

The “Donor Skelet”

Designing with reused structural
concrete elements

Master thesis by Alexandros Glias

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Designing with reused structural concrete elements

Msc Graduation Thesis

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December 2013

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PREFACE

This thesis is the result of eleven months of detailed investigations and it states the end of my post-graduate studies in Civil Engineering at TU Delft. The goal of “Donor Skelet” is to research the reuse of existing structural concrete elements on feasibility level. In order to reach the final result it was important to analyze the whole reuse process. This was made possible with combination of extensive literature research, discussions with experienced professionals with different specialties and finally a detailed analysis of a case study. Working on “Donor Skelet” was an intriguing process with very positive results and helped me to use and further expand my knowledge on civil engineering subjects.

This report is the outcome of close collaboration with many people. First, I would like to thank all the colleagues in IMd Raadgevende Ingenieurs for the friendly working environment and their support until the last day. Especially I would like to thank Pim Peters for being my mentor and inspiring me with his endless energy and passion.

Furthermore, I would like to thank my professors A.Q.C. van der Horst and Michiel Haas for their continuous guidance and encouragement. Their questions, comments and suggestions for further research were beneficial in order to find my way to the end. Additionally, I would like to thank the last but not least member of my graduation committee Sander Pasterkamp for our fruitful discussions and his great interest from the first moment.

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Moreover, I would like to thank all my friends for their support and understanding during the whole thesis.

Finally I would like to thank my family for being my A and Ω in my whole life. Their continuous encouragement and advices are priceless.

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ABSTRACT

The goal of this thesis is to research the feasibility level of reusing existing structural concrete elements. Nowadays, a major problem that the Dutch building industry is facing is the high vacancy rate of office buildings. The available solutions for the vacant offices are transformation or demolition. Transformation is the best solution but it is not always possible due to the high costs. On the other hand demolition leads to a big pile of concrete debris which can be processed and recycled. It is a sustainable solution but it still demands a lot of energy. Another issue that is caused from the building industry is that the manufacture of new elements leads to the depletion of raw materials and increases global warming. It is possible to further reduce the energy used for recycle and minimize the environmental impacts of producing new elements by reusing existing elements. Furthermore it is a smart solution since the technical lifetime of a concrete element is approximately 200 years.

In order to identify the technical obstacles of reusing structural elements the whole reuse process was analyzed. The analysis was made with extended literature research, discussions with experienced professionals with different specialties and final with a detailed analysis of a case study. The basic actions are described below:

Inventory: In order to consider if an existing building is suitable for deconstruction it is important to examine the old drawings. The criteria are the structural system, the amount of elements and the deconstruction costs. As long as it is decided that a building is suitable for deconstruction, all the structural elements and their properties have to be recorded in an inventory.

Quality check: Before reusing the elements it is important to examine their condition and if the building is constructed according to the existing drawings. This can be done with inspection of the existing drawings, with visual inspection of the building and with existing testing methods. The results of this step, together with the building inventory create the Element Identity (EID) of each element. It is a certificate that proves that an element is suitable for reuse.

Deconstruction: In order to remove the elements from a building it has to be deconstructed. The disadvantage is that the existing buildings are not meant to be deconstructed and at the moment it is not preferred due to high risks and costs. The deconstruction of a building demands detailed planning and extra attention in order to remove the elements safely and with the less damage. There are different ways to remove an element and the criteria to choose the most proper way are the costs and the loss of structural mass. Deconstruction is the process with the highest costs and environmental impacts.

Modification: After removing the elements from the building they have to be modified in order to be reused in a new construction. The elements were reconnected with existing connections use for prefabricated elements. Furthermore, it might be needed to saw the element on size in order to fit in the new design.

Storage: According to the Decision Analysis matrix that was applied, the most appropriate solution is to keep the building intact and deconstruct it only when there is a new project. It is possible to deconstruct the building and store the elements only when it is facing structural vacancy, the value of the building is depreciated and there is an existing market for reused elements.

Transportation: Transportation is the process that influences the environmental impacts. It is suggested reusing the elements in a project in the same area with the deconstruction site in order to minimize the distances.

Construction: The construction process of the reused elements is the same as with new elements.

The previously mentioned actions determine the reuse percentage, the total costs and the environmental impacts. In order to calculate these factors a case study was performed. Two office buildings from Amstel III were used in order to reuse their structural elements and design houses for the area. The buildings were chosen based on their deconstruction ability.

The reuse percentage of the total structural mass of the elements is 64%. This is due to the deconstruction method that was used, the new connection and the sawing to size of the elements. A structural assessment of the elements according to the requirements of the Eurocode was performed in order to reassure that the elements are suitable for reuse. The results of the structural assessment showed that the reuse of the elements is feasible.

The costs of the reuse process are the deconstruction, the modification, the storage, the transportation and the construction. It is calculated that the total construction costs of the houses build with reused elements are 10% less compared to new elements with the same dimensions. It is possible to further reduce the costs when extra experience is gained.

In order to calculate the environmental impacts a LCA was performed. The reused elements of the buildings in Amstel III were compared with new elements that contain 100% recycled concrete aggregates. The system boundaries of the reused elements are the deconstruction, the modification and the transportation while the system boundaries of the new elements are the extraction of raw materials, the manufacture and the transportation. The results of the LCA showed that the environmental impact of the houses with reused elements is reduced 75%. These results demonstrate the big advantage of reusing structural elements.

The main conclusion is that the reuse of existing structural concrete elements is technically feasible and it leads to lower costs and environmental impacts compared to new elements. Besides these, it can be considered as an extra solution for vacant office buildings. These results are positive and encouraging in order to further research the reuse potentials and realize a pilot project with reused elements in the foreseeable future.

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CHAPTER 1

INTRODUCTION

In this introductory chapter the framework of this graduation project is presented. The motivation for choosing this subject will be explained, followed by a formulation of the problem. Then the research objective is stated together with the research questions. At the end of the chapter the methodology that was used is presented.

Planet earth is not considered invulnerable anymore. The modern lifestyle of the developed countries which promotes the careless use of fossil fuels and raw materials has led to a climate change that cannot be ignored. In order to reverse this situation and before the consequences become detrimental, environmental awareness must grow in the society. Governments, companies, scientists and citizens must take the appropriate measures to protect the environment.

1.1. MOTIVATION

Global warming is one of the most important environmental issues. It is the result of the increased concentration of greenhouse gas emissions in the atmosphere and especially CO₂. The goal of the EU countries for 2020 is to cut emissions to 20% below 1990 levels. In the meantime the Netherlands proposed that the goal for 2030 should be a reduction of 40% below 1990 levels [Hof et al., 2012].

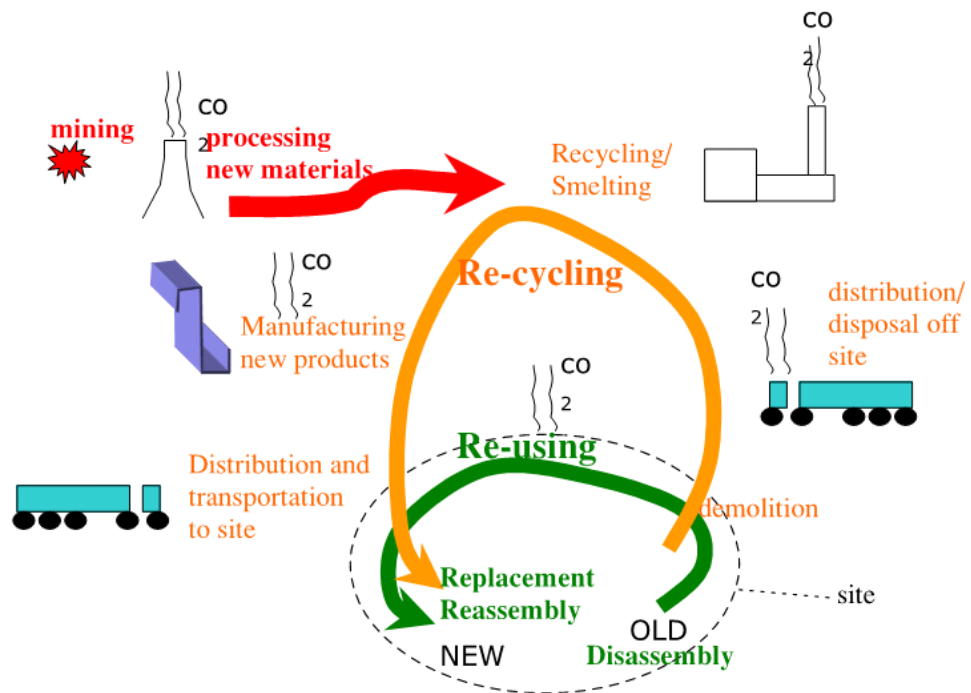
Besides global warming another important issue is the scarcity of raw materials. The earth population is growing fast and in 2050 it is estimated to be 40% more than the population of 1950. This increase will lead to a larger consumption of goods and therefore to a larger consumption of raw materials [Wouters and Derk, 2009]. Measures must be taken in order to minimize the damage caused by the extraction of raw materials from various places of the earth; otherwise serious problems will arise in the forthcoming years. Minimization of the use of raw materials can be achieved either by using different types of raw materials or by recycle and reuse. The reduction of the use of raw materials will also result to the reduction of CO₂ emissions [Coolrec].

It is estimated that the building industry is responsible for 38% of the global greenhouse gas emissions while it uses 40% of the global energy. The wastes from the construction, renovation and demolition of buildings are estimated to be 40% of the solid waste streams in developed countries. At the same time the building sector is responsible for the consumption of approximately 3 billion tons of raw materials annually [Comstock et al., 2012].

One major problem that the Dutch building industry faces nowadays is the increase of empty office buildings. Due to the economic crisis and the short functional life time of buildings there is a high vacancy rate (14,7% at the mid of 2013, according to DTZ Zadelhof). Usually these buildings are redeveloped and transformed with respect to the demands of the new users. In many cases, due to the unsuitable position of the building for new functions or due to the lack of demand from new users, these buildings remain empty for many years and they need to be demolished.

The demolition of the buildings will lead to a big pile of waste. The recycling of the waste will lead to degradation of their quality although their technical lifecycle is still not completed. If the construction wastes are not recycled or reused they will be disposed to a landfill which is the worst case scenario. In the Netherlands, 98% of the Construction and Demolition (C&D) wastes are recycled or reused and 2% are incinerated or landfilled [Rijkswaterstaat, 2013] which is a very good rate compared to other countries.

Figure 1.1 – Reuse versus recycling
 [Source: Haritos N., Lam N. T. K.; 'Reuse – Issues and Challenges in Structural Engineering Applications'; International Conference on Sustainable Built Environment 2010 (267-273), Kandy, 2010]



1.2. FORMULATION OF THE PROBLEM

In terms of energy consumption, reduce and recycle of structural building elements are the most favorable solutions in building industry among the 3R's of sustainability (Reduce, Recycle and Reuse). On the other hand, reuse is not so widespread [Haritos and Lam, 2010].

Recycle has a well-established market and it is a very positive solution for the protection of the environment. Nevertheless, there are some negative aspects which can be solved by closing the loop higher to the chain of creation or in other words turn towards reuse of the elements. When demolition wastes are recycled, a certain process must be followed which demands big amounts of energy due to transportation, recycling, processing, manufacturing and then again distribution. With reuse these amounts of energy are minimized (see fig. 1.1).

In addition, recycling of building elements means that a whole new construction process takes place. As a result, a large amount of energy is used during the construction of the buildings, the manufacturing and the transportation of the building elements. Moreover, the manufacturing of new construction elements that cannot be made from recycled wastes will demand the use of raw materials.

Until today, although reuse seems to be a better option in terms of environmental reasons it is not the preferred process. There are certain inhibitors and this is mainly because of economic, technical and institutional obstacles. The previous years a lot of studies have been carried out about Design for Deconstruction (DfD) of new buildings, but structural elements of existing buildings are not designed to be deconstructed. This will increase the costs that are needed to disassembly a building. In terms of technical issues, there is not an approved standard procedure for disassembly, which makes the disconnection of the structural elements an unsafe procedure. Also, there are doubts and uncertainty for the strength and the integrity of the structural elements that are going to be reused. Moreover there are institutional obstacles, like lack of standardization for reused structural elements that does not promote their reuse.

The challenge is to increase the amount of reused building components than recycled and reach a higher level in the waste management hierarchy (see fig. 1.2). With reuse, degradation of the element is prevented so less embodied energy is wasted and the element can be used with the same function at a new building.

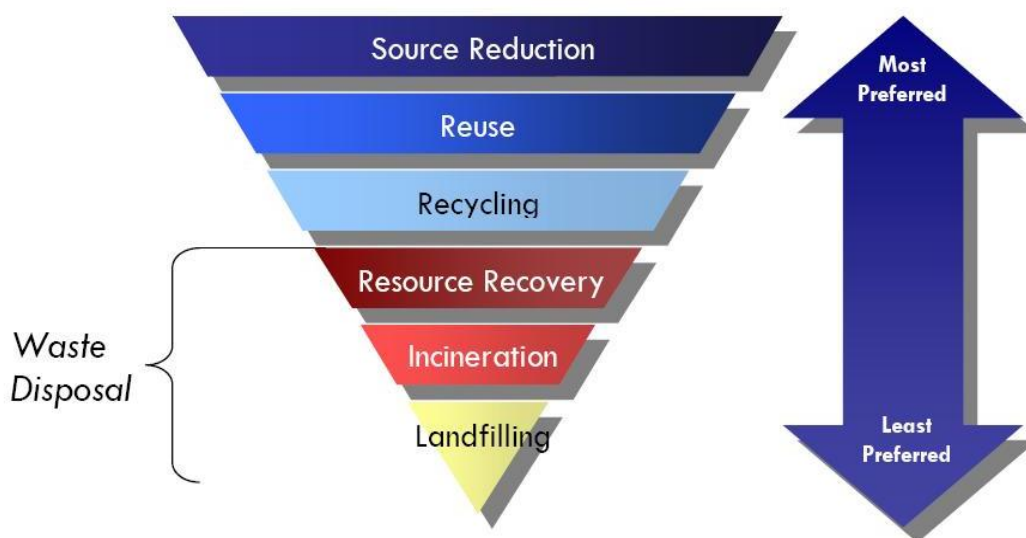


Figure 1.2 – Waste management hierarchy [Source: Fairfax County Solid Waste Management]

There are examples from other industries, like car industry, where they managed to reuse the skeleton of an old car and construct a new one (Burton Car Company). In a building there are a lot of different elements, structural and non-structural, which can be reused. Structural elements have long service life and in many cases longer than the building itself.

1.3. RESEARCH OBJECTIVE

In order to reach a sufficient level of knowledge and convince constructors and designers to reuse structural elements, a lot of research should be made. There are already a lot of projects where deconstruction of steel structures took place but it is not the same with concrete structures. As a result extra effort and research should be made for the reuse of concrete

structural elements. Due to the broad field of the subject, **the objective of this research is to identify the technical obstacles of reusing reclaimed structural concrete elements in new buildings.**

1.4. RESEARCH QUESTIONS

Main research questions

- 1) Which are the technical obstacles that prevent the reuse of reclaimed structural elements in new buildings?**
- 2) Can these obstacles be solved?**

Sub-research questions

Literature research questions

- 1) What are the advantages of the reuse of building components and why it is not widespread like recycling?
- 2) Which are the existing disassembly procedures?
- 3) What are the advantages and disadvantages of deconstruction compared to demolition?
- 4) With respect to their function, which buildings are suitable for reuse in the Netherlands?
- 5) Which methods can be used for the structural assessment of an existing concrete element?

Inventory questions

- 6) Which areas in the Netherlands are the most urgent for solutions against structural vacancy?
- 7) Which properties of the structural elements will be contained in the inventory?
- 8) What are the types and the quantity of the structural elements found in the empty buildings?

New design questions

- 9) Which is the most appropriate function for the design of a new building with reused elements?
- 10) Which elements from the inventory are more suitable for reuse?
- 11) Which types of connections from the prefabricated elements can be applied on the reclaimed structural elements?
- 12) Which are the technical problems derived from the connections and the structural assessment?

Evaluation of the new design

- 13) What are the costs of reused elements compared to new elements?
- 14) Which is the contribution of the reuse of structural elements to the reduction of greenhouse gas emissions?

1.5. RESEARCH METHODOLOGY

The process of the research is separated in 2 phases (see fig. 1.3).

The first phase is consisted from 2 parts: the literature research and the creation of the inventory. During the first part an attempt was made to acquire sufficient knowledge about several subjects related to the reuse of structural elements. The advantages of reusing building components and the reasons that it is not widespread like recycle was explored, followed by a comparison between recycle and reuse. After that a research was made for the different demolition and deconstruction options. The next section is a research for the most suitable function of buildings in the Netherlands for reusing their structural elements. When the function of the building was determined then a typology analysis was made for the different types of the different building systems in the Netherlands and the structural elements that can be found in these buildings. Then the different methods of assessing the structural systems and elements of an existing building were explored. The final section is a research about Life Cycle Analysis (LCA) of buildings and building components and how can it be performed.

Along with the literature research an inventory was created. The inventory contains the different structural elements that can be met in a building and their properties. Examples of properties are their dimensions, their type, potential damages and other properties that will arise from the literature study. The first step to create the inventory was to find suitable empty buildings in the Netherlands. This depended on the vacancy rate of the area, the potential for transformation and the demand for new buildings. When the appropriate area was located, then the structural drawings of the buildings were acquired from the municipality and the inventory was created according to them.

The second phase is a case study. The goal of the case study is to examine which elements can be reused, which cannot and which technical obstacles prevent their reuse. The first part was to design a new building, using the elements from the inventory created in the first phase. The function of the new building was decided and the appropriate elements were chosen depending on their properties. Then the proper type of connections of the reclaimed structural elements was determined. An attempt is made to identify the potential technical problems and suggest possible solutions. The solutions derived from the structural assessment of existing buildings, from connections of prefabricated elements and from the "Design for Deconstruction" theory.

After the design of the new building an evaluation is followed. First the costs of the construction with reused elements were calculated and then a comparison was made with the construction of the same building with new elements. After that the environmental impacts of the reused elements were calculated and compared with the new elements. The method that will be followed for these calculations will be decided after the design of the new building.

Due to the nature of the subject and the limited related published literature, interviews took place between the two phases. The goal of the interviews was to find out information for the reuse of structural elements from experienced personnel and structural engineers working in demolition and construction companies.

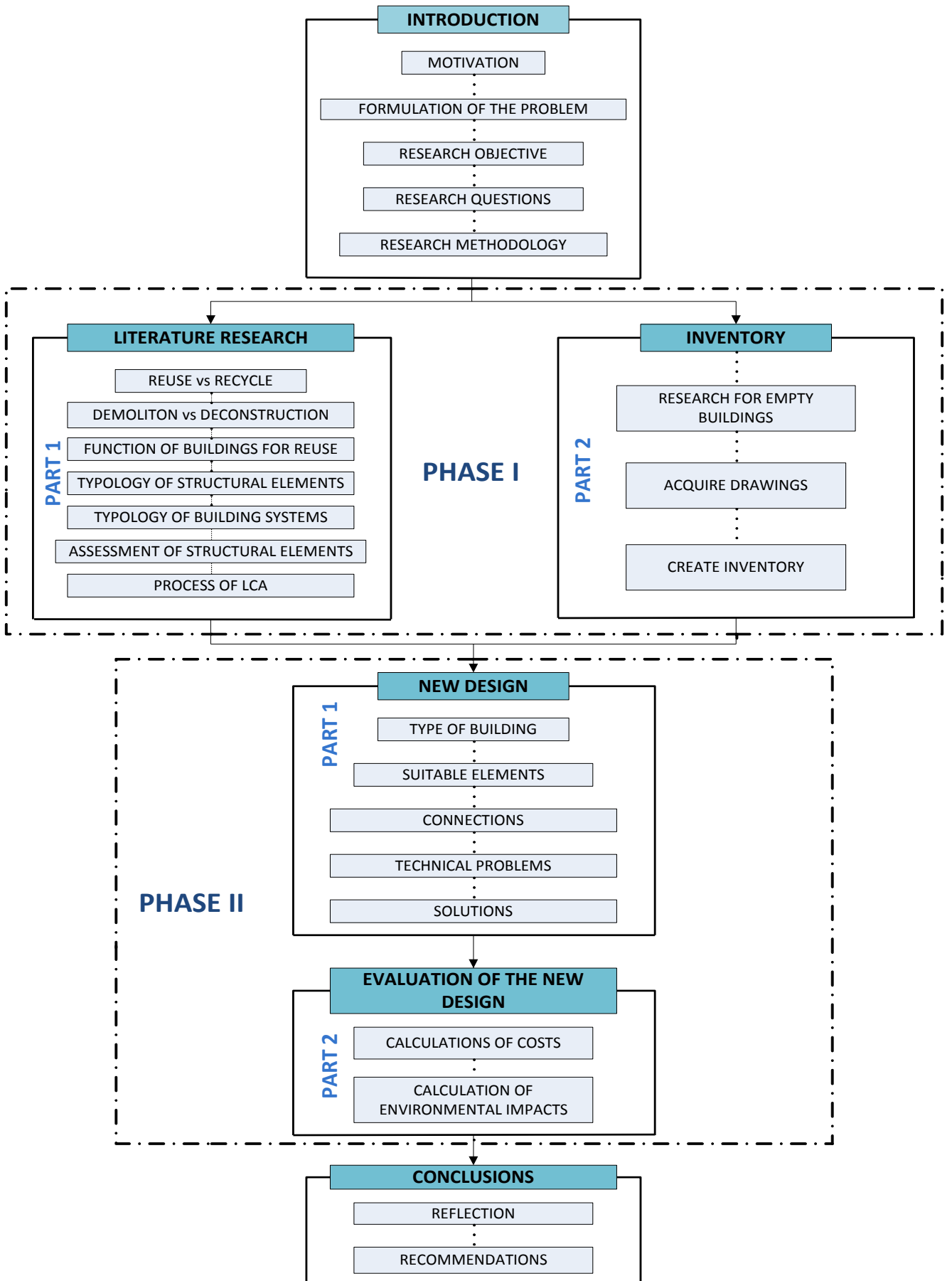


Figure 1.3 – Research Methodology

CHAPTER 2

LITERATURE RESEARCH

The purpose of this chapter is to research the recycle and reuse potentials of structural concrete elements. The first part is an introduction of the environmental problems caused by the construction industry followed by the measures applied in the Netherlands to tackle these problems. In the third part is the recycling methods of concrete are analyzed together with their advantages and disadvantages while the fourth part is referred on the reuse of structural elements made from concrete and steel. Finally the conclusions complete the research of the recycle and reuse potentials.

2.1. "CLOSING THE LOOP"

Introduction

The world population keeps on increasing year by year and as a result more resources will be needed to cover the needs of people [Worldometer, 2013]. The inhabitants of our planet and especially of the developed countries must realize that the Earth's ability to provide resources and absorb pollution is not unlimited. This means that people have to adopt sustainable development in their everyday activities. The definition of sustainable development according to *Our Common Future* is: "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [WCED, 1987]

The main global environmental issues that our planet faces are the CO₂ emissions, which are responsible for the global warming of the planet, the waste landfilling which is responsible for the destruction of the ecosystem and the depletion of primary resources which will cause poverty in the future generations (fig. 2.1). It is estimated that the building industry is responsible for 38% of the global greenhouse gas emissions while it uses 40% of the global energy. The wastes from the construction, renovation and demolition of buildings are estimated to be 40% of the solid waste streams in developed countries. At the same time the building sector is responsible for the consumption of approximately 3 billion tons of raw materials annually [Comstock et al., 2012].

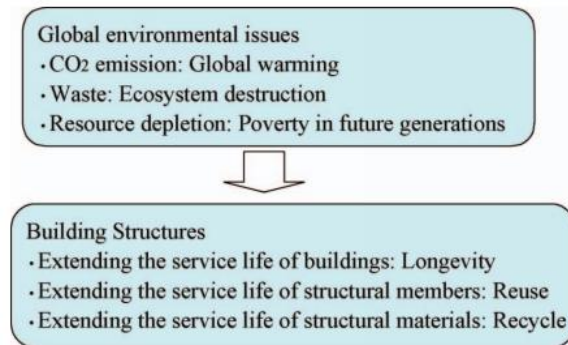


Figure 2.1 - Environmental performance of building structures [Fujita et al, 2008]

In order to reduce CO₂ emissions from the transportation and production of building materials, decrease the consumption of primary resources and reduce the waste that are landfilled; processes of **Reduce**, **Reuse** and **Recycle** should be implemented in the building industry. Reduce can be achieved by avoiding constructing new buildings thus extending the service life of the existing buildings. Reuse can be done by extending the service life at the structural member level while Recycle can be done by extending service life at the material level (fig. 2.1).

Governmental Measures

Waste Management Hierarchy

The government, in order to face the problem of wastes, developed different models whose aim was to reuse the Construction & Demolition waste in its own cycle and as a result minimize the use of primary resources and the production of CO₂ emissions.

One of the first models was the Ladder of Lansink, which was published by the Dutch government in 1980 and it is a top-down order for waste treatment [Dijk van K., 2001]:

- Prevention
- Element reuse
- Material reuse
- Useful application
- Incineration with energy recovery
- Incineration
- Landfill

The Ladder of Lansink was replaced by the Delft Ladder which is more flexible and all options should be evaluated for a specific project. The Delft Ladder is consisted of:

- Prevention
- Object renovation/ Construction Reuse
- Element reuse
- Material reuse
- Useful application
- Immobilization with useful application
- Immobilization
- Incineration with energy recovery
- Incineration
- Landfill

The goal of Prevention is to prevent the production of construction and demolition waste while with Object renovation the goal is to reuse a great part of the building as it is on site. Element reuse is the reuse of an element that is reclaimed from a building without serious damages while Material reuse and Useful application focuses on the recovery of materials for reuse and recycle applications. Immobilization focuses on the recovery, neutralization and reuse of hazardous wastes. Incineration is used for energy recovery and for volume reduction while Landfill is the last option and it is prohibited in the Netherlands [Dijk van K. et al, 2000].

Regulations

In the Netherlands, the Minister of VROM has to lay down a National Waste Management Plan at least every 6 years. In the late 1980s there were political and social resistances about the construction of more landfill and incineration sites. This resistance led the government to stop the planning for the construction of the new sites and inland barges were used to store the waste. These factors resulted to the publication of the first plan 'National Waste Management Plan: Part 1' (LAP 1) in 2003 and the main goal was recycling of 90% of the waste. Following the Ladder of Lansink, the preferable order in the plan is material recovery (reuse, recycle) and if it is not feasible then waste can be used for fuel [Brower et al, 2008],[VROM, 2003].

In 2009 the second plan 'Het Landelijke Afvalbeheerplan 2 (LAP 2)' was published and it is valid from 2009 to 2015 with a view to 2021. In this plan it is stated that the goal of reuse, recycling and other useful applications for Non-Risky Build and Demolition waste (Brick work and Concrete) of material is 95% which is much higher than the limit of 70% for 2020, stated in the European guideline: 'Framework Directive on Waste (2008/98/EG)'. [Naber, 2012],[VROM, 2009]

The overall objectives of the 'Het Landelijke Afvalbeheerplan 2' (LAP 2) are [EIONET, 2009]:

1. Limit the growth in waste generation (by decoupling from the economic growth).
2. Reduce the environmental impact of "waste" (by optimising recovery and reuse).
3. Minimize the environmental product chains (raw material extraction, production, use and waste management including reuse).

The effects of the Ladder of Lansink and the National Waste Management Plans can be seen in Figure 2.2

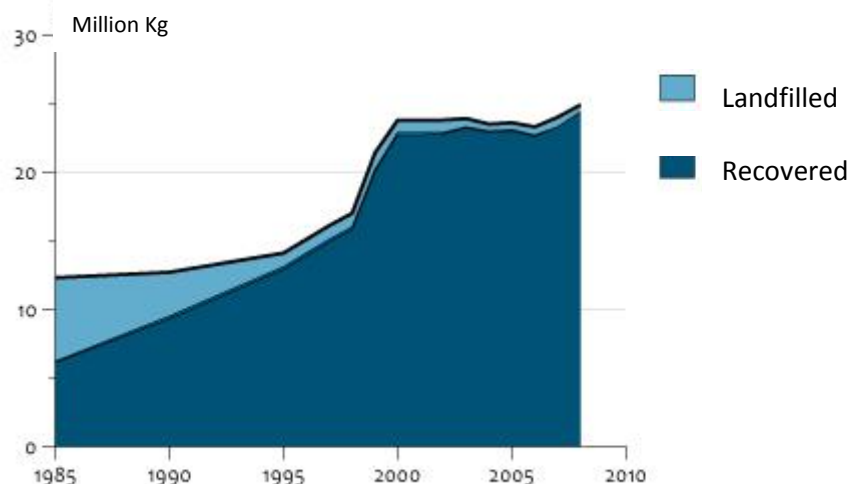


Figure 2.2 - Release and process of construction and demolition wastes from 1985 – 2008
[Source: www.compendiumvoordeleefomgeving.nl]

Prevention of C&D waste is the optimum solution but most of the times their creation is unavoidable. After prevention the most optimum choice is reuse of the whole or a big part of the building itself in the same site or moved to an alternative site. This step is also known as adaptive reuse (fig. 2.3). Sometimes this step is not possible to happen due to physical, architectural, economic and social reasons, which mean that the building should be demolished. So this leads us to the next two options: **Reuse** of elements and **Recycle** of materials. The following figures show the Reuse and Recycle steps in the waste hierarchy management:

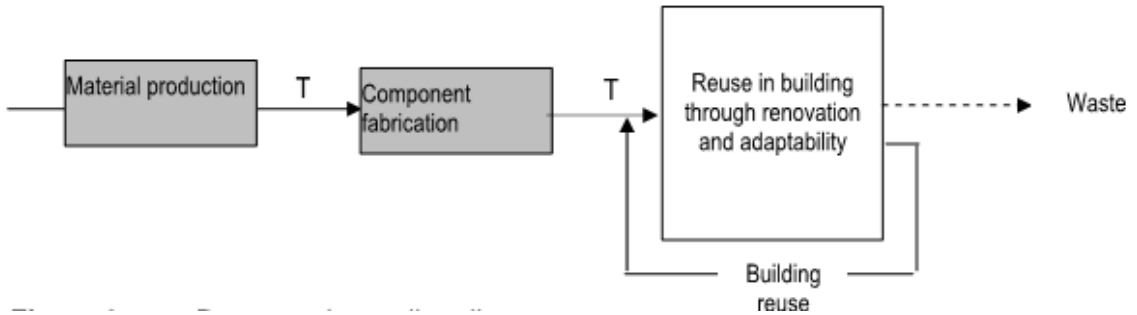


Figure 2.3 - Reuse of the whole or part of the building [Source: Gorgolewski et al, 2006]

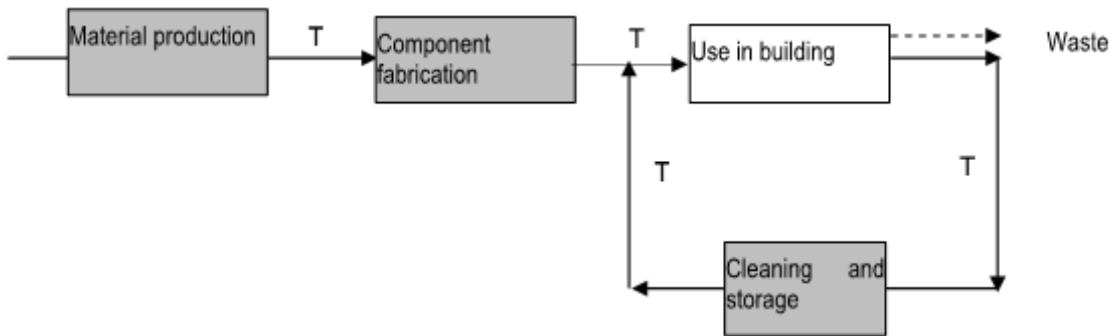


Figure 2.4 - Reuse of element [Source: Gorgolewski et al, 2006]

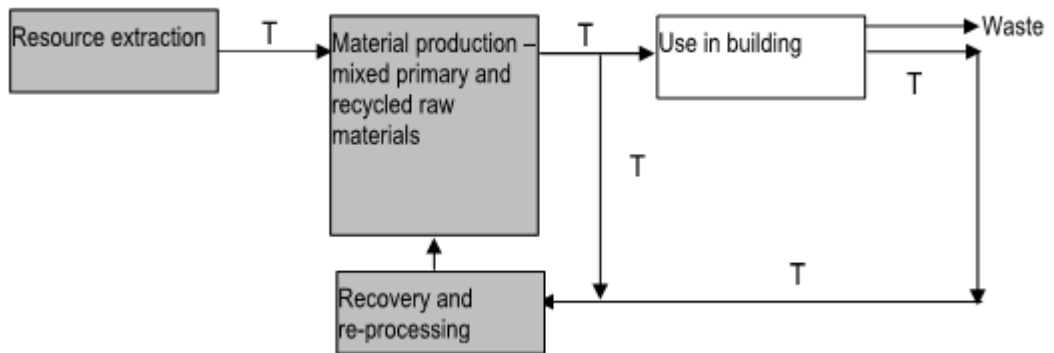


Figure 2.5 - Recycle of material [Source: Gorgolewski et al, 2006]

Recycle

The implementation of the National Waste Management Plans (LAP1, LAP2) had very positive results on the treatment of wastes in the Netherlands. Especially, as far as it concerns the Construction and Demolition (C&D) wastes the results were more than sufficient as it can be seen in table 2.1.

