order to get information for the traditional demolition process steps and how they affect the reuse potential of the materials, desk research was required. From the review of the relevant literature, the potential needed changes were identified, and the initial flowchart was developed. To gain input from the practise a case study and interviews were used. Interviews were conducted with frontrunners demolition companies and clients that have made efforts to adopt circular demolition. Qualitative analysis was performed with the use of Atlas.ti. The interviews were analysed with codes that were created based on the perceived needed changes. Also, new codes were created from the data collected from the interviews. The findings of the qualitative analysis were used to develop the final demolition process flowchart and provide recommendations to the actors involved.

Findings

Since the traditional demolition process is still in use by some countries, it was decided to take it as a starting point for the development of the new demolition process flowchart. The traditional demolition process was created based on international literature. It is simple with a few steps. Not a lot of attention is given in the pre-demolition and waste management planning. The demolition is done, the waste is collected, transported to a facility where most of them are landfilled, and some of them might be recycled. This process doesn't allow the materials to be reused since most of them are destroyed in the process. The new circular demolition process that is suggested in this thesis incorporates steps that will allow the demolition companies to retrieve components and materials for reuse.

The new flowchart includes more activities that will help the actors to behave more circular. In all the project stages some actions are required in order to be able to retrieve components and materials for reuse. In the tender stage, it is important to have sustainability criteria or requirements for reuse. In this way, it will be a price-quality tender and not a lowest price. The client can invite parties for a tender or give the project to a specific company. In the case that it is a redevelopment project, the demolition contractor should be involved in the planning of the new project. In the audit stage, it is essential to have site visits that include building and structural survey and test for hazardous materials. From that stage, a detailed inventory list needs to be created with all the components and materials of the building. It should contain all the materials that can be reused, their quality, condition and quantity. The demolition technique is decided based on the structural survey, and it should not be destructive for the components. In the planning stage, if the client does not intend to reuse the materials and components himself, it is essential to find buyers for most of them through the network of business of the company. If this is not possible, the materials can be advertised and sold through an online marketplace. From the expected revenue of the sale of the components cost estimation can be made along with scheduling and resource allocation. A waste management plan should be produced containing all the information of where the materials will go. At the end of this stage, the demolition plan is produced.

In the execution stage, all the hazardous materials should be removed first from the site. Then, all the components and materials that are going to be reused are removed from the building in stages. When they are removed, they need to be separated into different materials streams. When everything that can be reused is removed, the rest of the structures can be demolished. The materials can be reused, recycled or sent to landfills. The materials and components that are going to be reused are given a QR code. Some materials can be reused on the site. In this case, they need to be stored until they can be used or send for cleaning and refurbishment. If the materials are sold, they need to be transported to the new location. This can be a new construction project, a storage facility, a second-hand store, a remanufacturer or they can be sent back to the initial supplier.

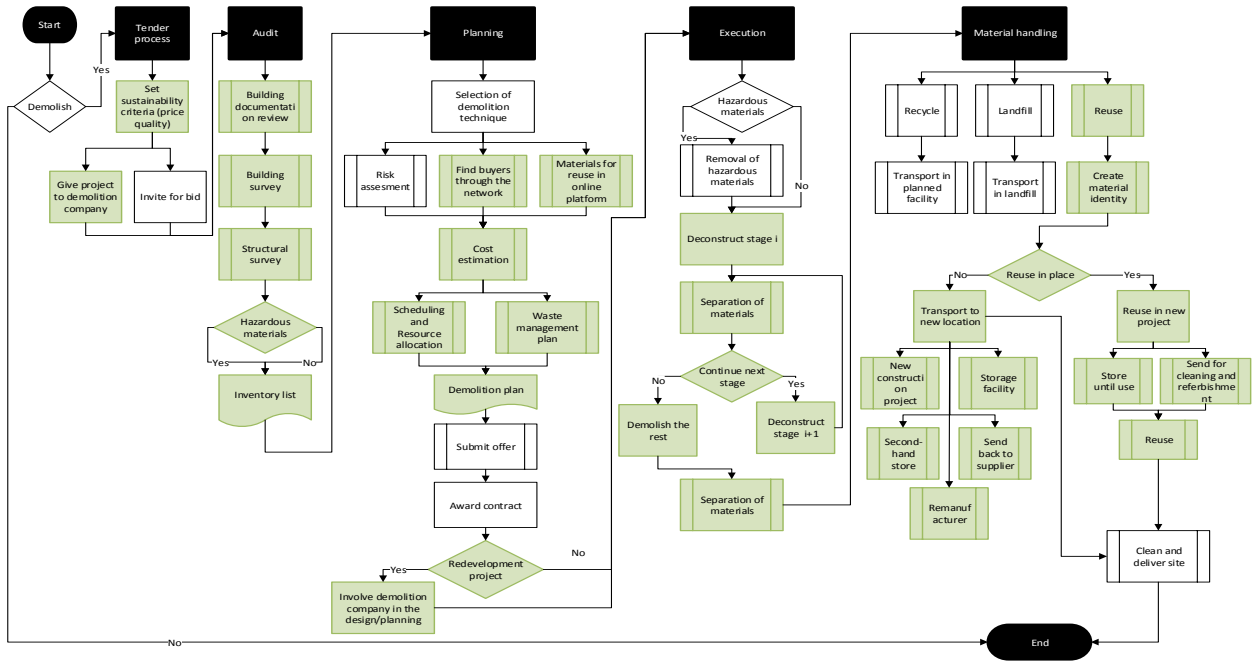

Figure 1: Circular demolition process flowchart

Apart from the demolition process, the actors involved need to change their attitude and actions toward circular demolition. For this reason, several recommendations are given to them. First, the clients should consider demolishing circularly and reusing components and materials in their new projects. If not, they should allow the demolition company to retrieve them and sell them to a third party. The clients that own a lot of properties, they should consider the whole portfolio of their projects in order to see if they can reuse materials from one project to another. They should also consider the option to purchase reused materials for their maintenance and renovation activities. In the case of demolition and redevelopment, the clients should cooperate with companies that have the expertise and vision of reusing materials. It is also important to have a direct contract with the demolition contractor and involve him from the beginning of the project.

The demolition companies should try to take materials for reuse. They should show the clients the benefits and importance of circular demolition and reuse of materials. In this way, they can convince them to reuse material or at least allow them to retrieve materials from the project and give them the time needed. The demolition company should develop a network of businesses to sell the materials. They should invest in training. More labour is needed for deconstruction, and there is a shortage of skilled people. They should invest in people with circular mindset, in creative people and experienced labour. The demolition companies should cooperate among themselves and develop an internet network (cloud) for exchanging reused materials in order to save time and money in the development of the new projects.

The government should adopt laws and regulation regarding circular demolition and reuse of materials. These laws and regulations should encourage the reuse of materials and avoid more restrictions. They can also implement programs to train unskilled labour.

The companies that produce construction materials must develop new components and materials that can be easily deconstructed. The producers of the materials need to change their products. Suppliers should take back their components, refurbish and make them available for reuse in other projects. The materials can be sold in second-hand stores, they can be reused by manufacturing companies or by individuals. The architects and contractors should consider using them in new projects.

The demolition process flowchart and the recommendations can be used by the actors involved to help them adopt circular demolition process and take more material for reuse. Even if only some of the recommended steps are adopted, the demolition companies will be able to retrieve materials for reuse. It is believed that if the actors involved follow this flowchart and the recommendations a lot more components and material could be retrieved from the demolition sites and be reused, and this will be beneficial for the environment since fewer materials will be downcycled and landfilled.

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1. Introduction

Large infrastructure and buildings are required for today's emerging economies. The construction industry uses a lot of raw materials to facilitate the needs and produces a great amount of waste. In the period 1900-2010, the extraction of raw materials increased by 37%, and it is expected to grow more in the future. This causes exhaustion of the natural resources and increases the CO_2 emissions in the environment (Krausmann et al., 2017). The waste produced by the construction industry in the European Union is approximately 25-30% of all waste generated (European Commission, 2016). In the Netherlands, due to demolition and renovations, the industry produces approximately 25 million tons of waste each year (Schut et al., 2016). The amount of waste that is generated is mainly caused due to the linear economic model that the construction sector uses. In a linear economic model, the take-make-dispose plan is followed. In this model, new materials are used for construction, and when the building has reached the end of its useful lifetime, the components and materials are disposed of (Ellen MacArthur Foundation, 2015). This model contributes to the problem of the exhaustion of natural resources, the increased CO_2 emissions and the landfilling.

In order to decrease the extraction of raw materials and the waste generated by the construction industry, the existing materials need to have longer service lifetimes (Krausmann et al., 2017). To achieve that, the European Union have set a goal that by 2020 a minimum 70% of non-hazardous construction and demolition waste need to be reused, recycled or go through material recovery (European Commission, 2016). In order to achieve that more sustainable approaches need to be adopted. The notion of the circular economy is now emerging proposing a new economic model that promotes reuse of components and materials. The components should not be disposed of in landfills, but instead, they should be retrieved, maintained or restored, reused and recycled. This cycle can be done for more than one time until the materials reach the end of their useful life (Ellen MacArthur Foundation, 2015).

The circular economy is based on the 3R's theory where the three R's are reduce, reuse and recycle. The first choice should be to reduce the amount of waste that is produced. Then reuse of materials should follow where the components should be reused for their intended purpose. The last option should be recycling where the components are broken down to raw materials and are used again to create new components (Gomathi & Pradeep, 2017). Reuse of components and materials should be preferred over recycling since with reuse more embodied energy and value are preserved (Ellen MacArthur Foundation, 2015).

The most common practice with demolition materials is recycling. In the Netherlands, most of the waste (95%) are already downcycled and used in infrastructure as road base materials and filler materials (Schut et al., 2016). The current processes don't allow the construction materials to retain their utility after the end life of a building. Even with recycling, the initial utility of the materials is reduced (Rose & Stegemann, 2018) and the energy that is needed to recycle the materials has adverse environmental effects (Kibert et al., 2001). This means that the current practices and the industry's massive extraction

of raw materials are continuing, causing negative environmental impact (Rose & Stegemann, 2018). To minimise that, more environmentally friendly practices need to be adopted (Kibert et al., 2001).

1.1 Problem statement

The necessities of today's societies lead us to have more and more construction projects which benefit society but have a negative impact on the environment. The excess extraction of raw materials, the produced CO_2 emissions and the waste that end up in landfills are some of them. Construction projects have a lot of phases, and each phase has a different impact. Demolition is one of the phases that has the most negative impact on the environment. At this phase, a lot of waste is produced, which some of them end up in landfills, and others are recycled. Those waste became waste from the moment the building is being demolished. Before that, they were useful components and materials that served a specific purpose. The demolition process that is followed cause the materials to become waste.

In the demolition process, several decisions are made from the involved actors that affect the future of the materials of the building. The materials can be reused, restored, recycled or they can become waste. This depends on the way they are retrieved. When the materials are reclaimed properly, they can be reused in other construction projects. Unfortunately, this does not happen in most of the countries. The most common practice with demolition waste is recycling or landfilling. Even in countries with very high recycling rates, the reuse of materials is limited. In the Netherlands, the building sector uses mostly new materials for the construction and renovation projects. Only 3-4% of the materials used are secondary materials which show that the building industry is not circular (Schut, et al., 2015).

When a building comes to the end of its useful life the most common practice that is used is demolition, where the materials get destroyed, and they can't be reused. The demolition methods they use are distractive for the components, and they cannot be easily reused. Most of the materials end up in the same waste streams without or limited separation. The components are treated as a liability instead of an asset. The contractors don't see the value the materials could have if they were appropriately dismantled (Rose & Stegemann, 2018). The demolition projects are driven by time and cost. However, sustainability and circularity should also play an important role in the demolition process. From all the above the following problem statement can be defined:

The current demolition processes don't facilitate the reuse of the components and materials in the building industry.

1.2 Objectives

Based on the problems listed above the goal of this research is to find ways to change the demolition process in such a way that more components and materials can be taken for reuse. To achieve that a new demolition process flowchart is designed that will enhance the reuse potential of the components and materials in the building industry. Based on the analysis and findings of this research several recommendations are given to the involved actors in order to help them adopt more circular demolition processes.

Circular demolition is a new concept. A lot of countries still use the traditional demolition process where most of the materials are landfilled or recycled. The Netherlands gives feasibility for this research since the construction sector recently started acting more circular. A certain amount of demolition companies have made some effort to adopt more circular demolition. Also, clients that value sustainability are willing to invest in circular demolition. Frontrunners were interviewed, and they gave a great and realistic input for the research and the produced findings.

Input from scientific research and practice is evaluated and examined in order to design the flowchart. The parts of the process that contribute to the problem are identified, and ways to change them are given. The current research will help to improve the demolition processes. The actors involved can use the flowchart and the recommendations in order to have more sustainable processes and allow the recovery of more materials for reuse. The demolition process flowchart and the recommendations are widely applicable. It doesn't concern only counties with high recycling rates like the Netherlands but also countries that follow traditional demolition process. The findings can be adopted and help to increase the overall reuse rate of materials in the building industry. It can help to adopt more circular demolition and enhance the sustainability of the demolition projects. It can also contribute to the policy that the Netherlands should achieve 100% circularity by 2050. This includes the construction sector, since more materials should be reused in order to achieve that goal (The Ministry of Infrastructure and the Environment, 2016).

Demolition is a topic that is not widely researched. There is some research on the processes of demolition, in the planning and the reuse of the materials. There are still some gaps that need to be filled especially in the sustainable demolition process. Most of the research on demolition processes emphasise on traditional demolition process, the recycling of the materials and not the reuse. The existing literature is not focused on circular demolition processes that give reuse potential to the materials. This is the gap that this research is intended to fill.

1.3 Research Question

Based on the research problem and objective the following question and sub-questions were formulated.

How could the demolition process in the building industry be adjusted in order to enhance the reuse potential of the building components and materials?

To find the answer to this question more knowledge needs to be obtained. The following sub-questions will help to answer the main research question.

1. What are the steps of the traditional demolition process?
2. How can each step of the process affect the reusability of the components and materials?
3. What are the barriers and opportunities for circular demolition and reuse?
4. What are the perceived needed changes in the demolition process?
5. How can the involved actors affect the reusability of the materials?
6. What needs to be changed in the process?

1.4 Thesis Outline

The introduction along with the research problem, objective and questions are given in the previous part. Based on that, the research methodology follows, explaining the research approach, methods and stages. The following chapter is the literature study. There the traditional demolition process is given, and the demolition stages are analysed in detailed regarding reusability. Then the barriers and opportunities for circular demolition and reuse of materials are provided. In chapter 4, the perceived needed changes for the demolition process and the actors are identified. The development of the initial demolition process flowchart is presented in detail. Chapter 5 follows with the data from the case study and the interviews. The analysis along with the findings from practice are given in chapter 6. The flowchart is adjusted based on the findings, and the results are validated. In the end, the discussion, conclusion and recommendations are given. The following figure contains the outline of the report, showing what is included in each chapter.

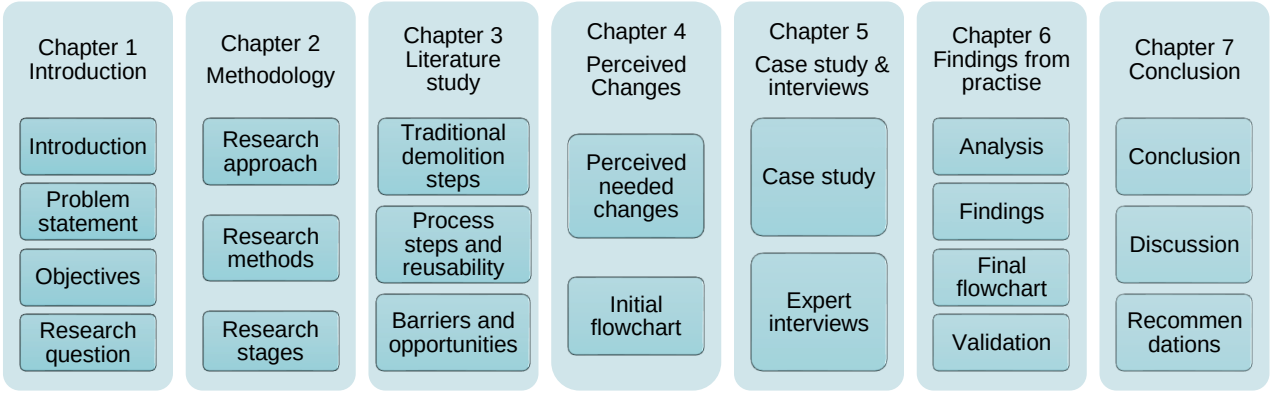

Figure 2: Thesis outline

2. Research Methodology

2.1 Research approach

The research is focused on answering the following research question: *How could the demolition process in the building industry be adjusted in order to enhance the reuse potential of the building components and materials?* Several sub-questions have been defined that helped to answer the main question. To achieve that qualitative research was contacted which was based on desk research, a case study and interviews with experts.

As a starting point for this research, the traditional demolition process needed to be established. The European Union had set a goal that by 2020 all the member states need to recycle, reuse or undertake material recovery for 70% of the construction and demolition waste. To do that the member states need to adjust their processes to divert the construction waste from landfills. The recycling rate varies between the member states. There are countries that recycle 90% of the waste, but there are others that recycle less than 10% (European Commission, 2018). The countries that have low recycling rate most of the time are using traditional demolition process, and they sent the construction and demolition waste in landfills. In countries with very high recycling rate like the Netherlands the demolition companies don't follow the traditional demolition process, but they have made efforts to adjust their process to recycle as many materials as possible. However, in most of the time, the materials are recycled and not reused. Only 3-4% of the components and materials are reused in the Netherlands in the construction industry. In the demolition process, the materials are retrieved for recycling and not for reuse. In order to enable the retrieval of components and materials for reuse, the demolition process needs to be adjusted. For those reasons, it was selected to take the traditional demolition process that exists in the scientific literature as a starting point for this research. In this way, all the adjustment can be made even if the traditional demolition process is followed.

From there all the steps of the demolition process were analysed in detail to see how they affect the reuse potential of the materials. All the steps that are followed, the actions taken have an impact on the reuse potential of the components and materials, and they needed to be analysed. Moreover, the barriers and opportunities were identified in order to see how the opportunities can be used and how the barriers can be mitigated by the new process. Based on the finding of the literature study the potential needed changes were determined, and the initial flowchart of the demolition process with the changes was created. Those findings were used as input for the next part of the research.

Input from frontrunners in practice in the field of circular demolition and reuse of materials was necessary in order to adjust the demolition process. The Netherlands could give valuable information in that area since some of the demolition companies, and building owners have recently embraced circular economy and tried to adapt their practices in order to have more circular processes. This means that some of the demolition companies try to retrieve components and materials for reuse and some of the building owners are more open in reusing materials.

To gain this input form practice a specific case study and expert interviews with frontrunners were used. The questions for the interviews were created based on the potential needed changes that were identified during the literature study. All the data gained from the interviews and the case study were analysed based on codes that were created. Two set of codes were created one on the potential needed changes and one on the barriers and opportunities of circular demolition and reuse of materials. Also from the data new codes emerged giving new information. The results from the analyses were incorporated in the final flowchart of the circular demolition process which was validated by the interviewed demolition companies.

2.2 Research methods

To answer the research questions, input from theory and practice was necessary. First, to address the theory, desk research was carried. Input from practice was taken by a case study and interviews with selected actors.

Desk research

The first research approach was desk research. In the desk research knowledge and data produced by others were checked. The data were gathered from literature and secondary data. The sources were books, articles, conference proceedings, and empirical data compiled by other researchers (Doorewaard & Verschuren, 2010). Also, European and local standards, regulations and official websites of organisations gave input regarding the rules and guidelines for demolition and reuse of materials. The goal of this method was to answer the first two sub-questions, provide input for the third one and answer the forth sub-question. Data from international literature was used to establish the traditional demolition process. Also, it provided detailed information on how the demolition steps, the actors involved, European and local standards and regulations affect the reuse potential of the components and the materials. The barriers and opportunities of circular demolition and reuse of materials were identified. All those were used to answer the fourth question on the potential needed changes in the demolition process and the actors involved. Finally, it gave the basis for developing the initial demolition process flowchart.

Case study

The goal of the case study was to see how in practice they deconstructed and made materials available for reuse. The selected case study is a very specific project where the goal of the project was to reuse as many components and materials as possible. It is a demolition and redevelopment project where the components and materials produced in the demolition phase were used in the new construction. This case study gave input on the demolition process they used in practice, on how the actors approached the project to enable circular demolition and what materials they were able to reuse. It also gave input on the challenges they faced during this process and the lessons learned from this innovative project.

Interviews

The goal of the interviews was to get as many information as possible on the best practices that enable circular demolition. Interviews give the opportunity to discuss and learn and also can provide new ideas. Semi-structure interviews were used which gave the freedom to adapt some questions when needed. An alternative method to that was the survey, but

it has limitations since it doesn't provide the freedom to the responders to say everything they need to tell. Interviews also have some challenges. It is more challenging to have interviews instead of a survey since they require more time and there is no anonymity. Also, the interviewees may not be willing to share all the necessary information, or they might not give fulfilling answers. Apart from the drawbacks and limitations of this method, interviews allow having input from several parties from the industry.

The interviews were held with actors involved in the demolition process. The interviewees were people that are frontrunners, value circularity and have some experience with circular demolition and buildings. They could help to identify the best practices that could enable the retrieval of more components and materials for reuse. The questions created for the interviews were based on international literature on the potential needed changes in the demolition process. The interviews were semi-structured interviews. This type was chosen because it gives the opportunities to ask questions about a specific topic and the interviewee has the freedom to share his experience and opinions on the subject. The interviews were recorded with the permission of the interviewee. They were transcribed and were sent back for approval. This was done in order to make sure that the interpretation of their answers was correct.

2.3 Research stages

The research was divided into seven stages that are analysed below. In Figure 3 the research methodology with the research stages is given.

Stage 1: Introduction

The first stage of this research was the introduction where the research problem, objective and questions were established. The available literature and research methods helped to create the problem definition and the research methodology which can be found in chapter 1 and 2.

Stage 2: Literature study

The second stage was the literature study that helped to define the current state in the literature of all parameters relevant to the research. This stage gave input to the first three sub-questions which are analysed below. The results of the literature review can be found in Chapter 3.

The first question that was answered by literature study was: *What are the steps of the traditional demolition process?*

The steps of the traditional demolition process needed to be established first. International scientific literature was used, and it gave input on the demolition process used in several countries. Because there are still some countries that use the traditional demolition process where most of the construction waste ends up in landfills, and only a small percentage is recycled it was decided that the traditional demolition process should be taken as a starting point. In this way, the new flowchart could be applicable in every country. Desk research was used in order to get the picture that exists in the scientific

world about the demolition process steps, and it gave the basis for the development of the new flowchart.

When the steps of the traditional demolition process were established the following sub-question needed to be answered. *How can each step of the process affect the reusability of the components and materials?*

The demolition process has a lot of steps, and in each step, several decisions are made that affect the reuse potential of the materials. To find out which areas of the process affect the reusability of the components and how they affect it, all the steps of the demolition process were analysed in detail in order to find out what needed to change. The input was taken from international scientific literature and European and local regulations and standards.

The last question that was partially answered in this chapter was: *What are the barriers and opportunities for circular demolition and reuse?* For this question, input from practice is also given in chapter 6.

The barriers of circular demolition and reuse needed to be identified based on the literature in order to see if it was possible to find ways to mitigate or overcome them. By acknowledging the barriers, the new process could contain some steps that help to overcome them. It was also essential to find the opportunities of the circular demolition and reuse of materials. Those opportunities could show the potential and benefits of circular demolition, and they could motivate the actors to change their processes. The barriers and opportunities also gave input on the recommendation to the actors.