Amount of C&D wastes (kton)					
	2006	2007	2008	2009	2010
PREPARE FOR REUSE	-	-	-	-	0 (0,0%)
RECYCLING	21.155 (90%)	22.197 (95%)	23.228 (95%)	23.116 (94%)	22.439 (94%)
OTHER RECOVERY					
Energy recovery	354 (1,5%)	432 (1,9%)	543 (2,2%)	799 (3,2%)	833 (3,5%)
Filling material	-	-	-	-	-
Other forms	1.174 (5,0%)	22 (0,1%)	13 (0,1%)	1 (0,0%)	12 (0,1%)
DISPOSAL					
Incineration	69 (0,3%)	14 (0,1%)	15 (0,1%)	24 (0,1%)	14 (0,1%)
Landfill	657 (2,8%)	555 (2,4%)	570 (2,3%)	612 (2,5%)	437 (1,8%)
Dump	10 (0,0%)	53 (0,2%)	46 (0,2%)	44 (0,2%)	17 (0,1%)
TOTAL	23.417	23.272	24.415	24.596	23.752

Table 2.1 - Production and Processing of C&D since 2006 [Source: Rijkswaterstaat, 2013]

In LAP 2.1 the goal for recovery is set to 95%. In 2010 the total amount of C&D wastes was 23,8 Mton while the percentage of Recycling (94%) and Other Recovery (3,6%) summed up to 98% which was 3% above the required goal. Moreover, the landfilling of C&D decreased and in 2010 it was lower than 2%. [Rijkswaterstaat, 2013]

Besides the implementation of the waste plans, the increase of the percentage of recycling is a result of the rising costs of waste disposal and the limitation on the extraction of primary raw materials from the Dutch soil due to scarcity [Hendriks, 2001]. Manufacturers started trusting and using recycled waste as a cost-effective replacement of raw materials by altering the manufacture process of the existing products in order to use as efficient as possible the recycled materials.

Construction and Demolition wastes are consisted from different kind of materials. More than 90% are stony materials like concrete, asphalt and masonry. The rest are for example plastics, metal and wood [Rijkswaterstaat (website), 2013].

The structural systems of buildings are mainly made from concrete and steel. Steel is almost fully recycled but it is not the same for concrete. According to de Hoog, demolition companies are able to recycle 100% of the concrete from demolition waste though a certain procedure. The processing includes breaking of the existing structure, removing and crushing of the concrete. In order to become more sustainable, the concrete should be crushed, processed and reused locally. With this way the transportation costs and the emissions will be reduced.

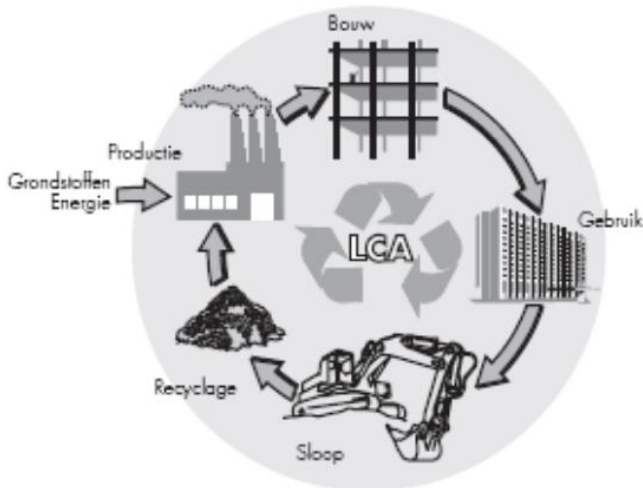


Figure 2.6 - Life cycle of concrete [Source: de Schepper, 2009]

The recycling of these materials will be beneficial for the environment by reducing Green House Emissions, minimizing the extraction of raw materials and reducing amount of landfilled demolition waste. Another advantage is that areas of recycled concrete that have not been carbonated, they keep on absorbing carbon dioxide. Also LEED® Green Building Rating System rewards the use of recycled concrete and for Construction Waste Management [PCA – Aggregates, 2013].

The products from the crushing of the concrete are the recycled aggregates¹ which are separated in two categories:

- i) Recycled Concrete Aggregates (RCA)
- ii) Recycled Concrete and Masonry (RCM)

There is one more category of recycled aggregate, the reclaimed aggregate, with the difference that it is not a product of the demolition process.

According to Cement Concrete & Aggregates Australia (CCAA) the recycled aggregates have the following characteristics and applications:

Recycled Concrete Aggregate (RCA)

Recycled Concrete Aggregate is the product after crushing clean demolition waste. It must be at least 95% of concrete and the total contaminant must not exceed 1% of the bulk mass. Other products that may be present in RCA are gravel, crushed stone, hydraulic-cement concrete or a combination while reinforcing steel must be completely removed.

RCA can be used in specific engineering applications. Class 1A RCA which is a good quality RCA with less than 0,5% brick content can be used for the replacement of virgin material (up to 30% of coarse RCA) in the production of concrete mix for non-structural work such as kerbs and gutters.

The Dutch VBT 1995 allows up to 20% replacement of natural aggregate with RCA or recycled mixed aggregates (RMA) without a need for additional testing, for all concrete up to a characteristic strength of 65 MPa and for all relevant environmental classes (Dutch Standard NEN 5950, 1995). In 2011, BAS had participated at the construction of a swimming pool with 100% recycled concrete aggregate in concrete. Great resistance grew because the prices of normal sand and gravel are very low compared to the reused concrete granules which make it almost impossible to get a good business case. As it was mentioned before, above 20% of RCA, extra testing is needed. A lot of tests were made for this case and as a result the cost of the concrete with 100% RCA was 4 times more than the normal concrete (Bovend'eert, 2013).

RCA has lower specific gravity and higher water absorption (fig. 2.7) than most natural aggregates. This happens due to the hydrated cement paste. It is mandatory to adjust the mix design (increase the paste content or the amount of water reducer [PCA-Aggregates, 2013]) in order to cover the effect of RCA on workability, absorption, strength and shrinkage. The cost of

¹ **Recycled Aggregates** are aggregates derived from the processing of materials previously used in a product and/or in construction [CCAA, 2008].

the increase in cement content due to the mix adjustments could be offset by the lower cost of recycled concrete aggregates.

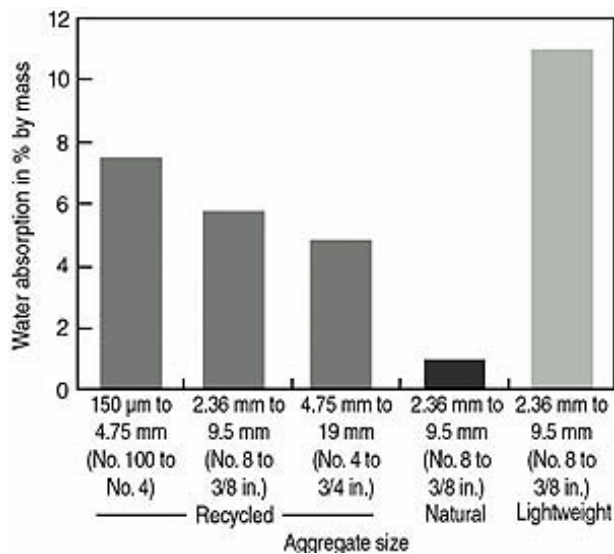


Figure 2.7 - Composition of water absorption of three different recycled aggregate particle sizes and one size of natural and lightweight coarse aggregate [PCA – FAQ, 2013]

Recycled Concrete and Masonry (RCM)

Recycled concrete and masonry aggregates are produced from clean waste concrete and masonry. The material may contain small quantities of brick, gravel, crushed rock or other forms of stony materials and can be used as granular base course and as road subbase material. As long as the properties and the quality of the RCM vary, using them for low-tech applications is the most suitable. This type of use is known as downcycling².

Reclaimed Aggregate (RA)

Reclaimed aggregates are the aggregates that can be reclaimed from the concrete that returned to the batching plant. The separation can be made either by washing the material with water or by letting the mix to harden and then crush it. The physical and mechanical properties of reclaimed aggregates are the same with those of the original aggregates except for their combined grading. It is used to replace part or all aggregates in concrete with mix adjustments made to compensate for the fine particles removed with water.

Many countries are focusing on recycled concrete aggregates (RCA) which is proven to be very practical for non-structural concretes and to a limited extent for some structural-grade concrete. However, the processing and quality control cost associated with their use plus the premium paid for mix design adjustment to achieve the same strength grade as concrete with natural aggregates can vary considerably. [CCA, 2008]

² **Downcycling** is the process of converting waste materials or useless products into new materials or products of lesser quality and reduced functionality (Wikipedia, 2013)

The advantages and disadvantages of recycle are as follows:

Advantages of Recycle

- Energy savings: With recycle it is possible to save energy by reducing the extraction and the transportation of raw materials from their origin and the transportation to landfills.
- Job opportunities: Recycling creates new types of jobs.
- Saves natural resources: Recycling can help to preserve the natural resources for future generations and maintain or hopefully regain a healthy balance in nature.
- Economic benefits: Recycling can lower the cost of producing new products (extraction, transportation, processing and manufacture) while it minimizes the transportation costs to landfills and the costs of disposal.
- Minimization of disposal wastes: Recycling reduces the amount of disposal wastes and as a result it saves space.

Disadvantages of Recycle

- Lack of standards: In many cases the strength characteristics may not meet the requirements when using RCA in concrete and as a result more testing is needed.
- Air pollution: The dust that is produced from the crushing of concrete might be harmful to the workers. Big amounts of water are needed in order to reduce dust production.
- Water pollution: The water from washing RCA may contain a high pH due to the alkaline nature of concrete and it is toxic to fish and other aquatic life. This water need to be purified before release.
- Poor image: People don’t trust recycled materials such as RCA because they believe that since they are not used from everyone there must be some disadvantages. Extra information is needed together with test data that proves the quality of the recycled materials.
- Lack of experience: Experience is required in order to ensure safe and reliable use of a new product.
- Low quality: Recycled materials are of a lower quality than virgin materials. Attempts are made to use the recycled materials without compromising the quality of structures. Also it is possible that the quality of RCA can vary from one site to another

The advantages and disadvantages of the recycle of concrete are summarized in table 2.2.

RECYCLE OF CONCRETE	
ADVANTAGES	DISADVANTAGES
Energy Savings Job Opportunities Saves Natural Resources Economic Benefits Minimization of Disposal Wastes	Lack of Standards Air Pollution Water Pollution Low Reliability Lack of experience Low quality

Table 2.2 - Advantages and disadvantages of recycle

Reuse

The reuse of structural elements is very rare. There are not many examples of reusing the whole concrete element besides crushing and recycling it as aggregate for the production of new concrete or as subbase for roads. Especially, in table 1, it can be observed that the amount of Construction & Demolition wastes that are prepared for reuse in the Netherlands is zero (0). Representative examples of reusing whole concrete elements in the Netherlands, Germany and Sweden are presented in this part, together with suggestions from the reuse of structural steel elements.

Reuse of concrete elements in the Netherlands

In the Netherlands there are two precast buildings that were deconstructed although they were not designed for this purpose. The first project was in Middelbrug in 1984. A residential building was leveled down 5 floors in order to increase the level of comfort of the rest of the apartments. Since the building was not going to be demolished and in order to protect the rest of the floors, the elements had to be taken out carefully. This was the reason that after their removal from the building, the elements were in a good condition and it was possible to reuse them. As a result 114 new houses were built with those reclaimed elements [Coenen, 1990]. The project was successful but it took two years and the costs were higher because of special equipment and the extra time needed.

The second project took place in Maasluis in 2000. Like in Middelbrug the aim of the project was to level down a residential building. The building was leveled down to the second floor but there were a lot of problems concerning the stability of the walls. According to de Graaf, they had to use approximately 300 supports in order to keep the walls standing because the building was not constructed according to the drawings (the floors were standing on 1,5cm of the wall instead of 5cm!). This made the deconstruction of the building economic unviable. At the end of the project the elements were not reused because it was difficult to synchronize the demounting of the existing building and the construction of a new one and also because the expected subsidy of the government for reusing old elements was not granted.

What can be concluded from these 2 projects is that the deconstruction of prefabricated buildings (even if they are not designed for deconstruction) is possible but attention has to be paid to the following issues [Naber, 2012]:

- A good planning is needed before starting the project in order to avoid delays. The planning will include the process of deconstruction but also the storage of the elements until they will be reused.
- An analysis of the existing drawings is important together with the foresight of potential technical defects.
- The most suitable equipment should be used in terms of efficiency and costs.

Reuse of concrete elements in Germany [Asam, 2006], [Asam, 2007]

A national wide assistance program (Urban renewal program in the East: cities to live in and attractive residential accommodation) was launched in 2001 by the Federal Ministry of Transport, Building and Housing in Germany. The aim of this program was to reduce the surplus of dwelling units by demolition. Besides the primary goal, the reuse of the elements was examined in the construction process of new buildings.

A number of pilot projects were developed. One of these was the “Recycled House” and it was part of the research project: “Recycling prefabricated building components for future generations”. The main goal of the project was to test the potential of dismantling and designing a house with reused components. The results of the project were the following:

- **Dismantling:** For the dismantling of the existing buildings a hand procedure, using light machines, is more applicable than heavy-duty machinery (fig. 2.8).
- **Transportation:** It must be carefully organized and proper storage must be assured (fig. 2.9).
- **Quality assurance:** From the moment that the components are dismantled, they lose their legal approval as construction materials. As a result measurements are needed in order to reassure the quality of the elements. These measurements are: Carbonization, Concrete compressing strength, Position of reinforced steel, Bearing capacity of components (fig. 2.10).
- **Treatment of components:** In order to find out how the elements can be treated under realistic costs different types of concrete cuttings were made and new fixings were tested.
- **Reassembly:** In order to minimize the treatment of the components it is advisable that the construction grid of the prototype must reflect the actual specifications. Cutting provides a smooth, butt-jointed wall joint comparable to new components (fig. 2.11).



Figure 2.8 - Dismantling



Figure 2.9 - Transportation

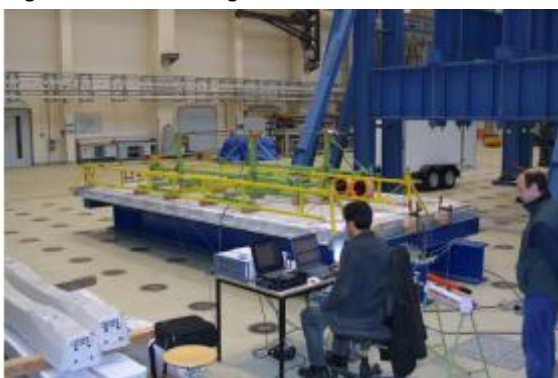


Figure 2.10 - Quality assurance



Figure 2.11 - Reassembly

The results of the research and pilot projects are summarized as follows:

- **The number of suitable donor buildings:** Although there are many buildings that contain the suitable elements and they are easy to dismantle; only a small number of them are deconstructed in a way that protects the elements. The reason for this is because there is no market for building parts and there is already an entire industry for recycled crushed stones.

- **The quality of the recycled components:** The elements that had problems with their quality were those that were exposed to the weather e.g. the balconies and the weathered surfaces of the outer walls. Also elements that are difficult to reuse due to their geometry are stairwells, lift and rubbish shafts, roof components and bath cubicles. On the other hand floor slabs and interior walls were proven to have high quality.

- **The architectonic scope for design when building with recycled components:** Due to the retention of the original structural module, compromises often had to be made in the function of the apartment floor plans.

- **Construction and processing possibilities when building with recycled components:** Since the available components are not building parts originally intended for dismantling and/or recycling, all the recycling activities are subject to compromise e.g. the original joints would fall off during the processing and as a result new joints were used made of a screwable heavy-lift dowel system.

- **The logistical optimal solution when building with recycled components:** When building with recycled components it is necessary to have access to a sufficient number of building parts. Since most of the times demolition was preferred than deconstruction there was a lack of building elements.

- **The economical significant of the method of building with recycled components for the building trade:** The results of the pilot projects showed that a reused concrete building part is 50% cheaper than a comparable new concrete building part. This is a due to the primary energy expenditure of cement which is 80% of the production of concrete. The total building costs with existing elements are 26% less than building with new elements (fig. 12). This happens because the deconstructed elements were not planned for reuse and this increases the costs of processing.

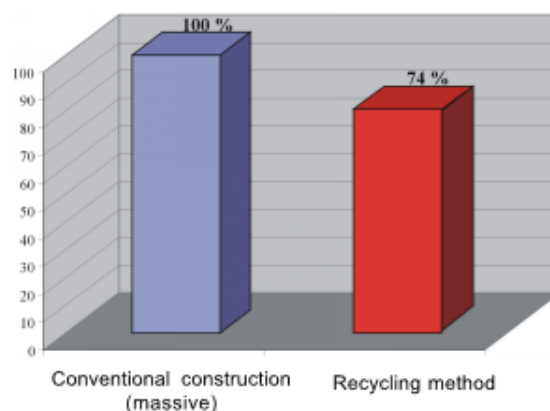


Figure 2.12 - Economical benefits [Source: Asam, 2006]

- **The ecological advantages of recycling compared to new construction:** A comparison is made between a reused concrete prefabricated part with different recycled concrete, new concrete and masonry (fig. 2.13). When comparing the recycled concrete mix 3 with the new concrete a 50% reduction in primary raw materials is observed for the recycled concrete but on the other hand there is no improvement on the energy values. This is mainly because of the increase of the cement content in recycled concrete than in new concrete. Since the cement remains the same when reusing an existing element the advantages are much higher in all categories.

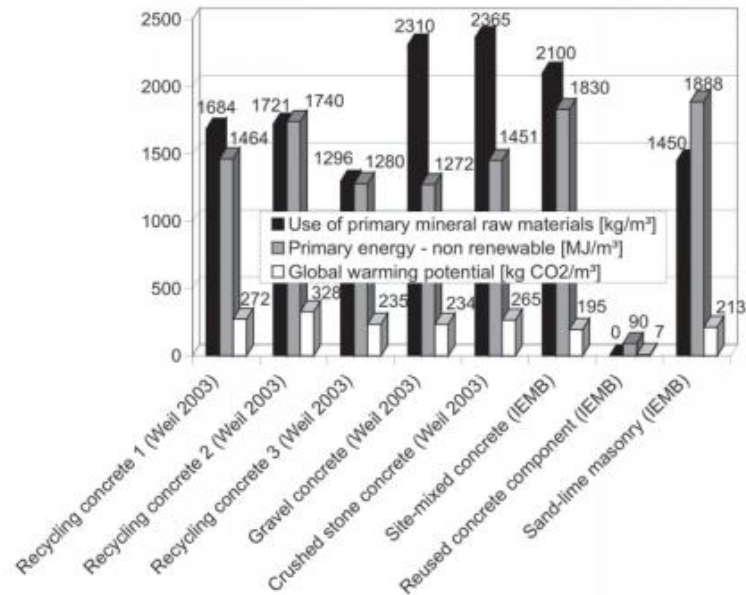


Figure 2.13 - Ecological-balance comparison of the production (up to the factory gate) of a cubic meter of building material of new materials, recycled and reused materials

Reuse of concrete elements in Sweden [Eklund M. et al, 2003]

In 1996, in Finspang in Sweden the Udden project took place. Due to a surplus of apartments, it was decided to demolish five buildings that contained more than 100 apartments. It was suggested to carefully deconstruct the buildings and build new apartments in another city where there was a shortage of houses. The deconstruction of the elements was made with a diamond saw since the buildings were constructed mainly from cast-in-situ concrete walls and beams. The deconstruction was made according to the needs of the new buildings. 50 large apartments were deconstructed and with their elements 22 smaller apartments were built. In terms of environmental performance reusing existing elements was proven to be a better option than using conventional building techniques and materials. If the elements would have been transported a distance longer than 140 km, the emissions of nitrogen oxides would be higher for the reuse project due to truck transport.

A second project, the Nya Udden, took place in 1999 in Linköping in Sweden. The goal was to build 500 new apartments by reusing elements from a refurbishment housing project that took place in Norrköping. The aim of the refurbishment project was to improve the area by reducing the number of the apartments. In order to achieve this, the upper floor of many buildings was removed. The houses were built with precast concrete elements which saved time compared to the Udden project. But the careful deconstruction turned to be more expensive than demolition and this led to the termination of the agreement the material supplier and the user of the material. As a result only a number of new apartments were built with reused materials and the others were built with conventional techniques.

The Udden project had the same general contractor responsible for the deconstruction and construction of the new apartment building. The advantages of this were that the workers could be used either on the deconstruction site or at the building site. This made them more cautious with the deconstruction of the elements because any problems that would come up from a careless deconstruction would cause them more troubles during the building phase. On the other hand in the Nya Udden project the contractors of deconstruction and construction were different and this led to a series of problems. The main problem was the handling and storage of the elements. The people that were deconstructing the apartments were not aware of the problems caused by storing the elements. The walls were stored and transported standing, which didn't cause any problems but the beams were stored lying down and in stacks of four. If this was not done properly, cracks could arise and then the beam had to be discarded.

The comparison of the two projects shows that deconstruction of precast elements seems better than having to saw cast in-situ concrete walls and beams. But on the other hand, although technical problems in Nya Udden project were easily solved, more problems were caused by the organization of the project due to different deconstruction and building teams. The extra costs that arose in both projects compared to a conventional project were 10% to 15% and they were compensated by governmental grants for "green building practices". Since these were pilot projects of a small scale and the contractors had no experience, it is estimated that these extra costs can be reduced easily in the future.

Reuse of structural steel elements

Although there are a few deconstruction and reuse projects of concrete buildings and elements, there are many projects of steel buildings where deconstruction and reuse of the structural elements took place. Gorgolewski et al, studied and analyzed a number of these projects that were executed in Canada and tried to identify issues and problems of steel component reuse in construction. From the projects studied, specific key factors were realized for the process of reuse and the problems that could be met during the design and construction process. Although these key factors are derived from the analysis of projects concerning steel reuse, they can be extrapolated and applied for projects concerning reuse of concrete structural elements. The key factors of the reuse process of structural steel elements are described in table 2.3:

	KEY FACTOR	DESCRIPTION
1	CLEAR GOALS AND COMMITMENT	It is important that the decision of reusing structural elements is made very early in the design process. The projects demand clear goals and commitment of both the design team and the client.
2	IDENTIFY SUITABLE COMPONENTS IN EARLY STAGE	The limited range of components requires the design team to be more flexible and to develop the building design around available reused components. It is essential that the specific reclaimed components are identified at an early stage in the design process.
3	INVENTORY OF AVAILABLE COMPONENTS	The starting point of the new design must be an inventory of available components from deconstructed or future deconstructed buildings. This approach requires that the available components are identified early in the design process, and that these are purchased or reserved to prevent the salvage contractor from selling them elsewhere. An alternative is to buy a building that contains suitable components and it is condemned for demolition.
4	FLEXIBILITY IN THE DESIGN	In case that pre-purchase of components is not possible, it is important to be flexible in the structural design, so that the design can be adjusted to suit available components later in the process. The reuse of the components will be easier if the design team uses similar structural layouts and maintains original span sizes from the old building.
5	ESTABLISH ROLES	The person or design team that is responsible for identifying the reclaimed components needs to be clearly established. Reuse may involve the design team in considerable additional research in order to identify, locate, inspect and choose appropriate components.
6	ENHANCE RELATIONSHIPS WITH OTHER ORGANIZATIONS	It is important for the designers (engineers, architects) to enhance their relationships with organizations that they are not traditional in contact with (demolition contractors). This will help them to increase their awareness of available salvaged materials and as a result improve their choice on salvaged components.
7	REUSE COMPONENTS ON SITE	It is possible to reduce material costs but there will be extra costs due to additional labour hours and due to the extra time that the design team will need to design with reused elements or identifying the suitable components. The highest savings usually occur for projects that focus on reuse of existing building materials and components already on site (where possible) rather than taking components from another site.
8	STRUCTURAL ASSESMENT AND COMPLIANCE WITH CODES	Procedures for grading components need to be established in order to ensure local code compliance. The structural characteristics of the elements can be easier identified as long as the original drawings and specifications are available.
9	INFORM CONTRACTORS ABOUT BENEFITS	Contractors might be nervous about tendering for unusual projects of this kind. There is a need to educate contractors and work with them to ensure that full cost benefits can be realized.

Table 2.3 - Key factors of the reuse process and their description [Source: Gorgolewski et al, 2008]

Besides Gorgolewski et al, Fujita et al proposed a model that will assist the process of reusing structural steel elements. This model can also be applied and used for the reuse of concrete structural elements.

The main idea of the model is that the whole reuse process is based on a database (DB) which contains information on the structural elements from existing buildings. All the life cycle of a building is circulating via the database through a cyclic process: design, fabrication, construction, maintenance, demolition and storage. Figure 2.14 presents a reuse flow diagram (cyclic process). The dotted line shows the information flow and the continuous line shows the flow of reusable members.

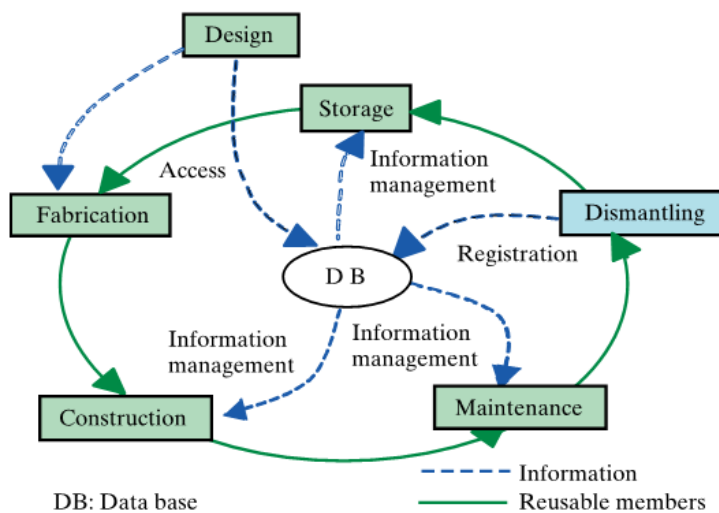


Figure 2.14 - Reuse flow [Source: Fujita et al, 2008]

Fujita et al proposed that in the design phase, structural engineers can access the DB in order to choose the suitable components. It is essential to add that structural engineers should cooperate with architects during the design phase in order to avoid delays due to absence of suitable components and mismatches with the design. Both of them should have access to the DB and identify which elements are available. As mentioned before at the key factors from Gorgolewski et al, the DB can contain components from demolished buildings but also from buildings currently in service or planned for demolition. During the fabrication phase reclaimed members are adjusted and fixed either at the construction site or at the fabrication shop in order to meet the specified requirements (fig. 2.15)

During the construction phase, the constructor orders structural members (reused or new) selected by the structural designer and the architect based on drawings and specifications. In the maintenance phase when there is a serious damage a decision is made either to repair the building or demolish it. When a decision is made to demolish the building, its structural members are registered in the DB as reusable members (fig. 2.16).

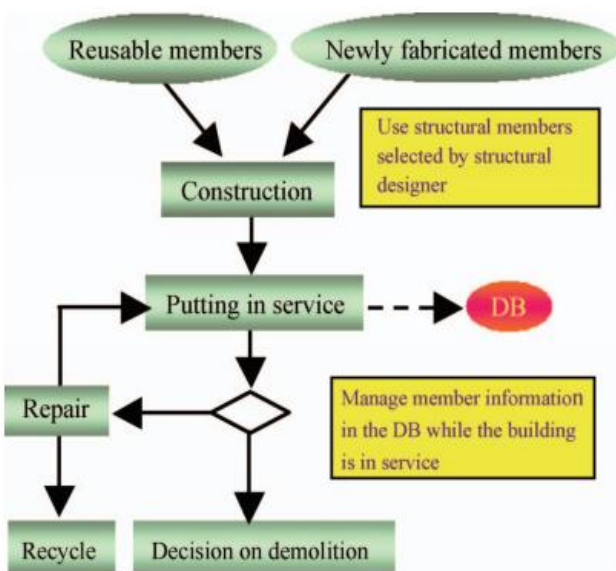


Figure 2.15 - Design and Fabrication flow [Source: Fujita et al]

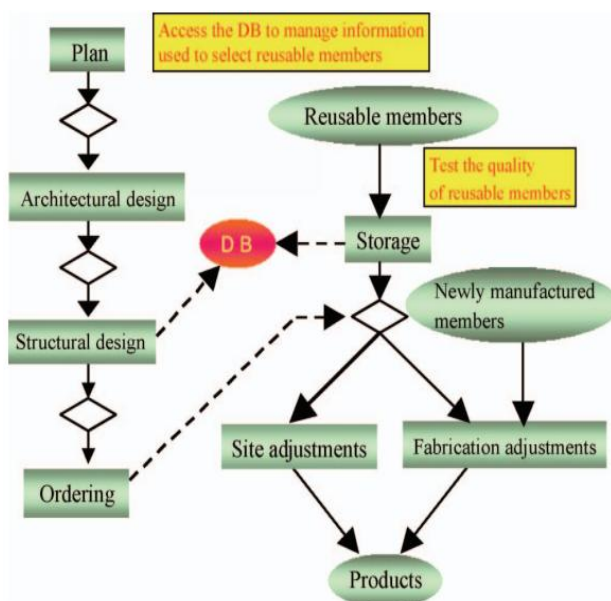


Figure 2.16 - Construction and Maintenance flow [Source: Fujita et al]

After the decision for demolition and the permission of the owner to become the structural members reusable they are registered in the DB. The members are assessed and then classified for reuse, recycle and disposal depending on the results of the assessment (fig. 2.17).

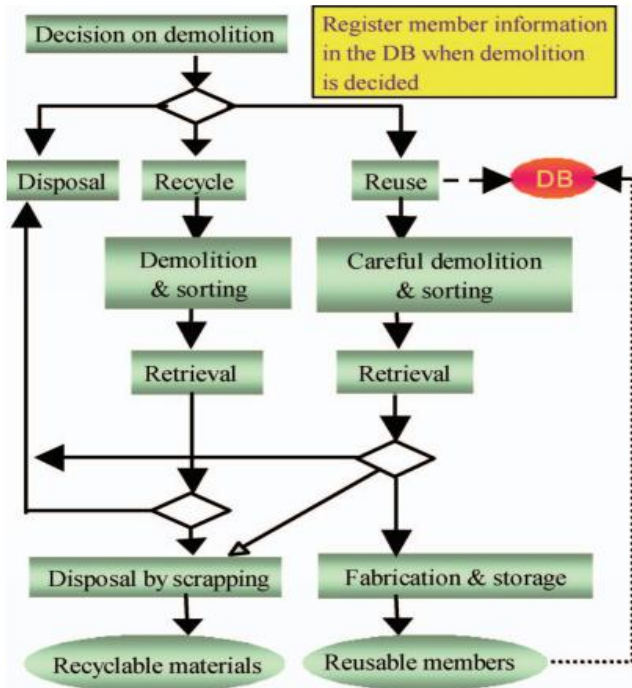
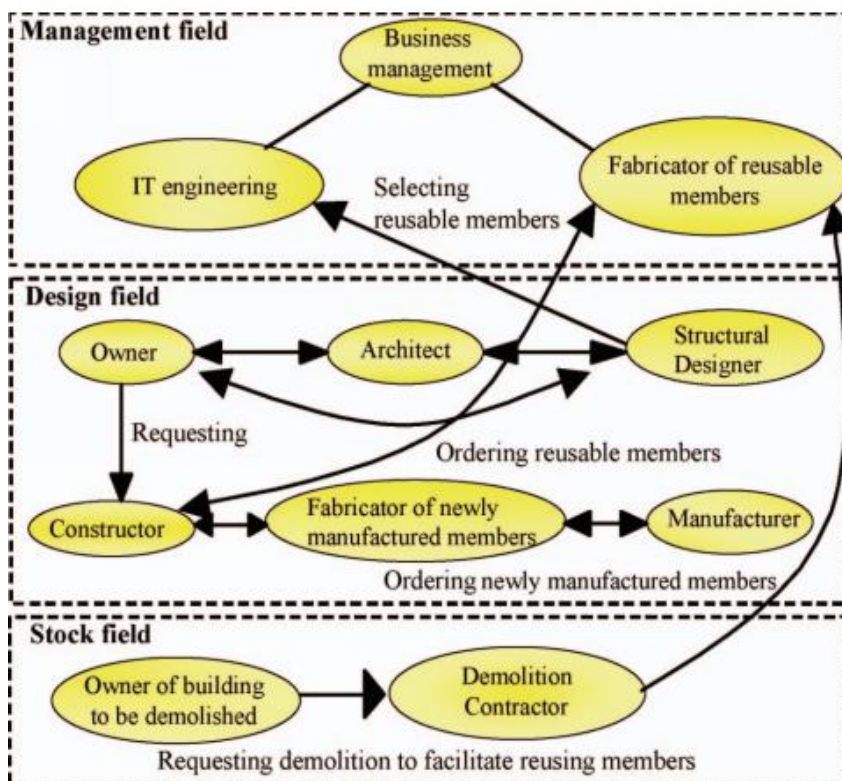


Figure 2.17 - Demolition flow [Source: Fujita et al]



The main concern of people to reuse structural elements is the increased and uncertain costs that might occur due to increased labor costs, design fees and delays of the suitable elements. In order to tackle these problems, Fujita et al proposed a reuse management model which will assist the reuse industry to become economically viable. This model consists of three fields:

- a) Management
- b) Design
- c) Stock

Figure 2.18 - Reuse Management model [Fujita et al, 2008]

The role of the members in each field is described in the following tables:

Management field	
Business management	Occupies central position in the reuse management model, manages the reuse business and controls information technology (IT) engineering and fabricators of reusable members.
IT engineering	Creates a system for unified management of information on reusable members, and builds and maintains the DB on the performance of reusable members. The reuse system is provided on the internet to give DB access to an unlimited number of structural designers and others.
Fabricators of reusable members	Responsible for fabricating and storing reusable members. They test the quality of reusable members and register all relevant information in the DB.

Table 2.4 - Roles in the Management field [Source: Fujita et al, 2008]

Design field	
Owner	Order a building according to his preferences
Architect	Designs a building according to the owner's request.
Structural designer	Decides if reusable elements could be used and access the DB managed by IT engineering to select appropriate reusable members.
Constructor	Orders both reusable and newly manufactured members based on drawings and specifications. Before ordering new members the permission from the owner and the architect is needed.
Fabricators of newly manufactured members	Fabricate reusable members in addition to newly manufactured and increase their business options.

Table 2.5 - Roles in the Design field [Fujita et al, 2008]

Stock field	
Owner of building to be demolished	Decides when the building will be demolished and what he will do with the elements.
Demolition contractor	The demolition and the sorting must be made with caution. After demolition, the members are inspected for their quality and they are kept in fabrication storage facilities.
Business management – IT engineering	The performance date of the reusable members is registered in the DB managed by IT engineering. Business management obtains data on the buildings from which reusable members are expected, including construction sites, demolition timing and quantity of structural members. This data will determine the economically efficient use of reusable members.

Table 2.6 - Roles in the Stock field [Fujita et al, 2008]

At the moment the main problem of reusing reclaimed structural elements is that there is not a real market for this type of construction. The main points that need to be developed for a successful reuse market are the following [Fujita et al, 2008]:

- i) Stock of reusable members
- ii) Reuse management model
- iii) Database procedure
- iv) Establishment of storage sites
- v) Careful deconstruction
- vi) Performance evaluation of reusable members
- vii) Fabrications procedures for reusable members

Conclusions

Reduce/Prevention, Reuse and Recycle are the three most optimal options in order to minimize the production of CO₂ emissions, to reduce the extraction of raw materials and eliminate the landfill of waste. Reduce/Prevention is the most optimal but from the moment that a building is decided to be demolished it is difficult to apply. On the other hand Reuse of elements and Recycle of materials are options that are more realistic and concern buildings that are condemned for demolition.

Both Reuse and Recycle have their advantages and disadvantages. Recycle has an already established market. Especially in Netherlands 100% of concrete structures can be recycled. Although it is a process that creates less environmental impacts than the production of new concrete from raw materials, it still demands energy for the crushing, the transportation and the process of the recycled materials. On the other hand reuse seems to demand much less energy than recycle but the costs, the processing of the reclaimed elements and the procedure of reuse needs further investigation.

It is estimated that 15 million tons of Construction and Demolition waste are needed for the base of a road of 250 km, six lane speedway, 20 meters wide and 2 meters thick. This is an enormous amount for a small country like Netherlands [Dijk van K., 2000]. On 2010 the C&D waste were 23,80 Mtons which is much more than what is needed for a road of 250 Km. Also according to the Green Deal for the Sustainable Recovery of AEC-bottom ash (signed on 7 March 2012) the goal is to reduce the landfilling of bottom ash to 50% until 2017 and to 0% until 2020. On 2011 the produced bottom ash was 1.3 Mtn which means that 650.000 tones should be used in different processes. One of the proposals is to use the remaining bottom ash as aggregate for products and as a result for the production of concrete [IenM, 2012].

These two examples show that although recycle is a very good and environmental friendly option there are still too much C&D waste that recycle methods cannot absorb. In order to solve this problem, the best solution is to turn towards reuse of structural elements which will eliminate the production of wastes and will reduce the energy needed for the production of a new or recycled element.

As Fujita et al mentioned, there is a series of steps that needs to be accomplished in order to achieve a successful reuse market. In this thesis the focus will be on the Stock of reusable members, the Demolition technique and the Performance evaluation and Fabrications procedures of reusable members.

2.2. DEMOLISH IT OR DECONSTRUCT IT?

The initial design and construction are the phases of a building life cycle that receives most attention from a scientific point of view. It is important that the same attention should be paid at the end-of-life phase of a building and more specific at the demolition or deconstruction. In fact demolition and deconstruction must become the beginning of a new project instead of the design of the building itself. Deconstruction is the method that will be used for the removal of the structural elements from existing buildings with the assistance of some already known demolition methods. The purpose of this section is to get familiar with the existing demolition and deconstruction processes, the advantages and disadvantages of each building removal method and to make a comparison between them.

What is demolition?

Demolition is an integral procedure in the building industry and is considered as the traditional method for disposal of buildings. From the ancient years, people were demolishing their cities in order to create new ones and they were reusing and recycling materials from previous structures. Although demolition is considered to be part of the construction processes it is actually a reversed activity. Important tasks of demolition that differentiate it from the construction are: survey of the building to be demolished, removal of hazardous materials and storage of demolition wastes.

An appropriate definition for demolition is given from the Australian government in the Work, Safe and Health regulations 2011 (WHS Regulations): "Demolition work means any work to demolish or dismantle a structure, or part of a structure, that is load bearing or otherwise related to the physical integrity of the structure."



Figure 2.19 - Low rise demolition of the PCH operational building in Ijmuiden with an excavator [Source: coastradio.intco.biz/]

There are different demolition methods depending on the type of the construction. What is interested for this thesis is the demolition of buildings. Low rise demolition is the demolition of any building until 8 stories high with cranes and excavators while high rise demolition is the demolition of any building above 8 stories with the use of explosives. When the use of explosives is not possible then the top floors are demolished one by one and the lower floors are demolished with heavy equipment.

Demolition process

During the demolition of a building it is very easy for the workers to get injured from falling debris or partial demolished structure. This can be a result of using wrong demolition methods or because the debris was not removed on time from the structure. Demolition, like all building processes, has a certain procedure that must be followed in order to avoid unpleasant events such as accidents and pollution.

Before starting a demolition, an assessment of the building is needed in order to select the most suitable and safest procedure. This assessment is done with a Building and a Structural Survey. For the Building Survey the existing and previous uses of the building are important, together with the type of construction and hazardous materials. Moreover, the location of the building must be part of the assessment. The condition of the nearby buildings and the potential for a site for debris close by the demolished building should be examined. Also the limits of the neighborhood for noise, dust, vibration and safety measures must be determined according to the location. Together with the building survey a record of the drawings should take place. On the other hand the Structural Survey concerns mainly the structural materials and structural systems of the building. Important factors are the method of construction, any deterioration of the structural elements, the structural conditions of the nearby buildings and the scale of the structure. Also a Structural Survey of the building will allow the demolition contractor to find the main stability points of a building which will help him to demolish it faster. The main problem of the contractors is that although they investigated the drawings of a building and they make a survey, when they start the demolition they find out that the building is not build as it is designed (de Graaf, 2013). This makes demolition unsafe.

After the Building and Structural Survey, the necessary plans for recycling, waste and safety are prepared. Then we have a complete plan and the demolition can start.

Demolition methods of concrete structures

The methods used for demolition depend on the factors mentioned before. Other important factors are the experience of the contractor with a certain demolition method and the costs of a new method. Contractors are willing to try new ways of demolition only if there is profit. Important role also plays the final disposal of the demolished materials. During the procedure of demolition different methods are used in order to protect the neighborhood from dust, noise and vibrations especially when there are adjacent buildings.

In the past demolition was a labor intensive activity made by hand and it was dealing with simple buildings. Nowadays due to the change of most of the business to more mechanical processes, machines replaced workers. Demolition companies hire few but more skilled personnel and use more expensive machines. Then the demolition can be completed, faster, safer and with lower budget. This also changes the profit of the demolition companies and instead of earning money from selling the recycled materials, now they earn money from finishing the demolition quicker and safer. The hand methods are still in use, preferably for sites that machines cannot have access and where restrictions on noise and vibration are required. In most of the cases machines are used to demolish a building, rather than hand methods. The methods that are used to demolish a whole building or a part of it at once are the following:

Hand methods: The most known demolition methods for concrete structures operated by hand involve wire cutters, jack or pneumatic hammer, concrete slab saw and wall saw with diamond blades.



Figure 2.20 – Concrete slab saw
[Source: www.diamondhiresales.co.uk/]



Figure 2.21 – Jack hammer
[Source: electricjackhammer.org]

Deliberate collapse method: This method includes weakening of the key structural elements in such a way that it will lead to the collapse of the structure. Columns are weakened by pre-cuts and then a crane with a wrecking ball or a shear is used to demolish them. It is a fast method but it needs sufficient distance from nearby structures and careful design of the demolition procedure in order to avoid accidents.

Pulling/Pushing forces:

For this method columns are also weakened with pre-cuts but in the contrast with the deliberate collapse method they are dragged down by attached cables and a winching machine or by a hydraulic excavator. This is also a fast method but it needs space for the “fall zone”.

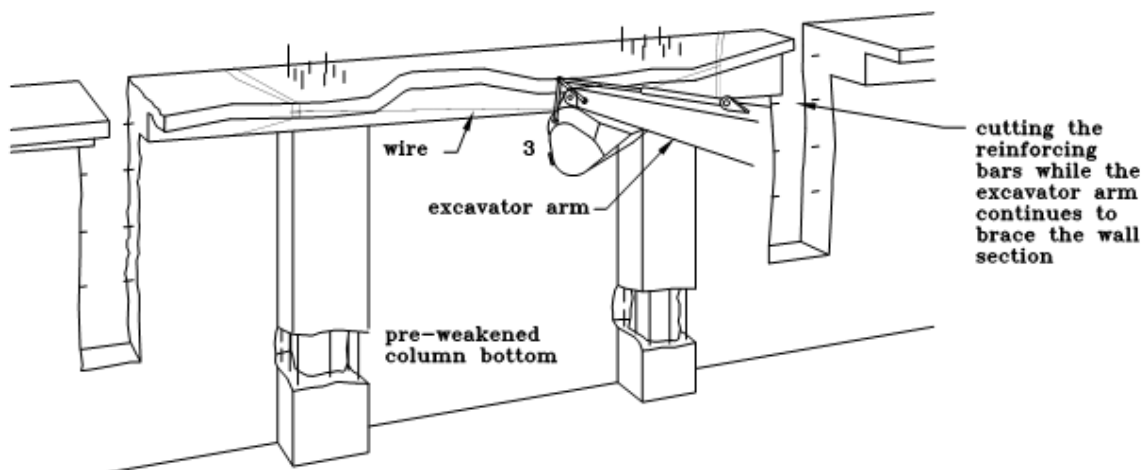


Figure 2.22 - Demolition of a concrete wall with pulling forces
[Source: Code of practice for demolition of building, 2004]

Wrecking ball:

The method of the wrecking ball is used since 1950. A wrecking ball is connected to a crane and it is swung towards the building. It is a method that requires experience to handle the ball and safety measures for the falling demolition debris. Nowadays it is not used anymore in the Netherlands (de Graaf, 2013).



Figure 2.23 – Demolition of a building with wrecking ball [Source: archiveattic.wordpress.com]



Figure 2.24 – A wrecking ball hits a column [Source: www.relocationfocus.com/]

Implosion-Explosion: In this method explosions are used to weaken the structural elements and then the building is demolished by gravity. It is an ideal method for structures that suffered prior damage e.g. fire, earthquake or when time is critical. It requires sufficient space and assessment of the risks and impacts on the area. Due to the soft soil of the Netherlands the use of explosion is not allowed because the shock caused from the implosion will break the concrete piles of nearby buildings. Moreover, the use of explosions is not allowed in respect of the old people from the World War 2 (de Graaf, 2013).



Figure 2.25 – Implosion with controlled explosions of a 14-storey building in New Zealand [Source: www.heraldsun.com.au/news/cancer-patient-jayden-halliwell-helps-implode-quake-damaged-building-in-christchurch/story-e6frf7jo-1226443136766]

Machines with high-reach booms: In this method, a machine with a high-reach boom is used where shears, grapples and concrete “crackers” can be attached. It is considered a safe and quiet method and it is suitable for areas with restricted access. A crane with a shear is the most used method in the Netherlands (de Graaf, 2013).



Figure 2.26 - High reach boom³



Figure 2.27 - High reach boom⁴

Cut and lifting: In this method the structure is cut into pieces and they are lifted by crane or a winch to the ground for further demolition. Safety measures should be taken for the loading of the remaining structure from the cut pieces and for the lowering of the pieces to the ground.



Figure 2.28 – Lifting of a section of a footbridge
[Source: www.gilldemolitions.co.uk]

³ Source: www.volvoce.com/dealers/en-gb/patodonnell/products/demolitionequipment/highreachdemolition/pages/introduction.aspx

⁴ Source: www.gilldemolitions.co.uk/demolition-services/high-reach-demolition.php

Floor-by-floor (top down): This method is used for buildings over 12 stories and it used when there is not sufficient space for implosion or cranes with shears. Mini-excavators are placed at the top of the building with the aid of cranes, where they break the structural elements. Then the demolition debris are removed either through shafts or by a crane. The areas around the shaft should be supported in order to withstand the extra weight from the debris. According to the Code of Practice for Demolition of Buildings the demolition sequence of the structure of a building that must be followed for the top down method is the following:

- All cantilevered structures shall be demolished before the demolition of the internal structures.
- Demolition of the floor slabs shall begin at mid span and work towards the supporting beams.
- Floor beams shall be demolished in the following order: (1) cantilevered beams, (2) secondary beams, (3) main beams.
- Non-load bearing walls shall be removed prior to demolition of load bearing walls.
- Columns and load bearing walls shall be demolished after removal of beams on top.

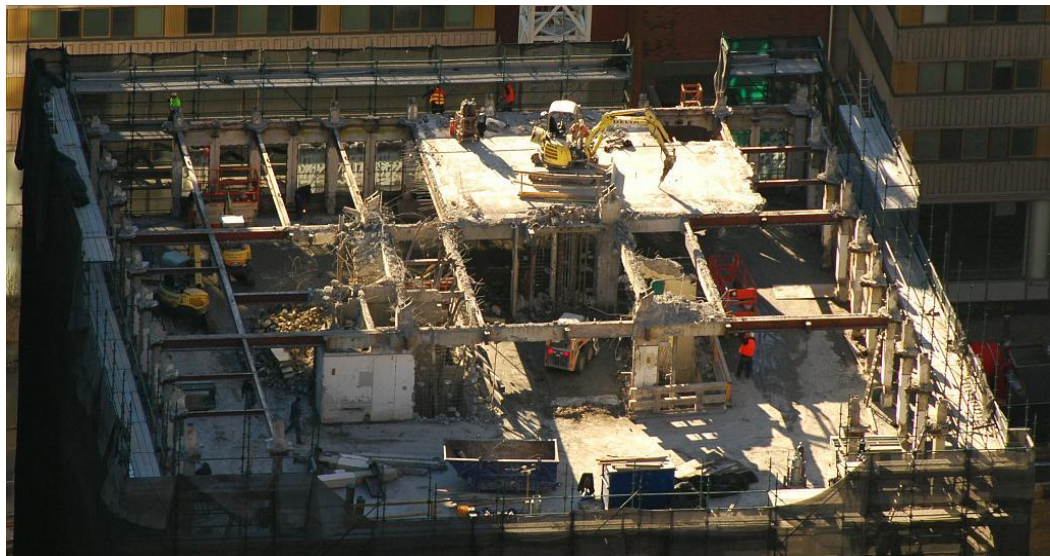


Figure 2.29 - A floor-by-floor demolition [Source: mugley.blogspot.nl/2006_07_01_archive.html]

Special structures

- Pre-stressed concrete structures: With pre-stressing the tension forces are applied before the concrete is cured. For buildings with pre-tensioned members the demolition is the same with cast in situ concrete. The tensioned cables are bound to the concrete so they are not dangerous when the concrete is broken and the tension is released. It is possible to cut pre-tensioned members from their attachments and lower them down.

- Post-tensioned concrete structures: With this method metal or plastic tubes that contain loose tension cables are cast in the concrete and when the concrete reaches a certain design strength, the cables are tensioned. In this case the cables are not bound to the concrete so when the concrete is broken, the cables are violently released and it may cause the launch of the anchors and the collapse of the post-tension member. Post-tensioning demolition needs to be designed by experts due to its unique features.

- Prefabricated structures: The demolition of prefabricated structures is made with the reversed order that they are build. The elements are disconnected, removed and destroyed at the ground. After the removal they are not suitable for reuse because they are designed specifically for one building so they don't have a regular size. The only possibility to reuse them is if the owner of the building asks to rebuild the same building at another place). Then a disassembly plan is needed and the marking of every structural element [de Graaf, 2013].

Demolition debris

Demolition is not completed after the wrecking of the building due to the accumulation of piles of debris. All the above methods, especially the methods that demolish the whole building, will result in big piles of debris. This debris is known as Construction & Demolition wastes (C & D) and they are generated either during construction or during demolition. The safe and effective removal of this debris is a high priority procedure. This can be reassured with the design of a debris disposal planning.

The C&D must be separated for recycling or reuse instead of depositing them in a landfill. This means that a separation of the different materials is needed. This can be achieved by the way that a building is demolished. First the elements that are non-ferrous must be removed and then the skeleton of the building that is made from concrete or steel or both is demolished. After the demolition, the separation of the materials is done with the aid of excavators or they are driven to a site where they are broken at a special machine and with the use of a magnet concrete and steel is separated.

What is Deconstruction?

Deconstruction (also known as disassembly) is the process of partial or complete dismantling of a structure in its components, generally in the reverse order of its construction, in order to recover the maximum amount of reusable and recyclable materials [Guy B., 2000]. It is possible to minimize the wastes that are generated by the construction industry, one of the largest industries in the world, and eventually close the loop of the material flow. It is a method that can increase the environmental and economic benefits of removing a building.

There are 2 main types of deconstruction: Non-structural and Structural deconstruction. Non-structural deconstruction is the removal of non-load bearing components like windows, doors, appliances and others. On the other hand Structural deconstruction is the dismantling of the structural system of a building [Macozoma D., 2001]. In general non-structural deconstruction is simpler than structural deconstruction. Their differences can be seen in table 2.7:

	Non-structural Deconstruction	Structural Deconstruction
Items	Windows, doors, appliances, covers, etc	Beams, slabs, walls, columns, etc
Tools	A few tools – mainly hand tools	A range of tools – mainly mechanical
Labour	Unskilled	Skilled and unskilled
Safety	Typical safety measures	Strict safety measures
Duration	A few days to a couple of weeks	A few weeks to a couple of months

Table 2.7 - Characteristics of Non-structural and Structural Deconstruction

Building deconstruction besides being used as a building removal technique and a waste minimization strategy, it can be used as an urban renewal tool to dismantle, renew and reuse old abandoned buildings. It can also be used as a community economic generation strategy to help create employment, local business and use local resources [Macozoma D., 2001]. The new employment and local businesses that can derive from deconstruction are the dismantling of buildings, the transportation of recovered components and materials, the remanufacturing or reprocessing of components and the reselling of used components and materials [Kibert C., 2003].

The main factors that affect the deconstruction process are the technical requirements, the costs and time constraints. One of the main differences between deconstruction and demolition is that deconstruction is a highly intensive labor process while demolition is a mechanical process and as a result deconstruction takes more time than demolition (two to ten more times) [Rentz et al, 1994]. This means that deconstruction will have more labor costs than demolition. In order to cover the extra time that is needed and succeed a feasible deconstruction, a high effort is needed for initial inspection and planning. Also the extra labor costs can be offset by the value of the salvaged materials and the avoided disposal fees. Additional costs are the pre-deconstruction costs for the protection of the workers, the transportation costs of the salvaged elements and the estimation of the marketing costs. Optimization of building deconstruction can be achieved by selling the salvaged materials as close to the building site as possible [Guy B., 2000].

One of the main advantages of deconstruction is that it helps divert large volumes of C&D waste away from landfill sites. This helps conserve landfill space and extend their lives. The recovered waste materials that are reused in construction, they replace raw materials. This reduces the demand for raw material extraction, thus preserving our natural resources. Reduced material extraction reduces the pollution associated with extraction, transportation and process of raw materials. Also another important factor is the reduction of energy consumption from the extraction of raw materials till the delivery of the final construction element on site. The salvage of materials for reuse conserves the embodied energy that is already contained in the materials in the building. This means that building deconstruction helps to close the loop on material flows [Macozoma D., 2001].

The benefits of deconstruction that derived from different literature sources [NAHB, 1998], [Kibert, 2003], [Guy, 2000], [Simon, 2007], [Macozoma, 2001] are the following:

- 1) The release of hazardous materials from breaking, crushing, abrading and grinding commonly associated with mechanical demolition is eliminated.
- 2) Deconstruction might cost less than demolition because of the value of the salvaged materials and the avoided disposal costs.
- 3) It has reduced impact to the local site, the soil and the vegetation.
- 4) New jobs are created by training unskilled workers for manual deconstructing buildings.
- 5) Since the materials are salvaged, less C&D wastes are produced and as a result less wastes end up in a landfill.
- 6) Potential reuse of building components.
- 7) Enhanced environmental protection, both locally and globally.
- 8) The embodied energy of materials is preserved, thus reducing the input of new embodied energy in processing or remanufacturing materials.
- 9) It can be used in urban renewal plans to rehabilitate dilapidated buildings, abandoned buildings and unhealthy buildings.
- 10) New economic stream is developed (the secondary materials industry of retail businesses for salvaged materials, recycling businesses and recycled content product manufacturers).
- 11) Cost savings from avoided procurement costs of virgin raw materials.
- 12) The reputation of the company/owner that allows deconstruction is increased.

As it was mentioned before, deconstruction has social, economical and environmental advantages. Despite all these advantages people still prefer demolition in most of the cases. The reasons for this choice are the following [Kibert C., 2008], [Macozoma D., 2001]:

- Existing building have not been designed for dismantling.
- Building components have not been designed for disassembly.
- Tools for deconstructing existing buildings often do not exist.
- Disposal costs for demolition waste are frequently low.
- Dismantling buildings require additional time.
- Re-certification of used components is not often possible.
- Building codes often do not address the reuse of building components.
- Economic and environmental benefits are not well established.

In order to find solutions against the disadvantages, a good planning of the process of deconstruction is required. The following steps are important when planning for Deconstruction [1], [8]:

STEP	PROCESS
<u>Permitting and Environmental Assessments</u>	The steps required to obtain a permit and identify hazardous materials are similar to demolition process.
<u>Building inventory/ Site assessment</u>	The most important step of deconstruction is a detailed inventory. It is necessary to estimate the quantity of materials that can be salvaged, their type and condition, the way they are secured to the structure, construction methods and any hazardous materials. All these aspects will affect the cost-effectiveness of salvage.
<u>Planning for Deconstruction</u>	Deconstruction requires a contractor with an understanding of demolition, construction and the efficient flow of materials. Based on the Building inventory, it can be decided whether or not deconstruction is a suitable technique for building removal. The site layout should ensure smooth material removal from the building, processing and storage without conflict with respect to space and timing. Also it is important to take in account that deconstruction requires more time than demolition, depending on the type of building and the size of the crew.
<u>Site conditions</u>	Provide security to the workers and the general public, as in the case of demolition, but also protect the salvaged components and materials. Provide safety to the workers from potential operational hazards. The workers must be aware of critical building supports and ensure that the collapse of the structure is prevented at all times.
<u>Labor</u>	Since building deconstruction is a labour intensive activity, the workers need to be protected from physical and environmental hazards. The contractors need to provide general liability insurance for the project while the workers need to be trained for deconstruction.
<u>Hazardous materials</u>	The regulations for hazardous materials abatement, like ACM and LBP ⁵ , are the same for deconstruction and demolition. Any hazardous material must be identified and removed before a building can be deconstructed.
<u>Building disassembly</u>	The process of deconstruction is simply "construction in reverse". The materials that were installed last in the building are the first to go and so on. Throughout the stripping process, the structural integrity of the building should be monitored to prevent the building from collapsing on its own. When structural components are stripped, it is advisable to erect scaffolding to ensure stability, worker access, mobility and safety. In addition, some building sections may need bracing to maintain rigidity.
<u>Marketing the salvaged materials</u>	Deconstruction requires either a ready market for the salvaged materials or the ability to store the materials (on-site or off-site) until they are sold. If managed properly, salvaged materials can save costs and generate revenue for the project. Factors like the type of materials, year, the strength of the local economy and the current retail price of building materials will affect the net value of the salvaged materials. Different methods to sale secondary building materials are: 1)Direct marketing to retailers, 2)Site sale and auction, 3)Using a broker, 4)Regional periodic auctions, 5)Internet.

Table 2.8 – Deconstruction process

⁵ ACM: Asbestos Containing Material , LBP: Lead-Based Paint

Comparison between Demolition and Deconstruction

Deconstruction and Demolition affect the surroundings and the workers in different ways. Nanda Naber, who did a research about the reuse of hollow core slabs, made a comparison of dust, noise, vibrations and safety between deconstruction and demolition and the results are the following:

Dust	The deconstruction of a building cause less dust compared to demolition due to better control of dust and the less concrete surface that has to be broken. This is good for both the workers and the surroundings.
Noise	The amount of noise produced during demolition and deconstruction does not differ very much so it does not have any difference for the surroundings. The workers have to wear ear protection which increases the risk in case of danger.
Vibrations	The manual deconstruction of a building, especially with a pneumatic hammer, causes a lot of problems to the workers. Cutting or sawing should replace this tool. On the other hand, the demolition of a building is causing more vibrations to the surroundings than deconstruction.
Safety	The deconstruction of a prefab building needs to be planned carefully and remove the elements with caution because the workers are inside and on top of the building. For the surroundings a disassembly process is more favorable when there is not enough space because it will eliminate the risk of damages when the building is demolished.

Table 2.9 - Comparison between demolition and deconstruction

Conclusions

Demolition and Deconstruction have a common goal: remove an existing building in order to empty the plot and/or construct a new one. The main difference is that with Demolition the building is removed and the products of demolition are only suitable for recycle or landfill while with Deconstruction the goal is to dismantle the building in such a way that the elements are suitable for reuse. For this reason Demolition uses mechanical equipment and it lasts a few days while deconstruction uses a mix of labor and mechanical equipment and that’s why it lasts a few weeks.

Both Demolition and Deconstruction are separated in two main phases. For Demolition the first phase is the planning and careful destruction of the building while the second phase is the removal of the debris, preferably for recycle. For Deconstruction the first phase is the detailed planning and careful salvaging of the elements and the second phase is the reuse of the salvaged elements in other buildings.

Also the income of demolition and deconstruction is depended on different factors. Demolition income will depend on the landfilling costs of the C&D wastes, their transportation and their market value as recycled materials while the income from deconstruction will depend on the value of the salvaged materials and the avoidance of landfilling and transportation. This means that as many C&D wastes are diverted from disposal and sold for recycled materials then as higher will be the demolition income. On the other hand the income of deconstruction will be increased if an efficient deconstruction takes place and as long as there is a market for the salvaged materials.

In the Netherlands 95% of the C&D wastes are recycled which minimizes essentially the landfilling costs. This means that demolition has economic advantages through the minimization

of the landfill costs and environmental advantages through the recycle of the C&D wastes. It is an already established method and everybody is familiar with it. Deconstruction has also economic advantages through the selling of the salvaged elements and environmental advantages through the reuse of the elements. The economic advantages of deconstruction can be even higher from demolition but this depends on the existence of a market for second hand elements. This can lead to the conclusion that deconstruction has two main challenges. One is to salvage the materials in the highest quality as possible and the other is to find the markets to sell the salvaged materials.

2.3. BUILDINGS FOR DECONSTRUCTION This section is a research in order to select the building function of buildings which are in favor of deconstruction and reuse of their structural elements in the Netherlands during this period.

Suitable function

The main criterion to choose the most suitable function is the vacancy rate. There are four main building functions in the Netherlands: Houses, Retail, Industries and Offices. Starting from houses, it is estimated that the demand in their market will increase following the growing of the population and some regions will even face scarcity of houses [CBRE, 2012]. The vacancy rate of houses on January 2011 was 4.2% [Regeer, 2012]. As far as it concerns the retail market, the percentage of vacant retail premises in the mid 2012 was approximately 6.8% [Jonas Lang LaSalle-On.point, 2012] while the vacancy rate of the industrial buildings at the end of 2012 was 3.5% [DTZ Zadelhof, 2013]. The office market at the first half of 2013, had a vacancy rate of 14.7% [DTZ Zadelhof, 2013] which placed it at the first position with the highest office vacancy in Europe [Sebus, 2012].

Comparing the above four different building functions, it is clear that the most urgent market for immediate solutions is the office market because of its high vacancy rate. Since demolition and by extension deconstruction is more possible to happen at this market, the research for the reuse of the structural elements from existing buildings will focus on offices. The research of the elements of the other three functions would be also very interesting but due to time limitations it is not feasible for this thesis.

Office development during time

The office market started growing after the 2nd World War due to the increase of business and financial services. Companies started investing on real estate in order to rent them. This created a different situation where the owner is not the user and as result there was distance between them. The Dutch office market experienced the same changes and it is estimated that 65% of the offices in the Netherlands are rental offices (Bak, 2008). This led the rental organizations to feel less attached to their buildings than the owners-users and made it easier for them to move when it was necessary.

The office location has changed according to the needs of each period. During the industrial revolution offices were built near the industries or in the city centers mixed with other functions (Bluestone 1991). Then the separation of industries from other functions was proposed in order to protect the leisure-time of workers. Cities are still being planned based on this idea although the economy is changing from industry to information.

Also during the industrial revolution the first specialized offices were developed by the owners of the industries in order to meet the increase of administration activities. Due to the increase of the employment, standard offices were developed as an effort to meet the demand of all the office organizations in short time and with low cost. This type of offices is not suitable any more for the current flexible way of working [Remøy, 2010].

The situation of the office market in the Netherlands

“The Dutch office market faces the highest vacancy rate in Europe. It is not just over-supplied, it is under-demolished”, said an experienced asset manager who wanted to remain anonymous. “The Netherlands is a grave-yard” said Pierre Vaquier, chief executive officer of AXA Real Estate Investment Managers. The previous quotes show the situation in the Dutch real estate office market. A characteristic example is the KPMG’s former Dutch office (fig. 2.30) in Amstelveen (47.000 m²) which is less than 25 years old and since January 2010 it is empty.



Figure 2.30 - Former KPMG's office in Amstelveen

During the past years, the high office vacancy rate has become a big issue for the Dutch government and the municipalities. The first post-war crisis in the Dutch office market was faced during the 70's and 80's but it was overcome due to the IT and internet service sector. Between 2001 and 2005 there was again a rise of the vacant offices. New offices were still being built without the removal of existing buildings and as a result the vacancy rate at first half of 2013 was 14,70% according to DZT Zadelhof. This percentage is increased compared to the percentage of 2011 (14,10%). There are 7.269.000 m² of empty offices from a total of 49.384.000 m² (see fig. 2.31).

The Netherlands is facing this problem due to a combination of decisions of the Dutch planning system. The increased demand of office buildings at the end of last century led to a structural over-building which was financially supported from the banks for new projects. Together with that, the municipalities, in order to increase their profits started selling land at the perimeter of the cities. This led to a decentralized planning with big business parks across the country [Sebus, 2012].

The situation has changed upon the arrival of the crisis. It started on 2001 and it became more severe after 2008. The crisis forced a lot of companies to move out of their office and seek more efficient solutions. Since the Netherlands has a small size, companies did not have any hesitations to move to another office as distance was not a problem.

Companies do not prefer big offices any more, but they turn to small-scale offices where they develop more efficient use of space and they reduce their rent expenses. This movement was also a result of the new way of working in combination with the rapid development of ICT, where people work less hours or they work from their home [CBRE, 2011].

Due to the above reasons there was a mismatch between demand and supply in the office market which caused an oversupply of office buildings, increasing thus the vacancy rate. Older buildings are left for new buildings that fulfill the demands of the users and as a result the vacancy is a characteristic of the older stock.

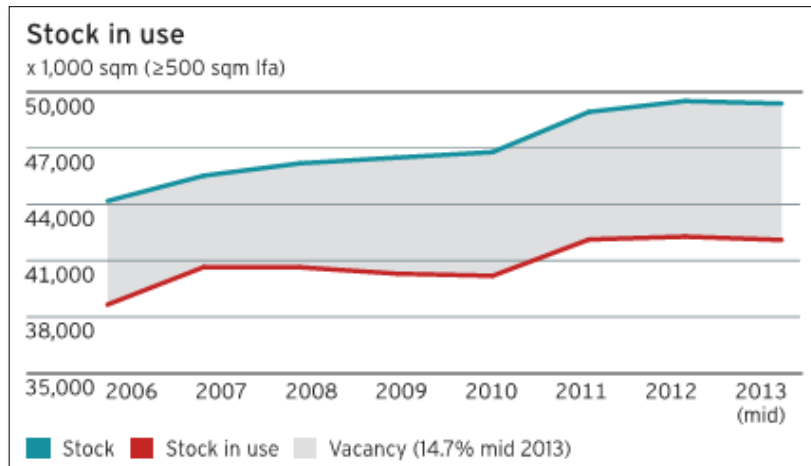


Figure 2.31 - Stock of office buildings at the first half of 2013 (Source: Bak, DTZ Zadelhof)

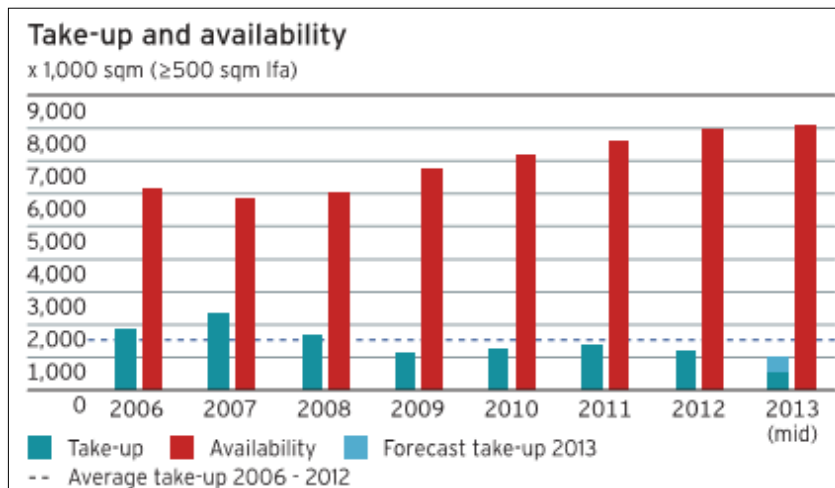


Figure 2.32 - Supply and demand at the first half of 2013 (Source: Bak, DTZ Zadelhof)

The office vacancy can be found in every city in the Netherlands. Table 2.10 shows the situation of the office market in four big cities of the Randstad area at the first half of 2013, where the biggest problems are situated.