Stage 3: Perceived needed changes

In the next stage, the perceived needed changes that derived from the answers of the first three sub-questions were given. All the data gathered in chapter 3 were used to establish the perceived needed changes and answer the following sub-question: *What are the perceived needed changes in the demolition process?* The results of this stage can be found in chapter 4. Based on the finding of how each step of the process affect the reuse potential of the components the perceived needed changes were identified. Those changes concerned the demolition process and the involved actors. The results of this stage provided input for the interviews with the experts and the analysis of the data gathered in the interviews.

To present the main results of the research, it was chosen to create a flowchart. The flowchart could represent the new demolition process. It illustrates the whole demolition process and the detailed steps that need to be taken by the actors if they wish to retrieve materials for reuse. The alternative was to give simple recommendations and show the main results in tables. This was not the best option since it lacks the visual effect that makes the reader understand the result and the process. When everything is incorporated in a flowchart people can understand better the process, how each actor affects the reusability of the materials and what changes need to be made in the current process.

The initial flowchart was created taking into account those changes. First, the traditional demolition process was designed based on the input from the literature, and from there

all the changes were made to develop the initial flowchart with the perceived needed changes.

Stage 4: Case study and interviews

The next stage of this research was the case study and interviews. The goal of this stage was to get input from frontrunners in practice. The questions for the interviews were created based on the potential needed changes that are mentioned in Chapter 4. To get the information about the case study two interviews were contacted. The case study provided specific information on the process they followed, the execution of the project, the problems they encountered and lessons learned from the project. The information for this stage can be found in Chapter 5.

Stage 5: Findings from practice

All the data gathered from the previous stage were analysed in order to provide answers to sub-questions 5 and 6 and also partially answer sub-question 3. The answers to these questions are given in chapter 6.

To analyse the data from the interviews qualitative analysis was performed. The transcripts of the interviews were imported to Atlas.ti for the analysis. Atlas.ti is a software that enables the qualitative analysis of large bodies of text, graphics, audio and video. It enables to create codes and connect the data from the text to these codes. Links between the codes and the documents can be made. The analysis began with the creation of codes from the results of the literature study. The codes that were created showed the potential needed changes in the demolition prosses and also the barriers and opportunities. Those codes were used in the analysis of the interviews. The goal was to see if there were different codes produced from the literature study and the interviews, in which interviews the same codes appeared, the views from practice and contradicting views between the actors.

The analysis was performed to provide an answer to the research fifth and sixth sub-questions. It was necessary to get the input from practice and the actors involved in the demolition process. For this reason, the following question was created: *How can the involved actors affect the reusability of the components and materials?*

The involved actors can affect the reuse potential of the components and materials. They make decisions and take actions that allow or not the materials to be reused. In order to answer this question input from the forth sub-question was taken as a starting point for the interviews. The fact that the interviewees were frontrunners gave an advantage since they have knowledge of how their actions affect the reuse potential of the materials and they could provide valuable input. The case study gave also input in this question since it showed how in practice the actions of the involved actors enabled the reuse of the materials.

The last sub-question that was answered in this and the next stage was: *What needs to be changed in the process?*

Based on the analysis of the interviews and the cases study the final needed changes in the process were identified. The changes concerned the demolition process and the actors. Those changes were used to create the final flowchart of the next stage.

Stage 6: Flowchart development and validation

In this stage, the final flowchart was created, and the results of the research were validated. The flowchart that was created represents the main findings of the research. In that flowchart, all the changes are visible, the steps in the process that need to be changed, removed or added. All the changes from the initial flowchart to the end result are shown in the final flowchart.

The results of the research needed to be validated by experts. The method that was used to validate the results is called member checking or respondent validation. In this method, the participants of the research are requested to validate the results in order to see if the results of the research are plausible. This method helps to increase the accuracy, validity and credibility of the research by gaining feedback on the results from the participants themselves(Thomas, 2010). This method was chosen because the demolition companies that participated are frontrunners and they already adjusted their processes in order to take more components and materials for reuse. It is believed that they were the most suitable actors to validate the results since they have experience on that topic and the results of the research concern mainly the demolition companies in general. For this reason, only the demolition companies were asked to validate the findings.

To perform the validation, the demolition companies that were interviewed for this research were asked to validate the results. The developed flowchart of the demolition process and the recommendations were shown and explained in detail to the companies. The companies were asked to give their feedback on the findings and the new process.

Stage 7: Conclusion

The last stage of this research was the conclusion which provided the answer to the main research question: *How could the demolition process in the building industry be adjusted in order to enhance the reuse potential of the building components and materials?* Recommendations were given to the demolition companies, clients, future users and the government. Also, the limitations of this research and suggestions for future research were provided in the last chapter.

Stage	Goal	Method	Research question
1	**Problem definition & research methodology**		
2	**Literature study**	Desk research	S.Q 1,2,3
3	**Perceived needed changes** **Initial flowchart**	Desk research	S.Q 4
4	**Input from frontrunners in practice**	Case study Interviews	S.Q 5,6
5	**Findings from practice**	Qualitative analysis	S.Q 3,5,6
6	**Final flowchart development** **Validation**		S.Q 6
7	**Conclusion**		Main research question

Figure 3: Research methodology

3.Literature study

Building demolition is the last phase of a building's lifecycle. It comes after the planning, design, construction, and maintenance. The purpose of demolition is to remove the existing building but, in the process, a vast amount of waste from different materials is produced (Pranav et al., 2015). The demolition process is not always the same since each project is unique. The steps and the involved actors might vary. In this chapter, the traditional demolition process is established. The demolition process steps and the factors that affect the reusability of the components are analysed in detail. At the end of this chapter, the barriers and opportunities of circular demolition and reuse of materials are given.

3.1 Traditional demolition process

The traditional demolition process is simple with a few steps. The conventional procedure starts with the demolition preparation as can be seen in Figure 4. At this stage, the permit to demolish the building is granted by the municipality. The next stage is the planning where the demolition procedure and techniques are sketched briefly (Liu et al., 2005). The upfront planning in the traditional demolition process is limited. The contractors use strict timeframes, and this causes the destruction of components (Pranav et al., 2015).

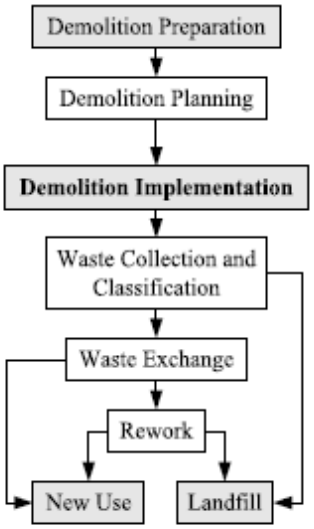

Figure 4: Traditional demolition process(Liu et al., 2005)

After the planning is done, the works start. From this step, a lot of waste is produced. In the traditional process, the demolition is done mostly with heavy machines, explosion or implosion. The waste that is generated by these methods is a mixture of different kinds of materials. In order to remove them, waste collection and classification needs to take place. Their classification and reuse are most of the time impossible since a lot of them are destroyed. That step takes even more time than the actual work since all the activities that allow waste reuse and recycling happen after the demolition is already done.

Another issue is that there is no prior planning and communication between the waste producers and demanders. This lead to materials that are unsatisfactory for the demanders, so the materials need be modified. This doesn't help the reduction of waste. Some of the materials after the modification goes in a new project and the rest end up in landfills. With this method, the value of most of the secondary materials is lost (Liu et al., 2005).

A more detailed process is given by Abdullah et al., 2003. They divided the demolition process into four main stages. The tendering stage, the pre-demolition stage, the actual demolition and post-demolition stage. The tender stage includes an invitation for bidding,

site visit, risk assessment, selection of demolition technique, planning and contract award. The pre-demolition stage includes site preparation, decontamination, and soft-stripping where all the non-structural elements are removed from the building. Followed by the actual demolition where the structural elements are demolished. Finally, there is the post-demolition stage where the site is cleaned and delivered to the client (Abdullah et al., 2003). In this process also, the planning and handling of material don't play an important role. It is partly incorporated in the tendering stage but not very elaborated.

3.2 Demolition stages

The traditional demolition process is given by Abdullah et al., (2003) and Liu et al., (2005). Other researchers described some different stages of the demolition process. Bhandari et al., 2013 specified in more detail the steps before the demolition starts. Those are the surveying of the site, the removal of hazardous materials, the plan preparation with implementation strategy, stability report from local authorities and safety measures to be used. According to Kühlen et al., 2016 the demolition process starts with building auditing and planning of preliminary decontamination and site clearance. Then demolition takes place with, crushing, sorting, reprocessing and recycling operations.

The demolition process can have a lot of stages and steps. The input from the research mentioned earlier gives ideas of what the stages can be, but each researcher has a different perception. The steps are different, and the way the waste is treated differs however there are some similarities in the process. In order to be able to enhance the reuse potential of the components, the new process needed to incorporate the best practices found in literature and practice. The different stages used in this research are tendering, auditing, planning, execution, and material handling. Each of those stages is analysed further below.

3.2.1 Tender stage

The beginning of the demolition process is when the decision is made by the client to demolish the building. The client with the help of planning engineers formulates the tender specifications and award criteria (Kühlen et al., 2016). The contract can be awarded to the lowest price or to the economically most advantageous tender (EMAT). EMAT can be based only on quality, or it can be price-quality tender. Most commonly the lowest price is used where the contract is awarded to the bidder with the lowest price. When the tender is a price-quality tender, there are weights for the price and quality which are defined in advance. The total score of the bids is calculated based on those weights. In this way, the contract is not awarded to the lowest bidder but to the bidder with the best price-quality offer (Bergman & Lundberg, 2013). Quality criteria are set by the client which may concern recycling rate, CO_2 emissions, noise etc. One of them can also be the reuse rate of materials from his demolition project. In this way, the demolition contractors can be encouraged to retrieve materials for reuse.

When the specifications are ready, the demolition companies are invited to bid. The demolition companies need to audit the building themselves and bid for the project (Kühlen et al., 2016). In order to do that the demolition contractor needs to visit the site and have all the important information about the building to be able to prepare the risk assessment. The risk assessment identifies the risks (e.g. presence of asbestos and other hazardous materials) that the project has, and measures are taken to mitigate them or remove them before the works start. In this stage, the most appropriate demolition technique needs to be selected. It is selected based on the demolition contractor skills, knowledge, and experience. After that, the detailed planned activities and demolition techniques are given. All the bids go to the client, and he decides who is going to execute the works (Abdullah et al., 2003).

3.2.2 Auditing

Auditing is an essential part of the demolition process. It requires site inspection, contamination inspection, and documentation review. In the auditing phase site conditions, the availability of space, existing building elements, and mass calculation are gathered (Volk, 2017). Identifying the building components and materials, their location and estimating their quality accurately is essential in order to plan and develop a waste management strategy (Ge et al., 2017). The characteristics of a building are considered since they result in different materials and components. The different building types and years of construction result in different materials (Volk, 2017). In order to enhance the reuse potential of the components and materials, a detailed audit is needed. It includes several steps which are analysed below.

At first, the building auditing takes place. The record drawings need to be studied before the site visit (Bhandari et al., 2013). When the drawings and documentation of the building are present, the auditing is easier since they can help to see the materials used and the construction techniques. In a lot of cases, those documents are not available, and the audit is more difficult (Hurley, 2003). If there is no actual documentation, manual building auditing and analyses of building properties is needed which is costly but necessary to be able to do the planning and cost estimation (Volk, 2017).

The first step of the manual building auditing is the site survey which includes building and structural survey. Site surveys are essential in order to investigate the quality, conditions, and fixtures of the components and materials. In this way, their financial value and availability for reuse can be determined. The size of the building and the availability of information will determine the time that is needed to spend on the site (Hurley, 2003).

The building survey checks the construction materials and their quality, the usage purpose of the building, the presence of hazardous and toxic materials, dangerous areas, surrounding properties and the site conditions, drainage conditions and possible problems with water pollution and erosion, common facilities with adjoining buildings and traffic conditions (Bhandari et al., 2013). The demolition company needs to investigate if there is presence of hazardous materials and this can be done with sampling and testing. If they exist, they should be removed by the demolition company or by a specialised

subcontractor. Extensive safety measures are required in order to remove them (Van Dijk et al., 2000).

After the building survey is done, the structural survey follows. The structural plans need to be studied at first, and then the structural materials and their quantity need to be determined (Bhandari et al., 2013). The different building types and construction methods will result in different components, and they need to be considered. There are three main types of buildings according to the demolition contractors in the Netherlands. The first type is buildings with bricks, wooden floors, wooden roof structure and flat roofs with bituminous roofing or roof tiles. The second type is buildings with concrete skeleton frames, and the last type is buildings with a steel frame structure (Van Dijk et al., 2000). The building type indicates the primary materials in the building. Their reuse potential depends more on the way the materials were bound together and also their quality and condition (Hurley, 2003). During the survey, the correctness of the structural data needs to be checked. When there is no data the survey should include onsite measurements, tests and check of the present structural elements in order to ensure the stability of the building during all the stages of the demolition (Bhandari et al., 2013).

All the information gathered during the auditing are used in order to calculate the materials and masses. Also, an inventory list is created that contains all the information about the building components, their quality, and quantity and condition (Volk, 2017). Based on the calculations and the results from the auditing phase the planning of the demolition works is created which is analysed in the following paragraph.

3.2.3 Planning

When the auditing is completed the planning stage follows. In this stage important decisions regarding the demolition process need to be made. The demolition technique is decided, cost estimation, scheduling, resource allocation, risk management and material handling plans are made. In the end, the management plan is produced.

Demolition technique

Every demolition project is unique, so the planning needs to consider the specific characteristics of the building in order to design the deconstruction process. The first important decision that needs to be made in the planning phase is the selection of the demolition techniques. The building type, the age (Hübner et al., 2017), the materials used, the resource availability and the available space on site will determine the demolition techniques but also the crushing and sorting techniques. Those techniques will be used to deconstruct the building components and materials in order to be able to transport them, reuse them or recycle them (Kühlen et al., 2016). In the deconstruction planning the components need to be separated one at a time, and each component might need a different deconstruction method. This process needs to be made in an efficient way by extending the components lifetime without increasing the costs (Sanchez & Haas, 2018).

There are two main types of demolition techniques. The explosive and non-explosive methods. In the explosive method, the explosives are used to trigger the demolition. The support structure of the building fails, and the whole building collapses. This technique

is very quick but doesn't allow the material reuse. After the explosion, the waste that is left is a mixture of materials that are not separated (Ge et al., 2017; Pranav et al., 2015).

The second type are the non-explosive methods that include several techniques. The top-down method with the use of a hydraulic crusher is one of them. The building is demolished floor by floor, and the materials can be separated more easily (Pranav et al., 2015). Other methods are by using a crane with wrecking balls, high reach arm and rope pulling. The most preferred method for material reuse is the selective demolition where everything that can be reused is deconstructed first, and then the rest of the building is demolished. Most of the existing buildings are not designed for disassembly, so it is not possible to disassemble the whole building but parts of it (Sanchez & Haas, 2018). With this method interior equipment, wall, floor, ceiling, and exterior components can be separated (Ge et al., 2017).

Demolition planning

When the demolition technique is decided, the demolition planning needs to be made. This includes risk assessment, cost estimation, scheduling with resource allocation and waste/material handling.

Risk management

In the planning phase, the demolition contractor needs to carry out a risk assessment, which will identify the risks of the work and find ways to mitigate them before the work starts (Abdullah et al., 2003). The main risk in the demolition projects is the presence of hazardous materials such as asbestos. The demolition contractor needs to examine the site and the building documentation in order to find out if such substances exist in the building. In the unforeseen event that those substances exist and the demolition contractor didn't detect them the allowances are used. The demolisher estimates the allowances based on experience in most of the cases without using risk management and advanced modelling. This leads to having too low or too high allowances (Miankodila et al., 2016). To change that Miankodila et al., (2016) developed a model that uses PERT-Beta and Monte Carlo simulations to estimate the allowance associated with the risks affecting the project. The allowances are included in every project, and they affect the overall cost of the project.

Costs

The cost is a big driver in almost every project. The cost of deconstruction can be higher or lower than demolition, and this can be affected by several factors. The location, building types and regional markets are some of them. The economics of the region, of the people and business, are contributing factors (Kibert et al., 2001). Other factors that affect the cost of the project are labour cost, material benefit, environmental cost, administrative cost (Liu et al., 2005), labour productivity and the contractor's experience (Dantata et al., 2005).

The cost of traditional demolition is different form deconstruction. A significant difference is the labour cost since in deconstruction more labour is needed (Tatiya et al., 2017) and the extra time needed. Circular demolition can be considered sometimes as a more expensive end of life option than demolition because of that. However, it has some

economic benefits. The materials that are recovered could be sold in secondary markets and also the disposal fees will be limited (Dantata et al., 2005; Tatiya et al., 2017).

The demolition and deconstruction total cost can be calculated in order to find out which is the most economical option. The net demolition costs are the sum of labour, equipment, disposal cost and other costs such as permits and testing for hazardous materials and profit margin. The net circular demolition cost is the sum of the cost of labour and equipment, overheads, profit margin, disposal cost, permitting and testing minus the profit of the sale of the materials (Dantata et al., 2005; Tatiya et al., 2017; Van Dijk et al., 2000). In Figure 5 a comparison in the costs and revenue between traditional and circular demolition is illustrated. The main difference between circular and traditional demolition is the revenue from the sale which is higher in circular demolition, the increased labour cost, and the reduced disposal and recycling costs. When more materials are sold for reuse, the amount that ends up in landfills or goes for recycling is reduced, and thus the cost for these is less.

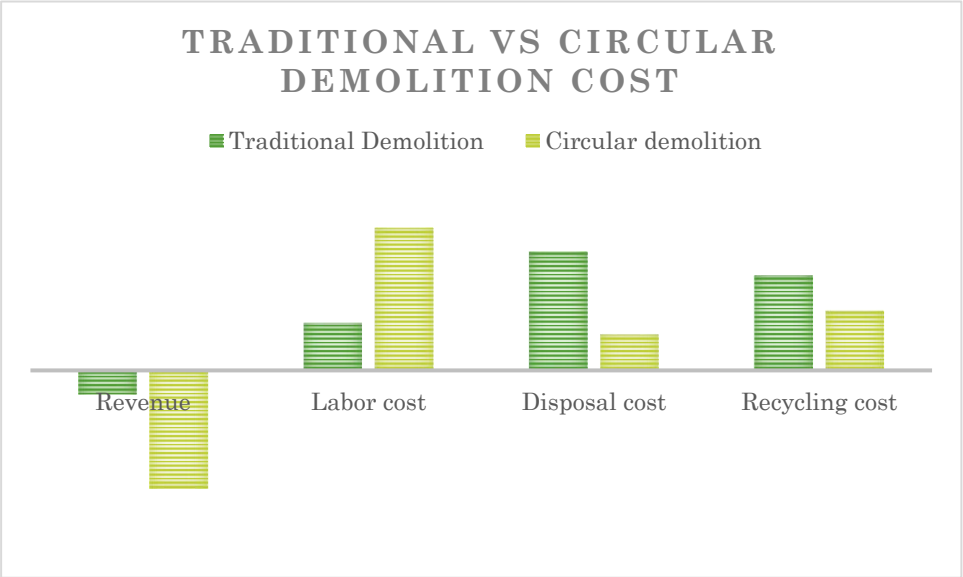

Figure 5: Traditional vs circular demolition costs

The total cost of traditional demolition can be higher or lower from the circular demolition. This is highly dependent on the acquired revenue form the sale, the labour, disposal and recycling cost. In every country those costs are different, and the acquired revenues dependent on the sale opportunities so it cannot be said that one method cost less than the other.

Scheduling and resource optimisation

The demolition project needs to be scheduled in order to show the processes and the time that the components will be dismantled. The demolition schedule contains all the activities, demolition products, resources and time intervals that will take place (Liu et al., 2005). The number and capacity of resources (machines and staff), the size of crew

staffs and their capabilities should also be included (Abdullah et al., 2003). A scheduling tool can be used for product and process planning containing various resources (Liu et al., 2005).

The activities that need to be done are not always the same. They depend on the type of building, the dismantling techniques and the objective of the final product. Regulations about the level of separation of the waste that each country has can lead to different activities. When the activities are determined the resources of each activity and the duration are given in detail. When the activities and resources are determined the resources and schedule can be optimised. In this way, the reuse potential of components can be maximised taking into account time and cost (Liu et al., 2005).

Waste management plan

From the auditing phase, an inventory list of the components and materials used in the building is produced. This document is used in the planning phase in order to make decisions about the handling of the materials. Based on the selected techniques and cost estimation the materials that can be reused or recycled will be decided in this phase. Also, decisions need to be made on where the materials will be transported after they are deconstructed (Kühlen et al., 2016). When the materials cannot be reused or recycled, they need to be disposed of. They can be sent either for incineration or to landfills (Ge et al., 2017)

Management plan

A detailed and comprehensive management plan needs to be developed before the execution starts in order to have a successful project. All the information gathered during the previous steps will be integrated into a management plan. The plan should include site supervision, schedules, labour organisation, tools and equipment and site safety (Zahir, 2015). The plan should show the steps for demolition, precautionary and emergency measures and handling and disposal of the materials. It should also show the building location, topography, and surrounding buildings. Also, a detailed plan of the layout of the floors, their usage and the materials they contain and a plan showing the structural arrangements need to be produced (Bhandari et al., 2013). This plan will be used during the execution phase.

3.2.4 Execution

When the works start, the first step is the site preparation. This might include fencing, site office, toilet etc. When the site is set the decommissioning process begins. First, the removal of hazardous materials like asbestos and other chemicals takes place (Abdullah et al., 2003). Asbestos can be found in roofing, insulation, exterior and interior walls, water pipes, internal heaters and stoves, texture paint and decorative ceiling coatings (Ge et al., 2017). Next is the soft stripping where non-structural components are removed such as appliances, windows, doors, frames, leaded glass and sanitary, marble fireplaces, floor coverings, suspended ceilings, radiators, boilers, ventilation, finishing materials and precious wood such as oak. A lot of those materials if removed correctly can be reused or recycled (Abdullah et al., 2003; Kühlen et al., 2016; Van Dijk et al., 2000).

When all the non-structural components are removed the building is demolished with the selected demolition technique. When the goal is to retrieve materials for reuse deconstruction is the most preferred method.

Deconstruction is done in stages. The goal is the recovery of the materials to be maximised but in a normal timeframe and low costs. In each stage, there is the option to deconstruct and recover more materials or to demolish what is left. Aidonis et al., (2008) developed an optimal deconstruction model that calculates the cost of demolition in terms of the deconstruction stage and finds the optimal economic solution. Table 3 shows the stages and the materials they contain that are used in the model (Aidonis et al., 2008).

Table 1: Deconstruction stage and components (Aidonis et al., 2008)

Stage	**1**	**2**	**3**	**4**	**5**	**6**
Components	Heating components Doors Windows Shutters Sanitary devices	Floor covering Roof covering Wallcovering	Electrical Installations Sanitary installations Plumbing installations Heating installations	Roof frame	Walls Insulation materials	Floors Stairs Reinforced concrete walls Foundations

The deconstruction stages mentioned above are standard in every building. However, the demolition process changes in the last stage according to the building. For brickwork buildings, the actual demolition starts when only the brickworks and floors are left. The building is demolished floor by floor. The beams and the wooden floors are removed using a crane and equaliser beam. The bricks are cut into sections and transported to a crusher plant. For the buildings with concrete skeleton, the demolition starts removing the roof. The bituminous material, the gravel, and the wooden roof structure are removed first. The concrete structure is cut up using breaker shears and taken to a crusher plant. In the buildings with steel frames, the structure is disassembled if the steel can be reused. If not, the structure is cut up and sent for recycling (Van Dijk et al., 2000).

When all the demolition work is done, the site must be cleaned and delivered to the client in a safe and secure condition(Abdullah et al., 2003). During the demolition execution, the project performance and progress need to be reported to the project planner (Kühlen et al., 2016) in order to make sure that no delays and extra costs occur. Competent people need to be responsible for specific activities (Zahir, 2015) to ensure the safety of people and the environment.

3.2.5 Material handling

After the materials are removed they are separated into waste streams. The components and materials can either be reused, recycled, used for energy recovery or landfilled.

Reuse

To prepare the components and materials for reuse, some actions need to be taken. They need to be packed, transported, cleaned and documented (Romnée et al., 2017). If they are not sold directly, they need to be secured in a dry storage space until their next use (Kühlen et al., 2016). Each component requires different cleaning and repair action. The methods that can be used are chemical with the use of a solvent, mechanical which includes sandblasting, brushing or short blasting and thermal with heating or thermal shock (Romnée et al., 2017).

Most of the materials can be reused if they are removed correctly and without damage. Iacovidou & Purnell, 2016 divided the components according to their reuse potential as shown in Table 4. The structural steel has a high potential for reuse since it is a flexible and durable material (Romnée et al., 2017). After demolition, a lot of steel components such as beams, and columns are sold for reuse since steel has a long life (100 years)(Splunter, 2016). Structural and non-structural timber can be easily reused when properly deconstructed (Romnée et al., 2017). When it is deconstructed, the nails are removed from the wood by punching. The second-hand wood can be reused for floors for example, and because it is fully seasoned, it will not shrink (Van Dijk et al., 2000). It can be reused as building timber in a new project as well.

Bricks have reuse potential, but this depends on the time that is available for their removal and the material that was used for their binding (Romnée et al., 2017; Van Dijk et al., 2000). The tiles, masonry and paving stones can be sold as second-hand materials if deconstructed properly and when they are not bound with Portland cement (Iacovidou & Purnell, 2016; Splunter, 2016).The concrete is the only material that is difficult to be reused especially if it is cast in situ. However, prefabricated elements and reinforced walls can be reused(Iacovidou & Purnell, 2016). Concrete reuse is a new development, and the concrete agreement is done to enable it. It is possible to recover all raw materials from concrete granulate and produce new concrete form them (Splunter, 2016). Appliances, sanitary components, doors, windows, electrical and mechanical installations can be easily deconstructed and reused when their quality is good (Abdullah et al., 2003).

Table 2: Reuse potential of construction components and materials (Iacovidou & Purnell, 2016)

No potential	Low (<50%)	Medium (50%)	High (>50%)
Clay bricks (cement mortar	Mineral wool	Steel cladding	Clay bricks (lime-based mortar)
Steel Rebar	Gypsum wallboard	Steel cold formed sections	Structural timber
Structural concrete	Timber trusses	Pre-cast concrete	Concrete building blocks
Asphalt Roof	Concrete cast in situ	Slate tiles	Concrete paving slabs
Plastic pipes, roof sheets, floor mats, plastic windows		Timber floorboards	Concrete roof tiles
Non-ferrous metal components (Aluminium windows	Concrete staircases		Stone (paving and wall)

frames, curtain walling, cladding, copper pipes)	
Glass components	

Recycling

When reuse is not an option the most common practice is recycling. The waste from demolition sites goes to recycling plants. The recycled materials are used for the production of new materials and products. However not all the new products enter the building sector, some of them might end up in other industries.

Materials that can be recycled and re-enter the building industry are metals, gypsum, and concrete. The stony materials have the highest volumes in demolition projects. It includes any elements of concrete, masonry, paving stones and roofing tiles. They are recycled with the concrete producing mixed granulates. The mixed aggregates are used as filling material in place of sand and gravel under walkways and driveway. Concrete aggregates can also be used in PPC work as landfilling material (Patel & Patel, 2016; Splunter, 2016). The metals when they are not sold for reuse they are sorted in different classes of steel and aluminium and send outside from the Netherlands and EU for recycling and new metal is produced (Splunter, 2016)

The materials that can be recycled and are not entering or partially entering the building industry is wood that goes to chipboard industry, plastic and glass that can become glass wool or new glass(Mulders, 2013). Materials that can't be reused or recycled are transported to a sorting plant, where they are separated in burnable and non-burnable materials, and they are burned or landfilled (Van Dijk et al., 2000).

Energy recovery/incineration

The waste that can be burned is transported to incineration plants. There electrical energy and heat are being produced from the incinerated waste (Mulders, 2013). A large amount of the wood leaves the chain and end up in incinerators for energy production. The wood that is released from demolition and cannot act as scrap wood is often not properly sorted. Different grade of wood-based materials are mixed together and delivered to a treatment plant. Since they are not separated the wood is burned and not used to the chipboard industry (Biomass Technology Group, 2014). In order to reduce the amount of waste that is burned and to promote recycling an incineration tax exist in the Netherlands (Deloitte, 2015).

Landfilling

The last option for the waste treatment is landfilling. In the Netherlands, a landfill ban exists for most of the waste. For the waste that can be put in landfills, there is a tax of 13€ per ton (Deloitte, 2015).

Market

The existence of a market is essential in order to reuse construction materials. A network of businesses is needed in order to allow the flow of the materials. After the components and materials are deconstructed they need to be adapted to desirable products to meet the market needs. Prospective buyers need to exist in order to sell the materials. The market requires the supply and the demand for those materials to function correctly (Kibert et al., 2001). The components and materials can be sold in an online marketplace or directly to a network of buyers.

Online Marketplaces

An online marketplace that has open access to the public can be used to advertise the materials and components. The components can be advertised there including information about their location, quality, quantity and availability date. The demanders can find the materials they need, and negotiations can be made. In this way requirements that the buyers might have can be met, and no additional adaptations will be needed. When everything is settled in advance, the owner can see the financial and environmental benefit reports. Those reports play an important role in demolition design and implementation. During the demolition implementation, the materials are delivered to the buyers, and their storage is avoided (Liu et al., 2005). In the Netherlands, there are a few online marketplaces (Gebruiktebouwmaterialen, Insert, Marktplaats) that offer components and materials for reuse but still, the supply is limited.

Transportation

Transportation is another factor that needs to be taken into account. The cost of transportation of the materials affects the overall cost of the demolition project. The distances should not be very long in order to minimise the transportation cost. It is desirable to find buyers in the area of the project if this is possible (Giorgi et al., 2018). Keeping the transportation cost low, it will allow more materials to be taken for reuse.

Storage

The materials that cannot be reused directly need to be stored. Having suitable storage space from the beginning of demolition is essential for maximising the number of the materials and components retrieved for reuse. The materials need to be placed in storage until they are sold or reused. This can also affect the cost of demolition (Oyenuga et al., 2017).

3.3 Actors

In a demolition project, several actors are involved. The main actors are the client and the demolition company. The client owns the building to be demolished, and he hires a demolition company to execute the works. In the traditional demolition process, the released materials go to landfills, sorting facilities or recycling facilities. Those actors don't really influence the demolition process since they don't have a lot of requirements for the materials they receive. However, when the components and materials are going to

be reused, a new category of actors come into the picture that needs to be taken into account, the future users.

Figure 7: Actors involved in the demolition process for reuse of materials

Different actors are involved in different project stages. The client is involved in all the stages, but in the tender stage, his role is crucial. He is the owner of the building to be demolished. In most of the cases, he is consulted by a planning engineer. He calls for tenders, set the requirements and then he awards the contract to one of the participated demolition companies. This company either performs the actual demolition process on site itself or acts as the main contractor and assigns single tasks to subcontractors and experts. The materials and components produced from demolition can be reused, recycled or landfilled, either by the demolition company itself or by a special recycling company(Kühlen et al., 2016).

When the components are reused, the new users can be the client who can take the materials produced from the demolition project and use them at the same location, in his redevelopment project or in another project of his. In the case that the client doesn't want to reuse them, the materials can be sold and used in a new construction project. In this case, the new owner of the materials can use them in the construction of his project.

The components that are reused in a project need to meet the specifications and requirements of the engineers, architects, and contractors. The architect needs to adapt the design in order to fit the reused components, the engineer needs to make sure that the components are suitable for use and develop the design with them. In the end, the contractor needs to be able to use them and build a new structure with the secondary components. These actors can influence the reuse potential of the materials in cooperation with the owner of the new building.

The components can also be upcycled. There are companies that take the reused components and transform them into something else. For example, the wood that comes from a construction site can be upcycled to floors, furniture or wooden decorative panels (Sloophout, 2017).

3.4 Regulations, guidelines and certifications

The demolition and reuse of materials are not highly regulated as construction. It was essential to identify what regulations and guidelines exist on that topic to see how they can enable or not circular demolition and reuse of materials. Local and European regulations were examined. There are some regulation and guidelines regarding demolition. These are also some certifications that demolition companies can have in order to ensure sustainable demolition practices which are analysed below.

3.4.1 Regulations

Demolition regulations in Dutch Building Decree 2012

The building act aims to protect the environment and prevent noise, vibrations, and dust. There is no demolition permit required, but a notification is required at least four weeks before the commencement of the works when the demolition produces more than 10 m^3 of demolition waste. The notification should contain a lot of information and between others the global inventory, the nature and amount of the released demolition materials and the discharge destination, planning of demolition and asbestos inventory (VERAS, 2012). Chapter 8 of the building act 2012 determines which materials need to be separated at the demolition site. The waste should be divided to the groups: hazardous waste (asbestos, tar, radioactive waste, PCBs, lead, etc.) , gypsum blocks and plasterboard, bituminous roofing, tar-containing roofing, tar-containing asphalt, non-tar containing asphalt, roof gravel, flat glass, lamps and other waste (VERAS, 2014). Those streams must be disposed of separately.

3.4.2 Guidelines

Demolition code

The Demolition code describes what professional clients, contractors and other parties involved in a demolition project can expect from each other during the tendering and execution of a demolition project. It is not binding but is recommended. It is made by VERAS the branch organisation of demolition companies. The main areas of interest are an open and fair tendering process, sufficient project information, transparency and pricing, adequate execution and mutual respect.

1. The parties are open about the conditions and criteria for the execution of the demolition project; clear about the tendering and contract form and the award criteria; the demolition contractor meets the quality requirements set by standards; in case of new build, the demolition phase need to be taken into account and time should be given so it can be executed properly
2. Sufficient information is essential for demolition works. In case of lacking information, the parties need to notify each other; the parties give the information that is necessary for realistic pricing on time; the parties should be informed for

asbestos inventory and be aware that unexpected circumstances that will impact the demolition work might arise;

3. The risk sharing should be clear to all the parties; inaccuracies of contract agreements should be discussed openly; the parties inform about the risk and uncertainties of the demolition work before the tendering; the parties agree on a scheme on dealing with risks; only if there is sufficient prior information can the demolition contractors be responsible for the risks; penalty clause and bank guarantees must be realistic; the parties should comply with the competition rules
4. The demolition contractor executes the work, complying with the requirements, safe working conditions and environmentally friendly demolition; ensures minimum disturbance and communicate with the interested parties; uses optimal technical and economical execution methods; the client gives freedom to the demolisher in the context of specifications regarding the manner of execution; ensures that there is expert supervision during the execution; the parties comply with the tendering process and during the execution with the legislation and regulations (SLOOPCODE, 2014)

EU Construction and Demolition Waste Protocol and Guidelines

The European union develop these non-binding guidelines in order help the member states to achieve the goal of the Waste Flowchart Directive which states that at least 70% of the waste of the construction and demolition activities shall be prepared for re-use, recycling or undergo material recovery. The guidelines propose waste identification, source separation and collection which include pre-demolition audit based on site visits and inventory, waste management plan and improved separation of the materials for better recycling. Waste logistics which include tracking and tracing to register the waste and deliver the waste within small distances. It also recommends waste processing and treatment that should follow the waste hierarchy of reuse, recycling and energy recovery (European Commission, 2016).

Criteria for sustainable public tendering

To have sustainable public procurement some criteria need to be included that enhance the sustainability of the demolition project. Those are the promotion of separate collection of waste segments, the responsible processing of stony materials and safe demolition. All the activities must be done according to BRL SVMS-007 which is analysed in the next paragraph. The specification of destination and processing of the waste needs to be included in the tender. How they will be processed and offered for reuse. The materials that should be included are debris, soil, concrete, plaster, wood A, B, C, metals, plastics, insulation materials, roof waste, mixed building and demolition waste, asbestos, glass, roof coverings, lights, and lighting fixtures. The more materials are offered for reuse then the valuation will be higher. Also, the demolisher needs to carry pre-demolition, which includes the removal of non-construction and non-stony materials (PIANOo, 2017).

3.4.3 Certificates

BRL SVMS-007 demolition certificate

The contractor with this certificate needs to follow the following four steps:

1. Advance inspection and create an inventory of materials. In this way, he knows if the contaminated materials will be released during demolition.
2. A demolition plan needs to be created which should contain the description of the demolition method will be used, the processing and removal of materials and safety measures and the implementation requirements of the client.
3. The execution should be done according to the demolition plan. The employees should be experts on demolition works. Certified demolition contractors should operate the equipment. The site should be safe, and the released materials should no contaminate the soil and the surrounding.
4. The demolition contractor creates a report of the released materials and gives it to the client if requested. (BRL SVMS-007, 2018)

BREEAM-NL

An instrument to assess the sustainability of a demolition project is with BREEAM-NL Demolition and Disassembly. The projects are assessed in eight categories, health, management, materials, energy, transport, water, pollution, land use, and ecology. The certificate can be obtained in two phases, the preparation phase, and the implementation phase. The total score is the sum of the eight weighted categories. The category with the highest weight is the materials with 40%. According to the final score, the project can get a minimum score of 30% in order to pass, and when the score is higher than 85%, the performance is characterised as outstanding. The certificate shows that the project was developed sustainably. This can give an insight into the sustainability performance of a demolition project. Also, it can attract investors and users that value sustainability (BREEAM-NL, 2013).

The purpose of the materials parameter is to promote the materials reuse that comes from demolition. The more materials are reused, the score is higher. In order to evaluate that the following are required in the preparation phase:

1. An inventory of the materials and the estimated quantities and their intended destination.
2. Signed contracts with the recipient of the materials,
3. A list of non-reusable materials and their final destination
4. A calculation of the expected amount for landfill.

In the implementation phase, the evidence that are needed are:

1. An inventory of the materials which contains the estimated and actual quantities and their intended destination.
2. Transport vouchers and receipts of the discharged materials,
3. A current list of the non-reusable materials and their final destination.
4. The complete waste file is needed (BREEAM-NL, 2013).

3.5 Barriers and opportunities

3.5.1 Barriers

The circular demolition and the reuse of large volumes of materials that come from demolition has its barriers. The cross contamination of waste, the additional time and cost needed, and the technological and organisational challenges are some of them (Ge et al., 2017). The barriers can be categorised to technical, economic and organisational barriers and are analysed below. An overview of the barriers can be seen in Table 3.

Technical barriers

For many demolition projects, the original building documentation might be missing. If the building was renovated the materials used might be different, and most of the times they are not documented (Ge et al., 2017). This will make the deconstruction more difficults. Also, the quality of the materials might be unknown (Kühlen et al., 2016).

The existing buildings and building components are not designed for disassembly (Kibert et al., 2001). The use of fixed joints might not allow the proper deconstruction of the building components (Kühlen et al., 2016). It is easier to deconstruct prefabricated components however they are not designed to be demountable (Durmisevic & Binnemars, 2014). Also, the deconstruction of framing members might be dangerous to remove, or special equipment might be needed (Kühlen et al., 2016). The reuse of structural components is the most challenging since their structural performance needs to be established. The engineers might not be willing to reuse structural components unless the quality of the materials is tested according to standards (Kühlen et al., 2016).

Economic barriers

Unfortunately, there is lack of financial incentives for using reused materials and components in new construction. The main reason is that the cost of new materials is low in most of the cases. Also, the expensive material sampling methods, the reduced quality and the uncertainty of demand and supply are other reasons (Kühlen et al., 2016).

The disposal cost for demolition waste are not very high (Kibert et al., 2001) and the disposal taxes are low (Durmisevic & Binnemars, 2014). Also, more time is required to dismantle a building, and in many cases, this is a barrier since most of the clients want the demolition to be quick in order to start a new project (Kibert et al., 2001). Deconstruction needs more time to remove everything carefully. Moreover, the high cost doesn't allow sorting of materials on site in separate sorting bins. Those materials need to be collected, transported, stored and prepared to be sold as secondary components. The demolition and construction companies operate on a tight profit margin. The companies are not willing to lose this profit and take the risk to deconstruct materials for reuse. They will only do this if there is immediate and significant profit (Kibert et al., 2001).

Another barrier is the cost of reused materials. In most of the cases, the cost of new materials is lower, and the buyers prefer the new materials. Only if the materials have some unique characteristics will make them interesting to the clients (Kibert et al., 2001). Also, the test for the structural ability of the materials is costly. Concrete components

might need to be stored, and transported from the old to the new site and this might increase more the cost of the new project(Kühlen et al., 2016).

The uncertainty of demand and supply is a significant barrier. Building components and materials are not deconstructed and put on the market because there is the notion there is no demand. Only high-value items are collected that can be sold quickly to a heritage market. The sellers are not willing to sell materials that are not highly demanded, and the consumers don't buy materials they don't know. There are some marketplaces that offer secondary materials, but in most of the cases, the quality of the materials is not always given (Kühlen et al., 2016). A lot of work is required by the design team to identify potential sources of components and to determine their requirements. The quantity of a component type might be insufficient and cannot meet the demands for the new project (Kühlen et al., 2016).

Organisational barriers

Demolition is not as highly regulated as the construction. There are no strict standards and procedures that need to be followed by the demolition contractors (Pranav et al., 2015). For that reason, it is difficult to provide specifications for proper deconstruction (Kühlen et al., 2016). Also, the building codes don't include directions and guidelines for the reuse of building components. In the case of reuse, re-certification is required and is usually not possible (Kibert et al., 2001).

There are some guidelines for materials reuse however the government is not willing to force more regulations in order to enhance the reuse of materials (Durmisevic & Binnemars, 2014). The lack of legal and economic push to reuse materials don't encourage the demolition companies to do it (Kibert et al., 2001). The existing regulations might not apply for small residential buildings, so the client is not forced to have a waste management plan, and in most of the cases the waste end up in landfills (Kühlen et al., 2016). In the Netherlands when the demolition waste is less than $10m^3$ no waste management plan is required (VERAS, 2012).

Another barrier is that the economic and environmental benefits of deconstruction are not well established (Kibert et al., 2001) so the demolition companies don't see the value of selecting deconstruction as demolition technique. The lack of awareness of demolition crews about the possibility of reuse of materials can lead them to remove the components as quickly as possible and destroying them in the process. Another barrier is that often the equipment and tools needed for deconstruction do not exist, or the demolition companies don't own them (Kibert et al., 2001). Also, the designers are not aware of supply sources of reuse materials and the actual materials that can be reused.

The lack of cooperation between the parties is another problem. The owner, designers, contractors and waste haulers need to understand that the purpose of deconstruction and reuse of materials is to protect the environment and the natural resources. If they don't have this common goal, the process might not be successful (Kühlen et al., 2016).

Table 3: Barriers of circular demolition and reuse of materials

Barriers	
Technical barriers	• Missing building documentation • Unknown quality of the materials • Components not designed for disassembly • Adaptable design
Economic barriers	• Low cost of new materials • Uncertainty of demand and supply • Not very high disposal cost and taxes • More time is required • Clients want the demolition to be fast • Limited separation of material due to high cost • High risk for the demolition companies to lose money • Costly tests for structural ability • Cost of transportation and storage
Organisational barriers	• Not highly regulated • Lack of awareness of reuse potential of materials from demolition companies • Designers not aware of the supply sources • Lack of cooperation between the parties

3.5.2 Opportunities

The increase of deconstruction and reuse of materials will help with the current environmental problems. Firstly the reuse of materials will reduce the extraction of natural resources needed for the production of new construction materials and components (Zahir, 2015). The CO_2 emissions caused by extraction, production methods and recycling of the materials will also be reduced. Moreover, the number of waste that end up in landfills will be decreased. (Kibert et al., 2001). In this way, the reuse of materials can help to enhance environmental protection. The following table contains an overview of the opportunities for circular demolition and reuse of materials.

Table 4: Opportunities for circular demolition and reuse of materials

Opportunities	
Technical opportunities	• Materials can be reused in other projects • They can be reused with a different function • Use of BIM • Material passport
Economic opportunities	• There is value in the sale of reused components • Economic benefit for the client • Can be used as materials in upcycling enterprises

	• Create new business • Create job training
Organisational opportunities	• Government develop regulation for reuse • Reuse material in public projects

Technical opportunities

The components and materials can be reused in construction projects with the same function as they were intended to or with a different function. The materials can be retrieved from the demolition project and be reused in the development of the new project. In this way, the client can save money from purchasing new materials, and he can contribute to developing more sustainable buildings. One example of this practice is the House of Rolf where they deconstructed a building and use all the materials to create the interior of the house. They reused the wooden floors, timber beams, radiators, window frames, structural profiles etc. in order to develop the interior. Wood that came from the floor was refinished and became walls and stairs. Radiators were used to construct one of the walls(Bruggink, 2014).

Figure 8: House of Rolf, materials from the building in the right picture were used for the construction of the interior of the house(Bruggink, 2014).

Hof-van Cartesius is another good example of reuse. There they constructed two pavilions of 545 m^2 with mostly reused materials. It was an effort made by people that wanted to build circularly and give a second chance to demolition materials. Some of the materials they reused were wooden beams, rainwater drainage, insulating materials, partition walls, hardwood doors, steel gates, balcony fences, sliding doors, windows, staircase, cabinets, sinks, etc. (Bianca Ernst, 2017).

The components and materials can be used in value adding manufacturing enterprises which give the material new purpose and value (Zahir, 2015). There are a lot of opportunities for this that need to be explored. The materials can be transformed into

something new (Kibert et al., 2001). For example, reclaimed wood can be used as raw materials for the production of new windows (Duurzaam Gebouwd, 2018).

Artists, craftsmen, individuals (DIY) and architects started embracing the reclaimed aesthetics. They reuse the reclaimed components in creative ways. As the reclaimed aesthetics is gaining momentum, people can use this opportunity to create and sell components from reclaimed materials (Zelechowski et al., 2012). Creative people have the opportunity to create something new from reclaimed components. For example, in the Faculty of architecture of TU Delft, the espresso bar is made out of reused aluminium windows (SUPERUSE Studios, 2008).

Figure 9: Espresso bar made out of reused aluminium windows (SUPERUSE Studios, 2008)

Another opportunity is the use of Building information modelling (BIM) in demolition projects. BIM is mainly used for construction projects however it could be a useful tool in the demolition process in the future. BIM models can provide more accurate waste management plans in a short period of time. This can be done because of the precise identification and estimations of deconstruction materials. This also helps to formulate adapted demolition and waste management strategies. In this way, more material can be taken for reuse and recycling(Ge et al., 2017). A BIM-based model has been developed under HISER project for supporting pre-demolition studies. The goal of the model is to help the collection and management of information on the existing elements and materials of a building that is going to be demolished. It will help to maximise the recovery rate of components and materials from the buildings. This can be achieved thanks to the visibility of the present materials in the pre-demolition stage. It will make the calculations of the audit phase easier which in most of the cases is done by hand. This model can be used by demolition companies, and it can improve the reliability and accuracy of materials quantification, facilitates the traceability of materials and help to reduce the time that is needed to evaluate the alternatives of demolition and recovery options (García et al., 2017).

The BIM model of most of the buildings that are demolished now doesn't exist since it is a new technology (Volk, 2017). The integration of laser scanning and BIM will be

beneficial in the future. Most of the existing buildings don't have 3d models, so it is difficult to develop and use the BIM model only by drawings(Mahdjoubi et al., 2013). If actual building information models exist, renovation, retrofitting and deconstructions processes can be planned and performed with smaller adjustments (Akbarnezhad et al., 2014).