CITY	STOCK (m ²)	AVAILABLE (m ²)	VACANT (m ²)	VACANCY RATE (%)
Amsterdam	6.956.000	1.287.000	1.210.000	17,4
Rotterdam	4.744.000	973.000	878.000	18,5
Den Hague	7.225.000	1.213.000	1.023.000	14,2
Utrecht	3.635.000	652.000	504.000	13,9

Table 2.10 - Office market in 4 big cities at the first half of 2013 (Source: Bak, DZT Zadelhof)

In a balanced market it is normal to face vacancy problems (natural vacancy) but when the vacancy rates are increasing for too many years and go above 8% (upper limit of natural vacancy) then the market is unbalanced. When vacancy rate stay high for many years then it is called structural vacancy. As long as the market remains unbalanced and new office space is

continuously added, structural vacancy is growing even higher. Structural vacancy can be defined as the vacancy of the same office spaces that are empty for a period of 3 years or longer and there is no perspective on future tenancy [Remøy, 2010]. Especially, according to DTZ Zadelhof, structural vacant are buildings that are empty for 2 or more years and built before 1990 and buildings that are vacant for 3 or more years and built after 1990.

According to Remøy structural vacant offices have the following characteristics. They:

- were constructed between 1980 and 1995
- are located in locations with insufficient facilities
- are located in low-status locations
- are located in mono-functional office locations
- have less parking places than other office buildings
- are functionally obsolete (inefficient and inflexible)
- have glass facades
- have a low quality interior appearance
- are in technical decay
- are not described by lack of climatic and workplace comfort
- are not described by accessibility by car and public transport

In order to solve the problem of structural vacancy, it has first to be recognized by the building owners and the investor of each building. Also since vacancy is mainly considered a location problem, municipalities are active stakeholders representing societal interests.

The most problematic locations in Holland are the office and industrial parks built after 1980s next to highways or ring roads. The choice of these locations can be understood because at that time the most important characteristic for the location was to be accessible by car [Korteweg, 2002]. The political support for urban expansion and the exclusion of office centers for commercial developments led to the development of mono-functional office parks and industrial sites. These buildings today (30 years later), they are functionally and economically obsolete [Remøy, 2010]. In these areas are located 70% of the structurally vacant office buildings.

Measures to be taken

All the previous mentioned reasons led to an increased oversupply. It is estimated that 80% of the buildings required till 2050 have already been build [The Royal Academy of Engineering, 2010]. As a result the existing stock of offices is sufficient to meet future demands with the addition of little or not at all office space. In order to tackle the oversupply the municipalities and the government divided the areas in terms of their rental prospects. Cuno van Steenhoven, CEO of DTZ Zadelhoff, said that only the 18% of the vacant supply could be characterized as “promising” while the 54% may be characterized as having some rental risk, and the 28% has little or no potential.

According to the Covenant on the Approach to Vacant Office Space, signed on 27 June 2012 between the government and professional organizations in order to revitalize the office market, there are four types of areas [Jonas Lang LaSalle – Pulse, 2012]:

- Growth areas, expansion of stock is still possible.
- Balance areas, consolidating and upgrading of stock.
- Restriction areas, stock will have to shrink, primarily by demolition and refurbishment.
- Transformation areas, integral area development towards different function(s).

The municipality of Amsterdam developed four similar groups with the Covenant:

- Areas experiencing offices decline (contraction areas). In these areas the focus is to reduce the number of offices either by transformation or by demolition. Second priority is the redevelopment.
- Balanced areas. In these areas the existing stock remains the same. A new office can be constructed only after the removal of an old one. First priority is redevelopment and the second is transformation or demolition.
- Areas of limited growth. In these areas there are limited options for adding new office properties. The redevelopment of existing stock is a priority.
- Areas of growth. In these areas, it is possible to add new office properties to the existing stock.

Besides the separation of the areas, the strategy of the municipality of Amsterdam includes the following solutions to tackle the problem of empty offices:

- Redevelopment in order to maintain the quality of the usable office stock at the required level
- Transformation and demolition of office property that has fallen into disuse, with a view to reduce the current stock of office properties
- Reduction and deferral of projected new build projects in line with lower future demand for office space

The most suitable solution will be to redevelop the current office buildings and transform them into buildings suitable for functions like housing, healthcare facilities or student houses. Especially housing is a very good solution due to the increased demand. Factors that affect the transformation of a vacant office are the urban context, safety issues and scale [Sebus, 2012]. Offices in the city centers are easy to be converted because they are easier to attract potential developers or private investors. On the other hand office buildings that are located in areas outside the city center are not favorable for conversion because of their mono-functional area. Also the scale and the shape of the buildings are important, e.g. square buildings are more difficult to transform compared to rectangular buildings.

Although transformation seems to be the best option it is not always possible. Hans de Jonge, chairman of the government’s vacancy advisory committee, competition jury, says that 15-20% of the existing vacant office stock can be given a new function and believes that a “considerable” portion will have to be demolished. According to NVM, 46% of the vacant properties have been empty for at least 3 years compared with 36% a year ago and the demolition of 400.000 m² has kept this percentage low [DutchNews.nl].

Up to now owners are hesitating to demolish their property and they are still waiting for the situation to change (Turpijn 2013). The Covenant mentions that regional funds have to finance demolition. According to Amsterdam’s alderman Maarten van Poelgeest the fund will be €50 million a year and it will be financed by the local authority, the developers and the owners [Jonas Lang LaSalle – Pulse, 2012].

Conclusions

The conclusion that can be derived from this section is that the high vacancy rate of office buildings is a problem that needs immediate solutions, especially for mono-functional areas that face structural vacancy. These offices in mono-functional areas are designed according to the standard office typology and constructed with low technical quality. Redevelopment and transformation of the existing offices are the most suitable solutions but are not always feasible. An important reason is that the location of the offices is unsuitable for housing due to lack of public transportation, safety, facilities and services and without attractive public spaces. Consequently demolition will take place as the only solution. In order to avoid demolition of structures and destroy elements that still have remained structural life and embodied energy, deconstruction is the best option. The results of the above research will be used in order to decide which area has the most suitable buildings for reusing their structural elements.

CHAPTER 3

MANAGEMENT OF THE ELEMENTS

People are familiar with the reuse of second hand objects, from big ones like cars to very small ones like mobile phones, until the moment the objects are not functioning anymore properly and they threw them away. The reasons behind this action are that the costs of fixing a malfunctioning object are higher than buying a new one and also because people are not familiar with the idea of reusing the components of an object. This leads to a big pile of wastes that either they are recycled at a material level or they end up in landfills. The same occurs with buildings. As it was mentioned before office buildings in Netherlands face a very high vacancy. A big number of offices are not able to be reused anymore and the final solution will be to demolish them since it is easier to construct a new building with new elements than deconstructing the old one and reusing the elements.

Figure 3.1. – Demolition wastes
(Source:www.cdglobal.com)



There are some examples in other industries like car industry where some pioneers reused the skeleton of an old car in order to construct a new one. It should be mentioned that the skeleton was from a different type of car. The same can happen with buildings. The achievement of reusing structural elements from buildings depends mostly on the careful design of the process and the management of the elements. It is important to have full awareness of the different processes that will take place in order to have maximum reuse. For this reason this chapter will analyze the different steps of the reuse process.

The first step is to locate the elements, and consequently the buildings, that are going to be reused and create an inventory. This inventory will contain all the important properties which will help their reuse. After having created the inventory it is very important to examine and certify the quality and condition of the structural elements. This starts already from the stage of creating the inventory and continues with visual inspection and specific testing. When all the elements are certified as suitable for reuse, the deconstruction process starts. This step has to be carefully designed in order to acquire elements with the best quality and less costs. The different methods of deconstruction are mentioned. The next stage after removing the elements from a building is to modify them according to the new design. Modification can take place either immediate after deconstruction or during storage. The different storage options are mentioned together with their advantages and disadvantages. Among all the stages, transportation of the elements takes place. It is a very important factor which affects the costs and the environmental impact. Finally, the last step of reusing a structural element is the actual placement in the new construction. At the end of the chapter the conclusions of the process are presented.

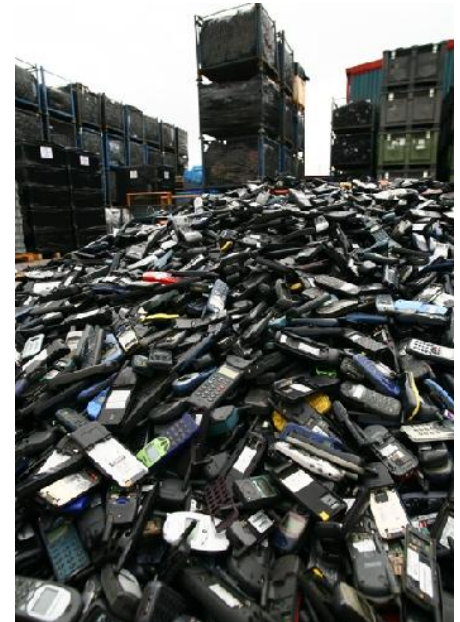


Figure 3.2 - Recycled cell phones
(Source: www.theinquirer.net)

One of the most important steps that have to be made in order to reuse structural elements from an existing building is to create an inventory of its elements. An inventory is: "A detailed, itemized list, report, or record of things in one's possession, especially a periodic survey of all goods and materials in stock" [American Heritage Dictionary] while a database is: "A collection of data or information organized for rapid search and retrieval, especially by a computer which is structured to facilitate storage, retrieval, modification, and deletion of data in conjunction with various data-processing operations." [Britannica Encyclopedia].

3.1. INVENTORY

The term inventory is more suitable for the purpose of this thesis than the term database because of the simplicity. For this thesis the inventory is a detailed, itemized list of structural elements of specific empty or partly empty buildings which contains general information. The purpose of an inventory is to identify the type and quantity of structural elements in a stock of empty buildings. Inventories from different buildings will be computerized and they will create a database from which perspective clients can easily access and review all the properties of an element. As soon as these elements and their properties become known, they can be used to design new buildings.

The buildings that their structural elements will be part of the inventory must be existing empty or partly empty buildings. It should be noted that by creating an inventory for a building it does not mean that the building has to be deconstructed but it has to be considered as an alternative solution besides demolition. The function of the buildings that are suitable for deconstruction

was chosen based on the analysis made on chapter 2.1 where it was shown that the offices are the buildings with the highest vacancy rate and as a result the most urgent for direct solutions. In the future, it will be useful to create the inventories of all the existing buildings, regardless of function and vacancy situation. At the moment, this is already happening for new buildings through the BIM process.

Properties of elements

In order to create an inventory of an existing building, its old drawings and calculations sheets have to be thoroughly inspected. This section presents the properties of each structural element that has to be recorded in an inventory before an inspection (table 3.1-3.8). In this thesis the inventory of the buildings will contain a number of these properties and only a few of the elements that are going to be used at the new design will have a detailed inventory. Also the properties that are needed in a more detailed stage for reusing an element are presented. It should be mentioned that the inventory will contain the details of the original drawings. After the removal from the building a number of details will change. These details will be presented in the Element Identity (EID) which is a type of certificated. EID will be analyzed in the quality check section.

BEAMS

GENERAL	MATERIAL	TYPE	SECTION	DIMENSIONS
Address Construction year Label Quantity Level	Type of concrete Type of steel	Precast Pre-stressed Post-tensed Cast-in-situ	Rectangular L Tee Inverted Tee	Span (L) Overall height(H) Width (W)

Table 3.1 – Beams – Inventory properties

REINFORCEMENT	SECTION	DAMAGES	LOAD	MODIFICATION	PROPERTIES
Amount Area Location	Effective depth (d) Cover Area	Location Type Severity	Max. Moment Max. Shear	Sawing Drilling Protection	Weight Volume

Table 3.2 – Beams – Element Identity properties

COLUMNS

GENERAL	MATERIAL	TYPE	SECTION	DIMENSIONS
Address Construction year Label Quantity Level	Type of concrete Type of steel	Precast Pre-stressed Post-tensed Cast-in-situ	Rectangular Round	Clear height (L) Section height (H) Width (W)

Table 3.3 – Columns – Inventory properties

REINFORCEMENT	SECTION	DAMAGES	LOAD	MODIFICATION	PROPERTIES
Amount Area Location	Effective depth (d) Cover Area	Location Type Severity	Max. Axial	Sawing Drilling	Weight Volume

Table 3.4 – Columns – Element Identity properties

WALLS

GENERAL	MATERIAL	TYPE	SECTION	DIMENSIONS
Address Construction year Label Quantity Level	Type of concrete Type of steel	Precast Pre-stressed Post-tensed Cast-in-situ	Rectangular	Clear height (L) Section height (H) Width (W)

Table 3.5 – Walls – Inventory properties

REINFORCEMENT	SECTION	DAMAGES	LOAD	MODIFICATION	PROPERTIES
Amount Area Location	Effective depth (d) Cover Area	Location Type Severity	Max. Axial	Sawing Drilling	Weight Volume

Table 3.6 – Walls – Element identity properties

HOLLOW CORE SLABS

GENERAL	MATERIAL	TYPE	SECTION	DIMENSIONS
Address Construction year Label Quantity Level	Type of concrete Type of steel	Precast Pre-stressed Post-tensed Cast-in-situ	Rectangular Round	Clear height (L) Section height (H) Width (W)

Table 3.7 – Hollow core slabs – Inventory properties

REINFORCEMENT	SECTION	DAMAGES	LOAD	MODIFICATION	PROPERTIES
Amount Area Location	Effective depth (d) Cover Area	Location Type Severity	Max. Axial	Sawing Drilling	Weight Volume

Table 3.8 – Hollow core slabs – Element Identity properties

Besides the already mentioned properties, EID will contain extra information about the following:

- Structural system
- Environmental gains
- Cost analysis

Area

The Netherlands had at the first half of 2013 a 14,7% vacancy rate in office buildings. This is the average vacancy rate in the country but there are areas that have much higher percentage. For example the highest vacancy rate is spotted at Capelle aan den IJssel with a 28,1% but only 140.000 m² available. The high vacancy rate has to be minimized but the small amount of available m² doesn't make the area of high priority. On the other hand, Amsterdam is one of the cities that measures should be taken immediately in order to minimize the square meters of empty offices. At the end of 2011, Amsterdam was the city with the highest vacancy rate between big European cities (see table 3.9). At the mid of 2013 the vacancy rate of offices in Amsterdam was 14,4% and there were 1.210.000 m² available. It is calculated that 60% percent of the empty office space in Amsterdam face structural vacancy [Remøy, 2009].

CITIES	Q4 2012	Q4 2011	Q4 2010
Paris	7,7	7,6	7,5
Moscow	10,5	11,0	16,0
London	6,6	6,9	7,5
Frankfurt	12,5	13,2	13,3
Madrid	15,1	13,4	12,9
Brussels	10,7	11,2	11,5
Amsterdam	18,0	18,0	19,8
Rome	6,5	6,2	5,8
Luxembourg	5,2	6,0	7,2
Stockholm	9,0	9,3	11,1

Table 3.9 - Vacancy rate Europe (Source: BNP PARIBAS Real Estate research 2013)

According to DZT Zadelhof some districts have a vacancy rate of 25-30%. As mentioned in chapter 2.1, the office areas in Amsterdam are divided in 4 categories:

- 1) Contraction areas: Teleport Sloterdijk and Amstel III. The goal in these areas is to reduce the number of offices by transformation or demolition.
- 2) Balanced areas: Overamstel and Schinkel. In these areas in order to build a new office an old one should be demolished.
- 3) Limited Growth areas: Riekerpolder and Amstel Station. Redevelopment of the existing stock is a priority while there are a few opportunities for new offices.
- 4) Growth areas: Zuidas and NDSM precincts. In these areas it is possible to construct new offices.

From the above categorization it can be concluded that the most problematic areas are Teleport Sloterdijk, Amstel III, Overamstel and Schinkel. After the meeting with Ingrid Turpijn from the Kantorenloods of the Municipality of Amsterdam it was decided that Amstel III is a suitable area for research because it is a mono-functional office area and it is difficult to transform them into a new function. The plan “Strategiebesluit Amstel II van monofunctioneel werkgebied naar multifunctionele stadswijk” made by Projectbureau Zuidoostlob was used for the analysis of the area.

Amstel III is located at the Northeast of Amsterdam and it was constructed at the end of 70s (mainly from concrete) as part of the urban expansion in the Bijlmermeer. At the past it was consisted from two unequal areas of offices and companies (300 m and 900 m wide respectively) but now they are both circa 600 m wide (see fig. 3.3). Today it is the 3rd largest worksite of Amsterdam with 26.975 employees. Due to the fact that the office region is a mono-functional office area, it faces problems of vacancy and it is often considered as a characteristic example for this kind of areas. The whole area is approximately 1.2 million m² and the total office area is 730.307 m² (see fig. 3.4). From these square meters 188.660 m² are empty which result to a vacancy rate of 25,80%. It is estimated that 50% of the empty offices have structural vacancy which means that they will not be used again as offices in the future.

Structural vacancy affects different actors. The owner of the building has loss of income and at the same time he has to pay for maintenance, insurance and taxes. Moreover, structural vacancy is a problem for the society. The location is decaying and downgrading because the owner is not willing to pay a lot of money for maintenance [Remøy, 2009]. The main reasons of the high vacancy rate are the new way of working, the availability in the area, the preference for new

buildings and the reduction of the working force. Modern companies want an urban environment with facilities and space where people can meet and discuss. This environment does not exist in Amstel III.

Measures have to be taken to reverse this situation otherwise a lot of people will lose their jobs. Proper solutions are the transformation of the existing empty buildings or the demolition and construction of new buildings with new functions that will improve the area. The main problem of these solutions is that the vacancy is spread across the area: only 10 of the 115 buildings are empty. Another reason is that the existing office building does not fulfill the current or future requirements.

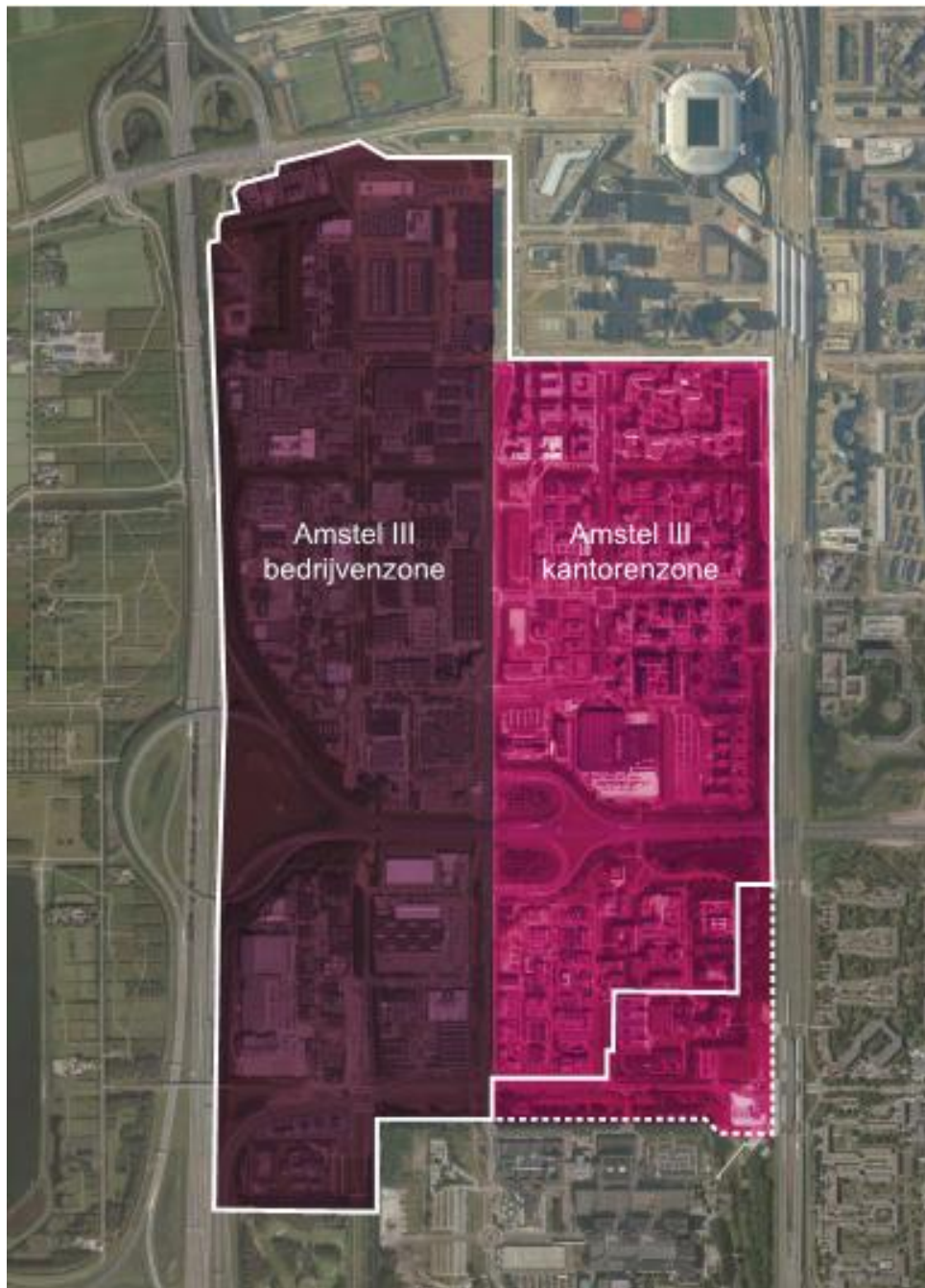


Figure 3.3 - Map of Amstel III –Business and office area (Source: Strategiebepsluit Amstel III-Projectbureau Zuidoostlob)

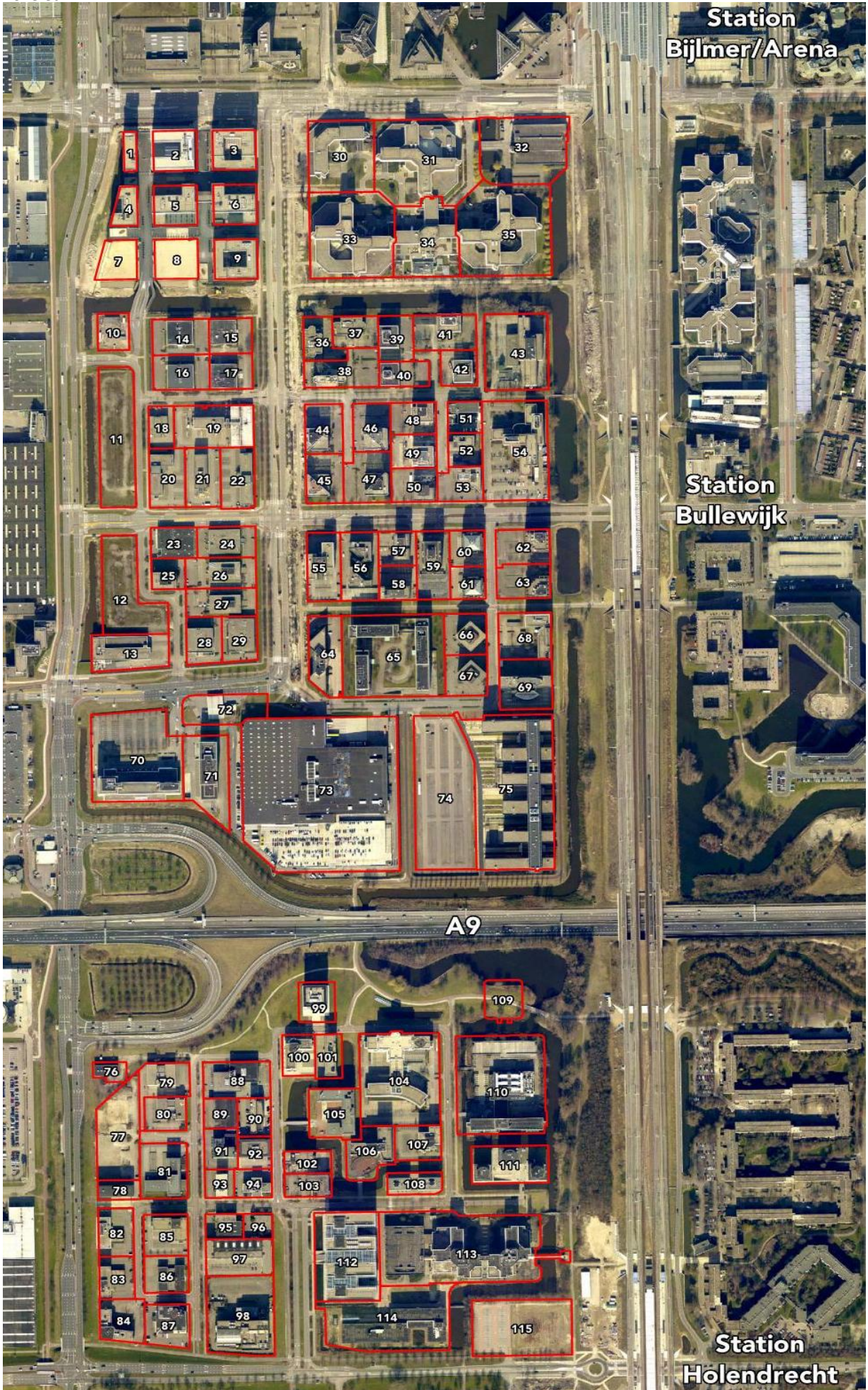
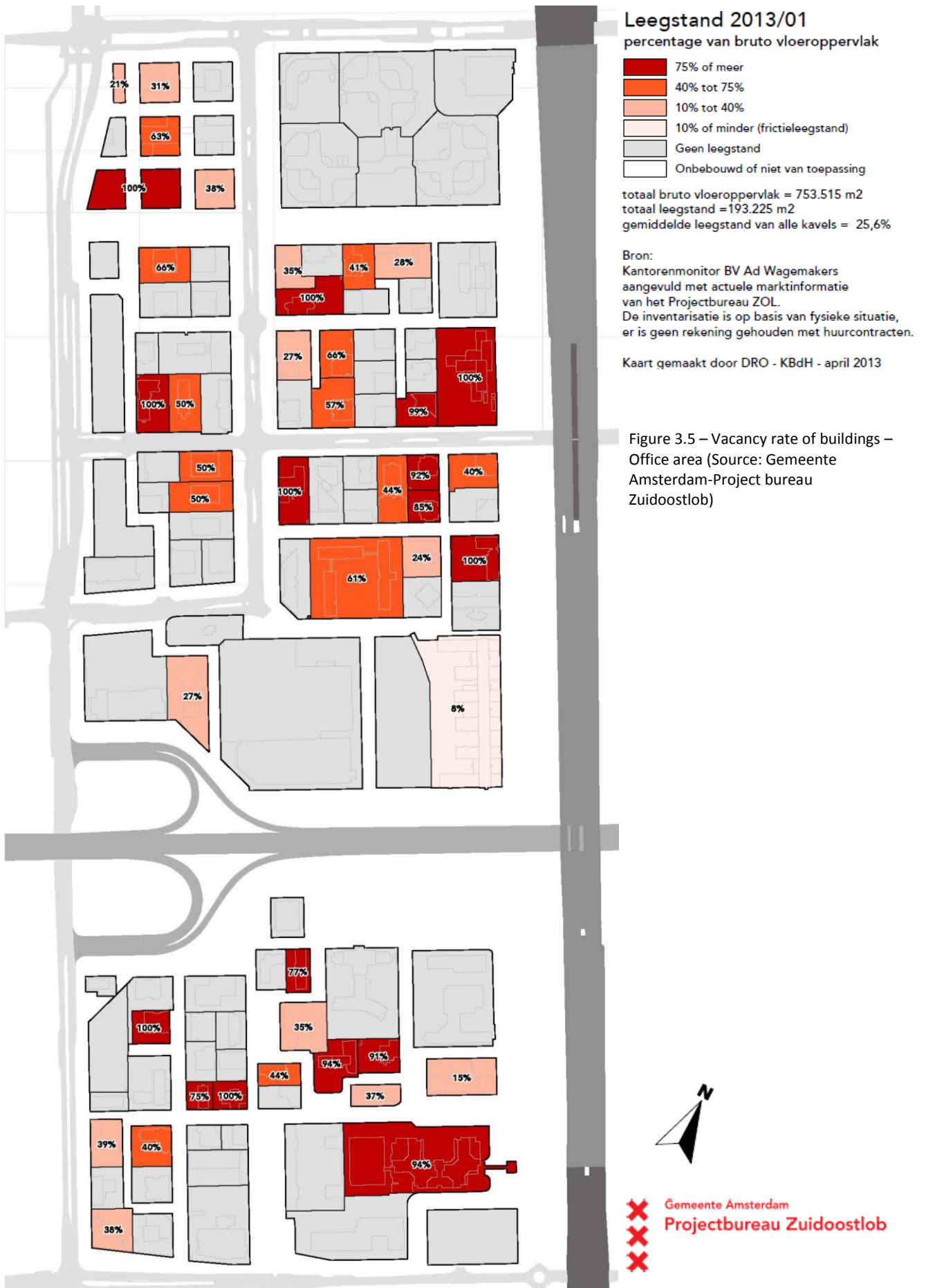


Figure 3.4 – Plot numbering of Amstel III – Office area (Source: Gemeente Amsterdam-Project bureau Zuidoostlob)



Buildings

As can be seen in fig. 3.5 a lot of buildings are vacant. The main problem of the area is that the vacancy is spread among all the buildings. Only a few building are complete or they have high percentage of vacancy and specifically 15 of them are vacant more than 75%. The existing solutions to the vacancy are transformation and reuse of the whole building or demolition. This master thesis proposes a third solution, the deconstruction of the buildings. The goal of the inventory is to include buildings that are empty (preferable facing structural vacancy) which enables them as suitable buildings for deconstruction. For the case study of the thesis 8 buildings were selected in order to create an inventory which will be used to design new structures. The selection criteria of those buildings are the vacancy percentage and the year of construction. Buildings constructed after 1990 are not selected because the possibilities to be deconstructed are less than those build before 1990. There were more buildings that were empty but it was decided not to be selected because they would not add anything extra at the process of the thesis.

PLOT NUMBER	ADDRESS	CONSTRUCTION YEAR	VACANCY	OWNER
38	Hogehilweg 3	1984	100 %	Real estate investment
39	Hogehilweg 15	1984	41 %	Institutional investor
46	Hogehilweg 10	1986	64 %	Institutional investor
53	Hogehilweg 18	1989	99 %	Institutional investor
54	Hogehilweg 22	1983	100 %	Institutional investor
55	Karspeldreef 2	1988	100 %	Housing corporation
80	Paasheuvelweg 8	1988	100 %	Real estate investment
113	Paalberweg 9	1980	94 %	Project developer

Table 3.10– Buildings included in the inventory

The inventory of those buildings was created with detailed inspection and analysis of the existing drawings which were obtained from the municipality of Amsterdam, Environmental and Building Department. Since these buildings are more than 25 years old, their drawings cannot be found in digital format but only in stacks of folders. For this reason only the necessary drawings were taken in order to limit the costs and the amount of drawings. For a real project it is advised to take all the documents in order to minimize the chances of missing the necessary drawing or document during the creation of the inventory and avoid any delays. Also it is possible that a number of drawings might be lost during the years. The solution for this situation is either to search for the drawings from other sources (e.g. owner, engineer) or inspect the building. This will be analyzed in section 3.2.

The selection of the necessary drawings was made after a quick inspection of a large amount of folders. In order to be computer accessible and accelerate the inspection process, they were photographed in parts (for better resolution) and later on they were edited as whole drawings. Another way to store the drawings in a computer is by scanning but this increases dramatically the costs. The drawings were separated in buildings and in categories in order to access them easier. All the drawings from every building were examined in detail and their inventory was created.

A short description of the properties of each building is presented and they are examined whether they are suitable or not for deconstruction. Also a summary of the inventory of each building is presented. The detailed inventory of each building can be found In Appendix I together with a sample of the original drawings.

HOGEHILWEG 3

The office building in Hogehilweg 3 was constructed in 1984. It is a 7-stories high building with 100% vacancy. There are 3 types of structural elements (columns, walls, slabs) and they are made from cast-in-situ concrete. Specifically the floors are made from pre-stressed steel⁶ which leads to the absence of beams. The pre-tensioned slabs cannot be reused after deconstruction because the tendons have to be cut and the capacity of the steel will be lost. The deconstruction costs will be high due to necessary extra safety measures. The only elements that can be reused are the columns and walls, but deconstructing them will cost much more than buying new elements. Therefore this building is not suitable for deconstruction.



Figure 3.6 - Office building on Hogehilweg 3

HOGEHILWEG 10

The office building in Hogehilweg 10 was constructed in 1986. It is a 7-stories high building with 64% vacancy. In this building there are only columns, walls and slabs made from cast-in-situ concrete. The slabs are pre-tensioned. For the same reasons as for the building in Hogehilweg 3, this building is also not suitable for deconstruction.



Figure 3.7 - Office building on Hogehilweg 10

HOGEHILWEG 15

The office building in Hogehilweg 15 was constructed in 1984. It is a 6-stories high building with 41% vacancy. Like the two previous buildings, there are 3 types of structural elements namely columns, walls and slabs and they are made from cast-in-situ concrete. The slabs are pre-tensioned and for the same reasons that were mentioned for the previous buildings, this building is not suitable for deconstruction.



Figure 3.8- Office building on Hogehilweg 15

⁶ V.Z.A. (Voorspanning Zonder Aanhechting). Pretension without attachment



Figure 3.9 - Office building on Hogehilweg 18

HOGEHILWEG 18

The office building in Hogehilweg 18 was constructed in 1988. It is a 5-stories high building with 99% vacancy. Unlike with the previous buildings this contains 5 types of structural elements namely beams, columns, walls, slabs and façade beams and all of them are made from precast concrete. Since all the elements can be reused, this building is suitable for deconstruction.