Another new technology that will help in the audit phase is, and it is related to BIM is the materials passport. The buildings are materials banks that can offer materials for reuse during demolition and renovation works. All the materials of the building are recorded to a material passport which can be used during the demolition and renovation works. In the Netherlands, the Madaster foundation exists that created materials passports. A BIM model can be used to create the passport. The model can be uploaded to the database, and the amount and prices of materials can be given. Data of the building can be added by everyone (owner, contractor, developer, architect etc) to Madaster's library and they are stored in the Cloud (Zijlstra, 2017). The Madaster platform gives identity to the materials and functions as a public online library of the materials in the built environment. It provides free access to everyone from individuals, companies, government, and scientific organisations. The material passport contains information about the materials used in a building, their quantities, quality, their location, and their monetary and circular value. Having all these information, it is easier to reuse materials, minimise waste and reduce the cost of material consumption (Madaster, 2018). A building that is going to be demolished can become a warehouse and marketplace for useful materials. When the material passport exists for the building, the materials are digitised and documented. This input can be easily used in the design and construction of the new building. With the help of Madaster, the materials reuse can be easily planned. Designers, developers and construction companies can find second-and materials through the database that are suitable for their project. The database will let them know when the materials will be available and at what price. This will require the participation of a lot of actors in the industry. When the supply is high, the new users can find the materials that they need in competitive prices (Heel, 2017). In the future, the materials passports will be widely used, and their input in the audit will be beneficial.

Organisational opportunities

The government can develop regulations that enhance the reuse of construction components. The current building code doesn't have regulations regarding reusing materials. They can create regulations regarding designing and building with reused materials. In this way, the architects and contractors will be more willing to reuse materials in their projects since there will be regulations in place (Tai, 2018). The government can give the example of reusing materials by developing public projects with reused materials. They can do that by requiring audits and inventories of salvageable materials for public projects and by setting requirements for reuse in their new projects (Zelechowski et al., 2012).

Economic opportunities

The deconstruction and reuse of materials can give the demolition company the opportunity to earn some money from the sale of the materials. There is a value for reclaimed building components (Kühlen et al., 2016). This can result in lower demolition costs since there can be revenues from the sale and the disposal costs can be avoided (Zahir, 2015).

There are also opportunities for creating new business. Physical reuse shops can open that will sell secondary components. The stores can cooperate with a lot of demolition companies in order to supply them with the materials (Zelechowski et al., 2012). The components that can be offered there can be appliances, cabinets, doors, lighting and plumbing fixtures, windows, lumber, etc. Individuals and companies can go there and buy the second-hand components. People can be employed there, where they can clean and refurbish the components in order to sell them (Tai, 2018). To stay competitive in respect to the new materials, the stores can own standardisation machinery for lumber, providing grading service to recertify it to meet the quality standards. They can also use advanced inventory software and advertising their stock online (Zelechowski et al., 2012).

Moreover, job training (Zahir, 2015), additional jobs and community revenues can be created from the reuse of materials (Kibert et al., 2001). There is the opportunity to train people to deconstruct the materials properly. When they gain proper training, they will get more job opportunities in the demolition companies that want to adopt deconstruction. Organisations can train unskilled people or unprivileged youth to learn how to deconstruct and create new job opportunities for them (Zelechowski et al., 2012). Also, professional that work in demolition companies can be trained in order to learn to work as efficient as possible in deconstruction projects. They can also learn techniques of how to deconstruct and handle the materials properly.

4. Perceived needed changes

The literature study gave input on the demolition process. The traditional demolition process was established, the steps of the demolition process were analysed in detail, and the barriers and opportunities were identified. Based on these, the perceived needed changes that can be made in the demolition process in order to enhance the reuse potential of the components were established. Changes can be made in the process but also the actors can make changes in their actions in order to have circular demolition. Those changes were used to create the initial demolition flowchart. In this chapter, the changes in the process, in the actors and the development of the demolition process flowchart is given.

4.1 Changes in the process

The changes in the process are provided in the defined stages of this research.

Tender stage
In the tender stage sustainability tendering criteria can be adopted. In this way, the demolition contractor that plans to reuse components or sell them for reuse will have a better chance of winning the tender even if the cost of his offer is a little higher. In this way, they will give the incentive to the demolition companies to try to take more components for reuse and have circular demolition. Another option is to have specific requirements for reuse if sustainability criteria are not used. Also, the requirements should not be very strict and should give freedom to the demolition contractor to take materials for reuse, even if the client doesn't require it.

Auditing
A detailed audit is needed in order to take components for reuse. Documentation review and site visits are essential in order to create an inventory with all components that can be reused, their quality, quantity, and condition.

Planning
In the planning stage, it is crucial to adopt demolition techniques that are not destructive for the components. Also, the cost, schedules, risks and resources should be calculated and optimised in order to maximise the component reuse by keeping the cost low. Also, the components can be reused by the owner or they can be advertised in a marketplace before the demolition starts giving detailed information in order to find new owners. Another option is to find buyers of the components through the network of business that the demolition company has.

Execution
During the execution, it is important to dismantle the components carefully using special equipment. The demolition should start with soft-stripping by removing everything that can be reused and then the deconstruction of structural components for reuse. All the components should be separated into different streams. The components should be dismantled according to the requirements of the new user , so minimum further processing is needed.

Material handling
The components should be cleaned and packed and transported to the new location or stored for future use. If needed they can be refurbished and then reused.

4.2 Changes for the actors

The actions and decisions of actors can also affect the reuse potential of components. Here are the perceived needed changes that the three categories of actors should make.

Client
The client should give more time for deconstruction. If more time is given, the components can be carefully dismantled and sold for reuse. He should also give freedom to the demolisher to take components for reuse if he is willing to. Also, he should be open to the possibility of reusing materials in his project. He can also use sustainability criteria in the tender in order to give the incentive to the demolition companies to take components for reuse. Another action that the client can make is to try to get sustainability certification. In this way, he can attract investors and buyers that value sustainability and he will also make sure that the components of his project are going to be reused. He can also consider creating a material passport for his building.

Demolition company
The demolition company should adopt deconstruction as the main demolition technique since it is the least destructive method for the components. They also need to perform a detailed audit and create an inventory of the building with all the important information about the components. Moreover, they should realise the value of reuse of components, and they should invest in training. Another wise change is to create a network of businesses to sell for reuse the retrieved components and materials. Also, they can develop good cooperation with other parties like clients and contractors. When they dismantle the components they should also try to meet the requirements of the new buyers. In order to have a profitable but circular demolition process, they should use optimization of cost and resources that maximise the components for reuse. Also, a more accurate estimation of the risks and allowances should take place.

New users
The new users should be open to reuse components in their project. They should set their requirements in advance, and they can publish their demand in an online marketplace. They should also start searching for components well in advance. The architects and engineers should develop an adaptable design that can fit the available components for reuse. They can also develop close cooperation with demolition companies in order to get information of components and materials that will become available.

4.3 Process model development

The input from the literature study was used for the development of the new demolition process. The main steps of the process were identified. Those are the tender stage, the auditing stage, the planning, execution and material handling as seen in Figure 10. Each of those steps affects the reuse potential the components will have after demolition.

Figure 10: Demolition stages

In the process, there are a lot of actors involved, but they are not involved in every stage. Figure 11 shows the involved actors in each stage of the demolition process. The client is involved in the whole process, but his role is of the highest importance in the tender stage. The demolition contractor is involved in every step of the project and he is the actor with the most impact. The future users are involved in the planning and the material handling stage. They are involved in the planning because there they make agreements about buying or reusing the components. In the material handling stage, the components are taken over by the new users.

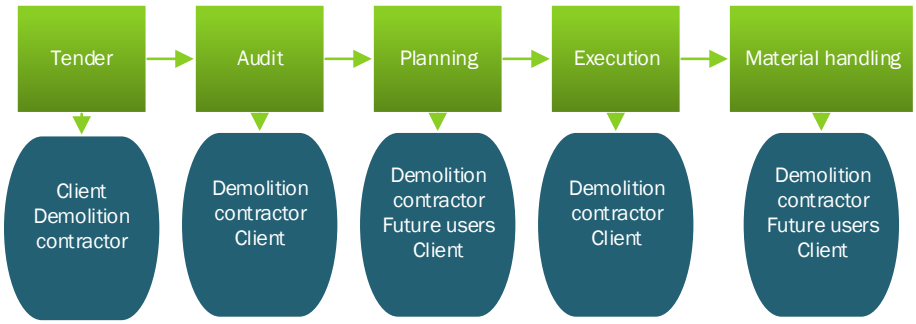

Figure 11: Process stages and involved actors

4.3.1 Traditional demolition process

As a starting point, the traditional demolition process is developed based on the findings of the literature study. The traditional demolition process is given in Figure 12. The traditional demolition process is simple with a few steps. In the tender stage, the client invites the demolition companies to bid. The demolition company makes site visits, risk assessment, select demolition techniques, create the planning, submit the bid to the client and he awards the contract. In the pre-demolition stage, there is the site preparation, decontamination, and soft stripping. Then the demolition takes place. The waste are collected and classified and transported to waste treatment plants. From there some materials that can be reused are retrieved. However, they need to be modified in order to be able to be used. The rest of the waste goes to landfills. When the waste is removed from the site, it is cleaned and delivered to the client.

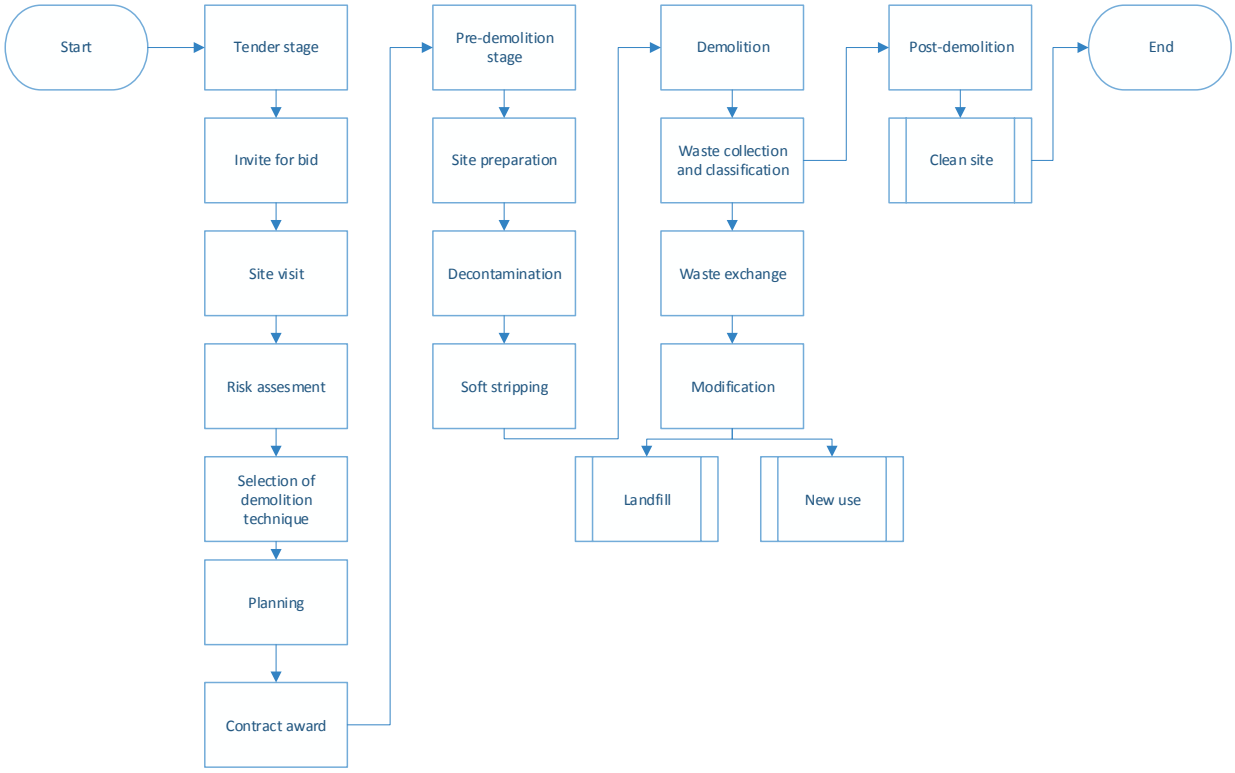

Figure 12: Traditional demolition process based on Abdullah et al., (2003) and Liu et al., (2005)

4.3.2 Developed process flowchart

Based on the literature review and the analysis of each step of the demolition process the new flowchart is developed. The developed process flowchart is shown in Figure 13. The first step is the decision to demolish. When the client decides to demolish the building, he starts the tender process in order to find the demolition parties. He sets the requirements, and he invites the demolition companies to bid in the project in order to award the contract to one of them. The demolition company needs first to audit the building. This should include documentation review, structural and building survey. He also needs to examine the presence of hazardous materials. From this stage, the inventory list is created.

Then the planning stage starts. The information gathered in the audit are used to make cost estimation, risk assessment, schedules and resource allocation and a waste management plan. The components that can be reused need to be published in an online platform. Then the demolition plan is created, and the contract is awarded to one of the companies.

When everything is ready, the execution of the works starts. The first step is to remove any present hazardous materials. Then the soft stripping is done. The first level of deconstruction is done, the materials are separated on site and then move to the next deconstruction stage. The same process continues until the desired stage of deconstruction is reached. Then the rest of the structure is demolished. All the components and materials are separated into different material streams.

Then the material handling follows. They are separated into three categories, the materials that will go for recycling, reuse and landfill. The materials that will be recycled are transported to the planned facilities, and the materials that will go to landfill are transported there. If the components and materials are reused on site, they will remain on the site for the new development. If not, they need to be transferred to the new project or go to a storage facility. After everything is arranged, the site must be cleaned and delivered to the client.

4.3.3 Differences from the traditional process

In the developed process, in the auditing phase, more steps are included. It is an important stage since there the components and materials that can be reused are identified. In the auditing phase, the building documentation should be reviewed. The site visits should include building and structural survey checking the quality and quantity of components and their reuse potential. They should also investigate if there is presence of hazardous materials and in the end, an inventory list should be created containing detail information about the materials and components of the building.

Moreover, the planning stage should be made in more detail than in the traditional process. It should contain cost estimation, scheduling and resource optimisation. The materials should be advertised on an online platform in order to find buyers before the demolition starts. Moreover, a waste management plan and a demolition plan should be created. In the execution phase, the reusable materials should be retrieved, and this might include structural components too, that are not removed in the soft stripping.

The traditional demolition process refers to waste and not materials. In the traditional process, there is no separation of the waste on site. In the new process, it is essential to separate the components and materials to different streams in order to enhance their reuse potential. The waste that can be reused in the traditional process most of the time needs modification and repairs since they are not retrieved in the right way, and they were mixed with other waste. Also, in the new process, more options for reuse are given. The materials can be reused on site, in a new project or they can be put in storage until their next use. The rest can be recycled, and a small portion that cannot be reused or recycled is going to landfills.

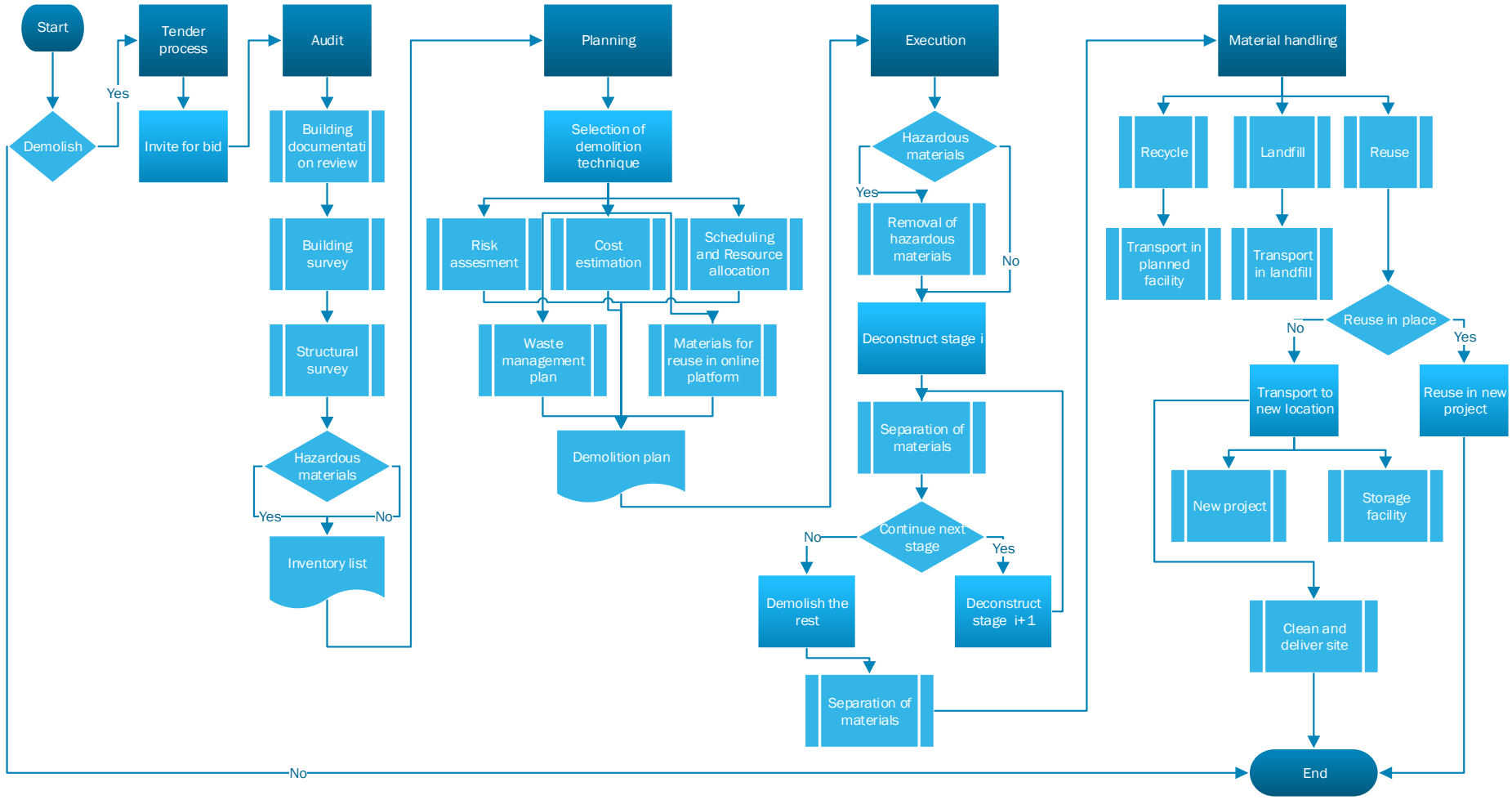

Figure 13: Developed demolition process flowchart

5. Case study and interviews

To further develop the flowchart more data from the industry were needed. In the previous chapters, input from theory was taken regarding the demolition process. The perceived needed changes were identified based on international literature. In order to see if the frontrunners on circular demolition recognise that same needed changes, input from practice was necessary. Also, it was essential to find out how the actors in practise could affect the reuse potential of the materials. To get the required information from practise a case study and expert interviews were used. The interviews were done with people that are involved with circular demolition and reuse of materials and have some knowledge regarding that. The selected case study is an innovative project that involves circular demolition and high scale reuse of components and materials.

5.1 Interviews

The interviews were conducted with companies that are frontrunners and value circular demolition and reuse of materials. In this way input from best practices regarding circular demolition process and reuse of components and materials was given. To create the interview questions input from the literature study and the perceived needed changes were used. The questions of the interviews can be found in the Appendix.

In the following table, the companies that were interviewed can be found along with the function of the interviewee in the company and the role they have according to this research. Interviews were done with four demolition companies, the branch organisation of the demolition companies, two clients and a consultant.

Table 5: List of interviewees and their roles

Company name	Function of interviewee	Actor role	Case
A. van Liempd Sloopbedrijven	Commercial manager	Demolition company	
Dusseldorp Infra, Sloop en Milieu	Director of Demolition and Residual Materials	Demolition company	✓
Weever bouw en sloopwerken	Circular manager	Demolition company	
GP Groot sloopwerken en saneringen	Senior project leader	Demolition company	
Veras	Association manager of branch organization	Demolition company	
HEEMwonen	Project manager	Client / New user	✓

Bo-Ex	Project manager	Client / New user
Buro Boot	Project leader Circular Demolition	Client (Consultant)

The demolition companies that were interviewed varied in size and the services they provide. Two of them are bigger companies, one is a medium company, and the other is a smaller company. Also, apart from demolition most of the companies offer other services like a shop that sells the reused materials that they retrieve from the demolition, waste sorting and treatment plat and construction services. All the companies differ in their size and the services they provide. The other services the companies offer can have a small impact on their actions and their processes. Each of them is a different company so the opinions on some topics might vary because of their process and their affiliated activities. However, all of them have tried to adopt circular demolition and take materials for reuse form their projects, and they provided valuable input for this research.

5.2 Case study

The purpose of the case study was to find out the how in practice they deconstructed and reused components and material in a new development. This case study was selected because of the innovative character. It is a very specific project since it is the first demolition project that will reuse components on such a big scale and information can be retained from this project. To get the information for the case study, the project manager of the project which is employed by the client (HEEMwonen) and the demolition company involved were interviewed.

5.2.1 Introduction

The case study that was used in this research is the SUPERLOCAL project. This project is located in Kerkrade, where demolition and redevelopment will take place. On the site, there were three high-rise buildings with 400 apartments. In their place, 125 new residential properties will be developed. The main parties that are involved in this project are the housing corporation HEEMwonen which is the owner, the municipality of Kerkrade and IBA Parkstad (SUPERLOCAL, 2018).

The properties didn't meet the housing requirements anymore, the population of the area is declining, and there is no demand for them (SUPERLOCAL, 2017). The owner decided to demolish, but he didn't want to waste the raw and reusable materials from the buildings that are released during demolition. He wanted to demolish in a sustainable way where the materials can be preserved and reused. In order to do that parties from the market were asked to come up with a proposal that will develop the new properties with reused materials. The selected parties were the demolition company Dusseldorp and the construction company Bouwbedrijven Jongen (Rautert, 2018).

The goal of the project is to develop a number of new properties by using only materials and components taken from the old buildings. The projects aim at 100% reuse and

recycling of the materials. It is an innovative project since reusing of buildings on this scale has never been done before. The project aims to generate 805.000 kilos of CO_2 emissions less compared to the construction of a new high-rise building (SUPERLOCAL, 2017).

The project received 4.7 million euros of European subsidy from the Urban Innovative Actions fund. This subsidy has been granted because the project contributes to a sustainable economy that deals efficiently with raw materials(Rautert, 2018). Because of the subsidy experiments are being made on site with new techniques and construction methods using the existing materials.

5.2.2 Demolition and Redevelopment process stages

Tender stage

The owner of the project is a housing cooperation, so they don't need to follow the official tender process that is required by public organisations. In this case, the common practice is to choose the cheapest offer, but in recent years, this has shifted from the cheapest to the best value for money. In this project the criteria of the owner were different. The goal of the tender was to find partners that have the same vision of reusing components and materials, and this could not be done at the lowest price.

There were two tenders, one for the building contractor and one for the demolition contractor. This was done because of the important role of the demolition contractor has in this project. For the demolition contractor, it was a price-quality tender. It was judged based on the cost of demolition but also on vision on how to reuse the components of the apartment building. The tender for the contractor was mostly based on vision on how to reuse the components of the existing building since there were no designs or plans. The surprising thing was that the demolition party had the most innovative solution. The demolition company had the idea of cutting out the whole apartment from one of the buildings and move it down in order to reuse it as it is. The contractor had the idea to use smaller components such as slabs, walls, part of the façade and make a building out of it. The owner combined those visions to develop the plan.

When the selection of the contractor and demolition company was done, the architect and engineer came into the project. They were hired directly by the owner due to their previous cooperation. The building engineer was familiar with the building since he worked on them before due to structural problems they had.

Plan development

When the parties were selected, they all started working on the plan as a team. The owner gave them the vision and the steps. First the expo building needed to be created and then the test dwellings and then the normal dwellings. Decisions needed to be made regarding the buildings. There were three apartment buildings, block B, C and D. Due to economic reason it was decided to demolish block D, renovate block B with new materials and deconstruct block C. An experiment was needed to see if reuse of the skeleton, the façade,

structural components, etc. was possible. It was decided to harvest the components and materials for the expo building from block D before its demolition.

Block C is financed by the European subsidy which will be deconstructed. The components and materials harvested from block C will be used for the development of the four test dwellings. Then the development of the 14-16 normal dwellings will take place with components form block C. The components and materials that will be left unused during the project will flow into the construction projects of the region.

Audit

Audit was needed in order to see what materials and components were inside the building and their quality. The material passport was created for block B only, since the buildings were identical. The drawings of the buildings were also studied, and the engineers examined the buildings with site visits. Also, a lot of tests were performed by a concrete technology firm. They did a lot of scans with Fero scanner and on-site tests to see what kind of reinforcement there was in the building and its quality. That was necessary since the buildings were made in the 60s and the building methods then were really different. The shape of the reinforcement was different, and the amount of the reinforcement was minimum, so it was necessary to know what there was inside the structure.

Execution - Development of expo building

The project started with the development of the expo building in June of 2017. Materials for the expo building were taken from Block D which was demolished when the harvest was done. The exhibition building was built with the realised materials. The exhibition building was an experiment to investigate the possibility to make new structures from materials realised during demolition. The building contains the most important elements of a regular home (Rautert, 2018). The building provided insight into whether reusing the materials from the demolished flat is useful in practice and on a large scale.

The expo building was made out of three units taken from the building. The units were cut as a whole structure including floors, walls, columns, beams and ceiling. Every unit was cut individually and transported from the top of the apartment building to the location of the expo building. It should be noted that the units were transported to the new location without having any damages. The process of the development can be seen in Figure 14.

In the expo building, 95% of the components and materials were reused. They couldn't reuse everything since there was a lot of asbestos in the building. All the glass was mounted with asbestos, and if it was removed the glass broke so new glass was needed. Also, the window panels were made from internal doors. A wall was created out of concrete bricks that were made by a supplier and contained 40% concrete from the flat. Some of the beams came from the old building but there was not a lot of steel in the old building so, some new steel beams were needed. All the pipes, electrical insulations and lighting came from the basement of the building.

Figure 14: Development of the expo-building (SUPERLOCAL, 2017)

Components material handling

The materials that were retrieved from demolition were separated into 24 materials flows. Some of them were wood, glass, plastics, aluminium, copper, steel, doors, lamps, ceiling panels, pipes etc. The components that were used in the expo building were mainly used as they were retrieved without further processing. However, to reach certain quality, the facades went back to the manufacturer to paint and repair them.

For the next phase of the project, an effort will be made to reuse everything as components since it is better for the environment. However, if this is not possible, they will be reused

as materials, or they will be recycled. The concrete rubble from the demolition of Flat D was saved on the site in order to create new concrete out of it and reuse it for the construction of foundations of the new dwellings. The wood will be used creatively. The inner doors will be used for a lot of things, and an option is to make insulation out of it. The wood from the windows will be reused, and beams will be made from the wood found in the building.

All the materials will be coded with a QR code, they will be scanned and appeared in a database, so the owner can trace which materials go to the four dwellings, to the 16 and those who go outside from the project site, to other project and companies. They are going to keep a log of what happens to them, and this is a big part of the European subsidy.

Plans for the next phases

The next phase is the development of the four test dwellings. Each of them will be developed with different building techniques. In the first one, the façade will be made out of clay, in the second will be made from a wall from the apartment buildings. The third one will be made from regular bricks that will be found in the building, and it will be combined with recycled concrete that will come from the apartment building. The concrete will be sent to a company, and they will send back the raw materials of concrete (sand, cement, rocks). The fourth one will be made by using units from the building like the expo building. The result of the four dwelling will be used for the development of the 14-16 dwellings.

5.2.3 Problems and Lessons learned for the actors

One of the most important lessons learned was that it is possible to take the whole unit from the top of a building and reuse it. There are a lot of uncertainties of how the structure will react in this move. It was unknown if lifting out and transport the structure was possible and if it could survive without any damages. Moreover, in a project like that, the normal building process cannot be applied. The architect needs to make the design with the components and materials that are available in the buildings in a way that the demolition company can harvest them, and the building contractor can reuse them.

The timing that the materials are deconstructed was a problem. The materials came out of the building in a specific order. Usually, those that come out last are needed first to start the new construction. For the rest, storage is necessary until they can be used. A good example is the need for foundation. Concrete comes out last, but the foundation is the first thing that is needed. It takes a lot more time to do everything in the specific order. This problem became apparent in the development of the expo building. To solve this, it was decided to use the rubble from the demolition of block D to create new concrete for the foundations needed for the houses.

There are no regulations regarding reuse of construction components and materials. One of the problems they faced with the reuse of the structure was the height from the floor to the ceiling. The height was 10cm lower than the one mentioned in the building regulations that concerns new construction. When it is a renovation project this is not a problem, they

accept the height that it was built. Everything that is built in a new foundation needs to have the highest quality level, high energy label etc. In the case that you reuse the structure, it is difficult to achieve that. The city had to judge the plans and give the permit. In order to be accepted, the dwellings will be judged as a renovation project and not as a new build. In order to find a solution, they needed to be creative with the regulations since there are still no regulations regarding these matters (M.Segers, personal communication, July 19, 2018).

5.2.4 Input for the research

This case study gave new information and input for the current research. That information was used for the analysis, in the model development and the recommendation to the actors.

- The parties that work in a project like that should have the same vision of reusing materials.
- When materials need to be retrieved for reuse, the tender should not be awarded to the offer with the lowest price. A price-quality tender is a better option.
- The tender was based mainly on the vision of how the material can be reused. In this way, the companies can use their knowledge and creativity to come up with the best solution for reusing materials.
- The parties should work together to develop the plans, and for that, good cooperation and communication are needed.
- The architect can develop the design with what materials are available, taking into account what materials the demolition company can retrieve and what materials the building contractor can reuse.
- Site visits and documentation review are essential in order to see what materials and components can be reused.
- When concrete components and units are reused, it is essential to have several tests to see their condition. The reinforcement of the components should be tested in order to see its quantity and quality.
- Testing for structural ability is not very expensive in this kind of project but essential in order to reuse them.
- The reuse of concrete components of this scale that were cast in situ it is possible.
- The concrete components have long lifetimes and are durable especially if they are not affected by the weather (inside units). They can be reused without any quality decline.
- The materials should be separated in as many streams as possible for better reuse and recycling.
- A QR code can be given to the materials that are realised during demolition.
- The timing that the materials come out of a demolition project is important. This needs to be considered when reuse will take place especially when reuse of concrete in materials level will take place. The rest of the materials might need to be stored until they can be reused.
- Despite the lack of regulations regarding reuse, solutions can be found when you are creative.

6. Findings from practice

6.1 Introduction

From the case study and the interviews, several data was gathered that needed to be analysed. The transcripts from the expert interviews and the interviews from the case study were analysed in terms of the perceived needed changes that were mentioned in Chapter 4, and the barriers and opportunities of circular demolition and reuse of materials. To perform the analysis, several codes were created. The findings for each code are given in the following chapter showing the opinion of the interviewees along with contradicting views that exist on some of the codes. The codes were divided into the process stages, the new codes that emerged from the interviews and the barriers and opportunities. Following that, are the concluding findings from the analysis of the codes. Based on those the final flowchart adaptations were made. Finally, the flowchart and the findings of this research were validated. The overview of this chapter can be seen in Figure 15.

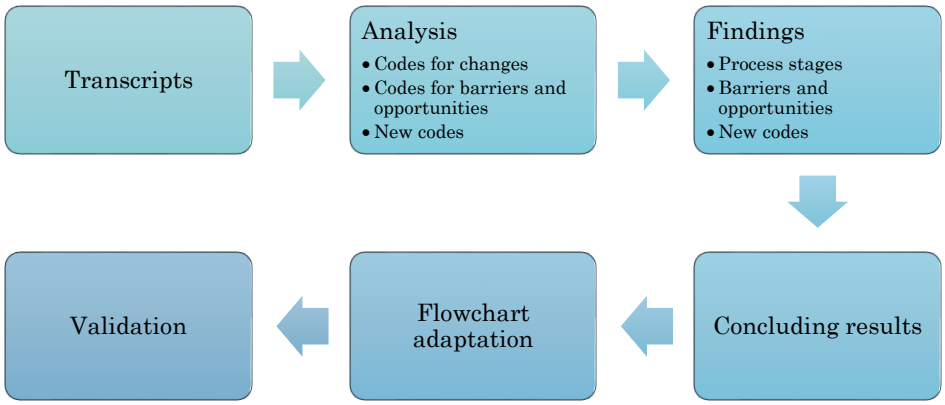

Figure 15: Analysis and findings process overview

6.2 Analysis

For the analysis of the data, the software Atlas.ti was used. From the literature study, some perceived needed changes were found. Those changes were translated into codes which can be seen in Table 6. First, the transcripts of the expert interviews and the interviews of the case study were examined to see if they contain the codes found in the literature study and to see if additional codes emerged from the interviews. Also, codes for the barriers and opportunities of deconstruction and reuse of materials were created which are given in Table 7.

Table 6: Codes for the changes needed in the demolition process

Code	Explanation
Sustainable tendering criteria	Sustainability criteria in the tender will encourage the demolition companies to take more components and materials for reuse, and they will not plan only based on cost.
Freedom to the demolition contractor to take materials for reuse	The client should give the contractor the liberty to take materials for reuse when he wants to do it.
Set requirements for reuse	The client should set requirements for reuse in his tender in order to encourage demolition companies to take components and materials for reuse.
Documentation review	The demolition company should first examine all the available documents to see what it is included in the building they are going to demolish.
Site visits	The demolition company needs to make site visits to perform the audit. There they see the actual materials, components, their quality and quantity.
Create detailed inventory	The demolition company should create a detailed inventory of all the components and materials of the building including information about their quality, quantity and condition.
Demolition techniques	The demolition technique that the demolition companies use should not be destructive for the components.
Cost	The deconstruction and reuse of components affect the overall cost of the project. In most of the times is the most important driver in the demolition of a building.
Time	More time is needed for deconstruction, and this affects the overall duration and cost of the project. The clients should be willing to give more time.
Labor	More labour is needed to deconstruct the components and materials for reuse properly.
Resources allocation	Good coordination of activities and resources can reduce the time and cost of the project and allow more materials to be retrieved.
Advertise the components in an online marketplace prior to the demolition	It is important to advertise the components before the demolition starts in

	order to find buyers in advance (reduces the risk of not selling them)
Buyers through the network before demolition	The demolition company cooperates with a lot of actors. They can sell their components and materials through their network of business.
Soft-stripping	Soft-stripping is essential since all the non-structural components are taken out of the building and can be reused.
Separate in different streams	The different components and materials need to be separated into different streams.
Dismantle according to the requirements of the new user	In order to maximise the reuse potential of the component and materials, they need to be dismantled according to the requirements of the new user.
Clean and refurbish the components	The components after they are removed they need to be cleaned and refurbished in order to sell them.
Transport in a new location	The components need to be transported to the new location.
Storage	Storage might be needed if there is no buyer.
Client consider reusing materials/ buying reused materials	The client should consider reusing materials in his project or buying reused materials.
Invest in training	The demolitions companies can invest in training in order to learn how to take components and materials for reuse.
Develop good cooperation with other actors	Good cooperation with the other actors can help to achieve the common goal and retrieve more materials.
More accurate estimation of the risks and allowances	More accurate estimation of the risk will decrease the budget and allow more materials to be taken for reuse.
Sale/Reuse of non-structural components	The non-structural components should be put for sale or reused in the same location.
Sale/Reuse of structural components	The structural components should be put for sale or reused in the same location.
Set requirements in advance	The new users need to set their requirements in advance before the demolition starts.
Adaptable design	The new design needs to be adaptable in order to be able to fit the reused components.
Material passport	The material passport can help during the audit and planning for demolition, in order to see easily what can be reused.

Table 7: Codes for barriers and opportunities

Code	Explanation
Barriers	
Missing building documentation	Missing building documentation can make the audit process difficult and more time-consuming.
Unknown quality of the materials	The quality of the materials might be unknown, and testing might be required.
Components not designed for disassembly	The components are not designed for disassembly. The use of fix joints might not allow the proper deconstruction.
Low cost of new materials	The cost of new materials is low, and the difference between the price of reused materials is not significant.
Uncertainty of demand and supply	The demand for the materials is not very high, and thus the supply is limited. The uncertainty about the demand makes the supply low.
Not very high disposal cost and taxes	The disposal costs and taxes are not very high, and this allows the companies to dispose of the materials.
More time is required	Deconstruction requires more time since the components need to be dismantled carefully.
Clients want the demolition to be fast	Most of the clients want the demolition to be over fast in order to start the new development.
Limited separation of material	The limited separation of materials reduced the reuse potential of the components since most of them are destroyed.
High risk for the demolition companies to lose money	Demolition companies don't want to take the risk to deconstruct and lose money from their profits.
Costly tests for structural ability	The structural ability of some components needs to be tested. Those tests cost money, and this makes the companies reluctant to retrieve them.
Cost of transportation and storage	There are certain costs for the transportation and storage of the materials, and this will increase more the costs of the project.
Adaptable design	The design of the architect needs to be adapted to the available materials for reuse. This gives a lot of restrictions to the architect which might not be desirable.
Not highly regulated	There are no strict regulations regarding demolition and deconstruction. Also, there

	are no regulations in the building codes regarding reused materials.
Lack of awareness of reuse potential of materials from demolition companies	The demolition companies might not be aware of the reuse potential that some of the materials might have and they are not taking them for reuse.
Designers not aware of the supply sources	The designers that might want to use secondary components might not be aware of the supply sources.
Lack of cooperation between the parties	When the parties don't cooperate the reuse of materials is not possible. They need to have a common vision in order to enable the reuse in the projects.

Opportunities

There is value in the sale of reused components	The demolition companies have the opportunity to gain some profit from the sale of the materials and thus have a lower bid.
Materials can be reused in projects	A lot of materials have the potential to be reused in projects with the same or different function that were intended to.
Economic benefit for the client	The client can have some economic benefit since he will not need to pay for new materials.
Can be used as materials in upcycling enterprises	Some of the retrieved material can be used for the production of new components.
Government develop regulation for reuse	The government has the opportunity to develop regulations for reuse since it is something that will grow in the future.
Create new business	There is the opportunity to create new business. For example, the creation of physical stores that sell reclaimed components.
Create job training	The deconstruction requires more labour. There is the opportunity to train more people and create more opportunities for unskilled labour.

6.3 Findings

The interviews were examined based on the codes given in the previous part. In the following paragraphs, the codes were grouped according to the demolition process phases. The main findings from the interviews for each code are given in this section.

6.3.1 Tender stage

Sustainable tendering criteria

The sustainability criteria are not used very often in practice, however, having sustainability criteria in the tender will motivate the demolition companies to take more materials and components for reuse. The contract will not be awarded to the lowest price since there will be a weight for the sustainability criteria. This will be helpful for the companies since they will get points for taking materials for reuse and they might win the contract even if they don't have the lowest price. It will also allow creativity. When the demolition companies are motivated to take materials for reuse, they will also be creative in the way they can reuse the materials. Also, the client will benefit from that since his demolition will be done more sustainably, and more materials could be reused.

Set requirement for reuse

Some clients want to demolish and develop their buildings circularly. When this is the priority, requirements for reuse should exist in the tender stage. When there are requirements for reuse, more points can be given to the demolition company that demolishes more circularly. They can also be judged by the percentage of the reusable materials they will retrieve. In this way, the tender will not be awarded to the company with the lowest price.

Freedom to the demolition contractor to take materials for reuse

In the tender, the client should give the freedom to the demolition company to take materials for reuse if they want to. One of the clients that was interviewed mentioned that they are willing to give this freedom in the tender. They also mentioned that extra points could be given to the demolition contractor that wants to reuse as long as he proves that he is actually going to sell the materials for reuse. From the side of the demolition companies, it might be beneficial if they have this freedom. The companies can have a profit from taking materials for reuse. Also, a company mentioned that it is their policy to retrieve materials for reuse even if the client doesn't require it.

Client consider reusing materials

There are clients that want to reuse materials to their projects. They can use the value of the materials and components retrieved from demolition. For them, there is the incentive that they don't pay VAT when they reuse their own products, and they save money from not purchasing new ones. Some of the materials can be reused easily but the reuse of some of the components might be challenging since some of them might not meet the current regulations. They need to think creatively about what can be reused or not, and what can be reused with a different function. The clients that want to reuse components, they need

to incorporate their wises in the tender stage. In this way, they will be able to find suitable partners that will help them realise their goals.

6.3.2 Audit

Documentation review

The documents of the building can be helpful when performing the audit. They indicate what is in the building that cannot be seen with visual inspections. They also help in the estimation of quantities of materials produced form demolition. Sometimes the documentation is not present, so the information is gathered only from site visits.

Site visits

Site visits are essential for the proper audit of the building. The demolition companies need to go to the site in order to see the actual situation of the building, the components and materials, their quality quantity and condition. During the site visits, they can see which material can be sold for reuse.

Create detailed inventory

Making a detailed inventory of the building is important. In this way, the company knows exactly what materials are in the building, their quality and quantity. The components and materials that can be reused are identified based on visual inspection and the experience of the person that does the audit. This detailed inventory is used for the planning and to find suitable buyers for the materials and components.

Material passport

The material passport seems to be useful mostly for the clients. They can do it for their buildings and use it for their maintenance, renovation and demolition activities. It contains information that can be useful during the audit and planning of the demolition. It can be helpful for the demolition companies in the future. The problem is that it is difficult to do the passport for the existing buildings since they need to know exactly what materials are in the building, in which quality and quantity and condition. It should be done for the new buildings that are developed now, and in the future, it will be beneficial in the demolition activities.

6.3.3 Planning

Buyers through the network before demolition

It is essential to have a network of business to sell the secondary components. All the interviewees mentioned that they cooperate with specific companies that sell some of the secondary materials. In most of the time, the businesses can be found in the area, which limits the transportation distance, the cost and the CO2 emissions. If this is not possible, then the components can be offered in an online marketplace. The agreements about the sale are made before the demolition starts, in the planning stage. Thus, the demolition

companies can make sure that the components and materials will be sold, and no expensive storage will be needed. Also, these agreements allow them to calculate their cost and deduct the profit from the sale in order to give a lower bid.

Advertise the components in an online marketplace before demolition

The components and materials can be advertised in an online marketplace before the demolition starts. The marketplace will connect the supply and demand of the materials. The available materials that come from demolition can be offered in the online platform. The marketplace is a good option to sell the materials when the demolition companies don't have direct buyers that they can sell them. One of the interviewed companies owns a marketplace, and they sell their materials to third parties through there, and it is profitable for them. Two of the demolition companies cooperated with 11 other demolition companies for the development of an online marketplace to sell their materials. Owners of buildings are also interested in participating in a marketplace and selling their components that come from demolition and renovation projects. The owners can also buy reused components from the marketplace in order to reuse them in their buildings. One of the demolition companies doesn't seem to find it profitable for them to offer the materials in an online marketplace but they prefer to sell directly to specific buyers.

Cost

The cost is a big factor in demolition projects and the reuse of materials. Usually, the clients want the demolition to be done with low cost. They are not willing to pay the demolition companies more money to take components and materials for reuse. In the traditional demolition there is maximum mechanisation of the project, so the time, labour and costs are low. When deconstruction and reuse take place, this affects the cost.

When the demolition companies sell some of the components they retrieve, they also make lower bids in the tenders since they have some profit from the sale. The price of the bid is calculated based on the demolition cost minus the expected profit from the sale of the components. In their calculation of cost, they take into account labour, cost of machines, recycling costs and landfilling costs. Also, the process of retrieving and selling the materials has certain costs, but in most of the cases, the profit from the sale of the components can balance the extra cost. Another cost is the logistics and the storage if the materials are not sold directly. When the materials need to be stored for some time, this increases the costs.

According to a client, there is a balance between time and cost especially in the case of reusing in his project. The extra time might cost more money but also the purchasing of new materials also cost a lot of many. When you find the balance between those two, you can reuse more materials.

According to one of the demolition companies, another problem is that a lot of new materials are cheap, and the salaries of the labour are high. When the duration of the project is extended by two or three days this cost more money mainly due to the labour salaries and the machines that are on the site.

Labour

Labour is needed in the demolition activities, and this has an impact on the cost. When materials need to be retrieved more labour is needed, and this might cost a little more money since the wages in the Netherlands are high. It is perceived that only 5-10% is the needed extra labour for deconstruction activities. When the demolition company makes a good profit from the components and materials that are deconstructed and sold this increase in the labour is not a problem. Even if the materials are going to be recycled, the building needs to be completely stripped down before the demolition of the concrete parts. This needs to be done from the labour since the machines cannot take out the different parts. If this doesn't happen, it cost more money since the concrete should not be mixed with other materials to be recycled. In both cases, the labour needs to remove everything from the building. The difference is in the way they remove the materials. When they deconstruct them properly the materials and components can be easily reused. Their skills, knowledge and experience play an important role as well. When the labour knows how to deconstruct the materials properly, they don't damage them in the process, and they do it quickly.

Time

Another crucial factor is time. The main problem with demolition is time. Most of the clients want to demolish their buildings as fast as possible. This is a big problem because the companies cannot take materials for reuse if they have a strict timeframe. However, some clients started to change their attitude, and they are willing to give more time to the demolition companies. One of the companies mentioned that since they have the reclamation of materials as their common practice, it doesn't take them extra time. They have adapted their practises and procedures with this as a factor and the time that they spend is the same if they used traditional demolition. The rest of the demolition companies claimed that they need more time in order to retrieve materials. When they have more time, they can take even more materials out. The demolition companies need to make a profit from the sale of the retrieved materials otherwise it is not wise to take them from an economic point of view. Time is directly connected with money. One extra day of work means additional cost for the labour, machines etc. The companies need to take that into account in their planning in order to be able to cover the extra cost form the revenue of the sale.

The clients that consider reusing materials in their project can give the time for reclamation since there is a balance between the extra time and cost needed for the circular demolition with the cost of buying new components and materials. Also, if the client gives the time, the demolition companies can take more materials out for reuse and have a circular demolition. They can also be creative of how to reuse the material or try to take materials that normally wouldn't take. Even in the case that the client doesn't want to reuse materials, he can give the time to the demolition company to retrieve and sell the materials.

More accurate estimation of the risks and allowances

The estimation of the risks is very important in a demolition project. The companies take their measures to mitigate the risk by making a detailed audit in advance in order to know the condition of the building and the presence of hazardous materials. They also include in their budget allowances for the case an unexpected event occurs.

Resources allocation

The time spent on site, the labour and machines needed, have an impact on the overall cost of the project. The planning and the resources that are used each day on the site can be optimised in order to have efficient deconstruction. For that, proper calculations and planning are needed beforehand.

Reuse/Sale of non-structural components and materials

A lot of non-structural components can be reused. A common problem for some of them is the presence of asbestos, which will make them unsuitable for reuse. Despite that, a lot of components can be reused such as sanitary, electrical and mechanical installations, radiators and fire extinguishers. Also, components such as internal and external doors, hardwood doors, windows can be reused not only in the function they were created but in other functions too. There are a lot of components that are not designed to be reclaimed, but they are suitable for it. If there is creativity, their purpose can be changed. A common problem is that some of the components don't fit the current building code regulations and cannot be reused in new constructions. Doors retrieved from demolition are not compatible with the current regulations. However, those doors can be reused in renovation projects, or they can be transformed into something else and used with a different function for example in the manufacturing of kitchens. The last option is to provide the doors in the chipboard industry. Only one of the demolition companies doesn't take non-structural components for reuse. The rest try to take everything that can be sold and reused. One of the demolition companies mentioned that they take the asphalt from the roof and reuse it. If the quality is good is given back as a material to the manufacturer, and new roofing materials are produced. If the quality is not that good is used to make asphalt for the roads.