Figure 3.10 - Office building on Hogehilweg 22

HOGEHILWEG 22

The office building in Hogehilweg 22 was constructed in 1983. It is an 8-stories high building with 100% vacancy. This building contains also 5 types of elements (beams, columns, walls, slabs and façade beams) with the only difference that the walls are made from cast-in-situ concrete and the rest from precast concrete. The fact that the walls are made cast-in-situ does not forbid their reuse. As a result, due to the large number of reusable elements the building is suitable for deconstruction. Nevertheless, the only elements that are possible to be reused are the slabs because there are limited drawings for the rest of the elements. For the purpose of this thesis the elements from this building are not used but in a real project, the details of the elements can be known through inspection.



Figure 3.11- Office building on Karspeldreef 2

KARSPELDREEF 2

The office building in Karspeldreef 2 was constructed in 1988. It is a 6-stories high building with 100% vacancy. This building contains 4 types of elements (beams, columns, walls and slabs) and they are all made from precast concrete. Since all of the elements are possible to be reused this building is suitable for deconstruction.

PAASHEUVELWEG 8

The office building in Paasheuvelweg 8 was constructed in 1988. It is a 3-stories high building with 100% vacancy. It contains 5 types of elements: beams, columns, walls, slabs and façade elements. The difference with the previous buildings is that the beams and the slabs are precast elements but the columns and the walls are cast-in-situ elements. Regardless this, all of the elements are possible to be reused and as a result this building is suitable for deconstruction.



Figure 3.12 - Office building on Paasheuvelweg 8

PAALBERWEG 9

The office building in Paalberweg 9 was constructed in 1980. It is an 8-stories high building with 100% vacancy. It contains 5 types of elements: beams, columns, walls, slabs and façade beams. The walls are cast-in-situ and the rest are precast elements. The large amount of elements enables the building suitable for deconstruction but like the building in Hogehilweg 22, there are a limited number of drawings and although it is suitable for deconstruction it will not be used for the case study of this thesis.



Figure 3.13 - Office building on Paalberweg 9

3.2. QUALITY CHECK FOR REUSE

The quality check is fulfilled in eight steps. The different steps can be seen at the following flowchart:

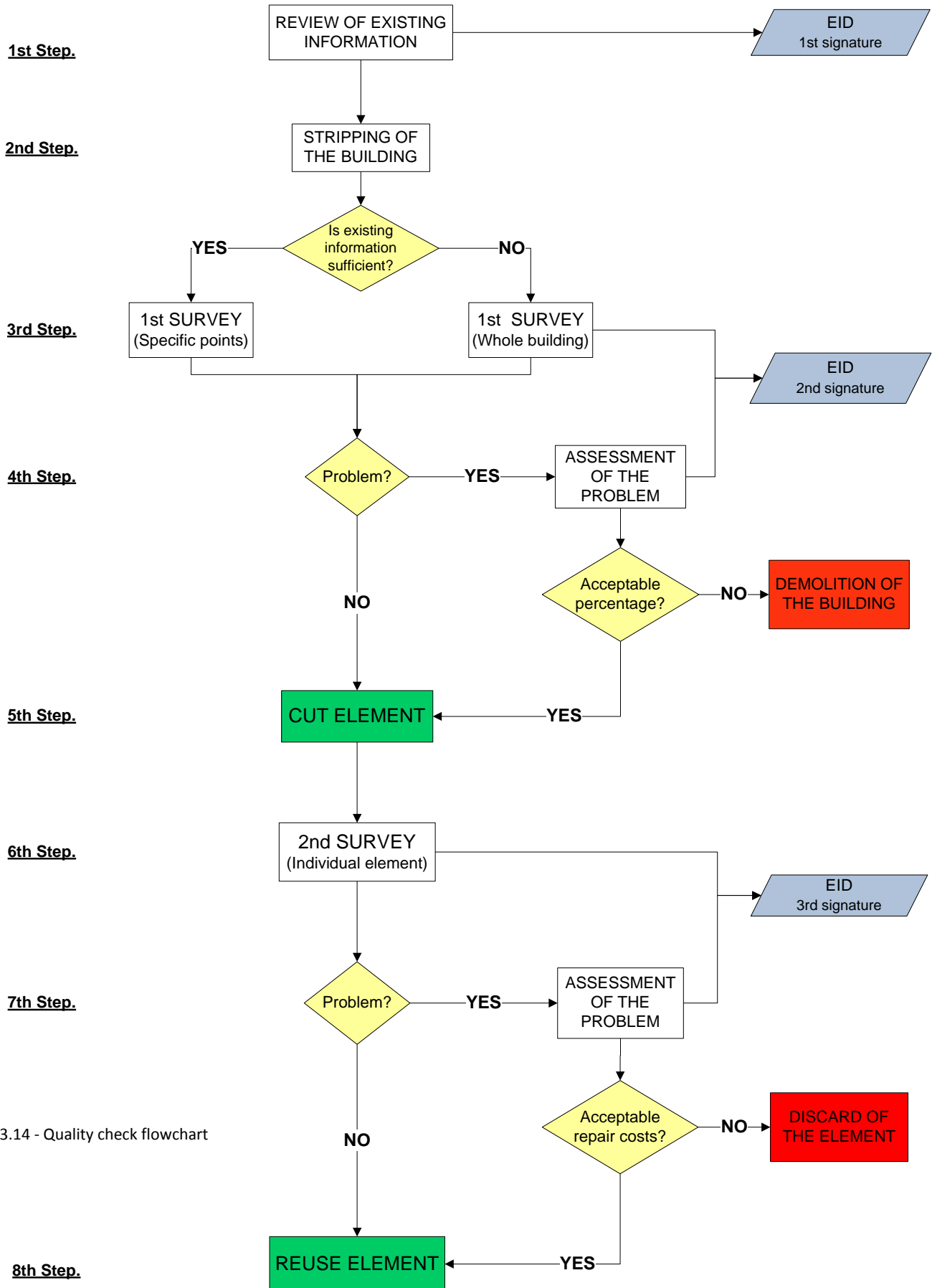


Figure 3.14 - Quality check flowchart

Due to changes during the construction process, the structural elements of a building might have different properties (e.g. dimensions, position, and material) than the ones mentioned in the original drawings. Also during the service life of the building, changes and damages might have occurred that will not allow the reuse of the element. In order to be sure that the elements from an existing building can be reused without risk, a quality check must be performed. The process of the quality check is presented in a flow chart in figure 3.14.

The purpose of assessing the elements is to examine the following issues:

- Mismatches between the original drawings and the real project.
- Structural integrity of the element.
- Durability – damages.

1st step: Research/ Review of any existing information

The goal of this step is to gather any existing information concerning the design, construction and service life of existing empty buildings that are going to be deconstructed in the near future. This information will be reviewed before the onsite inspection. It will be an asset to define the existing condition of the elements.

Information for the original design can be found in:

- Architectural and structural drawings and specifications (preferably structural drawings)
- Structural design calculations
- Material specifications
- Standards and local codes in effect at the time of construction

Possible sources of building documentation are:

- Local building department records (e.g. municipality)
- Files of the original or successor design firms and contractors
- Building owner and on-site staff interviews

All these information will make more easy and accurate the evaluation of the building and it will give a first impression of the difficulty to deconstruct it. In case that the information is not available or insufficient, the engineer must obtain the required information and data on site (Step 3). The research can be performed by a qualified engineer or by a research firm, who should become familiar with the design code and detailing practices in effect when the building was constructed.

Moreover, during this step, the inventory of the structural elements will be created. While the engineers are reviewing the available information, they can note the properties of each structural element and create the building inventory. As it was mentioned, the inventory contains basic information for all the structural elements that can be found in a building. This will be very useful for the deconstruction and the future reuse of each element. Next to the inventory the **Element Identity** (EID) of each individual element is created. The EID contains more details about the properties of the element than the inventory and it can be used as an element certificate. This certificate will reassure all prospective users (engineers, contractors, users, government) that the element is safe to be reused.

By the end of the 1st step, the EID will be at a preliminary phase because it will include information only from the review of the existing documentation. EID will be finalized after the completion of the 1st survey (step 3) and the 2nd survey (step 6). The properties will be different depending on the type of the element. Each time a step is finalized, the responsible engineer will

sign to confirm that the element is approved. The EID can also be used for new buildings. A lot effort is already made to gather all the information in one database with the BIM process during the design phase. A draft of an EID data form is shown in figure 3.15.

<u>ELEMENT IDENTITY (EID)</u>		
<u>BUILDING</u>		
Name:		<div style="border: 1px solid black; width: 100%; height: 100%; display: flex; align-items: center; justify-content: center;"> <p>PICTURE OF THE ELEMENT</p> </div>
Address:		
Year (drawing):		
Function:		
Location of the element:		
Structural system:		
<u>MATERIAL PROPERTIES</u>		
Concrete (f_{ck}):		
Steel (f_{yk}):		
<u>DIMENSIONS</u>		
Height:		
Length:		
Width:		
Type:		
Effective depth:		
<u>REINFORCEMENT</u>		
Main rebars:		
Stirrups:		
Cover:		
<u>LOADS</u>		
Maximum moment:		
Maximum shear:		
Maximum load:		
<u>OTHER CHARACTERISTICS</u>		
Openings:		
Damages:		
Environmental conditions:		
Type:		
Quantity:		
Price:		
Possible use:		
LCA:		
1) Existing information (Signature)	2) 1 st Survey (Signature)	3) 2 nd Survey (Signature)

Figure 3.15 - Draft Element Identity (EID)

2nd step: Stripping of the building

Stripping is a step that must be done when the building is meant to be demolished or deconstructed. During this step all the non-structural elements are removed and only the structural system is left standing. Buildings that are meant to be stripped are those that are already empty and they need to be removed because there is no future use.

Empty building meant to be deconstructed:

In this case the owner of the building wants to build something new or he wants to reuse the structural elements for another project. Since the building has to be removed the first step is stripping. After stripping it is easier to perform visual inspection and testing (step 3). When the 1st survey is completed the building can be deconstructed. After deconstruction the elements can be reused immediately or stored at a storage site.



Figure 3.16 – A stripped building in Thessaloniki

Empty building not meant to be deconstructed:

In this case the building is empty but it is not decided to be removed. Stripping of the building is not advisable because it is not known when and if it will be deconstructed. By keeping the building envelope, the structural elements are protected from the environment and in the same time it can be reused for a new function. Although the building is not yet meant to be deconstructed, step 3 can take place in advance for a future deconstruction. The existence of internal and external non-structural elements will make the testing and visual inspection of the building more difficult and as a result more costly. Therefore, the inspection should take place when the building remains vacant for a significant time and extra solutions for reusing the building are needed. When it is decided to consider deconstruction as a solution the building can be stripped internally. This will make the inspection easier and less costly.



Figure 3.17 – Building stripped from inside (Source: www.ggardner.myzen.co.uk/wordpressblog/?p=2250)

3rd step: 1st Survey – Elements attached on the building

After having collected and reviewed all the necessary information, the next step is an onsite survey in order to check the building’s structural condition and capacity. Moreover, the engineer will verify that the existing structural system and components meet the intent of the original design. The survey includes a number of tests and visual inspection. According to Joop Bovend'eert, manager of damage-expertise and inspection department of BAS – Research and Technology, the properties that need to be checked in order to certify an element as reusable are: **dimensions, reinforcement properties and concrete strength**. The nature and extent of the survey will vary, depending on the requirements of the client and the form of the building or structure. At the end of the survey a report will be made with all the results.

As long as existing construction drawings, calculations and specifications can be verified by non-destructive test and visual inspection, then it can be assumed that the building is constructed according to the existing information. This means that the risk of inadequate load-bearing capacity, by e.g. deviating bar diameter or different steel grade, is regarded as small.

- Sufficient existing information:

The research during step 1 has resulted in a sufficient amount of information in order to have a clear view of the structural properties of the building elements. In order to be sure that the information of the drawings matches with the actual construction, general testing and visual inspection have to be done. Also potential damages can be identified through this process. The existence of original drawings minimizes the amount of tests and time needed to perform the survey and as a result costs are reduced (Bovend'eert, 2013).

Reinforcement properties

From the review of the original drawings it is already known how the reinforcement is constructed but it is possible the real situation to be different. In order to minimize the risk of mismatches between the drawings and the real situation a number of tests must be done with the aid of a ferroskan or a ground-penetrating radar.



Figure 3.18 - Ferroskan



Figure 3.19 - Ground-penetrating radar

They are non-destructive tests and will verify the location, diameter, cover, spacing and number of steel reinforcing bars. The strength of the steel is mentioned on the drawings and only in case of old buildings (before 1975) testing is needed. The testing will be conducted in specific critical spots. If the results from the specific spots match with the original drawings then most probably the whole building matches with the drawings. In case the results don't match then an extended inspection of all the building is needed in order to find the actual reinforcement properties. If for any reason it is not possible to do the measurements or there are doubts for the results then

small cores are drilled on the reinforcement and a number of tests can be done that will provide the necessary information (Bovend'eert, 2013).

Concrete properties

The most important concrete property in order to reuse structural concrete elements is compressive strength. This can be tested with different methods but the most accurate is core drilling. In order to test the compressive strength, 3 to 15 cores need to be drilled depending on the size of the building. It is also possible to test other properties like the elasticity modulus, the bending strength, the tensile strength but extra cores are needed to be drilled. In order to test the tensile strength, 3 to 9 cores are needed (Bovend'eert, 2013).



Figure 3.20 - Concrete core



Figure 3.21 - Core drilling

There are also other tests that can estimate the in-place concrete compressive strength but they are not as accurate as core drilling. Some of them are presented in the following pictures:



Figure 3.25- Rebound hammer



Figure 3.22 - Probe penetration



Figure 3.23 - Pullout test



Figure 3.24 - UltraSonic Pulse Velocity (USPV)

Visual Inspection

With visual inspection all visual distress, deterioration and damage (spalling, cracking, etc) existing on the critical and representative structural components of the structure have to be located. It is necessary to obtain accurate information on the member properties, dimensions and positioning of the structural components in the building. It is easier to visual inspect the building if it is stripped from non-structural elements. Then all the structure is free to be examined. On the other hand, if it is not stripped, the inspection should be made in specific critical points because either wise it will cost a lot of money to examine all the elements.

Issues that have to be examined/ noted with visual inspection:

- Structural modification
- Dimension of elements
- Connections
- Damages from excess or improper loading
- Deflection
- Crack survey
- Delamination/ spalling survey
- Carbonation, chloride ingress, corrosion survey
- Unusual structural features
- Settlement or foundation problems
- Honeycombs



Figure 3.26 - Corrosion



Figure 3.27 - Crack survey



Figure 3.28 - Honeycomb



Figure 3.29 - Delamination / spalling

- Not sufficient existing information:

In case that the existing information is not sufficient, an extended inspection of the whole building is needed. The tests are the same with the case that the existing information is sufficient only this time more specimens are needed. After the survey new drawings are made that indicates the location of the structural elements, the position of the reinforcement and the properties of concrete and steel (Bovend'eert, 2013).

As long as there are no damages and the existing information matches with the results from general testing and visual inspection then the elements can be cut or they are marked as suitable to be cut (step 5). Also the EID will have its second signature. In the occasion that there is a mismatch between the original drawings and the results of the survey or the elements are damaged then an assessment of the problem is needed (step 4).

4th step: Assessment of the problem

If the outcome of the 1st survey shows that a number of elements are not suitable to be cut, then assessment of the problem is required. This means that an analytical assessment is needed which includes more specific tests and more detailed calculations.

With visual inspection any cracks, deterioration and abnormalities were recorded according to type, magnitude, location and severity. It should be made clear that not all the cracks need to be tested. When it is believed that the crack or deterioration are influencing the structural integrity of the element then extra testing is needed. In case there are indications that the damage is caused by the environment then extra testing is conducted. It is possible to calculate the carbonation depth, chloride ingress and corrosion potential but environmental damages are not usually an issue for office buildings. Nevertheless, selective tests can be done in order to reassure that damages will not occur during the reuse phase of the elements.

Internal concrete structures are everlasting as there are no mechanisms that will damage indoor concrete in normal condition. Their service life is assumed to be 200 years (European Concrete Platform ASBL, February 2009). Only if there is a visual mark that leads to environmental problem then extra tests are needed.

In case the existing structure does not match with the original drawings, extra analysis is needed in order to calculate the structural capacity of the elements. The fact that there is a mismatch, it does not mean that the elements cannot be reused. They can be reused but for different loads than the ones mentioned in the original calculations. Potential mismatches can be:

- Different element dimensions.
- Differences in the structural system.
- An element is missing or it is in the wrong position.

After the assessment of the damages it will be decided if the repair costs are acceptable or not. In case the costs of the damage are not acceptable then the element is marked as unsuitable for reuse. After the assessment of all elements, the percentage of suitable and non-suitable elements is derived. This percentage has to be above a certain level in order to achieve an economical feasible reuse. (e.g. 80% - 90%). If the percentage of the suitable elements is below this specified percentage then the damages of the elements are not worth to be repaired and as a result the building must be demolished. The percentage is different for each building and it depends on the type and the amount of the elements that can be reused.

5th step: Cut elements

At this step the properties of the structural elements are verified or became known and the element has been approved after being tested and visual inspected. This means that the quality check that has been made until now, concerning the structural properties, permits the cutting of the element. The elements can be either transferred, immediately after cutting, to the new construction site or can be stored and used in the future. After cutting the elements, a 2nd second final survey will be conducted and it will be made individually for each element (step 6).

6th step: 2nd survey – Elements detached from the building

During this step the Element Identity will be finalized. The most important information is already obtained from step 1 and step 4. After the element is approved from the 1st survey, the element is cut according to the specifications of the client or with the less possible damage. Then the element can be either reused immediately or send to the storage site.

Before reusing the element or at the storage site a 2nd survey is carried out, with visual inspection at the section of the element which will reassure 100% the existing drawings with the testing that was made. One issue that can be checked at this step is potential cracks that were created at the element during the cutting process (Bovend’eert, 2013). The advantage of a deconstructed element is that it can be examined thoroughly at the place that it was cut.

If the 2nd survey is successful then the element will have a final Element Identity and it will be certified as suitable for reuse (step 8). After a successful 2nd survey the element transferred to the construction site or at the storage site. In case the 2nd survey is not successful then the element has to be assessed again and examine whether the repair costs are acceptable or not (step 7).

During the 2nd survey any necessary modifications can be made. Especially, if there is already a buyer then the element will be modified according to the demands of the client. Otherwise a small maintenance will be made and then it will be stored at the storage site.

Maintenance – Modification:

- Painting
- Coating
- Filling of holes
- Remove any screws, nails, etc
- Modify the shape according to the clients demand
- Create holes for the new connection

7th step: Assessment of the problem

This step will assess any damage or unexpected issue that was found during step 6. As long as the repair of the damage is financial acceptable then the element can be maintained and finally reused (step 8). In case it is not acceptable then the element will be discarded. Since this element will not be reused as a structural element it can be used for extra destructive testing that will give some extra information about the properties of the materials (Bovend’eert, 2013).

8th step: Reuse of the element

Since the structural element has successfully passed both the 1st and 2nd survey then it is suitable for reuse. The element is located either in a storage site or it is transferred directly to the new construction site. Each element at the end of the quality check will have its own Element Identity (EID) which will contain all the necessary information for the structural engineer and architect that wants to reuse it. All the potential buyers will be able to find the EID of each element with all its properties online.

Deconstruction is the most important process of the management of elements. It is a process that has to be made very carefully in order to achieve the largest quantity of elements with the highest quality and the less damage. One solution to achieve highest quality is to use the same workers for the deconstruction and for the construction. In this way the workers will be more careful during the removal of the elements because if they don't do that they will have problems during the construction.

3.3. DECONSTRUCTION

In this section the process of deconstruction is analyzed for the type of buildings that were chosen as suitable for deconstruction in section 3.1. It is important to do this analysis in order to have a clear view about the process and the calculation of the costs. The different steps analyze the removal of the elements from one floor. It is assumed that the building is already stripped and only the structural elements are left. The estimations, the planning and the design of the process were made with the aid of the demolition advisor René de Hoog. The steps of the process are:

- Remove concrete topping
- Remove Hollow Core Slabs
- Remove Façade beams
- Remove Beams
- Remove Columns
- Remove Walls

Remove concrete topping

Concrete topping is a concrete layer above the Hollow Core Slabs and it can have two functions. These are:

i) Compression layer. It connects the slabs and allows the transfer of the lateral loads (diaphragm action). In this case the layer has a minimum thickness of 50 mm and it includes reinforcement. In order to remove the HCS, this layer can either be completely removed or be left on top of the slabs. If it is decided to be left on top of the slabs, the joints of the slabs have to be located in order to remove them. This might create difficulties because it is not sure where the joints are located. Secondly, if it is saw it cannot be used again as a compression layer since the reinforcement is cut. As a result a new layer has to be placed above it during the construction and the old one will create only extra loading. For these reasons it is decided to remove the existing compression layer. This can be done with a compressor with hammers.

ii) Finishing layer. The thickness of this layer is usually 20 to 30 mm and it doesn't include any reinforcement. Like before if the layer is left on top it will just add extra load so the best solution

is to remove it. This can be done again with a compressor with hammers. The removal will be faster than the compression layer because it is thinner and there is no reinforcement.

For the removal of the concrete layer the following workers are needed:

- 2 workers that will hack the concrete layer with a compressor with hammer.
- 1 worker that will shovel the debris from the hacking.
- 1 worker that will remove the debris through a tube.

A compression layer is 50 mm thick or more and it includes reinforcement. This makes the removal harder and slower so it is estimated that 4 workers can remove 150 m²/day. On the other hand the removal of a concrete layer functioning as a finishing is easier because it is 30mm thick and it doesn't include reinforcement so it can be removed faster. It is estimated that 4 workers can remove 200 m²/day.

Remove Hollow Core Slabs

The next step after removing the concrete layer is to remove the Hollow Core Slabs. The removal will start from the roof of the building. Before doing that the following processes have to be done:

1) Support walls and columns. It is important, for safety reasons, to support the walls and columns below the HCS that are meant to be removed. This can be done with the use of shores. It is suggested to support the walls after the removal of the concrete layer. Some columns are double or triple stories high so they have to be supported only once at the lower part of the column. Usually 2 shores are needed for a column and 2 or more for the walls (depending on the size).

2) Remove concrete between the slabs. Although the concrete topping is removed there is still concrete between the joints of the slabs. This can be removed either by hand with a wedge and a hammer or with a compressor with hammers. Two workers are needed: one will hack with the compressor and the other will shovel and carry the debris. It is assumed that the concrete will be removed easily since there is no connection point between the slabs and it is a thin layer of concrete. The costs of this process since they are time depending will be divided equal to all the elements regardless dimensions.

3) Saw the concrete joint between beams/facades/walls and slabs. The only part that needs sawing when the concrete topping is removed is the concrete joint between the beams/facades/walls and the slabs. It is important not to harm the element so a diamond saw will be used. The slabs will be cut on their small dimension so the costs will be the same for all the slabs regardless their length.

As long as all the above actions are completed then the Hollow Core Slabs can be removed. There are different ways to lift them from a building:

i) Drill chemical anchors. Chemical anchors can be drilled in the slabs and be used as lifting points. The number and their dimension depends on the weight of the slab. The chemical anchors can be drilled and placed in one day and they can be used the next day. It is a process that will allow to lift the slabs from anywhere in the building but it is the most expensive method.

ii) Drill holes. Instead of using chemical anchors holes can be drilled, insert steel chains and connect them underneath the slabs. It is cheaper than drilling anchors but still it is an expensive and time consuming process.

iii) Use a crane with a fork. The fork will grab the slab and will bring it on the ground. Before using the fork the walls from one side of the lower floor has to be removed. It is a fast procedure but the disadvantage is that the fork will not be able to go deep inside the building. It costs cheaper than chemical anchors.

iv) Use old lifting points. In order to use the old lifting points they have to be detected and assessed. In case they are in a good condition and they don't have damages they can be reused. Usually after usage they are destroyed or they have corrosion problems. It has to be checked on site if it is possible to use them again. It is the cheapest method but it cannot be decided during planning if it is possible to use them.

The following workers and equipment are needed for the removal of a HCS:

- 1 worker in the building and in order to connect the steel chains or fork with the slabs.
- 1 worker on the ground for placing the element at the correct position and disconnecting them.
- A lifting crane of 70 tn.

An estimation of the time that is needed to remove a HCS from a building is:

- Connect the chains to the chemical anchors= 5 min
 - Lift the element and bring it on the ground = 5 min
 - Disconnect the chains and bring them on top= 5 min
- TOTAL:15 min/slab

Remove Façade Beams

The first element that will be removed after the HCS are the façade beams (in case they exist). The façade beams are supported on walls or on columns and they are connected with 1 dowel per side. In order to remove them from the building their connections have to be destroyed. The methods to do that are:

i) Hack the connection. With the use of a compressor it is possible to hack the concrete around the connection and then burn the rebar. This method creates the largest damage and it is time consuming but no drawings are needed in order to locate the connection. Also extra sawing is needed on the ground in order to modify the element to the desired dimensions.

ii) Drill the connection. Since there are original drawings it is possible to locate the rebar of the connection. With the use of a drilling machine it is possible to destroy the rebar by drilling it out. Then the element can be easily lift since it is not connected anywhere else. It is a fast method and creates less damage than hacking but it might be difficult to locate the rebar in case there are no drawings or due to different construction than the drawings. Again extra sawing is needed for the final modifications.

iii) Saw the connection. The best method in terms of damage and time is to saw the connection. It might be difficult and dangerous to saw the connection in height and also it might not be accurate. In case the new dimensions are known and sawing is possible, the element can be sawn on size straight away.. It is the most expensive method than the two others but modification costs can be reduced.

Usually the elements are located in a certain height so in order to reach them scaffolding is needed. Before starting the deconstruction of the connection it is important to tie the element with the steel chains from the crane in order to avoid falling down. The steel chains can be connected either at the old lifting points (depending on their condition) or they can be tied around the element.

The following workers and equipment are needed for the removal of a façade beam:

- 2 workers in the building for dismantling the connection and connecting the elements.
- 1 worker on the ground for placing the element at the correct position and disconnecting them.
- 2 scaffoldings.
- 1 lifting crane of 70tn.
- 1 compressor with hammers or drilling machines or a diamond saw (depending on the method).

Estimation of the time that is needed to remove a façade beam (with drilling) from a building is:

- Bring the chains to the top + Tie the façade beam= 5 min
- Drill the connections = 15 min/ connection TOTAL: 25min/façade beam
- Lift the façade beam + Disconnect= 5 min

Remove Beams

After removing the façade beams, the next elements that can be removed are the beams. The beams in the selected buildings are simply supported either on a corbel or at the edge of a wall and they are connected with 2 steel dowels per side. The methods to damage the connection, lift the elements, amount of workers and equipment are the same like the removal of the façade beams.

A small difference can be spotted on the time needed to remove a beam compared to the façade beams, due to the thickness of the element:

- Bring the rope up + Tie the beam= 5 min
- Drill the connections= 20 min/ connection TOTAL: 30 min/beam
- Lift the beam + Disconnect the beam= 5 min

Remove Columns

The next elements to be removed are the columns. They are already supported with shores before the beginning of deconstruction. It is possible that the columns are 2 or 3 stories high so they will be removed when their lower part is reached. The columns are connected with 4 rebars with the columns of the lower floor. Again here the connection has to be destroyed in order to remove the element. The methods to do that are the following:

i) Hack the connection. This can be done with the use of a compressor with hammers. The lowest part of the column has to be hacked until the steel rebars are revealed. Then the rebars are burned and the element can be removed. This method creates the most damage and it is time consuming.

ii) Drill the connection. With the use of a compressor with drilling cores, it is possible to drill out the rebars at the lower part of the column. The drilling machine has to be placed as lower as possible in order to do the less damage. After taking out the cores, the column can be easily lifted since it is connected only with a thin layer of approximately 2 cm. A hammer can be used in order to aid the lifting. This method causes less damage than hacking.

iii) Saw the connection. In order to saw the connection a diamond saw can be used. This method will create the less damage compared to the previous methods and if the new dimensions are known it can be sawn on size and avoid modification costs. An issue that might occur is that the weight of the column might break the diamond blade. A solution to avoid that is to start lifting the element while the sawing is taking place.

Before starting deconstruction the columns have to be connected with a crane. There are various lifting methods that can be used such as:

i) Use the old lifting points. Before using them their condition has to be assessed. It is the cheapest method but it is not possible to reassure if the old lifting points can be used without inspection.

ii) Tie the column with a steel chain. A steel chain is used to tie the column. It is a cheap but not safe method.

iii) Drill a chemical anchor. A chemical anchor can be inserted at the top of the column. The size depends on the weight of the column. It is a cheap and safe method but it is advised to be used only when the top part is not going to be cut during modification because then extra anchor will be needed for the new construction. Also it needs extra time to dry before the anchor is able to be used.

iv) Drill a hole at the top part of the column and insert a rebar. It is possible to drill a hole in the middle of the top half of the column and use a steel rebar to lift it. In case it is known that the top part is going to be cut the hole can be made at a height that can be able to be reused again during construction. It is a cheap and fast method.

The following workers and equipment are needed for the removal of a column:

- 1 worker in the building for dismantling the connections and connecting the elements.
- 1 worker on the ground for placing the element at the correct position and disconnecting them.
- 1 scaffolding.
- 1 lifting crane of 70tn.
- 1 compressor with hammers or drilling machines or a diamond saw (depending on the method).

An estimation of the time that is needed to remove a column (with drilling) from a building is:

i) Bring the chains to the top + Tie the column = 5 min

ii) Drill the connection = 20 min

TOTAL: 30 min/column

iii) Lift the column + Disconnect = 5 min

Remove Walls

The walls are the last elements standing. Usually they are the heaviest elements among all the structural elements of a building. They are connected with steel rebars and a thin layer of concrete (2 cm) with the wall below.

The methods to deconstruct a wall are the same with the column. The only differences are:

- Drilling the connections takes more time because there are many rebars along the wall.
- When using a diamond saw the danger to destroy the blade is bigger because of the extra weight. In this case the solution to prevent this is to saw a few centimeters and then support the edge of the wall with a wedge.
- More anchors and holes are needed to lift the elements due to the extra weight.
- It is not possible to tie the element with a steel chain and lift it because of the size.

An estimation of the time that is needed to remove a wall from a building (with sawing) is:

i) Bring the chains to the top + Tie the column = 5 min

ii) Saw the connection (depending on size) = 20 min

TOTAL: 35 min/column

iii) Lift the column + Disconnect = 10 min

Various

During deconstruction an amount of concrete debris will occur from cutting the connections. Also there will be elements that were destroyed during the deconstruction process or they are characterized from the beginning as non-reusable. The debris and the non-reused elements have to be crushed, separate the steel and concrete and send them to a recycle concrete plant. In order to do that a crusher and a small crane is needed at the deconstruction site. The time that the crusher has to be used depends on the amount of the concrete that has to be crushed.

After Deconstruction

When the elements are removed from the building there are three scenarios for the management of the elements:

- 1) Modify the elements on site. The elements are made ready for reuse on site and then they are transported at the new construction site. This scenario can occur when there is already a new construction planned. It has to be organized in detail in order to avoid delays at the new project or excessive amount of elements. Also the elements than are not going to be reused at the specific project but are possible to be reused in another one they are transferred to a storage site.
- 2) Modify the elements at the new site. This scenario is the same with the only difference that the elements are transported straight to the new construction site and they are modified there. This solution is not preferred because it demands extra planning and space at the new site.
- 3) Modify the elements at the storage site. In case that there is not a new project the elements will be transported to a storage site which will be also the modification site. They will be stored until a client appears and then they will be modified according his demand. After modification they can be transported at the new construction site.

In all scenarios the debris from deconstruction, modification and the non-reusable members are transferred to a recycling concrete plant. The deconstruction procedures described above are summarized in the table 3.11.

<p>Remove concrete topping</p>	<p>Process Remove it because it will not have any function when it will be reused</p> <p>Equipment and stuff</p> <ul style="list-style-type: none"> - 4 workers - Compressor with hammers
<p>Remove Hollow Core Slabs (HCS)</p>	<p>Process</p> <ul style="list-style-type: none"> - Choose lifting method - Support walls and columns - Remove concrete between the slabs - Saw the joints between slabs and beams/walls/facades - Remove HCS <p>Equipment and stuff</p> <ul style="list-style-type: none"> - 2 workers - Compressor with hammers - 1 lifting crane
<p>Remove Façade Beams</p>	<p>Process</p> <ul style="list-style-type: none"> - Tie the element with steel chains - Dismantle the connections - Remove façade beam <p>Equipment and stuff</p> <ul style="list-style-type: none"> - 3 workers - 2 scaffoldings - Machine depending on the dismantle method - 1 lifting crane
<p>Remove beams</p>	<p>Process</p> <ul style="list-style-type: none"> - Tie the element with steel chains - Dismantle the connections - Remove beam <p>Equipment and stuff</p> <ul style="list-style-type: none"> - 3 workers - 2 scaffoldings - Machine depending on the dismantle method - 1 lifting crane
<p>Remove columns</p>	<p>Process</p> <ul style="list-style-type: none"> - Choose lifting method - Dismantle the connection - Remove column <p>Equipment and stuff</p> <ul style="list-style-type: none"> - 2 workers - 1 scaffolding - Machine depending on the dismantle method - 1 lifting crane
<p>Remove walls</p>	<p>Process</p> <ul style="list-style-type: none"> - Choose lifting method - Dismantle the connection - Remove wall <p>Equipment and stuff</p> <ul style="list-style-type: none"> - 2 workers - 1 scaffolding - Machine depending on the dismantle method - 1 lifting crane

Table 3.11– Summary of deconstruction process

3.4. MODIFICATION

The next step after deconstruction is to modify/repair the elements in order to be able to reuse them in a new construction. This step can take place either at the deconstruction site or at the storage site. The most efficient way to reuse the elements in a new construction is to use them as prefabricated elements. Building with prefabricated elements is an already known method and any issue that occurs during the construction process can be solved. Besides the simple construction process, the costs of building with reused elements will be the same as building with new elements.

Actions

In order to modify an element and turn it into a prefabricated element, ready to be used in a new project, a number of different actions have to take place. These are:

- Saw the element. In order to remove an element from a building the connections and as a consequence the edges of the element have to be destroyed. These destroyed connections are not able to be reused again so they have to be sawn according to the requested dimensions. The sawing can be done with a diamond saw.