Reuse/Sale of structural components and materials

The structural components mentioned in the interviews that can be reused are steel, wood, concrete and sometimes bricks. Steel is a very profitable material to take for reuse. The first option is to take it and reuse it as steel components. This can be the steel beams or columns. However, if this is not possible, it is sold to companies that melt it and create new elements. This is the process that is done with the steel rebars reinforcements since they cannot be reused in component level. Because of the revenue that steel has, the companies break the concrete and retrieve the reinforcement in order to sell it.

Reuse of reclaimed wood is also profitable since the quality of the wood is good and sometimes is even better than the quality of the new wood from young forests. The wooden components are easy to sell and reuse. The wood can be used for different purposes. It can

be used easily as structural beams and columns. It can be processed and used in floors, ceilings, and walls.

Reuse of bricks is possible when the binding material is not strong. However, in most of the cases they are bounded with cement which is too strong, and they cannot retrieve them. If this is the case, they crush them and use them as mixed aggregated for filling materials under the roads.

The concrete is the most challenging material to reuse. It is the material with the highest percentage in most of the buildings, and the price of demolition is highly depended on the concrete. It can be reused in component level and material level. There are three options for reusing concrete, to reuse the skeleton of a building, to reuse concrete compartments and components and to crush it process it and create new concrete out of it.

To reuse the skeleton is an option since the concrete is a very strong material and has a long lifetime. Also, the reuse of concrete components is also possible if the quality of the components has not been compromised. In order to have this kind of reuse a client that believes in reuse is needed. If the client is willing to try to develop his project differently, the demolition companies can be creative and help the client to do his project in this way. There might be a benefit for the client when he reuses the concrete in component level since a lot of money will be saved in purchasing the steel and concrete which is a significant cost in construction projects.

Most of the actors consider reusing the concrete as a material. They take the concrete and process it and take out of the concrete the cement, the sand and the aggregates and from those to create new concrete. This is considered very interesting and promising process since most of the buildings are made out of concrete and it is the material with the highest percentage in the buildings. However, in this case, the client needs to consider that the materials that they get back are less in percentage in respect of the provided concrete so concrete from other projects or new concrete might be needed. To enhance the reuse of concrete in the Netherlands, they agreed that in the production of the new concrete, 5% of the materials need to come from old concrete.

6.3.4 Execution

Soft-stripping

Soft stripping is essential when materials are going to be retrieved for reuse. This means that everything that is going to be reused needs to come out before the actual demolition. This is the practice in most of the cases, but when structural components are going to be retrieved the stability of the building need to be taken into account. In this case, some structural components might need to be taken out in a later stage.

Demolition techniques and retrieval of materials

The demolition technique depends on the building type and the materials that are in the building. In most demolition projects the demolition is done with excavation machines, cranes and rarely with ball or explosives. The demolition technique must change in order to take more materials for reuse. Deconstruction needs to be adopted as the main demolition technique. More manual work is required to retrieve materials suitable for reuse. The knowledge, skills and years of experience of the people also play an important role in the way the materials are retrieved.

Dismantle according to the requirements of the new user

The demolition companies can dismantle the components and materials in accordance with the requirements of the new users. Since the agreements of the sale are made beforehand, it is possible to disassemble the components according to their requirements. It is even possible that the buyer can dismantle the components himself as long as he is qualified to do it.

6.3.5 Material handling

Separate in different streams

The separation of specific materials is required by law in the Netherlands. The companies are required to separate them into 10 waste streams that must be disposed of separately. One of the companies mentioned that they separate them in 24 different streams. Some of them are glass, wood, concrete, plastics, aluminium, copper, steel, doors, lamps, ceiling, pipes, tar etc. In this way, more materials can be reused or recycled.

Clean and refurbish components

The processing after the materials are retrieved by the demolition companies is limited. The most common practice is to de-nail the wood. The rest of the components and materials are sold directly to a new business, where they might refurbish them or take them for further processing.

Transportation in the new location

Transportation is another factor that contributes to the cost. The best option is to reuse the materials in the same place but 90% of the times is not possible, so they need to be transported. The companies aim to find new buyers in the area. In this way the distances are smaller, the CO_2 emissions are not very high, and the cost is lower. Of course, this cannot be the case for every material since for some specific materials only one or two companies exist in the country that can take them.

Storage

The storage of materials is an issue for most of the actors. It cost a lot of money to store the materials. Especially in the case that the materials are in the storage for an extended

period, it is not profitable to take them and store them. The best option is to retrieve the materials and reuse them directly or sell them within a short period of time. It is not an issue when the company owns a plot that they can put them there, but when this is not the case, the storage is too expensive to rent it.

6.3.6 Non-process related codes

Develop good cooperation with other actors

The cooperation with several actors is an important factor. The demolition companies mentioned that they have close collaboration with clients in order to get the projects. Collaboration with big clients like housing associations is important. From the demolition of those buildings, they can retrieve more materials for reuse and also similar materials. The retrieved materials can be reused in a new building of the client, or the client can buy reused materials from them. In case of demolition and redevelopment project, it is important that the demolition company, client and contractor work together from the beginning. They investigate what they can reuse, and they make the new plan with the reused materials that will be available from the demolition.

Also, it was mentioned that cooperation with everyone in the chain is necessary when you believe in circularity. In order to demolish circularly, reuse materials and develop circular buildings where materials can be easily deconstructed all the actors in the chain need to collaborate. The clients, contractors, demolition companies, suppliers of the materials etc. are some of the actors that need to cooperate.

Adaptable design

When reuse takes place in a building, the design needs to be adapted to the available materials. It is a reverse process. The architect needs to take into account the materials he has available and based on that to develop his design.

Set requirements of the materials in advance

The user of reused materials should express his intentions in advance. In this way they can work together with the demolition contractor in order to take the materials they desire for reuse. Also, the demolition contractor can help with his knowledge and experience to show the opportunities that the materials can have for reuse.

Invest in training

One of the companies mentioned that they invest in training people in learning how to deconstruct. They learn through practice and some classes. There is a lack of labour, and this is an opportunity to train people. More people are needed to do the field job and they are essential when deconstruction needs to take place since labour is needed.

6.3.7 Codes overview

Contradicting views

For most of the codes the interviewees had common views but in some of them the opinions were different. In the following table the codes that the interviewees had different opinions are given.

Table 8: Codes with contradicting views

Code	Opposing views	
Material passport	More useful for the clients, can also help in their maintenance and demolition activities.	Demolition companies will use it in the future. It is difficult to do it for existing buildings.
Advertise the components in an online marketplace before demolition	Useful to sell components and material that cannot be sold directly to the network of businesses and they can make a profit.	One of the companies think that is not profitable for them to sell them through there.
Cost	With proper calculation, the companies can make a profit.	The extra labour and time needed affect the cost and is not always profitable.
Labour	Almost the same labour is needed even if recycling takes place and not reuse. The difference is in the way the labour deconstruct that enables the reuse.	More labour is needed that is expensive.
Time	For one of the companies it doesn't take them extra time.	The rest need more time.
Reuse/Sale of non-structural components and materials	Non-structural components can be sold for reuse.	Only one company doesn't sell them for reuse since it is not profitable for them.
Storage	Storage doesn't make sense since it cost a lot of money to rent it.	It is not an issue when the company owns the plot to store them.
Invest in training	They need to invest in training of people since there is a shortage of labour.	The rest of the companies don't do it.

Code's importance

In the following figure are the codes that were used during the analysis. The codes with the highest value were mentioned by all the interviewees.

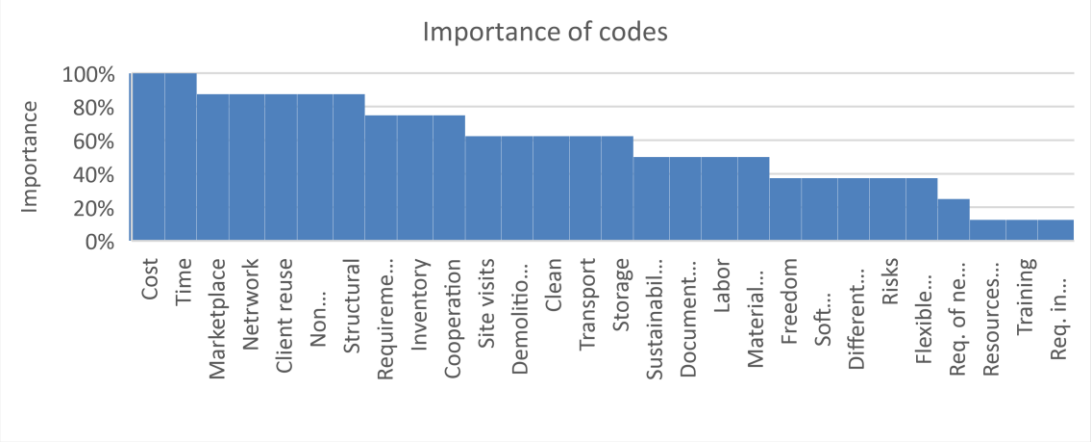

Figure 16: Codes mentioned during the interviews with all the actors

The cost and time are the two most important factors according to all the interviewees. The cost and time affect the decision of the actors to deconstruct and take materials and components for reuse or not. Next, to that, the existence of a marketplace and a network of business to sell the components are also important. In this way, the demolition companies can make a profit out of the sale, and this makes deconstruction possible. It is also important when the client considers taking materials for reuse since the client is the actor that makes the deconstruction possible with his decisions. A lot of components structural or not can be taken for reuse form the projects. Having requirements for reuse is also significant since this will enable the demolition companies to take more materials for reuse. The creation of the inventory is essential to see which materials and components exist in the building, what can be reused and its quality and quantity. Good cooperation between the parties is equally important in order to have successful circular demolition.

In Figure 17 the codes mentioned among the demolition companies are given. In comparison with the previous figure, the percentages are different for the codes. All the demolition companies mentioned most of the codes. Only the training, resource allocation and flexible design were mentioned fewer times.

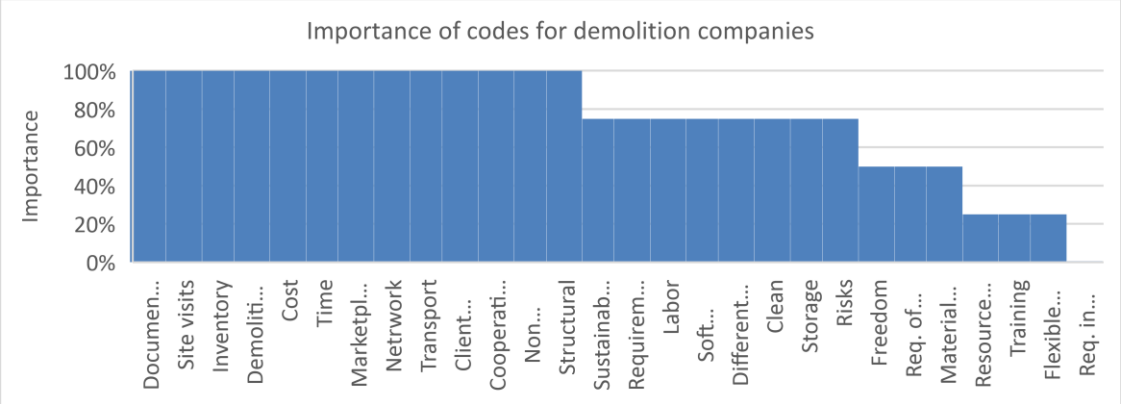

Figure 17: Codes mentioned in the interviews with the demolition companies

6.4 New codes found from the interviews

Clients consider their portfolio of projects

To enhance the reuse of materials in their project, the clients need not only to focus on an individual project but in their portfolio projects. This concerns mainly clients that own a lot of buildings. When the owner has several buildings, it means that he carries out maintenance activities for the buildings where he might replace some components. When the buildings are old renovation might take place. In those activities, materials can be reused. When the building reaches the end of its lifetime, the client will demolish it. In the demolition, a great number of components and materials are released. The activities of the client might also include redevelopment project after the demolition. Components can be used from the demolition to the new development. When the client will have some or all of those activities, he needs to consider his portfolio of projects. Components from one project can be reused in the other project. In this way, he saves some money in purchasing new materials, and he can have more circular activities. This requires long-term planning of the activities of the client and right timing in order to avoid storage costs. Also, if they cannot reuse all the materials to their projects, they can sell them in a marketplace or to specific suppliers.

Client plan for demolition ahead of time

Usually, the clients that want to demolish, make this decision after careful consideration of their options and their plans. It is not an easy and quick process especially when tenants occupy the buildings. The planning for demolition and redevelopment takes time. Since they take the time to plan everything ahead they can also give some extra time for the demolition process. A few more days can make a difference in the materials that the demolition company can retrieve from the old buildings.

Contractual relationship between the client and demolition company

It is important that the demolition company works together with the client. The demolition company can get the project either through a tender process or directly from the clients. When the client has a contract directly with the demolition company, the demolition company can take more materials for reuse. When the demolition company is hired by the building contractor, then no time is given. The building contractor usually wants to make the demolition cheap and fast, and this doesn't allow the demolition company to retrieve materials for reuse.

In a redevelopment project demolition company involved from the start

In a redevelopment project where reuse of components and materials will take place the demolition company should be involved from the beginning. The demolition company can bring the experience and show the reuse potential that components and materials could have to the other actors. They can work together and develop a plan that will allow the reuse of materials. They can work together to investigate what is in the building and what it is feasible to reuse. When the demolition company comes later in the process when the

plans and designs are already developed, it is difficult to influence them and propose changes. The other actors due to the lack of experience and knowledge might not take advantage of the material to their full potential.

Show clients the benefits and potential of reuse

The demolition companies can promote their company by showing the clients the benefits of reusing materials and how they can reuse materials in their projects. From circular demolition, some percentage of the materials can be reused in their new project. This can be a good promoting strategy that can give a competitive advantage to the company.

Invest in the company

The demolition companies should not only think short term but long term. In the short-term deconstruction and sale of reused materials might seem expensive and undesirable but in the long-term, it will be more profitable. The notion of circular economy and demolition is still in its infancy. Some companies try to investigate further on that. Those companies will have a competitive advantage in the future. Clients have started now to be aware of circular demolition, and in the future, they will require it in their projects. The companies that invest now and try to have more circular demolition will be the winners in the coming years. They will have adjusted their process and their relationships with other actors

The investment can be at several levels. It can be an investment in people that know about circularity and have a vision for the future. Those people can help to change the processes of the demolition company. Also, people that are more creative and can find innovative and creative solutions for reusing material. People that see the reuse potential of components and materials should come on board. When they audit the building, those people know which materials can be reused (conventional and not). Experienced labour can also help. They will know how to deconstruct the components properly and efficently and give them for reuse.

Create a material identity

The components that are retrieved from demolition can have an identity. This can show from which building they were retrieved and when. In this way, the components will contain useful information for the new users. Also, the client can learn where the materials of his project were sold and for which use. In this way, the added value of reclaiming components can be shown to the client and the new buyer. This can be used for marketing purposes. The components that have a story to tell may be appealing to some buyers, and they even might be prepared to pay a higher price to acquire them.

Create awareness

In order to enhance the use of secondary components, the demolition companies can create awareness among the actors in the building industry. The contractor and architects are also important actors. They need to see the potential and benefit of reusing materials to increase the demand.

New materials

The development of new materials that are demountable is necessary for the future. In this way, the materials could be retrieved easily and reused again. There is a massive problem with the materials that are combined together during construction. It is very difficult for the demolition companies to separate them and retrieve them. For this reason, it is essential to develop materials that can be easily deconstructed.

Suppliers take back materials

Another factor that can enhance the reuse potential of components is when the suppliers of specific components take them back when the building is demolished or renovated. The clients can have several agreements with suppliers to take back their components. The suppliers can refurbish the components, upcycle them and put them for reuse. In this way, more materials will be saved and reused, and the circularity of the building and materials will be increased. The suppliers will be motivated to develop components that can be easily dismantled, have better quality, and the cost will not be too high since they will have the ownership of the materials.

Create a cloud for reuse

A cloud can be created that will contain all the materials available for reuse. The components and materials from one demolition project can go to another project. The client that demolish a building and wants to reuse the materials from his demolition he can take the same materials from the cloud but not his own. This is because it is difficult and very time consuming to reuse the materials that come from demolition since most of the time some processing is needed or they will need to be stored until they can be reused on location. When everything is in the cloud, they can deliver a certain quantity of materials and receive the same quantity back, but this will come from another project in order to save time.

6.5 Barriers and opportunities

The interviews were analysed in order to see if the barriers and opportunities mentioned in the literature are identified in practice.

Barriers

Missing building documentation and unknown quality of materials are common barriers mentioned in the literature. This is not considered a barrier anymore since the demolition companies have site visits in order to inspect which materials are in the building, their condition and their quality.

Most of the components are not designed for disassembly. This is a problem that the companies face today. In most of the cases, the materials are combined, and it is difficult to dismantle them without damage. However, there are cases that the materials can be retrieved and reused even though they weren't designed for that. The example of the Superlocal project where they deconstructed a concrete structure that was cast-in situ

proves that it can be done. Another barrier is that the deconstruction and reuse are not highly regulated. The legislation and norms are all based on new materials. The concept of circular buildings and reuse of materials are new, and the government doesn't have any regulation.

The limited separation of material was also mentioned in the literature. In the Netherlands, they need to separate the materials in at least ten waste streams. Some companies separate them into 24 waste streams. The higher the number, the better is for the reuse of the materials.

The uncertainty of demand and supply was also mentioned. To mitigate this barrier, an online marketplace was developed where 13 demolition companies participate and offer their materials. In this way, the supply of a variety of materials can be high, and more demand will be created due to the availability of materials. The prospective buyers which affect the demand might prefer new materials since the quality and aesthetics of the reused materials might not be very pleasing to the new users. However, there are materials that can be refurbished and look more modern, or materials that will not be visible can be reused. Another factor that affects the demand is the architect. The architect cannot design a building from the beginning without considering the existing materials that he will reuse. He must create the design with part of the materials that are available to be harvested from the building.

More time is required for deconstruction, and the clients want the demolition to be fast. This is the reality in demolition projects. Most of the clients want the demolition to be done fast. However, this has started changing. There are some clients that give the time now in order to retrieve materials. Especially in the case of circular demolition and redevelopment with reuse of materials the clients are giving time because their goal is to reuse materials, and this needs more time.

The cost is one of the most important barriers of deconstruction. The low cost of new materials was another factor that was mentioned in the interviews. The materials are cheap, and the clients are most likely to choose new materials when the difference in the price is small. In the case of reuse of structural components, the cost of the tests for their structural ability was mentioned. Those tests cost money however the purchase of new materials also cost money. Both costs need to be taken into account when the decision is made. Another barrier mentioned in the literature was the low disposal cost and taxes. In the Netherlands, most of the materials are not even allowed to be disposed of in landfills and for those that are permitted there are certain costs and taxes. Also, there is a tax for burning the waste. In this way, most of the construction materials are at least recycled if not reused. Cost of transportation and storage is another barrier. All the interviewees mentioned that there are certain costs involved in the transportation and storage of materials that need to be taken into account. The storage of materials is expensive especially when they stay there for long periods of time. The demolition companies are reluctant to take the risk to deconstruct because they are afraid to lose money. Some of them don't invest because there is limited demand or because the profit that they will make is limited. However not all the companies are like that. There are companies that take the risk and take materials for reuse, and they make a profit out of this process.

Lack of cooperation between the parties is another barrier mentioned in the literature. The interviewees indicated that cooperation is essential. In the Superlocal project, the actors were involved from the start, they had a common vision, and they cooperate in order to develop the plans. In this way, they overcame this barrier.

Some other barriers were found during the interviews. A lot of materials are covered with asbestos. The cleaning of asbestos is very expensive, and sometimes it cannot be removed without the materials to be destroyed. Moreover, the salaries of the labour are too high in the Netherlands, and this makes the demolition companies reluctant to adopt deconstruction since more labour is needed. Another barrier that might make the architects reluctant to design with reused components and materials is that the responsibility for the building belongs to the contractor and not the architect. If the contractor doesn't share the same vision of reuse, the architect cannot make the design with reused materials.

The timing that the materials come out of the building is also a problem. They come out in reversed order than the building process, so the finishing, appliances, electrical and mechanical installations etc. come out first. The structural components come out last. When redevelopment happens in the same place, those materials need to be stored somewhere until everything is deconstructed. Also, when the reuse of concrete takes place, this will delay the construction because it is a process that needs time. Time to remake the concrete, and the waiting time that the concrete needs to dry. These factors need to be taken into account since it might delay the process and can cost a lot more money.

Opportunities

However, there are some opportunities in reusing materials. There is a value from the sale of reused materials. For specific materials, the demolition companies can make money, and this is mainly from the sale of steel and wood. Some companies also find profitable to sell other construction components like doors, windows, sanitary etc.

A lot of materials can be reused in redevelopment projects. In this case, it is also possible to reuse structural components like concrete parts and concrete skeleton as they did in the Superlocal project. The demolition company involved see potential in this filed, and they are willing to do it again. The client can develop circular building in this way, and he also has the benefit that he doesn't pay for a lot of the materials he is reusing.

From the interviews, a few new opportunities arise. The fact that the materials are reused can be used as a marketing strategy (materials that can tell a story). By including information about the place they were retrieved the materials might be appealing to some buyers, and this can be used as a marketing strategy.

The concrete structures are very durable and have a long lifetime. They can be reused again. The reuse of concrete seems to be the most promising option among the companies. It is the material with the highest percentage in the buildings that are demolished. The technology that is developed now that can create new concrete form the old concrete will

solve some problems. There is the opportunity for the companies that make construction materials to develop more durable, demountable and circular materials. Companies with circular mindset can work together in order to develop them.

6.6 Concluding results

The interviews were analysed based on the codes of the perceived needed changes that emerged from the literature. In the tender stage sustainability criteria can be used or there should be requirements for reuse. In both cases, the companies need to retrieve materials since they are judged based on that. When sustainability criteria are used, the parties are selected based on a price-quality tender. Both the cost and the sustainability criteria are used to find the best offer . The client should give the freedom to the demolition contractor to take materials for reuse, and he should also consider reusing materials in his projects. They should also provide sufficient time for the deconstruction.

In the audit phase, documentation review is required if they exist. The most important step is the site visits that contain the building and structural survey. From there a detailed inventory should be created that includes all the information about the components and materials, their quality, quantity and condition. The material passport seems to be a useful tool, but the existing buildings don't have it. This will be more useful in the future where the demolition companies can use it in order to do better auditing. For this reason, the material passport will not be included in the new process flowchart.

In the planning stage, risk assessment should be done based on the finding of the audit. The components and materials should find new buyers. The demolition companies should make agreements with buyers from their network of business. When they don't have a buyer, they should offer their components in the online marketplace. There they can make agreements with future buyers before the demolition starts. From the expected profit, they should make their cost calculation. The calculation should be based on the labour needed, the machines, transportation costs, recycling and landfilling cost, allowances and the revenue from the sale. The scheduling and resource optimisation will help to deconstruct the building retrieving the materials on time and budget. A little more labour might be needed however when proper calculations are made the deconstruction is possible. A lot of structural and non-structural components have reuse potential, and the demolition companies need to consider all the suitable materials. The following table presents the components and materials and their reuse potential based on the findings of the interviews. There are some materials that can be reused easily and others that their reuse potential is limited. The concrete that was cast in situ was perceived to have low reuse potential according to the literature. However, based on the findings of the case study the concrete that was cast in situ can be reused when the proper tests are made, and its structural performance is checked. Also, bitumen roofs were perceived to have no reuse potential, but one of the companies retrieve it for reuse. Also, carpet tiles is a material that couldn't be reused according to the literature, but one of the companies retrieved it and sold it easily. This shows that a lot of components and materials can be

reused even if it seems that there is no potential. However, some materials cannot be reused or recycled, and solutions need to be found since they are harmful to the environment.

Table 9: Components and materials and their reuse potential based on the interviews

Low reuse potential (need to find a solution for them)	Medium reuse potential	High reuse potential
Insulation materials	Bricks	Wood
Ceiling panels	Lighting	Steel
Gypsum	Concrete cast in situ	Concrete (material level)
Aerated concrete	Precast concrete	Doors
Plaster	Bitumen (roof)	Windows
Tiles (with cement binding material)	Carpet tiles	Radiators
Concrete bricks		Sinks, Sanitary
		Electrical Installations
		Mechanical Installations
		Fire extinguishers
		Door handles

In the execution, all the materials that are going to be reused need to be removed from the building. This can be done in stages. The components need to be separated into several streams. In this stage, if the new buyer has specific requirements, the materials should be deconstructed according to his requirements. When the materials are removed from the building, the processing that is done by the demolition companies is limited. The components and materials are sold in the state they were retrieved, and only the wood might be de-nailed. The new buyer needs to process the materials further. Material identity can be created in order to track the components. This can be used for marketing purposes too. Then the transportation of the materials takes place, and it is preferred to be done in the area. The materials can be stored if the demolition company has the space. However, it is not desirable for the demolition companies to store them since it cost money. For that reason, the agreements for sale are done from the planning stage in order to avoid storage.

Apart from the process changes, the actors can make some additional changes when circular demolition and reuse of materials is desired. The clients need to consider their portfolio of projects. In this way, they can reuse materials from demolition projects to their new projects, or in renovation and maintenance activities. They should give some extra time for the demolition since they know well in advance when a building is going to be demolished. It is advised that the client hires the demolition company directly and not through a contractor in order to allow them to take materials for reuse. In redevelopment projects, the demolition company should be involved from the start, so they can develop the plans together and take full advantage of the components and materials that are present in the building. When the goal of the client is to reuse materials, he needs to choose parties that share the same vision as him.

Good cooperation between the actors is essential. The demolition companies should have close collaboration with clients to get the projects. They should show the clients the potential of reuse of their material and the benefits that this could have in their project. Also, close collaboration with the contractors, new users, architects and engineers is important in order to promote the reuse of materials and create awareness. They should have good cooperation with everyone in the chain to achieve circular demolition. The demolition companies should invest in training. More labour is needed for deconstruction, and there is a shortage of skilled people. They should invest in their company, in people with circular mindset, in creative people and in skilled labour.

The demolition companies can cooperate and further extend their marketplace. They can create a cloud that the materials can be exchanged. When demolition takes place, the components and materials can be retrieved and go for further processing. In the new development that follows demolition, materials can arrive on the site when needed with the difference that will be from a different project. This will happen because of the time needed for some materials to be processed. With this option, the materials with the same characteristics can be exchanged between projects and in this way, the overall time of the demolition and new construction can be reduced.

The architects need to make an adaptable design in order to fit the reused materials. The architect can develop the design with what materials are available, taking into account what materials the demolition company can retrieve and what materials the building contractor can reuse. New materials need to be created that can be demountable and reusable. The suppliers need to consider taking back their materials, refurbish them and reuse them in a new project. They should create materials that are demountable, durable and reusable.

The responsibility and risk should be transferred from the demolition companies to another actor. In order to achieve circularity, when the materials are removed from the demolition site they should be sold directly to another party. In this way, the demolition contractor will not be afraid to take components and materials for reuse since his risk will be lower. Most of the times the components and materials need some processing in order to be reused. The demolition company cannot perform those activities since it is not part of its operations. For this reason, a new organisation should be involved before the materials can be sold to the end user.

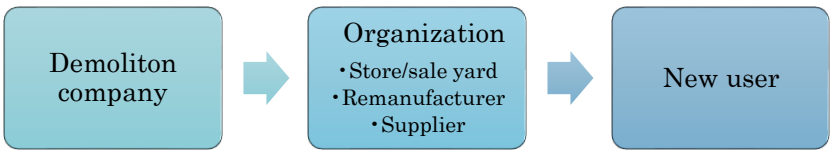

Figure 18: Transfer of risk of the demolition company to another organization

The following table is created based on the finding of the barriers and opportunities. Some of the barriers can be reduced when the actors can take the opportunity that is presented to change the situation, or they can use the proposed ways to reduce them.

Table 10: Barriers of deconstruction and reuse and ways to reduce them

Barrier	Ways to reduce it
Missing building documentation and unknown quality of materials	Site visits and detailed auditing
Lack of regulations	The demolition parties and new users can be creative with the current regulations. The government should take the opportunity to create regulation for circular buildings and reused materials
Limited separation of material	Separate the material in several streams
Architect has restrictions in the design	The architect has the opportunity to explore his creativity by making a design with materials that he has available, changing their function and purpose.
The cost involved with deconstruction and reuse is too high.	The companies can take the opportunity to investigate more their options. They can try to see if they can make a small change and start taking a small number of materials for reuse to see how it will affect their costs and profits. Each company has a different system of calculating so a small change might be possible, and it will contribute to the circular economy.
More time is needed	The demolition companies can make the clients understand the importance of deconstruction in order to convince them to give more time.
Buyers prefer new materials	QR-code, materials that can tell a story. This can be used as a marketing strategy in order to promote them.
Lack of cooperation between the parties	In order to be able to maximize reuse in circular demolition, the parties need to cooperate form the beginning and have a common vision of reuse. If not, the process will not be successful.
Components not designed for disassembly	The producers of the materials and components need to take this opportunity and design them in a way that can be deconstructed and reused.
Uncertainty of demand and supply	The online marketplace can help to balance the demand and supply of the materials.
Timing the materials come out delay the process	The companies can cooperate to create a cloud that they can deliver their materials

	from demolition and take back the same materials for reuse without waiting time from their processing.

6.7 Model adaptations

The analysis of the case study and interviews gave new input and information about the demolition process, the opportunities and barriers. Those were used to develop further the flowchart that was created based on the literature study. In the following paragraphs, a detailed explanation of the flowchart is given indicating the new input. In Figure 19 the flowchart is given. The steps with the green colour in the flowchart indicate the additions from the traditional demolition process to the new process. In Figure 20 the main actors for each step of the demolition process are indicated.

The demolition process starts with the decision of the client to demolish a building. In order to do that he can have a tender process. There he needs to decide what requirements he will have and how he is going to choose the most suitable party. It is highly recommended to have sustainability criteria in the tender or to have requirements for reuse. In this way, the demolition companies can be creative and try to harvest as many materials as possible. Also, it is recommended that the client gives sufficient time for deconstruction since more time is required to harvest the materials.

The client can have the option to do a tender and invite a number of parties to participate or to go directly to a company and ask for an offer. The last option is possible only for private clients since for public clients it is required to have a tender. The parties need to audit and make a demolition plan and submit their offer to the client which he has to choose and award the contract to the best candidate. It is recommended that the client chose not to have a lowest price tender but to have a price-quality tender where sustainability criteria or reuse criteria are used. Retrieving materials for reuse is not always the cheapest option, so the parties should not be judged only based on price.

Additionally, in the case of redevelopment, the client should have separate tenders for the demolition contractor and for the building contractor since building contractors don't enable the retrieval of materials for reuse. When separate tenders are made, the demolition party will not be chosen based on the lowest price, and he can make an offer where he can take materials for reuse. Also, it is essential to involve the demolition party in the design and planning phase of the redevelopment project. He has the knowledge and experience of which materials can be retrieved, in which way etc. When this is done the team will develop the plan and design with the components that are feasible to be reused. Time will be saved, and the reuse of materials will be enhanced.

In the audit phase, the demolition companies should check the documentation of the building to see what they should expect. The most important part is the site visit that follows. There the demolition company should have a building and structural survey. They should check which materials are there, their quantity, quality and condition. The presence of hazardous materials should also be examined. In the end, they should create

an inventory list with all gathered information and specifying the materials that can be reused.

The planning stage follows. The selection of demolition technique is made. It is an important step since the demolition technique will enable or not the reuse of some of the materials. Risk assessment should also take place in order to minimise and mitigate the risks of demolition. The demolition company should offer the materials they have available to buyers from their network. They should also advertise the components in an online marketplace. Based on the estimation of what could be sold the cost estimation can be made deducting the expected revenue from the sale. The scheduling and resource allocation should follow and the creation of the waste management plan. At the end of the planning phase, the demolition plan is created. The demolition companies submit the offer to the client, and the client awards the contract based on the criteria set in advance.

The execution stage follows. At first all the hazardous materials need to be removed from the site if they exist. Then the deconstruction of the non-structural components should follow. All the materials that are deconstructed for reuse should be separated into different streams. Then the next stage of deconstruction should follow until everything that is going to be reused is removed from the building. The remaining structure should be demolished completely or partially demolished for deep renovation. All the materials from demolition should be divided into separate streams.

Then the materials handling follows. There are three options for that, the reuse, recycling and at last the landfilling. There is also the option to send some of the waste to a waste treatment plant where they are burned for energy production. However, this method is not suggested since it is preferred to recycle them at least. The components that are going to be recycled will be sent to the agreed recycling facilities. The materials that should be landfilled should be sent in landfills. The materials that are going to be reused should be given an identity containing information from where they are retrieved and when. This can be done with a QR code. Therefore, the new owner can know where his product came from, and the client can see where his components and materials went.

The first option should be the reuse of the materials. There is the option to reuse on-site or not which is already decided in the planning stage. If the components are not used on the site, they need to be transported to the new location. This can be a new construction project, a storage facility or a second-hand store. Another option is to send them to a remanufacturer. He can take the materials and use them as raw materials in order to upcycle them and make new components out of them, or he can refurbish them and sell them with the same function. The last option is to send them back to the suppliers. The suppliers can take back their materials, refurbish them and use them again.

If the materials are reused in place, they should be stored until they can be reused, or they can be sent to a company for cleaning and refurbishment. When everything is ready, they can be reused in the new project. At the end of the process, the site must be cleaned and returned to the client.

Changes in the flowchart

The new inputs in the model are the possibility to give a project directly to a demolition company which was mentioned in the interviews. To have sustainability criteria or requirements for reuse in the tender which were important points made from the interviews and to chose based on price-quality, not on the lowest price. In the case of redevelopment project, it is essential to involve the demolition contractor from the design phase in order to maximise the reuse potential. Another important factor is to find buyers through the network of business. It was mentioned that this is the most common practice and also it is better for the CO2 since usually the buyers are located in close distances. The creation of materials identity is a good addition since it will give marketing advantage to the materials including information of their origin and destination. In the reuse phase, the materials can go to the supplier, to shops and remanufacturing enterprises. When they are going to be reused in place, they should be stored until their use or sent for cleaning and refurbishment.

Further remarks

The created flowchart concerns the demolition process for buildings in the near future, and it ends when the materials are reused for the first time. The materials that are released during demolition and they are reused get a material identify that contain all the necessary information. In the case that the new building that the secondary materials are used is being demolished there could be a loop in the flowchart. However, this would have complicated the flowchart. In that case, more actors should be included like the architect, engineers and building contractors that are going to reuse that materials for the second time. However, only the demolition process is in the scope of this research, so the loop is not included. Also the second demolition will probably be in minimum 20 years, since most of the buildings have longer lifetimes. With the development of materials passports to the new buildings and the new technologies that emerged it cannot be said that in the long run, this should be the demolition process, so the loop cannot be included.

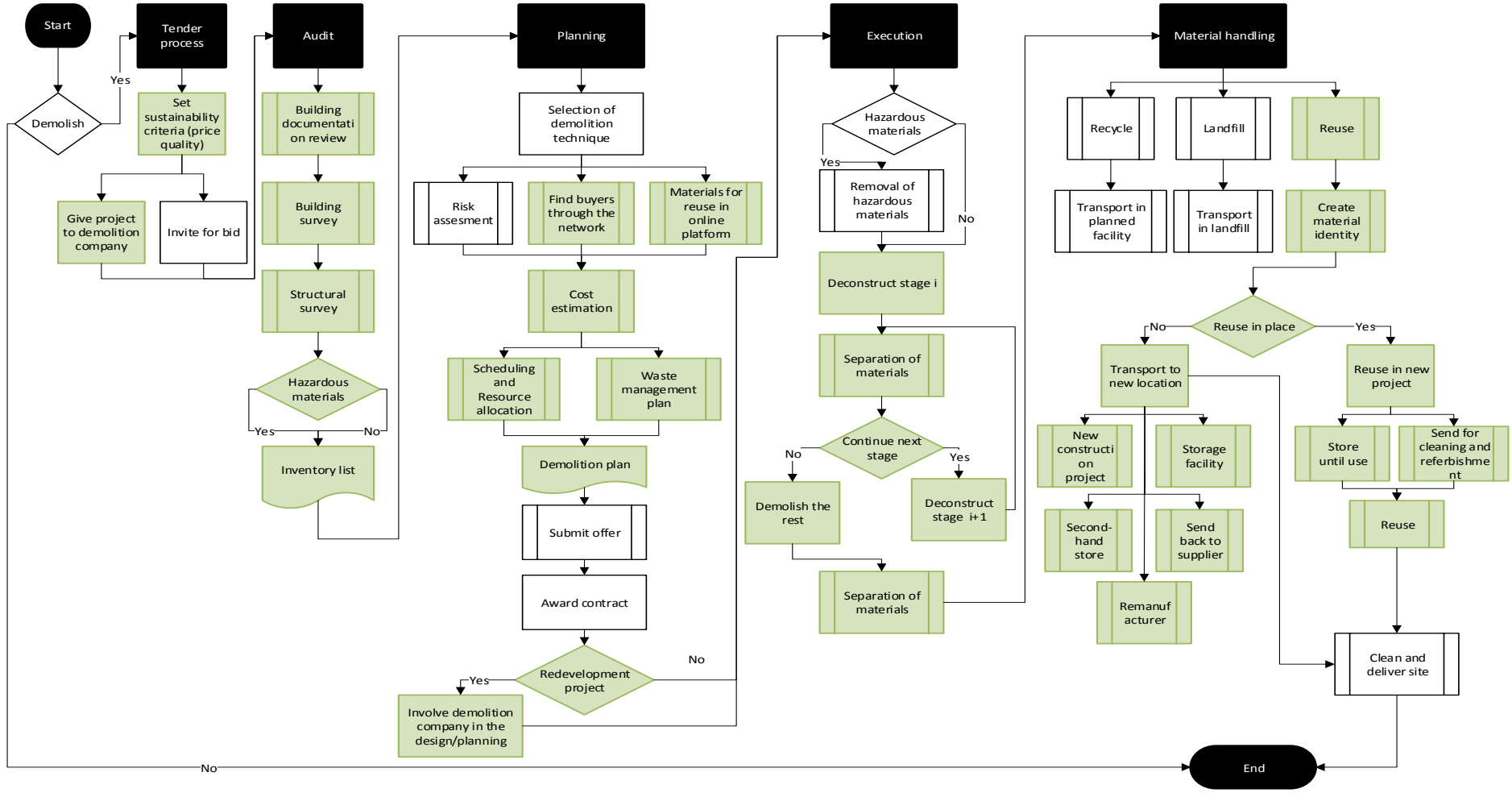

Figure 19: Circular demolition process flowchart

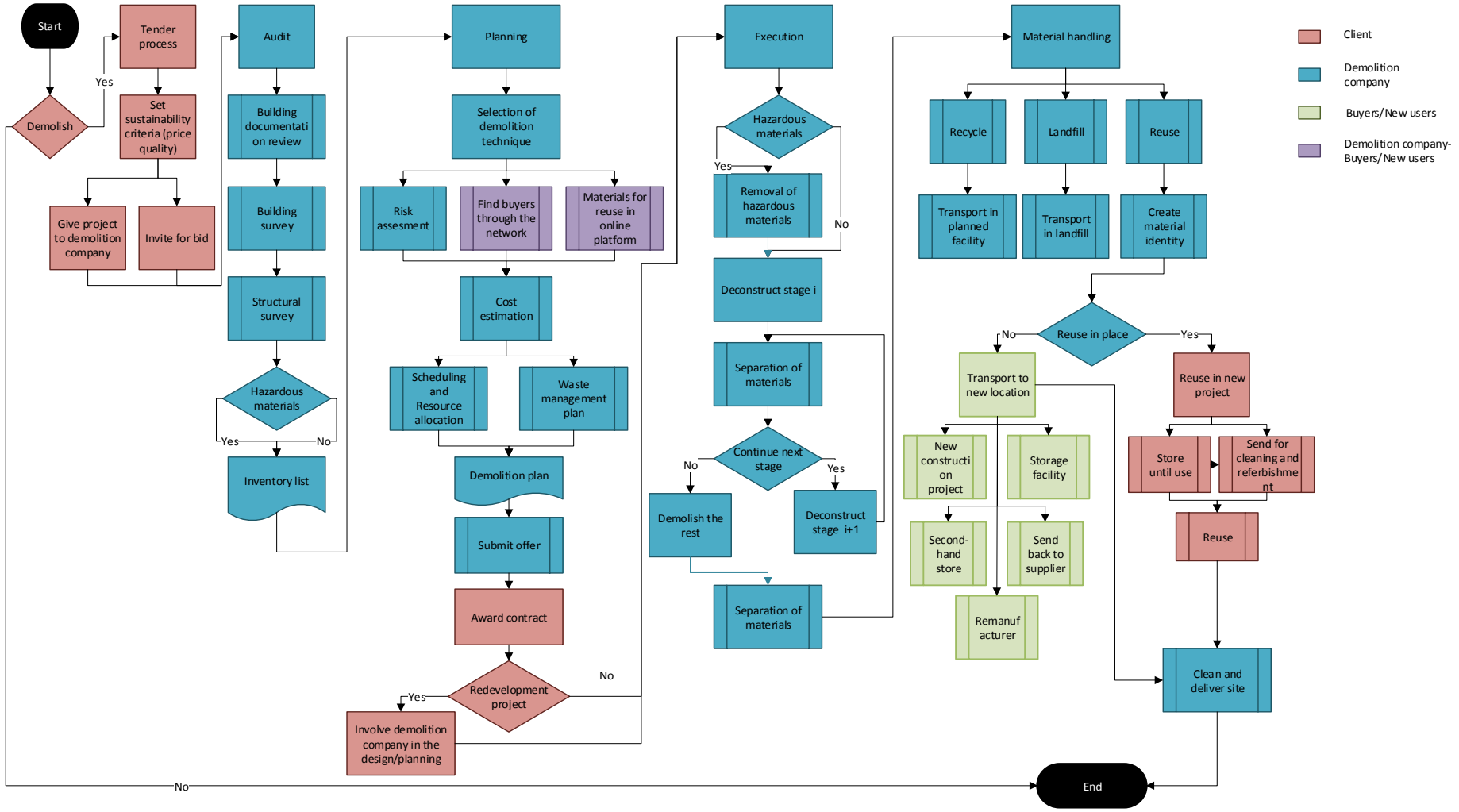

Figure 20: Main actors in each stage of the circular demolition flowchart

6.8 Validation

The demolition process flowchart was developed, and validation was needed in order to see if the created process is realistic and can be applied in practice to some degree. The method that was used to validate the findings of the research is called respondent validation. In this method, the interviewees are requested to validate the results of the research. This method was chosen since the demolition companies that were interviewed are frontrunners, and they have adapted their processes in order to take materials for reuse. They could ensure that the results of this research are valid and can be applied in practice.

The demolition companies that were interviewed were asked to review the process flowchart and its steps. For the validation, only demolition companies were asked to participate since they are the main actor in this process and they are the companies that need to make most of the changes in their process and activities in order to be able to take more materials for reuse from their projects. They gave their feedback through an interview or in writing.

The results of the validation of the process flowchart are the following. The flowchart seems to be feasible. The steps that need to be taken are not very extreme and in some level most of the companies that were asked already follow most of those steps. However, it needs to be noted that the demolition companies that were interviewed are the companies that make an effort to have circular demolition or are working towards that. From the validation, the comments were that the inspection for hazardous materials for some companies is done by external parties and not by them, but this doesn't affect the process. Also, the selection of demolition technique is made as soon the structural survey is completed. They reacted positively to this process since they believe that it will help to take more materials for reuse if those steps are taken by the main actors.

The demolition process flowchart might not be entirely feasible in the short term for the companies that have very traditional demolition processes. From those companies, much more effort is required in order to change their processes. However, the model offers several steps, and if some of them are adopted the companies can still take some materials and components for reuse. For example, the detailed audit can be taken as a starting point, where they can identify what can be reused. They can start by retrieving a few components that can be sold easily, and on a later stage, they can expand their activities.

7. Discussion, Conclusions and Recommendations

7.1 Discussion

The construction industry uses a lot of raw materials and produces a huge amount of waste each year. The waste comes mainly from the demolition sector, where the materials are destroyed in the process and cannot be reused. The problem is that the current demolition process doesn't facilitate the reuse of secondary components and materials that come from demolition. This research intends to mitigate this problem by providing a new demolition process flowchart that will enhance the reuse potential of the retrieved materials and components and provide recommendations to the actors involved. To execute the research, literature study, a case study and expert interviews with frontrunners were used to get all the necessary information. The data were analysed qualitatively, and several findings emerged.

To develop the flowchart, the traditional demolition process is established based on the literature. The steps of the process are analysed in detail in order to see how each step affects the reuse potential of the components. From the findings of the analysis of the data, the new demolition process flowchart is developed. The flowchart contains several steps that the actors can take in order to have circular demolition in their projects. The most significant changes are that the clients should include sustainability criteria in the tender in order to have a price-quality tender and they also need to give more time for the deconstruction. They should consider reusing materials in their redevelopment projects and in this case the demolition contractor needs to be involved from the beginning.

The demolition companies need to make some changes in their processes. They need to perform detailed audits and create an inventory list in order to see which materials can be reused, their quality, quantity and condition. To make a profit, they need to arrange the sale of the materials from the planning stage. To do that they need to create a network of business to sell their materials. If they don't find any buyers there, they need to advertise their components and materials in an online platform where anyone can access and purchase the components and materials. Based on the materials that can be sold the cost estimation can be done by deducting the revenue from the sale. The cost is highly depended on the labour productivity, the time spend on the site, the resource needed, the revenue from the sale, the disposal and recycling costs. Also, a waste management plan should be created containing all the information on how the materials and components of the demolition will be handled and where they will be sent.

The execution of the demolition should be done in stages until everything that can be reused come out of the building. This is decided in the planning stage, based on the calculations of the company of what is feasible regarding the time given by the client and the cost. All the materials should be separated into several streams. The materials can be reused in place, or they can go to a new construction project, in storage, in a second-hand store, in a remanufacturer or send back to the supplier. By making arrangements for the sale before the demolition starts the demolition company transfers the risk to the buyer.

In the case that the materials are sold to a second-hand store, a remanufacturer or a supplier they are responsible for further processing the materials and the final sale to the new user.

Apart from the demolition process changes, the actors can also take some action that will enhance the reuse of construction materials. The findings of the research in this area indicate, that the clients should consider their portfolio of projects to circulate their materials from the demolition project to their other buildings, in their renovation and maintenance activities. The demolition companies should show the clients the benefits and potential of reuse of components, in order to motivate them to adopt it in their projects. The demolition companies can also invest in their companies to change their processes to circular demolition. They can invest in people that have a circular mindset in order to help them make the change. They can invest in experienced labour and in training of people that will help them deconstruct the projects more efficiently. Awareness needs to be created to the actors that are involved to enable the reuse of materials. The close collaboration of the actors is crucial in order to have circular demolition and reuse of materials. All the actors in the supply chain need to cooperate in order to be able to circulate the materials in the construction sector. New materials need to be created that can be easily demountable. The producers of the construction materials can take the opportunity and adapt the products in order to be demountable. The suppliers can take back their components when the building is demolished and prepare and provide them for reuse in another project. Another finding that might solve some of the problems is the creation of an internet network (could) for reused materials. This will help to solve the timing problems of the projects. The overall time of demolition and redevelopment can be decreased with the use of this concept, and this will enable more circular demolition and redevelopment projects to be realised.