- Drilling. After the element is sawn on size a new connection has to be created. This can be done by drilling new holes for the rebars. The number and the length of the drills depend on the loads and the size of the rebar. The drilling can be done with a concrete drilling machine.

- Reinforcement cover. The reinforcement in a new element is covered from all sides in order to be protected from the environment and fire. When an element is removed from a building and sawn on size the reinforcement at the edges is exposed. A special corrosion resistance coating has to be applied on this reinforcement in order to reuse it in a new construction.

- Filling. Elements like walls and slabs have openings and holes that have to be filled in order to be reused. Small holes in slabs that don't affect the structural integrity of the element can be filled with insulation while big holes have to be filled with concrete. The small holes in walls can also be filled with insulation and the big ones can be filled either with masonry or insulation since the element can function with or without them.

- Refurbishment. The surface of the elements has a number of screws, nails and fixings that have to be removed. Moreover, it is possible that the surface is damaged and it needs to be repaired and be painted. It is suggested to avoid refurbishment because it will increase the final value of the element. The reused elements should keep the old surface in order to create a contrast between new and old.

All the above actions are relevant for columns, beams, walls and slabs. From these actions only sawing and drilling of the element together with the protection of the reinforcement are important actions in order to reuse the elements in a new structural system. The filling of small holes and the refurbishment of the surface are also important but they don't affect the structural properties of the element.

Location

The modification can take place in 3 different locations:

i) At the deconstruction site. Straight after being removed from the building, the elements are placed on the ground and they are modified. This implies that there is already a client for a new project and the elements will be modified according to his demands. After modification the elements are ready to be transferred to the new construction site where they can be used as prefabricated elements without further changes.

ii) At the new construction site. After deconstruction, the elements that are meant to be reused to the new building are transferred to the new construction site. The modification will take place

there and when they are ready they can be immediately used. This demands extra space at the construction site which might cause organizational issues. For this reason it is rejected as potential location. Only minor modifications can occur at the construction site.

iii) At the storage site. In case there is not a new client the elements will be transferred to a storage site. They will be stored without any modification until a new client appears. Then the elements will be modified according to his demands. This can also be the case for the number of elements that are not able to be reused to the new building.

Another stage of the reuse process is the storage of the reusable elements. This can occur after deconstruction and/or before modification. The amount of elements that needs to be stored depends on the existence of a new project and the reuse percentage. Until today, a building is demolished when it is empty for a long time or when there are plans for a new construction. From now on when a building is meant to be removed, besides demolition, deconstruction must also be considered as a solution.

The results of the quality check will show if a building is suitable for deconstruction. During the quality check it should be decided whether to deconstruct the building or not and how the elements are going to be stored. The decision to deconstruct a building depends on the existence of a client and on the storage solution.

There are two options for the storage of the elements. One option is to leave the building standing and create a “virtual” storage and the other is to deconstruct the building and transport the elements at a storage site. It is important to assess these two different cases. For the examination and the comparison of the two options the following scenario is used: “A building is empty for 5 years and it is facing structural vacancy. The possibilities to reuse the building as a whole are minimized. The owner faces difficulties to rent or sell the building, so he wants to consider deconstruction as an alternative. He contacts an appropriate firm that practice deconstruction and asks them to assess his building. The building will be assessed with the methodology presented at the quality check step (section 3.2)”.

1st option: “Virtual” storage

Before analyzing the 1st option it is important to define the term “Virtual storage”.

“Virtual” storage is an existing empty building whose all his structural elements are noted in an inventory. It is characterized as suitable for deconstruction and it is left standing.

A preliminary assessment took place during the stage of the inventory and it was decided that the building is possible to be deconstructed. Then it has to be decided if the building will be stripped or not. If the building is stripped, it has to be deconstructed in a short period since the elements must not be exposed to the environment for a long time. This can happen only when there is a potential client. In case that there is no client then the building will not be stripped in order to protect the elements from weather conditions and the building from intruders. Consequently, this means that the building will be left standing. Nevertheless, since it faces structural vacancy and it is not possible to be used again as an office, the building can be stripped only from the inside. This will help to conduct the 1st survey of the quality check. Besides that, the owner of the building will be able to rent it with a different function.

3.5. STORAGE OF THE ELEMENTS

After a successful 1st survey and with the 2nd signature for the EIDs, the building is considered for deconstruction and the available elements can be presented. After that a future client can deconstruct the building and use the elements for a new project.

When a building is empty it still has operating costs. These are:

- i) Fixed costs (depreciation, taxes, ground rent if applicable, insurance costs, interest of the invested capital)
- ii) Energy costs
- iii) Maintenance costs
- iv) Administration costs
- v) Specific operating expenses

An estimation of the operating costs of an empty building is € 24 per m² per year (Trouborst, 2012). From this value the depreciation of the building and the interest of the invested capital are excluded since it is assumed that the building has already depreciated his value. This is happening because even if it is decided that the elements can be stored these costs will be the same.

For comparison reasons the building in Hoge Hilweg 18 is used for the estimation of the operating costs. This building is 3174 m² and the estimated operating costs are € 76.000 per year.

2nd option: Storage site

The term storage site is defined as:

Storage site is a site specially configured for the modification, storage and management of structural elements.

A storage site like this will be used as an intermediate stage for the structural elements before being reused in a new project. Even if there is a new project for the deconstructed elements, immediately after being removed from the building, it is not possible to use all the elements. Instead of crushing the remaining elements, they can be stored until a potential client appears. As long as a site like this is available any owner of an empty building can ask for deconstruction and store his element there. Then any client can visit the storage or the website of the storage company and choose the required type and amount of elements.

Demolition companies have already storage sites where they store non-structural elements (doors, windows, bathroom fixtures etc) and structural elements (steel beams and columns). A site like this can be used for the storage of structural concrete elements. Because of the large dimensions of the elements a lot of space is needed and it has to be covered in order to protect the elements. Also another case for storage is an existing company that produces prefabricated concrete elements. Besides the space, they also have the necessary equipment to modify the elements for reuse. A third option for the storage site would be a completely new type of company that manages and stores reused structural elements. This is difficult to happen at the moment since a relevant market does not exist yet.

As long as the results of the quality checks show that the building is suitable for deconstruction it can be dismantled and its elements can be stored. This is better to happen when the building is facing structural vacancy, has already depreciated its value and by standing empty it creates only extra costs. By deconstructing the building the owner avoids the operating costs but has to pay for the storage site. In order to calculate the money that is needed for the storage of the

elements the building in Hogehilweg 18 will be used. The storage costs of the elements are estimated as € 5 per m² per year (Naber,2013). Also the interest that is lost from storing the elements is estimated as 3% (Naber, 2013). The interest will not be used for the comparison of the storage site and the “virtual” storage because an interest is also lost when the building is staying empty. In order to calculate the storage costs the way of storing the elements should be decided:

- i) The HCS are stored in stacks of 10.
- ii) The beams are stored in stacks of 4.
- iii) The columns are stored in stacks of 4.
- iv) The façade beams are stored in stacks of 4.
- v) The walls are stored vertically.

The total space that is needed for the storage of the elements of the building in Hogehilweg 18 is 700 m² which means that the storage costs for a year are € 3.500. The costs of deconstructing and transporting the elements are not included because if the building is decided to be deconstructed they would be the same either if the elements are going to be reused immediately or they are going to be stored.

Advantages of “Virtual” Storage

- **No storage costs.** There are no storage costs since the elements are attached at the building. Eventually, a storage site will be needed for the elements that are not going to be used in a future deconstruction if they are not sent for recycle.
- **Ability to rent or sale the whole building.** The building can be reused as a whole in case there is future demand.
- **Less transportation costs.** The transportation between the old site and the storage site is avoided. The remaining elements after deconstruction still need to be transported to the storage site.
- **Less pollution:** Since there will be less transportation then there will be less pollution.
- **Protected elements.** The remaining building envelope, after internal stripping, protects the elements from the exposure to the environment.
- **Less modification costs.** The client can order to cut the elements in specific dimensions straight from the building. This will minimize the costs of modification.

Disadvantages of “Virtual” Storage

- **Restricted market.** If the client wants a limited amount of elements then it is not worth it to deconstruct the whole building.
- **Not a direct market.** If the client wants to buy the elements the same day it is not possible because it will take some time before the building is deconstructed. (This is not a disadvantage that can affect the procedure because the deconstruction and the treatment of the elements can be made in the same time with the design process.)
- **No flexibility.** The client will not be able to combine elements from different buildings. He will have to use elements only from specific buildings.
- **Increased risk of uncertainty for the quality.** The EID will not be completed, which means that there is a possibility of flaws to appear after cutting the element. This creates risks for the agreement between the client and the owner.
- **No client inspection.** It is not possible for the client to inspect the element or have a real picture of it. Only pictures from drawings or CAD.
- **Maintenance costs and taxes.** Although the building is empty operating costs have to be paid.

- **Temporary modification space.** Extra space has to be created at the old or new site for the assessment and modification of the elements that are meant to be reused. This extra space might create problems during the construction or deconstruction process. It is not always possible to have free space (buildings in the city center have no extra space)
- **Remaining elements.** If it is not possible to reuse all the elements then the remaining have to be transported at a storage site or be send for recycle. The separation has to be made at the old site.

Advantages of Storage site

- **No uncertainties for the quality of the element.** The element will be fully checked (1st and 2nd Survey) and it will be ready for reuse.
- **Transparent procedure.** The client will be able to inspect the actual element, ask for modifications and buy it at the same time.
- **Flexible procedure.** The client is able to buy any type and amount of element he needs for his project.

Disadvantages of Storage site

- **Storage costs.** Since the elements are placed at a storage site there will be extra costs for the storage of the elements. This will increase the price of the reused element.
- **Transportation costs.** Transportation costs will be increased because the elements will be transported from the old site to the storage site and from there to the new construction site.
- **Flexibility.** It can be an advantage but also at the same time a disadvantage. If the client has the ability to buy any elements he wants then remaining elements from the same group will be difficult to be sold. Also if the client wants to buy only a group of elements e.g. columns then it will also be difficult to sell the matching elements e.g. beams, walls. This can be solved with creative solutions and connections.
- **Extra modifications costs.** The elements will be cut on site and then it might be needed to cut the elements again at the storage site according to the demands of the client.
- **Restricted solutions:** After dismantling a building the only solution is to sell the elements for reuse. The owner loses the ability of renting the building.

Comparison

In order to compare the two solutions a Decision Matrix Analysis is used. Different factors are used and each factor has a weight from 0 to 5 where 0 is absolutely unimportant and 5 is very important. Then the two options of storage are graded from 0 to 3. The different factors are:

Flexibility of the market (weight = 1): In terms of flexibility the solution of the storage site is better because any potential client will be able to inspect the elements, choose any type and amount of element he wants and most important he can have them delivered in a few days at his place after their modification. On the other hand, when the elements are stored in a building, the clients don't have the ability to choose from a large database of elements but they are restricted only at elements of specific buildings. This might be considered as an advantage in terms of limiting the options.

Fixed costs (weight = 5): Storing elements in a site does not generate any costs besides the renting of the area. Keeping a building empty has some minimum operating costs which are much more than the costs for storing the elements. More specifically the operating costs of the building in Hoge Hilweg 18 are € 76.000 per year while the storage costs are only €3.500.

Therefore, a building should be deconstructed when it is facing structural vacancy, has depreciated his original value and there is a market for reused elements. An amount of money for the deconstruction will be needed but this money will be the same if the building is deconstructed in one year or more years. On the other hand it is not suggested to deconstruct a building when its value is not depreciated because an extra amount of money is needed to buy the elements.

Different solutions (weight = 4): The “virtual” storage gives the owner more solutions than storing the elements in a storage site. By keeping the building standing the owner can rent the building for another function. When the elements are in a storage site the only solution is to sell the elements. Before deconstructing a building it is important to examine all the potential solutions for reusing the building as a whole.

Environmental impact (weight = 3): An empty building does not create any emissions. On the other hand, when the building is deconstructed, the environmental impacts of transferring the elements at a storage site are more than transferring the elements to a construction site due to the extra distance in km for transportation.

Modification costs (weight = 2): The modification costs are the costs that are needed to prepare the element for reuse. If there is a new design immediately after deconstruction, the elements must be cut at the required dimensions during their removal from the building. When there is no client and the elements have to be stored, they have to be cut at their maximum dimension. While being at the storage site and after the interest of a client the elements will be modified according to his demands. As a result the modification costs are higher when the elements are stored at a storage site.

Transportation costs (weight = 2): When the building is left standing there are no transportation costs. If there is a client the elements will be transported from the deconstruction site to the new site. On the other hand, when it is decided to deconstruct a building and store its elements then there are more transportation costs. The elements have to be transported once at the storage site and from there they will be transported to the new construction site.

Quality risk (weight = 1): The quality of the elements at the storage site is checked and they are able to be reused in a new project. When a building is left standing, the quality of the elements can be checked with the method mentioned in section 3.2 but they are not 100% assessed. There is a possibility that the elements are not suitable for reuse after being removed. This creates a disadvantage for keeping the elements stored in a building.

CRITERIA	Flexibility	Fixed costs	Solutions	Environmental impact	Modification costs	Transportation costs	Quality risk
Weight factor	1	5	4	3	2	2	1
Storage site	2	3	1	1	1	1	2
“Virtual” storage	1	1	3	2	3	2	1

Table 3.12. Decision matrix

CRITERIA	Flexibility	Fixed costs	Solutions	Environmental impact	Modification costs	Transportation costs	Quality risk	Total
Weight factor	1	5	4	3	2	2	1	30 35
Storage site	2	15	4	3	2	2	2	
“Virtual” storage	1	5	12	6	6	4	1	

Table 3.13. Generic Decision matrix

3.6. TRANSPORTATION Transportation of the elements is a necessary process when designing with reused elements. During a construction with new elements, transportation of the elements will occur between the prefabricated plants and the construction site. Different elements might come from different prefabricated plants. On the other hand when constructing with reused elements, transportation will occur between the old deconstruction site and the new one. It is possible that the elements might derive from two or more buildings so different transportation routes must be followed. This is happening also with new elements with the difference that when using reused elements all type of elements can come from each building.

These extra transportation routes and the fact that all type of elements come from each building might create confusion at the construction site. It is important that a good planning of the transportation routes is made. More specific the elements must arrive at the construction site according to the sequence they are going to be reused and on time. This was an issue at the previous attempts to reuse elements where confusion was made with the synchronization of the arrival of elements. It is important that construction follows deconstruction. This case will not be an issue when the elements are already stored at a storage site.

The amount of transportation routes and the kilometers that have to be traveled influence the total costs of the project and the environmental emissions. The optimum scenario is to transport the elements straight from the deconstruction site to the new site and avoid the storage of the elements.

There are 5 different transportation routes that can occur:

- 1) Deconstruction site → Construction site. This is the best solution. The needed elements are already modified at the deconstruction site and they are transported to the construction site ready for reuse.
- 2) Deconstruction site → Storage site. This route can be used either to transfer the remaining elements that are characterized as reusable but not possible to be reused in the new project or transfer all the elements from the deconstruction site.
- 3) Deconstruction site → Recycle plant. This route is used to transfer all the debris from the deconstruction and the debris from the crushed non-reusable members to the recycle plant. It is possible that the recycle plant is the storage site.
- 4) Storage site → Construction site. This route is used to transfer the elements that are needed to the new construction site. This means that they were already transferred from a deconstruction site which will increase the costs and the emissions. The only advantage of this route is that good planning of the construction can be made and the elements can arrive on time without depending on the deconstruction process.
- 5) Storage site → Recycle site. This route is used to transfer the debris from the modification of the elements to the recycle plant. Again in this route the costs and emissions are increased because the elements were already transferred from the deconstruction site to the storage site. It is possible that the storage site is also the recycle plant. In this case the costs and emissions of this route are zero.

3.7. CONSTRUCTION

The final step and the goal of the reuse process is the construction of a new structure with reused elements. In order to avoid any unnecessary confusions and delays at the construction site it is important that the elements arrive ready to be used as prefabricated elements. Building structures with prefabricated elements is an already very well-known process and contractors will not have any issues besides the ones that they already face.

By doing this the costs of constructing with reused elements will be the same when constructing with new elements. The most important issue, which is also an issue when building with new elements, is to organize the arrival of the structural elements and bring them on time to the site in order to avoid delays.

The optimum solution is to use as much as possible reused structural elements in a construction and use new elements when it is not possible to find reused elements that match the criteria of the client. This has to be arranged from the design phase in order to avoid any unpleasant surprises during construction.

For this thesis all the elements are considered reusable except of the foundations. For this reason the foundations will be excluded from the comparison of the costs and environmental impacts between a building with reused elements and a building with new elements.

3.8. RESULTS

Inventory:

The inventory is the cornerstone of the reuse process. Everything starts from here. Like a building needs good foundations to be able to exist, the same happens with the reuse process. In case there is no inventory or the inventory does not include all the necessary information it is 100% sure that problems will occur which will jeopardize the whole process and even cancel it. Creating an inventory for an existing building, especially without drawings in digital format, is a time consuming process due to the time that has to be invested for the research and the inspection of the necessary drawings. Although “time is money”, it is preferable to invest extra time on the creation of a complete inventory instead of having to spend double or triple time to solve the problems that might occur due to the incorrect choice of elements. The conclusion is that the more time is spent on the formation of the inventory the less issues will occur during the design phase and consequently during the construction phase. It is better to solve the problems before they start and the way to do that at the reuse process is to create a complete and detailed inventory.

Quality check:

Reuse of structural concrete elements as individuals into a new design occurred very few times and it is important to reassure that they are safe to be reused. These elements were used for many years as part of a building and they proved that they can function properly. After the removal from the building they have to be checked in order to reassure that they can be used for 50 more years. Quality check is the process that will reassure the people that the elements are possible to be reused. Though this process a certificate is created, the EID, and it proves the good quality of the elements. The tests are already known but they were never used for the assessment of elements meant to be reused individually. It is a process that can happen either in stripped or not stripped buildings and it is preferred to take place when there are intentions to deconstruct the building. It is not an expensive process compared to the deconstruction costs especially since it will identify any potential risks that might hinder the whole reuse process.

Deconstruction:

The inventory might be the cornerstone of the reuse process but deconstruction is the most crucial process of reusing structural elements. It is the process that provides the elements that are going to be reused in a new project. It is important to be done very careful in order to maximize the quantity and quality of reused elements. In order to achieve that, good planning is needed at a preliminary stage. Although there is a few if any experience, it consists from already known sub-processes like sawing and drilling of concrete elements and estimations can be made for the total process. It is possible that during practice differences might occur with the original planning. The estimations were made to the conservative side and there are margins to improve the process. A good solution to acquire more experience is to realize a pilot project.

In order for a building to be characterized as suitable for deconstruction it must have a sufficient number of reusable elements. The selection of the suitable buildings that was made for Amstel III was based on the type and amount of elements. The buildings that have pre-stressed slabs have large deconstruction costs and few reusable elements. For this reason the reuse of these elements is uneconomic.

The size, the weight or the volume of the elements doesn't affect the total time of deconstruction. These three properties affect only the lifting crane which has a wide range of the weight that can lift. The same time is needed to remove a beam of 2 meters and a beam of 5 meters with the same section. The deconstruction process is affected by the number of elements

existing in a building. The more reusable elements exist in a building the less will be their price when the deconstruction costs are proportionally allocated.

The connections of prefabricated elements are not meant to be deconstructed and they have to be destroyed. This means that the old connections cannot be used in a new construction and new connections have to be created. Even if one element is not going to be reused it has to be removed carefully in order to protect the rest of the elements. The method that will be used for the deconstruction has to create the less damage with the lowest costs. A preliminary analysis of which method is more suitable has to be made at the beginning of each project. This leads to the conclusion that every project has to be treated as unique. Detailed inspection has to be done (inventory stage) which will identify any issues and problems.

Modification:

This is the phase where the element is getting ready for reuse in a new construction. The aim is to use elements with less modification as possible. In order to achieve the maximum reuse of elements with their original dimensions the architect and the engineer have to work together from the beginning of the design. For a new design that it is not designed based on reused elements, it is difficult to reuse the elements without modifications. If modifications have to take place the best solution is to modify the elements during the removal from the building. In order to accomplish this, a new project is needed where the dimensions are already known. On the other hand, if the elements have to be stored before being reused, it means that there is not a potential client and as a result the elements have to be removed at their maximum dimensions. Later on, when there will be a client the elements can be modified according to the new design. This will result to the maximum costs of modification. Although it is a costly and handwork procedure it has to be done very cautious in order to avoid mismatches during the construction. The location of the modification depends on the existence of a client. If there is a client before the building is deconstructed then the elements can be modified at the old site but if there is no client the elements will be modified at the storage site.

Storage:

The storage location of the elements can be either a storage site or a whole building which is called "virtual storage". The results of the Decision Matrix analysis show that it is better to leave the building standing and use it as a "virtual" storage. The storage site is better in terms of flexibility, fixed costs and quality risk while the "virtual" storage is better in terms of solutions, environmental impact, transportation costs and modification costs. The "virtual" storage has the highest total score but it has the lowest score at the fixed costs which is the factor with the highest importance. From an economical point of view, the fixed costs of an empty building are much more than the extra transportation and the modifications costs of a storage site. On the other hand, from an environmental point of view, keeping a building standing it creates fewer emissions since the elements will be transported straight to the new construction site.

It should be made clear that a building that is suitable for deconstruction doesn't mean that it has to be deconstructed immediately. Deconstruction has to be considered as an extra solution besides demolition at the end of the life of a building or when it faces structural vacancy and all the solutions were explored.

The best solution in terms of storing the elements is to keep the elements stored in a building until its value is completely depreciated. After that the building should be deconstructed and use all the elements immediately in a new project or sent them to a storage site. With deconstruction

it is possible to avoid the fixed costs of keeping a building empty. Moreover it is possible to earn money instead of demolishing a building.

At the moment there is no market for reused structural concrete elements. Even if it is possible to reuse the elements from an empty building, it has to be left standing until a client is found. When a market for reused elements is created, an empty building after depreciating its value has to be deconstructed and store the elements in a storage site. In case there is a new project the maximum percentage of elements has to be reused which makes it challenging for both engineers and architects. Eventually when the deconstruction and reuse of elements becomes a real market, a storage site has to be created for the elements that are possible to be reused but not immediately after deconstruction.

Transportation:

Transportation is a process that determines mostly the environmental impact of the reuse process and plays an important role at the formation of the total costs. There are different routes that can be followed. It is important to organize efficiently the different routes in order to minimize the costs and the emissions.

Construction:

The construction phase is the last phase of the reuse process. Building with reused elements has to be the same when building with new elements. It is important to bring the elements at the new construction site ready for reuse as prefabricated elements. This will prevent any unpleasant surprises and confusions. Building with prefabricated concrete elements is a well known process and contractors know very well how to solve any problem that occurs. In order to avoid unexpected issues it is advised to use the same workers for deconstruction and construction. With this way, the workers will be more cautious during deconstruction and they will be used with the idea of using existing elements. This means that deconstruction and construction has to be one phase while at the moment they are separate.

CHAPTER 4

NEW DESIGN

In order to demonstrate the benefits of reusing structural concrete elements a case study of a new housing project is used. This chapter presents the new buildings that will be designed with reused structural elements in Amstel III area in Amsterdam. The first part of the chapter presents and analyzes the criteria that were used to choose the proper function and determine the dimensions of the new construction. The second part demonstrates the new design. At the beginning, the first idea is presented followed by the necessary alterations that were made during the design process. At the end of the second part the final design is presented. The chapter is concluded with the presentation of the results of the design process.

It is important to mention that the purpose of the new design is to demonstrate the feasibility of reusing structural concrete elements from existing office buildings into new houses taking in consideration only the structural design. Other factors like installations and facades are omitted from this case study.

4.1. CRITERIA

The decision for the function of the buildings to be designed with reused structural concrete elements is based on the following specific criteria:

- The demands of the area
- The loads of the different functions
- The available structural elements

Demands of the area

As it is presented in Chapter3, Amstel III is an area that faces structural vacancy problems for which immediate solutions need to be taken. Amstel III is a mono-functional area and the goal of the municipality of Amsterdam is to turn it to a multifunctional district. In order to analyze the demands of the area and to find out which functions are needed the plan "*Strategiebesluit Amstel II van monofunctioneel werkgebied naad multifunctionele stadswijk*" made by *Projectbureau Zuidoostlob* was used.

The key elements of the Amstel III strategy are:

- Market participants are enabled and encouraged to introduce other functions than offices.
- The municipality performs a passive land policy, thereby the key terms are facilitating and encouraging.
- The financing of municipal commitment is based on the principle "first do then get rewarded", so first deserve the money, and then spend it. The deployment of resources is primarily aimed at improving the public space and accessibility in line with transformation initiatives.

The basic goal of the plan is transformation of the existing offices into new functions. This is one of the solutions but in many cases the costs of the transformation are higher than demolishing the building and constructing a new one. For buildings that face structural vacancy the possibility to be used again as offices is very small. As a result the only solution will be demolition of the existing buildings and construction of a building with a new function that will improve the area. **Instead of demolishing the buildings and destroying the structural elements, this thesis proposes to deconstruct the buildings at the element level and reuse them to construct a new function.**

A number of goals concerning the new functions that need to be added in the area were set in the strategy plan. There are long-term and short-term goals. The long-term goals until 2040 are:

- Add 2.000 houses. They should not compete with the renewal of the Bijlmer area.
- Reduce office space to half (from 720.000 m² to 360.000 m²). Additional office space is not possible.
- Add 40.000 m² of facilities in the office strip.
- Add 50.000 m² of hotels (9.000 rooms).
- Add 10.000 m² of retails. They should not threaten the Arena Gate.
- Increase the PDV cluster by 40.000 m² (from 151.000 m² to 190.000 m²)

These targets are long-term and they are evaluated every 5 years. Then new targets are set for the next 5 years in order to achieve the final goal of creating a multifunctional area.

The short-term targets are set for the period 2011-2021. A short analysis of each desired function is presented:

HOUSING PROGRAM 2011-2021

The next 10 years, 50.000 m² are expected to be added at the area with an average size of 100 m² per dwelling (500 homes). The focus of the housing market will be students, starters, expats and collective private clients. This type of housing market doesn't compete the housing in the Bijlmermeer. At this moment an investment decision is prepared for student housing for AMC campus in Paalbergweg area, opposite the AMC and next to the railway station Holendrecht.

OFFICE PROGRAM 2011-2021

The goal of 2040 is not sure if it is realistic. This depends on the market and the positioning of Amstel III compared to other locations. For 2021 the goal is to reduce the office space by 35.000 m². No office can be added above 720.000 m².

FACILITIES PROGRAM 2011-2021

In order to strengthen the vitality of the area functions such as education, culture, sport and recreation, religion and other facilities such as kindergartens are needed. In recent years there has been about 33,000 m² of facilities added in Amstel III, largely situated in the business strip (including education, hospitality, fitness, church and youth prison). The goal for 2021 is to add 20.000 m². Especially for education the ambition is to add 1 or 2 medium educational facilities in the office strip.

CATERING PROGRAM 2011-2021

The goal is to add 5.000 to 6.000 m² of catering services until 2021. The risk is the limited response during the first years. According to the director of the "Coffee Company", it is busy only 2 to 4 hours during the day and completely empty during the weekends. The solution is to create drive-ins or lunch buses like in America.

HOTELS PROGRAM 2011-2021

The city authorities want to add as many hotels as possible outside the city. The goal is to add 30.000 m² until 2021. Two hotels are already planned to be built, one at the business strip along the A2 and one at the office strip, the Atlas Arena Complex for densification and transformation of the area. The plan is to construct 2 more hotels but it is not yet known where.

RETAIL PROGRAM 2011-2021

The goal is to add 1.000 m² retails, spread over small branches. They will also serve the existing offices and residents. The existing policy for adding retails is restricted and only the existing centers are strengthened. So it is hard to develop a retail area in Amstel III. But in order to create a multifunctional area the establishment of a neighborhood-related retail is important.

PDV, GDV, Outlets PROGRAM 2011-2021

These types of functions are expected to be added at the business strip area. An addition of 9.000 m² is expected for the period 2011-2021. For the office area it is expected that IKEA will expand.

Table 4.1 presents the long-term and short-term goals:

FUNCTION	LONG-TERM (2040)	SHORT-TERM(2011-2021)	AREA
Houses	2.000 houses	Add 500 houses (5.000 m ²)	Offices strip
Offices	Reduce to half	Reduce by 35.000 m ²	-
Facilities	Add 40.000 m ²	Add 20.000 m ²	Both strips
Catering	-	Add 5-6.000 m ²	Both strips
Hotels	Add 50.000 m ²	Add 30.000 m ²	Both strips
Retail	Add 10.000 m ²	Add 1.000 m ²	Office strip
PDV, GDV, Outlets	Add 40.000 m ²	Add 9.000 m ²	Companies strip

Table 4.1 - Long-term and short-term goals

After the study of the strategy plan, an interview was arranged with Eric Bijsterbosch, assistant project manager of the Zuidoostlob. According to Eric Bijsterbosch the main priority for Amstel III to become a multifunctional area is to add houses in order to attract residents. More specific the focus will be on expats and the working class. A suggestion is that the houses can be build from the companies in the area and rent them to their workers. There are 27.000 workers in the area and by adding new houses they can live close by to their work.

From the analysis of the study and the interview with Eric Bijsterbosch it can be concluded that houses are the most important function in order to start changing the area from mono-functional to multifunctional.

Loads of different functions

Another criterion that assists to choose the proper function for reused elements is the loads of the functions. These loads are the variable loads and they can affect significant the total forces on the structure. The office buildings were constructed between 1980 and 1990 and they were designed according to the Dutch norm “Technische grondslagen voor de berekening van bouwconstructies – Regulations for the calculation of building structures, General considerations and loading (NEN 3850)”. The loads of office building according to this norm are presented in table 4.2.

FUNCTION	UNIFORMLY DISTRIBUTED LOAD q_k (kN/m ²)	POINT LOAD Q_k (kN) over 50x50 mm
Offices	2,0	3,0

Table 4.2 - Design values q_k and Q_k for imposed loads on floors (Source: NEN 3850)

When the elements are removed from the building, although they are designed with a new norm the new function will be designed with the Eurocode. In order to make a preliminary selection of the different functions that can be designed with the reused elements, Eurocode 1 (Actions on structures - Part 1-1 and the National Annex of The Netherlands) was applied. The loads of the different functions according to Eurocode 1 are presented in table 4.3.

CATEGORY IN EC1	FUNCTION	UNIFORMLY DISTRIBUTED LOAD q_k (kN/m ²)	POINT LOAD Q_k (kN) 100x100 mm
HOUSES			
A1	Floors	1,75	3,0
	Stairs	2,0	3,0
	Balconies	2,5	3,0
OFFICES			
B1	Offices generally other than B2	2,5	3,0
B2	Offices at or below ground level	3,0	2,7
FACILITIES (education, culture, kindergartens, sport, etc)			
C11	Cafes and Restaurants	2,0	3,0
C12	Reading rooms with no book storage	2,5	4,0
C13	Classrooms	3,0	3,0
C31-C32	Corridors, hallways, stairs, landings	5,0	7,0
C39	Museum floors and art galleries for exhibition purposes	5,0	7,0
C 41	Dance halls, studios and gymnasias	5,0	7,0
E12	Reading rooms with book storage (e.g. libraries)	4,0	4,5
C21	Assembly areas with fixed seating	4,0	7,0
C51	Assembly areas without fixed seating, bars, etc	4,0	7,0
CATERING			
C11	Cafes and Restaurants	2,0	3,0
HOTELS			
A3	Bedrooms in hotels and motels	2,0	2,0
C11	Cafes and Restaurants	2,0	3,0
C51	Assembly areas without fixed seating	5,0	3,6
RETAIL – PDV – GDV – Outlets			
D1	Areas in general retail stores	4,0	7,0
D2	Areas in department stores	4,0	7,0

Table 4.3 - Design values q_k and Q_k for imposed loads on floors (Source: EC1)

According to the loads from Eurocode the functions that have the same or less load with the offices are the houses, hotels, cafes and restaurants. This comparison is not completely correct because the calculation of the actions with the old code is different compared to Eurocode. The actions on the elements with the old code were calculated by multiplying the sum of the permanent and variable load with 1,7 but without using material safety factors. On the other hand, the actions with the Eurocode are usually calculated by multiplying the permanent actions with 1,2 and the variable with 1,5 but also using material factor 1,5 for concrete and 1,15 for steel.

This is a preliminary selection and in order to identify the loads that the elements can support they should be assessed individually. This assessment is taking place in chapter 5

From the first 2 criteria it is decided that the new design will be a housing project. The total area of the new construction depends on the available elements from the existing office building. The main goal is to design houses of 100 m² that can accommodate a family of 4 persons.

Available structural elements

Before starting the new design it is important to know the type and the amount of the structural elements that can be reused. The available elements determine the total size of the new design, the loads, the stability system and the connections of the elements. In chapter 3 a first selection was made between the buildings that are suitable for deconstruction and those that are not. The buildings that are suitable for deconstruction are:

- Hogehilweg 18
- Hogehilweg 22
- Karspeldreef 2
- Paasheuvelweg 8
- Paalberweg 9

The buildings in Hogehilweg 22 and Paasheuvelweg 8 will not be used for the new design due to the restricted information of the elements for the creation of the inventory. These buildings can be used only when an onsite inspection is conducted. Then it is possible to record all the elements and their properties.

The building in Paalberweg 9 is suitable for deconstruction and all the properties of the elements are available but it is decided not to use its elements due to the large dimensions of the beams. There are 66 beams with $h=1110\text{mm}$ and $b=400\text{mm}$ which are difficult to be used in a housing project because it will increase the height of the interior space and as a result the whole building. The rest of the elements are suitable for the new design but they will not be reused because reuse percentage will be reduced.

Eventually the buildings that will be used for the new design are the buildings in Hogehilweg 18 and Karspeldref 2. Both buildings are made from concrete prefabricated elements which are presented in table 4.4.