The case study was used due to its innovative character. The most important finding is that concrete components and compartments can be reused even if they were cast in situ. Until now it was believed that this was impossible. Concrete buildings have a long lifetime, and they can be reused again when their quality is checked through several tests. Another important input from the case study is that the timing the materials come out of the building is a problem since the materials needed first for reuse come out last, and this can delay the project and expensive storage might be required for the rest of the materials. This is a problem especially in the case that new concrete will be created form the concrete of the demolished structure. It is very time-consuming to wait until the new concrete parts can be created. A solution to that might be the cloud that was mentioned earlier.

In the literature, a lot of barriers were found for the deconstruction and reuse of materials. Based on the findings of the interviews some of them can be mitigated when actors make some changes. The missing building documentation and the unknown quality can be solved with site visits, detailed audit and testing. The cost involved is a big barrier. However, when the company makes the proper calculations taking into account the revenue from the sale, the retrieval of materials for reuse is possible. The time needed for deconstruction is another barrier. However, the demolition companies can convince the client to give more time. The online marketplace can mitigate the uncertainty of demand

and supply. Having an online marketplace with high supply is important in order to create the demand that is needed. Those are some of the barrier and ways to mitigate them. The developed flowchart will also help to mitigate some of them.

Contributions of this research

The demolition process is not widely researched. Only a few articles talk about the demolition process and this only concerns the traditional process where most of the materials are recycled or landfilled. Circular demolition and reuse of materials is a relatively new concept. Still in a lot of countries the materials from demolition are landfilled or in the best case recycled. The Netherlands is one of the EU countries that has the highest recycling rates, but this is not enough. Reuse is the best option, and more work is needed towards that. There is the need for a new demolition process that can help to change the situation. The components and materials should be reused and not recycled. In order to enhance the retrieval of components and materials from the demolition sites, the new process is needed. With the use of the new process and the recommendations, the actors can change their processes and start taking component and materials for reuse.

The flowchart can be useful in the Netherlands, for the demolition companies that recycle most of the demolition materials. It could help them to change that, and start retrieving materials for reuse and only the materials that cannot be reused they will be recycled. Also, the clients can use some of the recommendations in their projects in order to enable circular demolition. It can also be used by other countries (EU/non-EU) that are new to this concept and until now most of their construction waste were landfilled. Since the flowchart had as a base the traditional demolition process the countries that still use it, can make the change by applying the steps of the flowchart in order to retrieve materials for reuse and minimize the waste they send to landfills.

There is the need for this flowchart. In the coming years, the demolition process as it is today will no longer be applicable. With the notion of circular economy, the clients will request the retrieval of materials and components from their projects. This flowchart will help the demolition companies to adapt their processes to be able to start retrieving materials and component for reuse. Even if they don't follow all the steps, they can work towards the change. Implementing some of the steps is also possible since it will help them to start changing their processes towards circular demolition. They can start by retrieving a few materials and components in order to see what is feasible for their company and then expand their activities to more materials.

Limitations of the research

The research has some limitations. Circular demolition is a new topic and is not widely researched. The literature found was based on traditional demolition process. The results of the research were based on the existing literature and the input from the current best practices from frontrunners in the Netherlands. In order to examine the practice, a case study and expert interviews were used. Only a few projects exist that were demolished and redeveloped with the reused materials and only from one case was possible to get

data. However, this case is the most innovative case until now, where they reuse components on a large scale, so it is considered that it gave valuable input. The project that was used is still in development. It will have been more useful to have a project that was completed since the views of the actors might have been different, but this was not possible. Another limitation was that the number of the interviewed parties was limited. The goal of the research was to develop a demolition process that enhances the reuse of construction materials. In the Netherlands, some demolition companies started taking materials for reuse. However, the number of companies is small, and some of them weren't available to give an interview. Also, the reuse of materials is a new concept, and not a lot of clients exist that have experience with demolition and reuse of materials. Ideally, more people would have been interviewed however it is believed that with the gathered data valid recommendations were made. Preferably, more actors would have been interviewed that belong to the new users. But since this research it is conducted in a specific timeframe this was not possible. The scope of the research regarded demolition projects that redevelopment will take place after the demolition. This affects the perception of the clients in terms of reuse and circular demolition. In the case that the client only wants to demolish the results might have been a little different.

7.2 Conclusions

Demolition is the last phase of a building's life where a lot of waste is produced. This waste can contain useful components and materials that if they are retrieved correctly can be reused in other places more than one time and their value will not be lost. In this way, landfilling and recycling can be reduced. To allow the materials to be retrieved and reused, the current demolition process needs to change. In order to reduce the problem, the following research question was used in this research. *"How could the demolition process in the building industry be adjusted in order to enhance the reuse potential of the building components and materials?"*

To answer this question, the sub-questions needed first to be answered. At first, the steps of the traditional demolition process were established based on international literature. The various researchers had a different perception of the stages of the demolition. Based on their input the main steps of the demolition process that were used in this research were determined. Those are the tender stage, the audit, planning, execution and material handling. The traditional demolition process is simple with a few steps. Not a lot of attention is given in the planning and the waste management, and the reuse of materials is minimum. In order to change that all the steps of the demolition process needed to be examined in order to see how they affect the reuse potential of the components and materials.

In the tender stage, the client plays an important role since he makes the decisions and sets the requirements. Those decisions affect the reuse potential of the materials since he can enable their retrieval or not. In the audit stage, the materials and components that can be reused are identified. It is essential that the demolition company takes the necessary actions to identify all the components and materials that can be reused from

the building. In the planning, the decision of the demolition technique plays an important role since it can be destructive or not for the materials of the building. Cost calculations are very important since the demolition companies need to have a profit in order to take materials for reuse, otherwise, they will not do it. In the calculation, the profit from the sale is deducted from the cost in order to calculate the final cost of demolition. To sell the materials, the demolition companies can advertise them in an online marketplace or sell them through their network of business. When the demolition companies can sell the materials they are enabled to take more material for reuse. Scheduling and resource optimisation can also enable the reuse since time and resources can be given or not for the proper deconstruction of the components. In the execution stage, the deconstruction of materials needs to take place. If the materials are not deconstructed properly before the actual demolition, they are going to be destroyed in the processes. When they are deconstructed they need to be separated into different materials streams. The components and materials retrieved from demolition can be reused, recycled, send to incineration or landfill. When reuse of the materials is desired, they need to be recovered properly and transported to a new location or stored.

There are several barriers and opportunities involved in the deconstruction and reuse of construction components and materials that need to be identified. Technical barriers such as missing building documentation, unknown quality of materials, components not designed for disassembly, and the unknown structural ability of components. Economic barriers such as the low cost of new materials, the high cost of sorting on site, logistic costs, uncertainty in demand and supply and low disposal cost. There are organisational barriers which are the lack of regulation regarding deconstruction and reuse, the lack of cooperation between the parties and lack of awareness of supply sources. However, there are some opportunities. There is a value from the reclaimed components, they can be reused in their intended function or another function, the use of BIM and materials passport will help in easier identification and retrieval, new business can be created, creativity can be used for their reuse, job training and new job opportunities can be created.

To answer the last two sub-questions input from the practise was needed. For that, a case study and expert interviews with frontrunners were used. The actors with their actions and decisions can affect the reuse potential of the components and materials. The client sets the criteria and the requirements and makes the decisions in the tender stage. When he put sustainability criteria in the tender or set requirements for reuse he can enable the demolition companies to retrieve materials from his project. In this way, the tender becomes a price-quality tender and not lowest price tender which allows the demolition companies to take more materials for reuse. He sets the timeframe of the demolition. When he gives extra time, the demolition companies can retrieve more materials for reuse. He can also provide the freedom to the demolition company to take materials for reuse, and he can consider reusing materials in his project. When he makes those actions, he can enable the retrieval and reuse of materials from his project.

The demolition company is the most important actor. They make all the decisions and arrangements for the project after the contract is awarded. The demolition technique, the prior planning for the sale of the components, the cost estimation and resource allocation they make, the way they deconstruct the materials and components, are crucial for the future of the materials. The new users need to be able to use the components they buy in

the state they purchase them or after further processing. They can get the materials they desire when they set their requirements in advance. For this research, the client could also be considered as a new user since he could reuse the materials in a construction project.

In the demolition process changes needed to be made at each stage. The tender stage should include sustainability criteria, requirements for reuse and it should be a price-quality tender. The audit should consist of building and structural survey based on site visits and creation of inventory list. The planning should include a non-destructive demolition technique, agreements with buyers through the network or online marketplace, cost estimation, scheduling and resource allocation, waste management plan and demolition plan. In the execution stage, all the materials that will be reused need to be deconstructed first, and then the normal demolition should follow. Material identity can be created for the reused materials. They can be reused on site after cleaning and refurbishment or directly. If they are not used on the site, they can be sent to a new construction project, in a storage facility, in a second-hand store, to a remanufacturer or they can go back to the supplier.

Those are the main additions and changes of the traditional demolition process that will help to enhance the reuse potential of the materials. It is essential to make those changes in order to have circular demolition and retrieve more materials for reuse. In the coming years, the traditional demolition process will be abandoned because of its destructive character. The regulations and clients will require the circular demolition where the materials will have to be retrieved.

7.3 Recommendations

7.3.1 Recommendations to the actors

To enhance the reuse potential of construction materials, an effort needs to be made by all the actors involved. The demolition companies who is the lead actor cannot do it alone. An effort needs to be made by the rest of the actors. In this way, more materials could be retrieved from demolition projects and be reused.

Recommendations for the clients

First of all, the clients should consider demolishing circularly and reusing materials in their new projects. To do that they need to give sufficient time to the companies to retrieve the components and materials. They should put sustainability criteria in the tender or requirements for reuse. Also, they should not award the contract to the lowest offer, but they should have a price-quality tender. In the case that the clients don't want to reuse materials in their projects, they should allow the demolition party to retrieve them and sell them to a third party. When the client plans to demolish and redevelop a project, he should involve the demolition party from the beginning before the planning, and the design is finalised. In this way, the demolition party can use his knowledge and experience to help the client to reuse as many materials as possible in creative ways. Moreover, the

client should consider giving more time since there is a balance on the extra time given and the cost that he will save from not buying new materials for his project and reusing his own. The clients that own a lot of properties they should consider their portfolio of projects in order to see if and where they can reuse materials from one project to another. They should also consider the option to purchase reused materials for their maintenance and renovation activities.

Recommendations to the demolition companies

The demolition companies should try to take more materials for reuse. There is reuse potential in a lot of materials. They need to make the clients understand the benefits of circular demolition and reuse of materials and they should convince them to give more time. The demolition company can have close collaboration with clients in order to get the projects. In the demolition process, they need to perform detailed audits in the buildings. They need to make site visits and to see the condition of the building and the materials and from there to create an inventory of the materials, including which materials can be reused, their condition, quality and quantity. They should choose a demolition technique that is not-destructive for the materials that are going to be reused. In order to increase the sales of reuse materials, they need to find buyers for the materials through their network of business. They can also advertise their components in an online marketplace before the demolition starts giving details of the quality, location and availability date of the materials. When the agreements are made at the planning stage, the demolition companies transfer the risk to the buyer, and they don't need to store the components and materials. The demolition companies that are new to this concept can start with retrieving specific materials and try to sell them. In this way, they can experiment with what is possible for their company and try to make the change in phases.

In the planning phase, the cost calculations are made. The demolition company should make the calculation taking into account the revenue from the sale of the components. Better cost calculation including resource optimisation can help the demolition companies to take some materials for reuse.

In the execution phase, they need to start removing first everything that is going to be reused. Labour is required in order to remove everything from the building before it is demolished. The difference it is the way the labour deconstructs the components and materials. They need to deconstruct them carefully and separate them in different streams. They should try to have as many streams as possible.

The demolition companies can also invest in people. They can hire people with a circular mindset in order to help them change their processes. They can also invest in people with experience in deconstruction. In this way, they can reduce the time that they need to deconstruct the materials and create more efficient processes. They can also invest in training new labour. For deconstruction, more labour is needed, and it is a good opportunity to train them now since in the future will be a shortage of labour.

It is also important to cooperate with other companies and actors in the supply chain. Making agreements with several parties to sell the materials to them will be very beneficial. The demolition companies should try to expand their network of business and

find new parties to cooperate. In the Netherlands they can cooperate with concrete producers and they can provide the concrete for reuse since 5% of the produced new concrete need to come from reused concrete. They also can try to sell their materials in stores that sell second-hand materials, remanufacturing enterprises, to sell them back to the suppliers or contractors. It is also important to find parties that share the same vision of reusing materials and cooperate with them. The companies should also cooperate in order to find solutions for the materials that are difficult to be reused or recycled and are harmful to the environment.

The demolition companies can cooperate and expand their online marketplace so that more actors can join. In this way, the supply will be high, and it will increase the demand. The demolition companies can also cooperate among themselves and create an online network (could) that the materials can be exchanged. When demolition takes place, the components and materials can be retrieved and go for further processing. In the new development that follows demolition materials can arrive on the site when needed. However, those materials will probably come from a different project. This will happen because of the time needed for some materials to be processed. With this option, the materials with the same characteristics can be exchanged between projects and in this way, the overall time of the demolition and new construction can be reduced.

The demolition as it is happening today it will change. In the future, the way the buildings are being built will change. Circular buildings will be developed, and there will be demand for deconstruction instead of demolition. The government policies will require deconstruction instead of demolition where the materials can be reused. The demolition companies need to start thinking about the future. This method might seem expensive now, and time-consuming but in the long term it will be very beneficial for their company if they start doing the change now. In a few years, the market will demand circular demolition, and the companies that can deliver that will have a competitive advantage.

Recommendations to the government

The government should create regulation regarding circular demolition, circular building and reuse of material. There are a lot of gaps in the current regulations since all the regulations concern only the use of new materials. They should develop regulations that will enable the reuse of components and materials.

The government can also develop programs in order to train unskilled labour to learn how to deconstruct in order to retrive more materials. In this way, new labour will be created that will be available to get hired by the demolition companies that want to adopt deconstruction. If more companies adopt deconstruction, there will be a need for more workers. In this way, the government can create more job opportunities for unskilled labour.

Recommendations for the other actors

Real marketplaces/stores can be created that sell reused components. The marketplaces can make deals with demolition contractors to buy their materials and resell them

through the stores. In order to increase the value of the components, the owners can refurbish the components, upgrade their quality and make them look nice. In this way, the possibilities that the materials will be sold will be increased. Their story and identity can also be used as a marketing opportunity.

Suppliers should consider taking back their components and materials after the demolition. They can use them to make new components or refurbish them and give them another chance for use. Also, they need to consider developing their new components to be demountable, have high quality and low cost. In this way, their materials could be used more than one time. It is an opportunity to start doing this now because in the coming years the market will demand those materials.

Manufacturing companies can also take materials for reuse and use them as raw materials for their production. For example, reused wood can be used for the production of new components. Also, there is the opportunity and take materials and upcycle them and give them a new function. For example, wood from demolition can be used to make new furniture, floors, windows etc.

Individuals that make small maintenance activities in their homes or small renovations they should consider purchasing reused components. A lot of the times they can find reused components that have unique characteristics that will upgrade their space and sometimes reused components are cheaper than new materials.

The architects should not be afraid to use reused components into their designs. It will give them the opportunity to explore their creativity and create something new giving new life to a reused component. However, they need to take into account that they need to develop their design with the available materials for reuse.

The contractors should consider purchasing or reusing secondary components and materials in their buildings. They can do that for materials that they know that meet the quality standards. Even if they cannot reuse components they should consider reusing materials such as wood or concrete. The reuse of concrete is something that is promising, and they should consider reusing it from demolition projects to the new projects.

New ways of building are needed so the buildings can be easily deconstructed. The current buildings are not designed to be dismantled. The new buildings and material should be designed for disassembly. In this way deconstruction and the reuse of materials would be easier. It is recommended that the new buildings that are developed now should have a material passport. In this way, in the future, it can be used for the renovation and demolition activities of the buildings, and it will enable the reuse of the components and materials it contains.

7.3.2 Recommendation for further research

Circular demolition is a new topic, and there are a lot of possibilities for further research. A more detailed research regarding the cost and time of circular demolition will be beneficial. Time and costs are the most important barriers that don't allow the actors to take materials for reuse. An in-depth investigation of this field is required. An economic

model can be developed that optimises cost, time, resources, materials retrieved, schedules etc. in order to maximise the retravel of reused materials.

Another option is to expand this research and focus on what happens to the components and materials after they are deconstructed. This research indicated the potential buyers of the materials. However, more in-depth research in this area is needed. By having the perception of the new buyers some recommendation might be different. Also, research can be done regarding specific materials. Each material has different actors that affect its reusability. A closer look can be given to materials that are not widely reused now, but they have the opportunity.

Another research topic could be on how the government can put regulations in place regarding the circular demolition and reuse of materials taking into account all the actors. The regulation should enable the circular demolition and should not put more restriction on the use of secondary materials.

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Appendix

The questions for the interviews are given. There are the questions for the case study, the question for the client and the questions for the demolition companies.

Questions for Superlocal

For Project manager (client)

1. What is your main role in this project?
2. In the tender process, what were the requirements and criteria for awarding the contract?
3. What actors did you involve from the beginning?
4. Auditing was performed to assess the quality and the condition of the building, the building components and materials. Was it performed in the three building blocks? At what phase of the project it was done? Was it performed by the selected demolition company or another company? Where any challenges there?
5. The reuse of components in this scale has a lot of risks. How are you handling them and who is responsible?
6. What were the main components released during the demolition? How did you handle them? Did you reuse them immediately or there was need for transport and storage in another location?
7. During the demolition, a lot of components and materials are realised. In order to reuse them some of them will need refurbishing or maintenance. Do you cooperate with companies that specialised in specific materials for the refurbishing?
8. Do you cooperate with other suppliers or recyclers?
9. Are you planning to distribute the materials that will not be used in the project in another project in the area?
10. What was the most challenging to deconstruct? What materials could not be reused in element level and need to be reused as raw materials and how are you planning to reuse them? (ex. Bad quality wood)
11. For the reuse as raw materials do you cooperate with other parties in the industry?
12. In the report, there were recommendations for reuse as raw materials, such as tiles because it was unknown how their quality would be if they are removed? Did you try to remove them and use them as elements?
13. Do you phase any problems because there is a lack of regulation and guidelines regarding the deconstruction and reuse of materials?
14. Are time and increased cost reasons that you will reuse as raw materials instead as elements?
15. How do you deal with the fact that the structure was not designed for disassembly?
16. What did you learn from the demolition and the development of the expo building? What are the plans for the 4 houses and further development?

17. The design of the buildings will be flexible in order to allow the reuse of the components that are available, or you modify the component to fit in the design?

For Demolition company

1. How did you got the idea to deconstruct the whole concrete part? Is this the first time that you do it?
2. Was it helpful that the client based the tender on the vision for reuse?
3. In how many streams do you separate the components and materials?
4. What were the lessons learned from the demolition?
5. Do you think this method cost more money? Are you willing to do it again?
6. Did you do any testing for the structural components. Is it expensive?
7. Did you cooperate with the architect and engineers?
8. Did you try to deconstrut bricks?

Interview questions for demolition companies

1. How do you get your projects? Do you bid on projects or you have close cooperation with contractors or clients and you directly do the job?
2. What is your opinion about taking components and materials for reuse from your projects?
3. When creating the planning do you consider taking component for reuse?
4. Do you audit the project in order to create an inventory of materials, components?
5. In the planning phase do you make arrangements for how you are going to handle the materials?
6. Do you cooperate with specific people to sell the components and materials (a network of business)?
7. Where do you send the materials?
8. Do you separate them in waste streams?
9. If it is not required by the client do you take the initiative to take materials for reuse?
10. Do you think that having material passport will help the demolition process and allow more components to be released for reuse?
11. Time and cost are factors that affect the reuse potential of the materials. Do you give that time or the clients are willing to give the extra time needed?
12. What is your experience concerning the costs of circular demolition? Is it profitable for you or not?
13. Do you think that you can take more materials for reuse but the cost and time don't allow you?
14. Do you think that the existence of a marketplace will help the situation and motivate you to take more materials for reuse?
15. How do you process the materials and components after you take them out of the building?
16. Do you store them or transfer them directly?
17. Are the uncertainties in demand a factor that you don't take more materials for reuses?
18. How do you handle the risks in the case of unexpected events? Do you have allowances?

19. Do you do soft-stripping, meaning taking everything out and leave only the skeleton to demolish? And if yes what do you do with those materials? Deconstruct them carefully or not?
20. Do you think advertising the materials in the planning stage would help in order to find new buyers and motivate you to take them out?
21. Will you clean and refurbish materials in order to sell them for reuse, or sell them like that?
22. Would you invest in training in order to increase the deconstruction?
23. There are evidence that selling components for reuse is profitable? Is this the case in your company or not?
24. The structural components need to meet the requirements of the client, engineers and architects? Are you willing to dismantle them in a way that the components meet the requirements?
25. When you bid for a project what is the process that you follow as a company?
26. The demolition technique that you use is the same in every project or the characteristics of the building affect that? What is commonly used?
27. Do you do test prior demolition regarding hazardous materials, structural conditions?
28. What do you think needs to change in the demolition process in order to get more materials for reuse?

Questions for the client

1. When and why you make the decision to demolish?
2. How do you give the project for demolition? Do you use tenders or directly you go to a demolition company?
3. Do you develop close collaboration with demolition companies for future projects?
4. What are your requirements as a client for the demolition party?
5. Do you put sustainability criteria in the tender? And in which base do you choose (lowest price, best value etc)
6. Are you willing to give extra time or money in order to have circular demolition?
7. Are you willing to give the freedom to the demolisher to take materials for reuse if he wants to or you prefer to have strict requirements regarding his techniques etc?
8. Are you willing to take the risk of deconstruction and reuse of materials?
9. Materials can be reused in component level and in material level. In terms of circular economy, components are preferred. What are your views on that?
10. Are you willing to circularly demolish a building, harvest components and materials and reuse them in a new development?
11. You are planning to do that in one of your projects? How did you develop it? With what parties did you cooperate? What are your goals? And what did you learn so far?
12. How are you going to handle the fact that some component might be difficult to be reused because of regulations? And also, how are you going to handle the fact that there are no regulations for reused materials?
13. Did you had a contractor and he is going to hire the demolition party?
14. What components are willing to reuse? Do you consider reusing structural components too? (like concrete columns, steel beams, wood etc)

15. When you are planning to reuse materials in a new development this affects the design. The design needs to be developed based on what it is available. What are your views on that?
16. Do you believe that having one demolition company to handle all your projects it is better for you since you develop close collaboration?
17. As the owner company of a lot of dwellings, did you consider purchasing reused components to put in your properties during maintenance and renovation?
18. If not, is a cost, quality, appearance factors that affect this decision? What are your criteria for reuse?
19. The quality of the reused components is sometimes lower than the new and their residual lifespan. Are you willing to buy them only if the price is lower than the new?
20. Do you cooperate with specific suppliers/contractors for that?
21. A lot of times some components can only be reused in renovation projects due to regulations. For example, the doors that come from demolition cannot be reused in a new development since they don't comply with the height regulation. Do you consider reusing them in your existing projects?
22. Do you think if you put reused components in a building will affect the opinion and reactions of the residents?
23. What do you think needs to change in order to reuse more component and materials in the buildings?