Building	Area (m ²)	Main beams	Façade beams	Columns	Walls	H.C.S.
Hogehilweg 18	3.174	45	115	60	50	430
Karspeldref 2	5.173	138	131	60	34	672
Total	8.347	183	246	120	84	1102

Table 4.4 – Available structural elements

There are different elements with different dimensions. The detailed properties of the elements can be seen in the inventory in Appendix I. The amount of elements derived from the inspection of the existing drawings. A potential division of large elements into shorter once will increase this amount and will result in more reusable elements.

All the elements are suitable for reuse in the housing project except the façade beams. These elements can be either send for recycle or send for storage. Different costs scenarios are presented in Chapter 6 about the use of the façade beams. The rest of the elements will be used for the design of the new housing project. Usually houses in the Netherlands are constructed mainly with walls and with a few columns and beams. For the new design due to the fact that there is a limited number of walls, the design will be based on the use of columns and beams. The walls will be used for the stability of the structure in order to transfer lateral loads and the columns and the beams will transfer only vertical loads. In chapter 5 the structural system of the new houses is presented.

First idea

4.2. NEW DESIGN

For the new project it was decided to take an existing architectural design. This is the project of the students Alexia Martha Symvoulidou, Emelien Schut and Virginia Siapera for the course Dwelling at the TU Delft Faculty of Architecture. The name of this project is “Tetris Houses” and arises from their unique typology.

The Tetris apartments were created in order to fulfill the ongoing needs of residents who live in a dense urban environment. These needs derived from different types of residents, like single people and families or ex-pats and permanent residents. Therefore, the requirements of having an apartment with a common space and a more than one private space were just the beginning.

This typology is based on the existence of different kinds of common spaces and levels that will have visual connection with each other in order to unify the dwelling. At the same time there should be private cores that will offer some areas of privacy. For that reason, intermediate zones between “outside”, common spaces and “inside” the apartments are being considered as one. On the other hand, the climate of the Netherlands was the factor that made the double-side view an essential feature for the dwellings.



Figure 4.1 – Ground floor and 1st floor of the Tetris Houses. Each color is one apartment.

In detail, the Tetris apartment is consisted of an L shaped space in two different levels. This characteristic is important for the form of the apartment because it offers the possibility to separate the private (corridor) with the public spaces but at the same time it is also important for the psychology of the residents as it offers them the sense that they live in a totally independent house. Moreover, the common rule of having one floor for one apartment is now rebutted and is being replaced by two apartments that both share the same two floors.

By this type of space division in the Tetris dwellings, along with the interior circulation that penetrates the central linear core of the building double, it is possible for all the apartments to

have three different types of facades. The first two types, the “outside”, are the ones that are set along the two main sides of the building and therefore are the most public. The third one, the “inside”, is more private and it is the one that faces the interior corridor of the building.

Usually an “inside” façade would not be considered as an actual one because the common corridors do not provide any kind of open space or more important any natural light. In the case of the Tetris Houses skylights are vertically penetrating the interior circulation. This factor enables the corridors as semi-open spaces that provide to the residents of the building natural light.

In the end, in terms of construction, the Tetris dwellings’ typology is a standardized form of construction with simple and clear parameters. It has standard construction grid and the structural system is consisted from hollow core slabs and bearing walls. This feature gives limitless possibilities of expanding vertically and horizontally, depending on the current needs of the area.

It was decided to choose this type of houses, instead of a common typology, because of the extra advantages that offer to the residents. With this way extra architectural value and living quality is added. This is important when designing with reused elements because, at least at the beginning, the new buyers will not be interested if the elements are reused or not. They will care more about the quality and the price of the house than the construction elements. By offering a house with extra living quality than typical houses, the fact that it is constructed with reused elements will be an asset and even increase the demand. On the other hand when a typical house is constructed with reused elements without any living quality then the reused elements add no value to the construction. For this reason it is essential to design houses that will have an architectural quality and will offer a pleasant stay to the users. Figures 4.2 and 4.3 present the preliminary 3D drawings of the Tetris Houses. The area of each apartment is 100 m². For the purpose of this thesis it was decided to design only 2-story high houses.

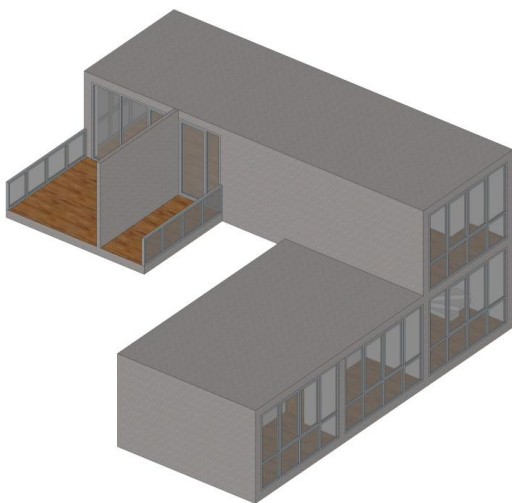


Figure 4.2 – Individual apartment of 100 m²

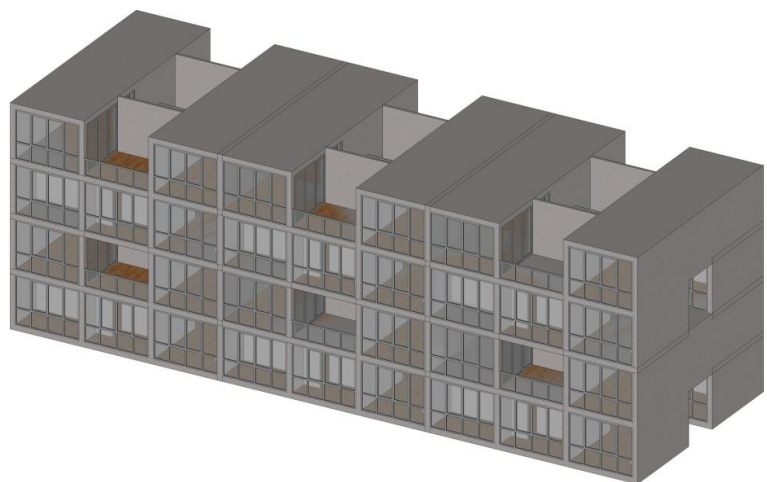


Figure 4.3- A building of four floors

Design process

This section presents the different structural systems that were used during the design process together with the reasons that forced the changes. At the beginning of a conventional structural design it is possible to change the dimensions, the type and the amount of elements very easy and without any costs since there are no restrictions besides the demands of the architect. When designing with reused elements these changes are restricted due to the incapability of changing the dimensions of the elements and due to the limited amount of elements. The limitation of the amount of elements can be solved when a real market of reused elements is created. At the moment this market does not exist and it is a doubt if it will exist in the future. As a result the elements that can be reused are only the ones that derive from the two buildings.

The goal of designing with reused elements is to achieve the maximum available area with the available elements and with the fewer modifications. Due to the fact that the elements of the existing office buildings are not meant to be deconstructed, a small part of the edges of the elements is cut when the connection is dismantled. Further sawing of the element after being removed from the building creates extra costs which should be avoided. A solution is to saw the element on size during the deconstruction process but this can happen only when the dimensions of the new design are known. In this way the extra sawing is avoided.

Regardless if the sawing is taking place after or during deconstruction a part of the element will always be send to recycle. The goal when reusing structural elements is to avoid reduction of the size and use the element as it is after deconstruction. In order to achieve this, the architect and engineer have to collaborate from the beginning of the design process. The role of the engineer becomes more active at the preliminary design phase by informing and discussing with the architect about the available elements and their properties. Then the architect can use this information and make the first drawings. At a conventional design the architect starts from preliminary drawings having in mind a number of restrictions like:

- Site restrictions
- Building height
- Function and typology
- Circulation
- Grid

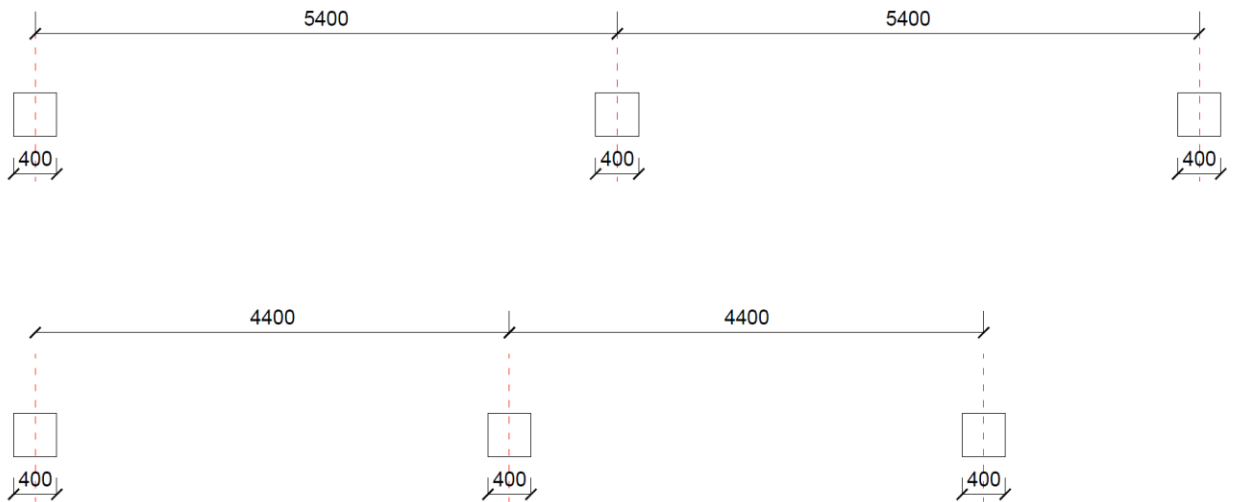
When designing with reused elements the dimensions of the elements are added in the previous mentioned restrictions. While at a conventional design it is possible to change the dimensions of the elements without any real costs, when designing with reused elements this is not possible since the elements have given dimensions. It is possible to reduce the dimensions but it is not possible to increase them. Also the reduction demands extra costs which increases the overall costs of the reuse process.

A basic step when starting a new design is to create the grid of the design. The chosen function and typology determines the size of the rooms which set the dimensions of the grid and as a result the position of the columns. At the beginning of the new design with reused elements it is important to identify the grid of the old buildings. With this way a first idea of the possibilities for the new design can be obtained. It is important to identify the changes of the dimensions of the elements and create the new grid.

The reused elements derive from office buildings. These office buildings have a standard grid which leads to a number of beams and slabs with the same sizes. These elements are the ones that determine the sizes of the openings in a building. When removing the beams from the offices a small part has to be cut – at least 200mm from each edge. The new size of the beam creates a new grid.

Furthermore, important role plays the way that the beams are supported. In the office buildings they were supported on corbels but this is not possible in the new design since the corbels are cut off. It is possible to add a new L-shape steel plate but this will create extra costs and it is not preferred as a solution. For this reason it is decided to support the beams on the columns and on the walls. This creates a number of issues which will be analyzed in chapter 5. One important change is the size of the grid. The building in Hogehilweg 18 is used as an example to identify the changes on the grid. The main grid is 5400 mm from the center of one column to another. The beams are supported on the corbels and as a result the length of the beams is 5000 mm. During the removal of the beams 200 mm from each side has to be cut in order to dismantle the connection. This makes the length of the beam 4600 mm. At the new design the beam will be supported on the column. At the external columns the beams will be supported completely on the entire column and at the middle beams the beam will be supported on the half column. The way of supporting the beams and the lost part due to deconstruction creates a new grid of 4400 mm (fig. 4.1). The advantage of supporting the beams on top of the columns is that the beam can be used in any direction. If it had to be supported on a corbel the beam could be only supported at the direction of the corbel which will limit the possible solutions. The percentage that is lost between the old grid and the new grid is 20%.

Figure 4.4 – Different grids



When designing houses with new elements the grid determines the position of the walls. Then the slabs are supported straight on the walls and as a result the dimension of the slabs depends on the size of the grid. It is possible to change the grid but it is preferred to keep the same grid for standardization reasons. When designing houses with reused elements the main elements are the columns and the beams. In this case the size of the beams determines the position of the columns and as a result the new grid. It is a reversed procedure. This creates a new typology. Moreover, the size of the grid can be decreased but it cannot be increased due to the restricted dimensions of the elements.

With this way it is possible to achieve the maximum reuse percentage of the elements. In the new housing project it was difficult to adopt this procedure because the design was made with the conventional methodology and taking in account that the dimensions of the elements are not

a restriction. This led to a conventional grid and it was necessary to modify the reused elements in order to fit in the new design. Attempts to use the elements at their original dimensions were changing the design significantly and this had to be avoided. This shows the importance of the collaboration of the engineer and the architect from the beginning of the design procedure where both have to taking in account the restrictions of designing with reused elements. Although a lot of elements had to be modified in order to be reused in the new project attempts were made to use the available elements as efficient as possible. The final design was reached after 3 phases.

1st phase

At the beginning of the design the idea was to use all the elements included in the inventory. This contained elements from 8 different buildings. It was assumed that all the buildings were deconstructed and the elements are stored in a storage site ready for reuse. With this way it would be possible to use a large amount of elements, with different dimensions. The elements that determined the design were the 12,8 m hollow core slabs from Hogehilweg 22. These slabs were very efficient due to the large area that they could cover. Usually in housing projects it is avoided to use slabs of this length in order to avoid vibrations and sound transmission from one apartment to another. In this case, this problem could be solved with the use of a floating floor. The amount of the slabs was enough to design 4 blocks. Each block would have 10 houses of 100 m². For the structural system of the building it was decided to use walls in order to transfer the lateral loads in both directions. In the inventory there was a large amount of walls that could be used. Besides the structural function, the walls could cover also big openings and as a result avoid costs for non-structural walls. The elements that were used for the 1st phase are presented in table 4.5.

Level	Main beams	Columns	Walls	H.C.S.
Ground floor	-	80	88	160
1 st floor	104	0	88	200
Roof	64	0	0	200
Total	168	80	176	560

Table 4.5 – Reused elements of 1st phase

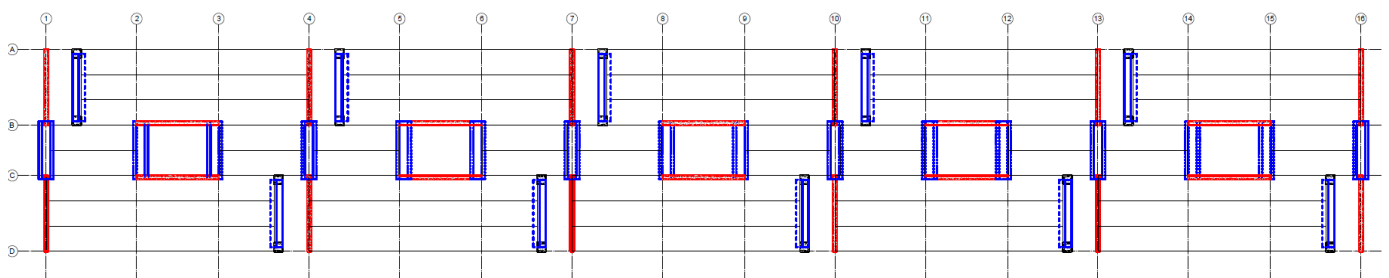


Figure 4.5 – 1st phase – 1st floor

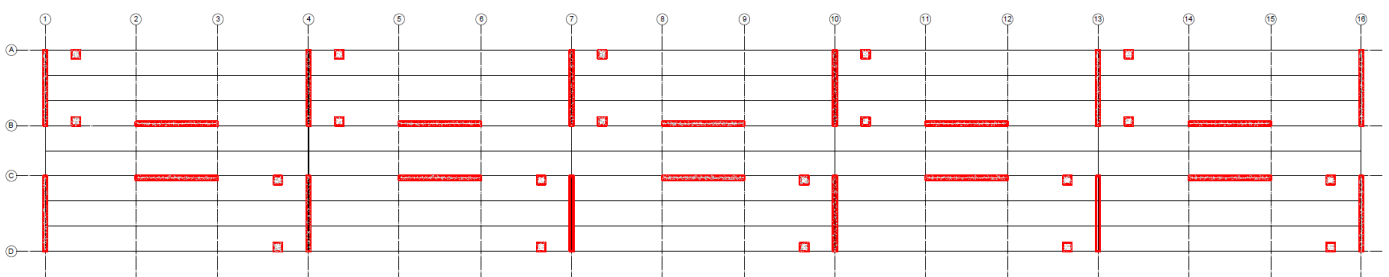


Figure 4.6 – 1st phase – Ground floor

2nd phase

During the process of the present thesis it was decided that it is not applicable to have all the elements in a storage site since it would cost a lot of money to deconstruct one building and use only a part of the total elements. Moreover, a market of reused elements does not exist and it is not sure that the remaining elements can be reused. The buildings that were excluded after this decision were the ones with the pre-stressed slabs since they are not suitable for deconstruction. This led to a smaller amount of elements. More specific in order to construct 4 blocks of 10 houses, new walls were needed. On the other hand there were a lot of columns and beams. Through structural analysis it was calculated that it is possible to use only 2 walls in the middle of each block for the resistance of the lateral loads at the small side. This reduced the amount of the walls but increased the amount of columns. The elements that were used for the 2nd phase are presented in table 4.6.

Level	Main beams	Columns	Walls	H.C.S.
Ground floor	-	144	56	160
1st floor	104	64	56	200
Roof	64	0	0	200
Total	168	208	112	560

Table 4.6 – Reused elements of 2nd phase

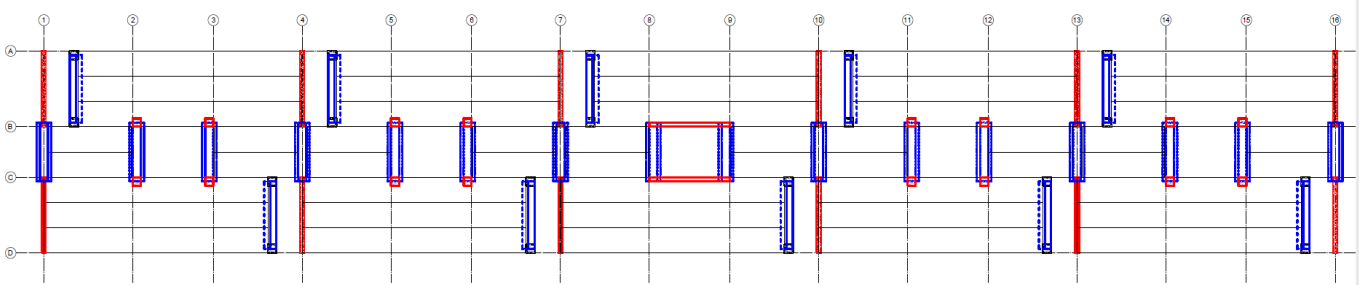


Figure 4.7 – 2nd phase – 1st floor

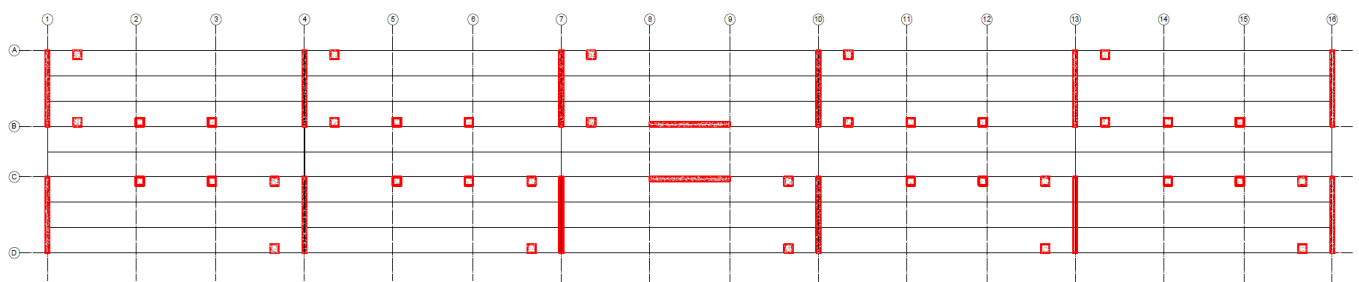


Figure 4.8 – 2nd phase – Ground floor

3rd phase – Final design

The buildings in Hogehilweg 22, Paasheuvelweg 8 and Paalberweg 9, although they are suitable for deconstruction, they will not be deconstructed because of the limited drawings and the large dimensions of the elements. If it was decided to use only a part of the elements from these buildings then a lot of elements would be send for recycle or storage. As a result only the elements from Karspeldref 2 and Hogehilweg 18 will be used. This change affected a lot the design. First, the 12800 mm slabs from Hogehilweg 22 were not anymore available and as a result extra columns, beams and slabs had to be used to bridge the gaps. Second, the available walls were not enough anymore for the construction of 4 blocks of 10 houses and it was decided to design 3 blocks of 10 houses. Moreover, due to the fact that the biggest slabs were 7000 mm the dimensions of the design had to change. This lead to a smaller atrium compared to the previous designs. During phase 1 and 2 only the ground floor and the roof had restricted dimensions. The 1st floor was possible to be adjusted since there were enough large slabs. In this phase also the 1st floor is restricted because the largest slab is 7000 mm. The elements that were used for the 3rd phase are presented in table 4.7.

Level	Main beams	Columns	Walls	H.C.S.
Ground floor	-	138	42	240
1 st floor	102	78	42	240
Roof	72	0	0	240
Total	174	216	84	720

Table 4.7 – Reused elements of 3rd phase

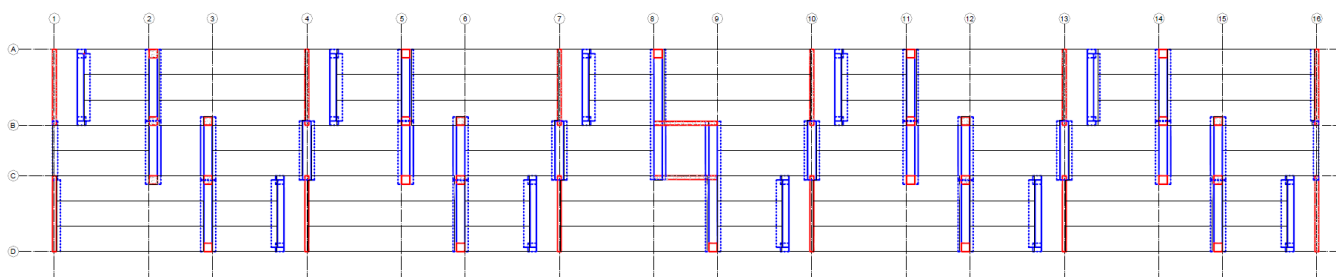


Figure 4.9 – 3rd phase – 1st floor

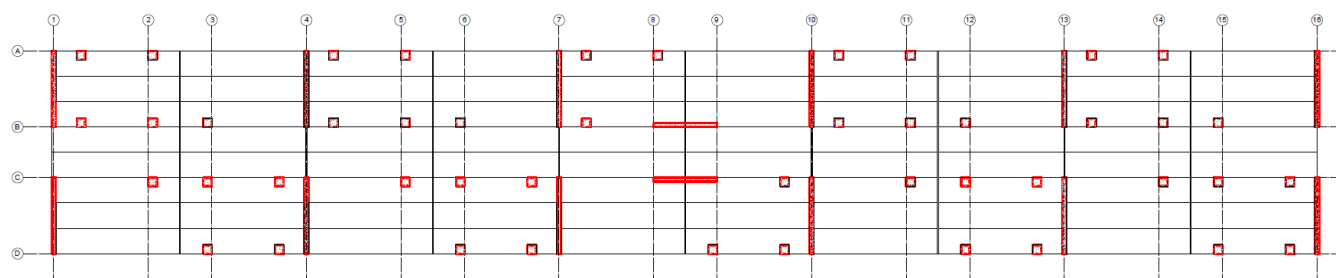


Figure 4.10– 3rd phase – Ground floor

4th phase

During the three phases the critical elements for the design were the walls. It is possible to further reduce the amount of walls and construct 10 more houses by replacing the walls in axis 4 and 13 with beams and columns. This change did not take place because there are not enough beams and columns. As a result the design at phase 3 is the final design.

Final design

The final design has 30 houses in 3 blocks of 10 houses. The total area of the construction is 5.432 m² and the houses are approximately 104 m² which is suitable for 4 persons. The architectural drawings of the houses can be seen in Appendix V. **All the structural elements are existing concrete elements deriving from the offices in Karspeldref 2 and Hogehilweg 18.** The only new structural elements are the steel plates that were used in the middle walls in order to support the slabs since the width of the walls is not enough (fig 4.11).

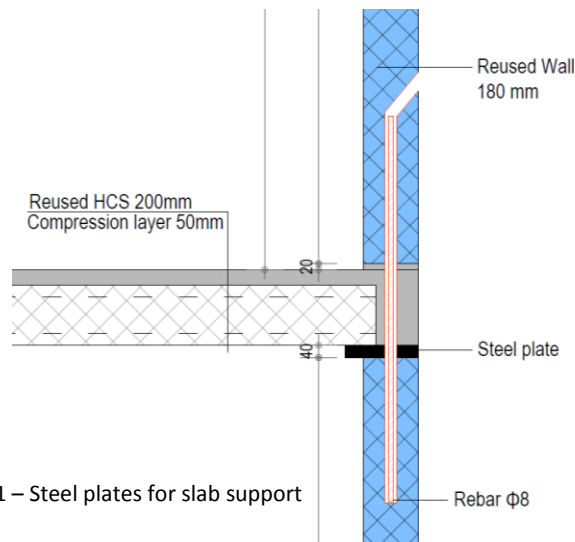


Figure 4.11 – Steel plates for slab support

In order to assess the new design with reused elements 3 different cases of reusability of the elements is calculated in percentage rate. The detailed calculations can be found in Appendix IV.

Reuse percentage on element level

This percentage shows the amount of elements that were used from the two buildings. It should be noted that although the original columns were 120 due to separations in segments the total columns are 229. The same is happening with the walls. Table 4.8 presents the reuse percentages on element level.

Elements	Main beams	Columns	Walls	H.C.S.	All
Total	183	228	101	1102	1615
Reused	157	216	84	720	1177
Percentage	86%	95%	83%	65%	73%

Table 4.8 – Reuse percentages on element level

Almost all the columns are reused while the walls and beams are reused in a smaller but still efficient percentage. Especially the atrium demanded extra columns and walls. On the other hand the percentage reuse of the hollow core slabs is low compared to the other three. This percentage can be increased with a different design without the presence of an atrium. The remaining elements will be sent for storage or for recycle.

Reuse percentage of area

This percentage shows the efficiency of the area of the new construction compared to the original area (table 4.9).

Building	Area (m ²)
Old offices	8.347
New houses	5.432
Percentage	65%

Table 4.9 – Reuse percentage of the original area

It is a positive percentage but there is room for improvement. Again here with a different design this percentage can increase. It is not possible to reach 100% since a number of slabs are not able to be reused due to their irregular shape and because the beams have to be cut at the edges.

Reuse percentage on structural mass level

This percentage shows the volume of concrete that is used from the elements that are meant to be reused. For elements like beams, columns and walls a part at the edges has to be cut in order to dismantle the connection. On the other hand, HCS can be removed intact. Table 4.10 presents the reuse percentage on structural mass level of the elements reused in the housing project.

Mass (kg)	Main beams	Columns	Walls	H.C.S.	All	Recycle
Total	359664	291594	422560	1572045	2645863	330784
Reused	279169	246190	359156	1430563	2315079	-
Percentage	78%	84%	85%	91%	87%	13%

Table 4.10 – Reuse percentages on structural mass level

The existing office buildings are not meant to be deconstructed and the existing dismantling methods will always disuse a part at the connections of the elements. For this reason it is possible to achieve 100% of reuse of the structural mass only for the H.C.S. Furthermore, the elements had to be modified in order to fit in the new design. This led to extra loss of structural mass.

Mass (kg)	Main beams	Columns	Walls	H.C.S.	All
Total	86%	95%	83%	65%	73%
Reused	78%	84%	85%	91%	87%
Percentage	67%	80%	71%	59%	64%

Table 4.11 – Reuse percentages on total structural mass level

Table 4.11 presents the reuse percentage on structural mass level of the total amount of elements of the two buildings. 64% is reused, 26% is sent for storage and 10% is sent for recycle. It should be considered as a rough estimation since there are elements with different dimensions.

The overall percentage of reusability is efficient but there is room for extra improvement. In all the 3 cases the decisive factor is the design methodology. This shows again the importance of taking in consideration from the beginning of the design process the fact that the new design will contain reused elements. The adjustment of an existing architectural design in order to use existing elements at their original dimensions is difficult to be realized without significant changes.

In order to achieve the maximum area with reused elements from existing buildings it is important to take in consideration the grid. When designing with new elements it is possible to adjust the dimensions of the grid but this cannot happen when designing with reused elements.

4.3. RESULTS

The factors that affect the percentage reuse on structural mass level are the losses due to deconstruction and the way the elements are supported. From this chapter it can be concluded that the design of a building with reused elements demands detailed design from the beginning of the process due to the restricted dimensions of the elements. The following sections analyze the reuse percentage of each element.

Slabs: The percentage reuse of the slabs on element level is 65% and on structural mass level is 91%. The reason that not all the slabs are possible to be reused is primarily because they are not needed in the specific design and secondary because a number of slabs have irregular shape. The slabs that are not needed will be sent to a storage site for future reuse. It is possible to construct more house blocks and reuse more slabs but new walls, columns and beams are needed so this is not considered as an option. The irregular slabs will be sent for recycle since it will be difficult to reuse them in a future project. In order to increase the percentage reuse of the slabs the new construction has to be made by taking in consideration from the beginning of the design the amount of available elements, the way they will be connected and the structural system. As it was mentioned, the grid has to be reduced from 5,4m to 4,4m which means that 20% of the slabs do not fit in the new design. As a result the maximum percentage of the slabs that can be reused on element level, when no new elements are used, is 80%.

The percentage reuse of the structural mass is considered as very high. This is happening because the slabs are the only elements that can be removed intact from an existing building and only an amount of slabs had to be modified in order to fit in the new design. The percentage can be increased almost to 100% when the new design is made with the condition that reused elements with restricted dimensions are used. A small percentage always has to be cut in order to create openings for cables and installations but this is not taken into account for this case study.

Columns: The percentage reuse of the columns on element level is 95% and on structural mass level is 84%. A 95% is considered as very high reuse percentage on element level. Only a few columns are not reused and this is happening because they are not needed in the specific design. The remaining columns will be sent to a storage site for a future reuse. The percentage reuse on structural mass is due to the deconstruction and the sawing on size. The existing columns are not connected in order to be deconstructed and always a part of the elements has to be cut. This is 100 mm for each column which is approximately 2% depending on the height of the column. Furthermore, the height of the column has to be reduced. The columns derived from office buildings are higher than those required for a typical house. Additionally, the beams will be supported on the columns which create extra height. For this reason the part of the column above of the corbel has to be cut. The reuse percentage can be increased to almost 100% but then the columns have to be reused at their original height which will create higher costs e.g. larger facade. The part that is lost due to deconstruction can be avoided only when the columns are meant to be deconstructed.

Walls: The percentage reuse of walls on element level is 83% and on structural mass is 85%. Also in this case, an 83% on element level is considered as high. The walls are used in order to receive lateral loads and the reuse percentage can increase in case the lateral loads increase. This can happen when extra floors are added. The walls that are not reused will be sent to a storage site for future reuse. The structural mass percentage is also considered very high. As for the columns, also the walls have to be cut due to deconstruction and in order to saw on size. The percentage can be increased to almost 100% but then also the facade costs increase.

Beams: The percentage reuse of the beams on element level is 86% and on structural mass level is 78%. The percentage of the elements can be increased with a different configuration. The percentage on structural mass level is reduced compared to the other elements due to the fact that the beams derived from office buildings are too large for houses and they need to be cut in order to fit in the new design. Moreover, the deconstruction method used to dismantle the connections led to the loss of 400 mm from each beam.

This section presents the final design. Figure 4.12 shows the effect of removing the office buildings and replacing them with houses in Amstel III area. No further research was made for the implementation of the houses in the area. Figure 4.13 and 4.14 shows the structural drawings of one Tetris house. The drawings of the whole block can be found in Appendix V. Figures 4.15 and 4.16 give an impression of the structural system. Finally figures 4.171 and 4.18 shows the interaction of the reused structural elements with the interior of the houses. The elements are left unexposed deliberately and they are part of the interior design. This shows the user the feeling of the reused elements.

4.4. ILLUSTRATIONS AND DRAWINGS

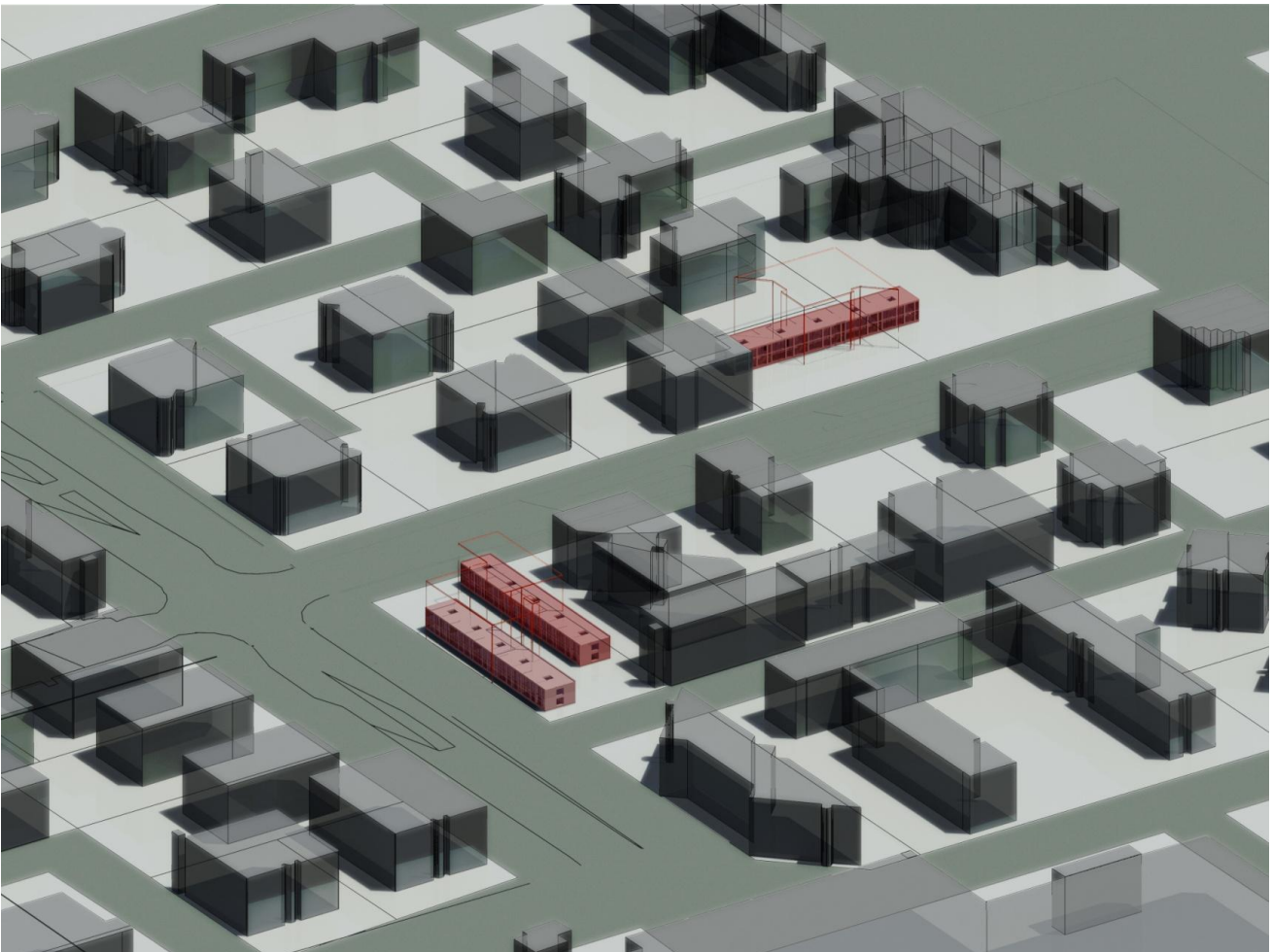


Figure 4.12 – Impression of removing offices and adding houses

Figure 4.13 - 1st floor plan

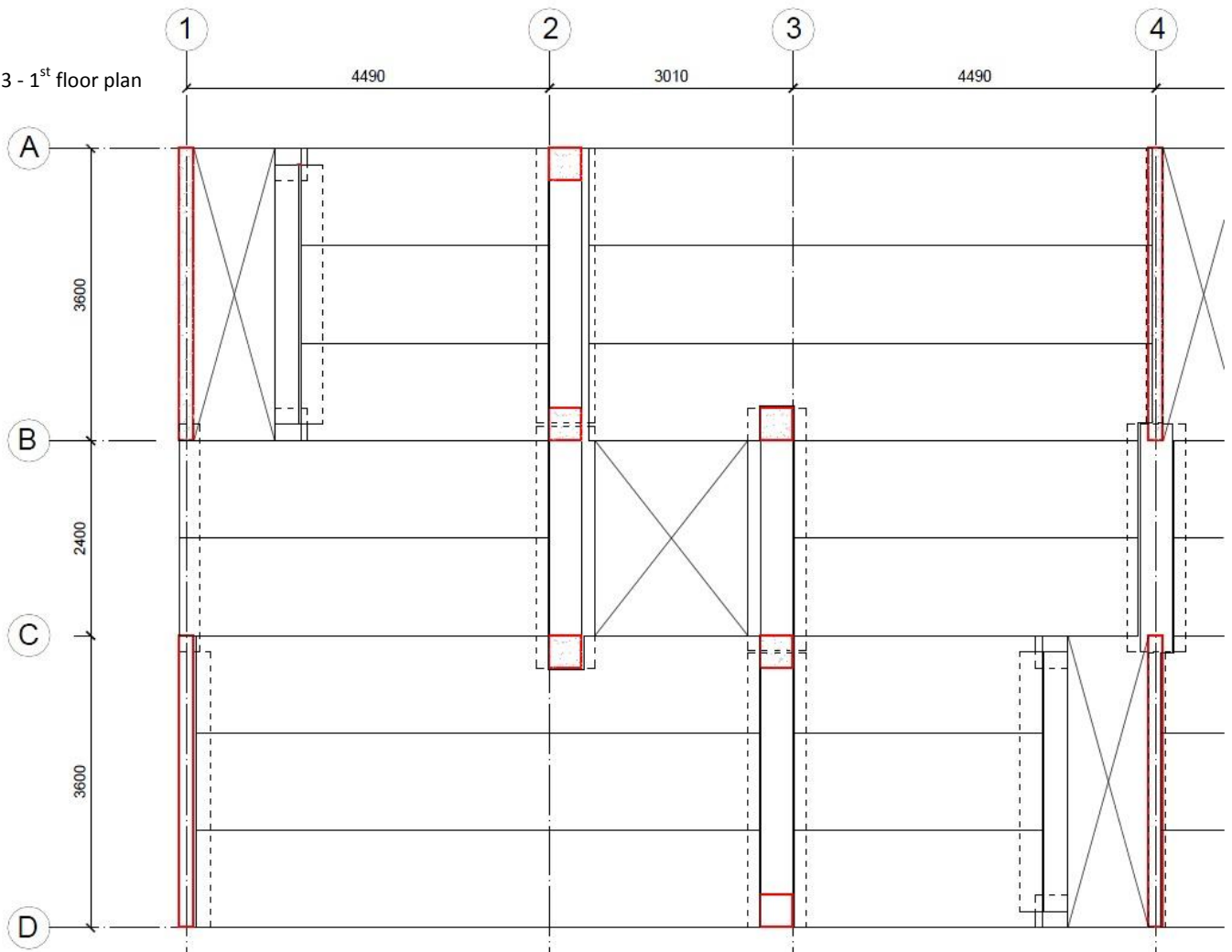
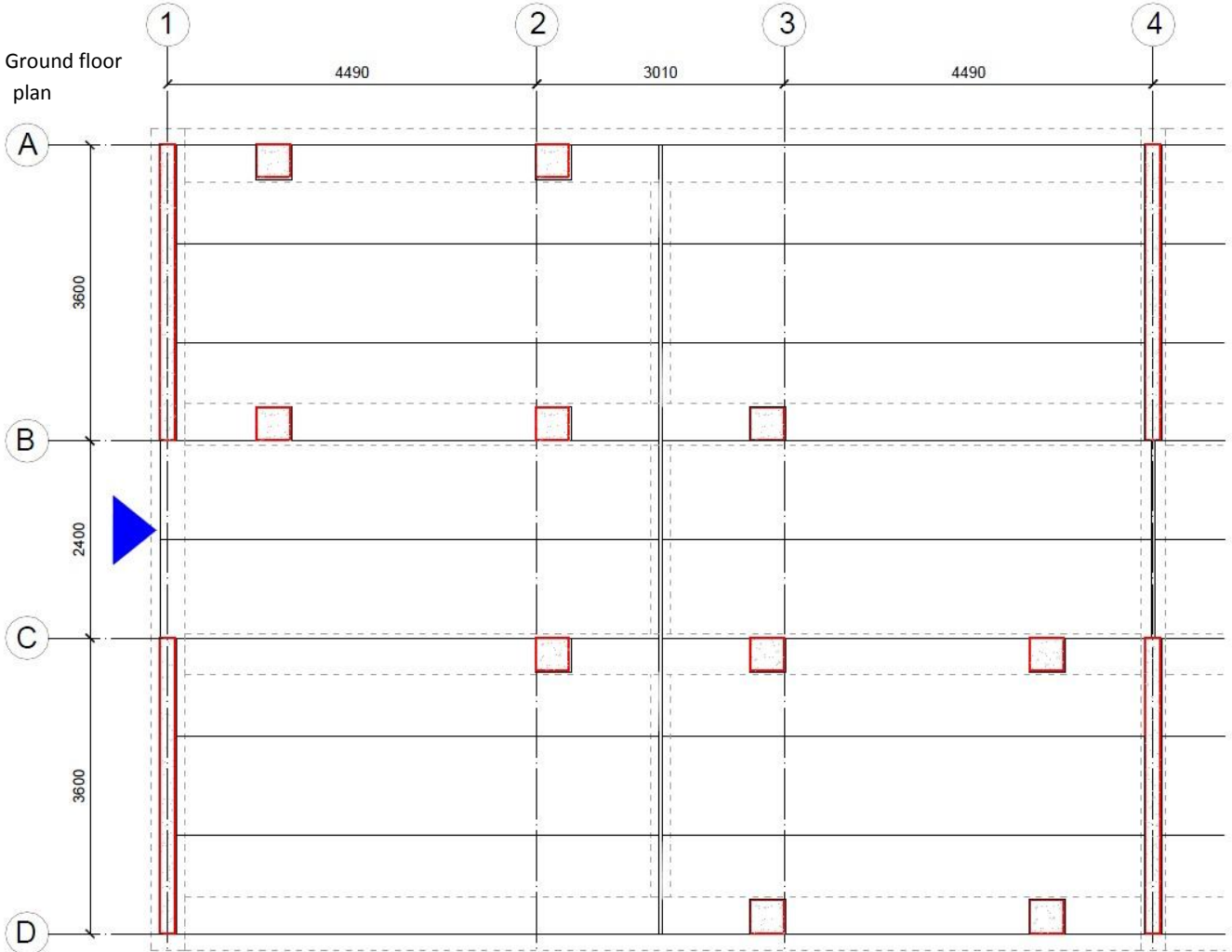


Figure 4.14 - Ground floor plan



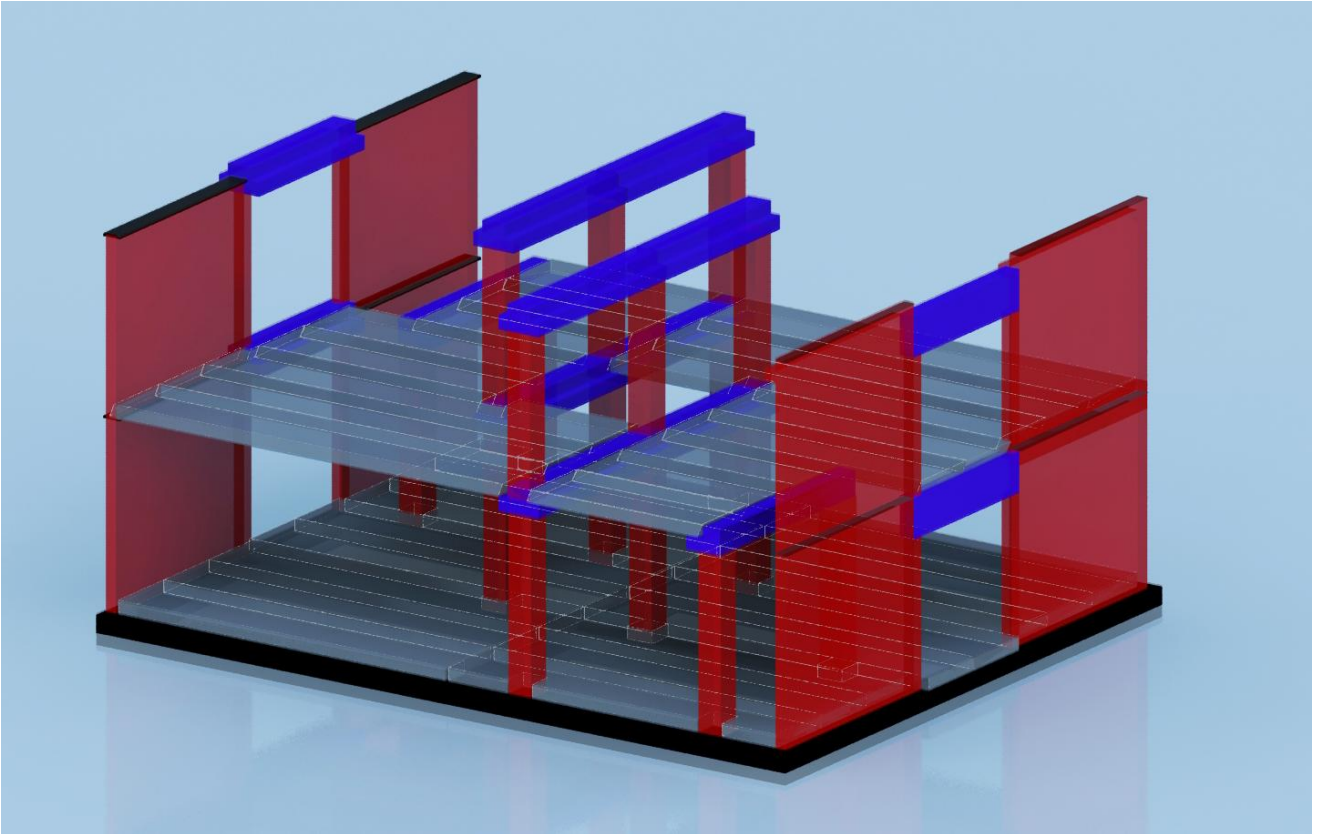


Figure 4.15 – Structural System 1

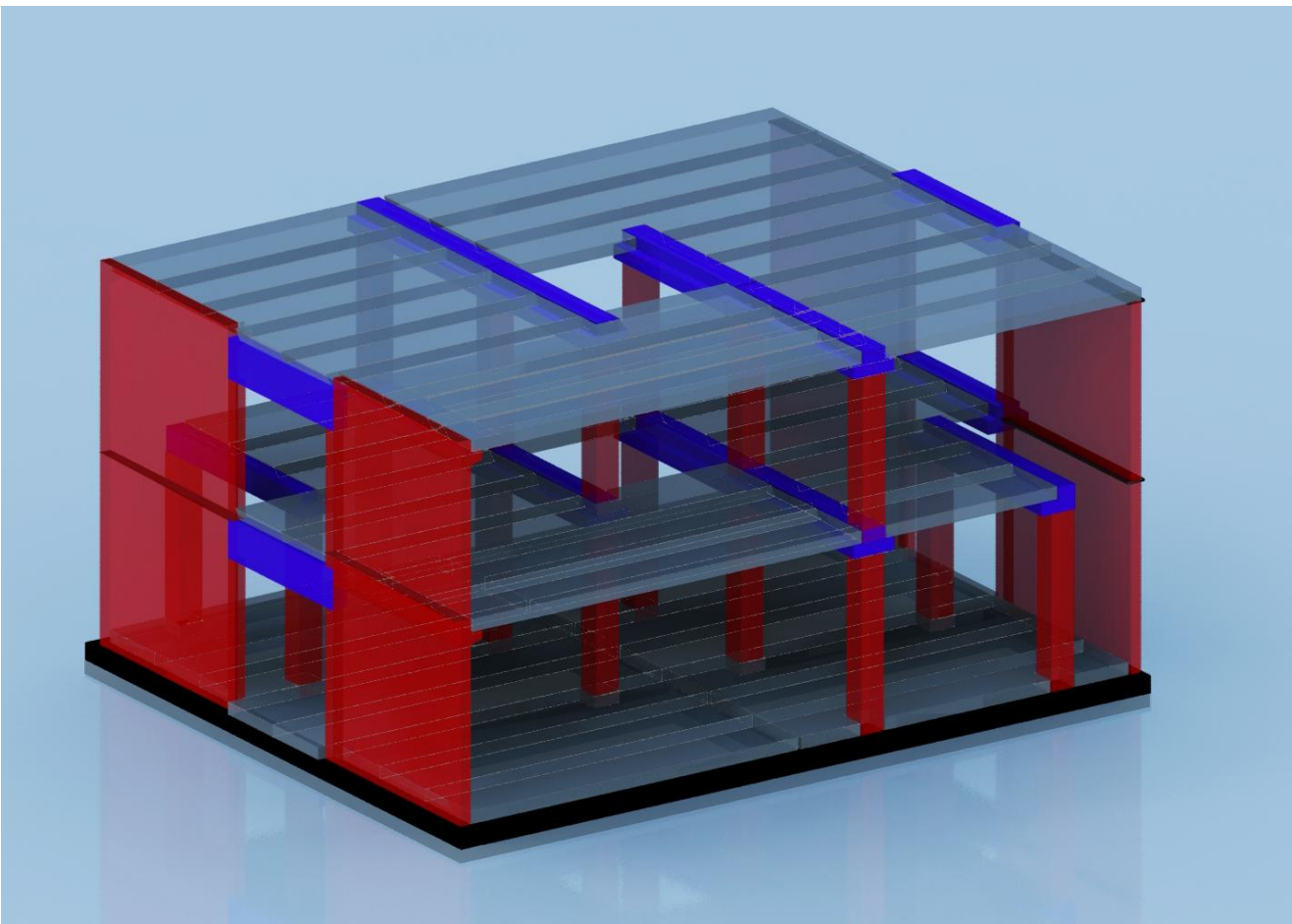


Figure 4.16 – Structural System 2



Figure 4.17 – Reused elements as part of the interior design – Isometric view



Figure 4.18 – Reused elements as part of the interior design – Interior view

CHAPTER 5

STRUCTURAL ANALYSIS

This chapter presents the structural analysis of the new houses designed with reused structural concrete elements. The goal is to research the feasibility of reusing structural elements in a new design and identify potential problems. At the beginning of the chapter the loads of the construction together with the wind loads are presented while at the second part the stability system of the new construction is analyzed. The next part assesses the properties of reused elements located in critical positions in the new design. Finally the conclusions of the structural analysis are presented.

5.1. LOADS

The first step of structural analysis is to calculate the loads of the construction. These are the permanent loads and the variable loads. Usually the permanent loads include the self-weight of the structure together with any architectural component like finishing, partitions, static equipment etc. The variable loads include the loads from human activity or wind action. Accidental actions are not taken into account for this design.

When designing a new building, preliminary calculations are made in order to estimate the sizes and the weight of the structural elements. In the second stage while all the sizes of the structural elements and the architectural details are established the permanent actions can be calculated accurately. On the contrary, when designing with reused structural concrete elements the self-weight of the elements is already known. This means that the step of preliminary calculations to estimate the size is omitted and it is possible to perform more detailed analysis earlier in the design process. In order to be more accurate the architectural details should be known also earlier in the process which shows that collaboration between architect and structural engineer is needed at the first stages of the design. In case this is not possible, the engineer has to advise the architect for the maximum loads that he can use.

For the design of the new houses the permanent loads that were taken into account are the self-weight of the slabs, the structural concrete topping and the finishing. The variable loads include the human activity in the house and the movable partition walls. The wind is considered as variable but it is calculated as a separate category. Any other architectural component is not taken into account since the architectural design is at a preliminary phase. The calculation of the loads was made according to NEN-EN 1991-1-1 General Actions, NEN-EN 1991-1-4 Wind Actions and the National Annex of the Netherlands. The permanent and variable loads (human activity and partition) walls can be seen in table 5.1 while the process of calculating the wind loads are presented in the next section.

The self-weight of the slabs were found from the old calculations of the existing buildings. It is important to carefully examine the calculations and pay attention on the dates. The documents that were obtained from the municipality include all the stages of the design which had different dimensions and as a result different weights. Examples of the old calculations can be seen in Appendix VI.

ROOF	
<u>Permanent loads (g):</u>	
Self-weight reused HCS (Hogehilweg 18 - 200mm)	= 3,3 KN/m ²
Concrete topping (50 mm)	= 1,0 KN/m ²
Roof cover	= <u>0,2 KN/m²</u>
	4,5 KN/m ²
Self-weight reused HCS (Karspeldreef 2 - 200mm)	= 3,0 KN/m ²
Concrete topping (50 mm)	= 1,0 KN/m ²
Roof cover	= <u>0,2 KN/m²</u>
	4,2 KN/m ²
<u>Variable load (q):</u>	
Roof not accessible	= 1,00 KN/m ²
1st FLOOR	
<u>Permanent loads (g):</u>	
Self-weight reused HCS (Hogehilweg 18 - 200mm)	= 3,3 KN/m ²
Concrete topping (50 mm)	= 1,0 KN/m ²
Finishing	= <u>0,5 KN/m²</u>
	4,8 KN/m ²
Self-weight reused HCS (Karspeldreef 2 - 200mm)	= 3,0 KN/m ²
Concrete topping (50 mm)	= 1,0 KN/m ²
Finishing	= <u>0,5 KN/m²</u>
	4,5 KN/m ²
<u>Variable loads (q):</u>	
Area for residential activity - Floor	= 1,75 KN/m ²
Partition walls < 1,0 KN/m	= <u>0,50 KN/m²</u>
	2,25 KN/m ²
GROUND FLOOR	
<u>Permanent loads (g):</u>	
Self-weight reused HCS (Hogehilweg 18 - 200mm)	= 3,3 KN/m ²
Concrete topping (50 mm)	= 1,0 KN/m ²
Finishing	= <u>0,5 KN/m²</u>
	4,8 KN/m ²
Self-weight reused HCS (Karspeldreef 2 - 200mm)	= 3,0 KN/m ²
Concrete topping (50 mm)	= 1,0 KN/m ²
Finishing	= <u>0,5 KN/m²</u>
	4,5 KN/m ²
<u>Variable loads (q):</u>	
Area for residential activity - Floor	= 1,75 KN/m ²
Partition walls < 1,0 KN/m	= <u>0,50 KN/m²</u>
	2,25 KN/m ²
Access roads (Corridor)	= 2,00 KN/m ²

Table 5.1. Construction and variable loads

Wind loads

The properties that should be known to calculate the wind load are the location of the building, the characteristics of the location, the height of the building and the structural system. The process of calculating the wind loads is presented in Appendix VI.

The structural system of the houses is a frame where all of the lateral loads are resisted by shear walls and none of the loads are transmitted to the columns and beams. This method of building houses differs from the already existing method in the Netherlands where houses are constructed only with walls. This is a result of the structural system that the elements are originating. The old office buildings are built as frames with concrete cores which receive the wind loads. This typology of construction results to a large amount of columns and beams and to a limited amount of walls. The final stability design was decided according to the availability of walls. An optimization process was followed in order to reach the final design. This process was explained in Chapter 4 in the design methodology.

The wind forces will be calculated for both sides of the building. The process of calculating the wind loads when designing with reused structural elements is the same with the process when designing with new elements. The only difference is at the stability check where the weight of the elements is already known and it can't be changed.

Wind forces on the long side (64,80 m)

5.2. STABILITY SYSTEM

A scheme of the final stability system and the way that it that will receive the wind loads is presented in figure 5.1:

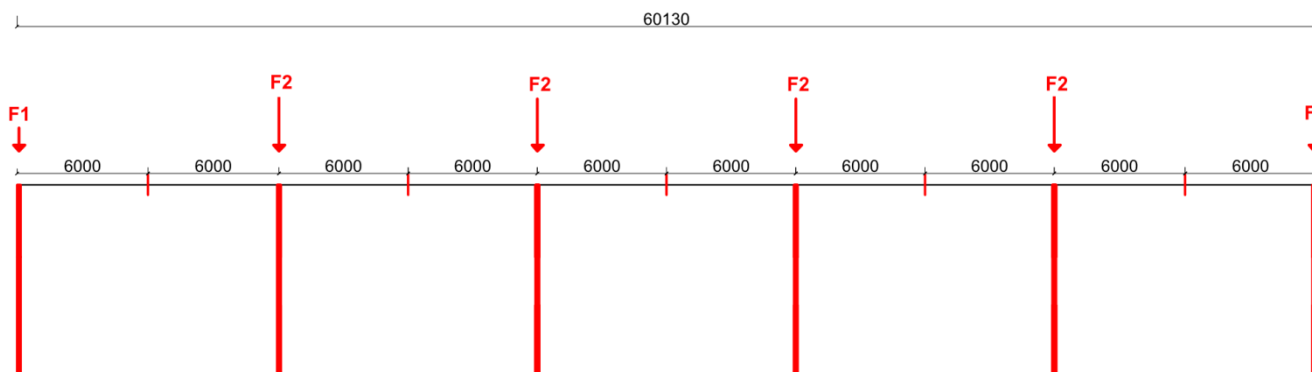


Figure 5.1 – Structural system on long side

The reference area of each wall is shown in the picture and it is used to calculate the loads. The calculation of the wind force is done with the following formula: $F_{w,e} = c_s c_d \times \Sigma w_e \times A_{ref}$.

The analytical calculations are shown in the Appendix VI.

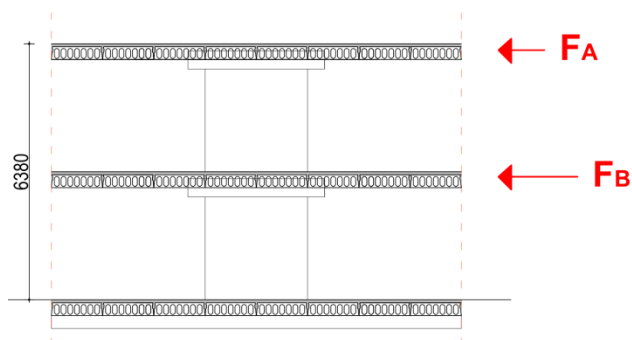


Figure 5.2 – Wind loads on the construction

The reference area of the walls is $A_{ref, middle wall} = 12 \text{ m}$ and for a height of 6,38m the wind forces on the 2 floors of the building are:

$$F_A = 18,75 \text{ KN} \ \& \ F_B = 37,49 \text{ KN}$$

These two forces create a moment at the foundation beam which is equal to $M = 253,09 \text{ KNm}$.

The shear forces on the foundation beam that occur from this moment are $Q = 26,36 \text{ KN}$.

The smallest reaction that occurs at the foundation beam from the self-weight of the construction is: $R = 168 \text{ KN}$ which is much larger than the shear forces from the wind. As a result there will be no uplift and the static scheme is functioning.

Since the difference between the reactions is big it is possible to increase the reference area of the wind by reducing the shear walls that receive the wind loads. The scheme of this stability system can be seen in figure 5.3.

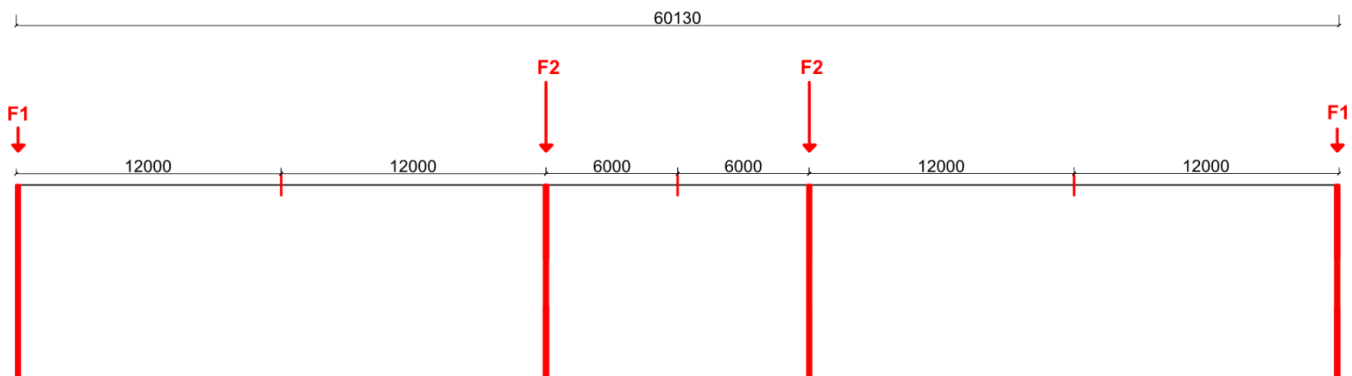


Figure 5.3 – Structural scheme on long side

The reference area of the middle walls is $A_{ref,middle\ wall} = 18\ m$. The height is still 6,38 m.

The wind forces on the building for this case are:

$$F_A = 28,10\ KN \ \& \ F_B = 56,21\ KN$$

These two forces create a moment at the foundation beam which is equal to $M = 379,38\ KNm$. The shear forces on the foundation beam that occur from this moment are $Q = 39,52\ KN$.

For a reference area $A_{ref} = 18m$ the reactions of the foundation pile from the self-weight are still much bigger: $168\ KN > 39,52\ KN$

Wind forces on the short side (9,60 m)

The scheme of the final stability system is depicted in the image below:

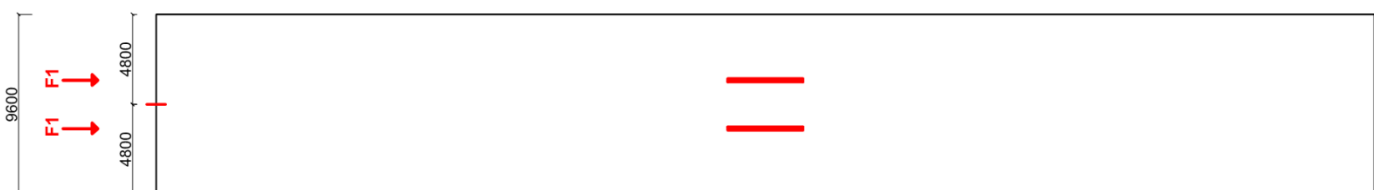


Figure 5.4 – Structural scheme on short side

In this case the reference area of the walls is the same. $A_{ref} = 4,8m$

The wind forces on the building for this case are:

$$F_A = 7,49\ KN \ \& \ F_B = 14,98\ KN$$

These two forces create a moment at the foundation beam which is equal to $M = 101,12\ KNm$. The shear forces on the foundation beam that occur from this moment are $Q = 33,71\ KN$.

The smallest reaction that occur at the foundation beam from the self-weight of the construction is: $R = 123KN$ which is much larger than the shear forces from the wind. As a result there will be no uplift and the static scheme is functioning.

5.3. STRUCTURAL ASSESSMENT OF ELEMENTS

The scope of this part is to assess the structural concrete elements that derive from the old office building according to the demands of the new design. In the Netherlands, when an existing building is meant to be reused the assessment of the structure is made with NEN 8700. On the other hand, when an element is removed from a building and it is reused in a new design it has to be checked if it complies with the Eurocode. For the assessment of the elements Eurocode 2 and the National Annex of the Netherlands was used. The elements that are going to be reused derive from the buildings in Hogehilweg 18 and Karspeldreef 2.

In order to have a complete structural assessment of the new design, all of the elements have to be checked. Since this is not feasible in the time frame of the thesis only the critical elements will be examined. Critical elements are those that have maximum load, different section and eccentricity.

The elements will be checked according to the original drawings that were found in the municipality. The structural assessment of the element related with the properties of the elements and the calculation of the maximum loads can be realized during the creation of the inventory. This will help the engineer to choose faster the element that fulfills the demands of his design. The elements have been designed with VB 1974/1984 but in order to make a comparison for a new design, their maximum capacity has to be calculated with the Eurocode. In this thesis due to the large amount of elements the checks were performed after the selection of the elements for the new design. It was safe to do this, because the elements derive from offices where the loads are larger. During a real project the maximum capacities of the elements has to be calculated during the formation of the inventory.

Beams

The beams are made from prefabricated concrete and there are 3 different sections:

- Rectangular
- L beam
- Inverted-T beam

Before starting the assessment of the beams it is important to note the properties of each beam. When creating the inventory the original properties of the beams will be noted. These will be the maximum dimensions, after the removal from the building and without any modification. During the design phase the properties of the beam will change according to the modification. The properties that have to be noted are:

- Length (mm)
- Section (mm)
- Weight (kg)
- Cover (mm)
- Concrete and Steel quality
- Longitudinal reinforcement
- Shear reinforcement

The beams have to be assessed according to the following checks:

Cover of reinforcement

According to Eurocode EN 1992-1-1, the concrete cover is the distance between the surface of the reinforcement closest to the nearest concrete surface (e.g. links, stirrups) and the nearest concrete surface. This cover is the nominal cover and it is defined as a minimum cover plus an allowance in design for deviation, Δc_{dev} : $c_{nom} = c_{min} + \Delta c_{dev}$.

The minimum concrete has to be provided in order to ensure:

- The safe transmission of bond forces
- The protection of the steel against corrosion
- An adequate fire resistance

The maximum value of c_{min} must be used:

$$c_{min} = \max \{ c_{min,b}; c_{min,dur} + \Delta c_{dur,y} - \Delta c_{dur,st} - \Delta c_{dur,add}; 10\text{mm} \}$$

The detailed calculations of the cover can be found in Appendix VI and the analytical procedure can be found in NEN-EN 1992-1-1, chapter 4 and in the Dutch National Annex.

Length anchorage

Another important property of the reinforcement bars is the length anchorage. In order to transfer safely the bond forces to the concrete and avoid longitudinal cracking or spalling, reinforcement bars must be sufficiently anchored. There are different methods that anchorage length can be achieved, e.g. straight, bend or loop.

The most common anchorage method for structural concrete elements for buildings and especially beams is the bending of the rebar at the edge of the element. When reusing existing concrete beams the rebar is already bended in the element and since it is mandatory to destroy the connection and cut the element at the edge, the bended bar is lost and it is not possible to bend it again. As a result straight anchorage length has to be used which demands larger supports.

The basic required anchorage length is: $l_{b,rqd} = \frac{\Phi}{4} \times \frac{\sigma_{sd}}{f_{bd}}$

The design anchorage length is: $l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,rqd} \geq l_{b,min}$

The detailed calculations of the cover can be found in Appendix VI and the analytical procedure can be found in NEN-EN 1992-1-1, chapter 8.4 and in the Dutch National Annex.

It is possible to reduce the anchorage length when the existing reinforcement ($A_{s,prov}$) is more than what is required ($A_{s,rqd}$). This can be done by reducing the design stress, σ_{sd} , at the position from where the anchorage length is measured:

$$\sigma_{sd} = \left(\frac{A_{s,rqd}}{A_{s,prov}} \right) \times f_{yd}$$

Main reinforcement

The beams that are meant to be reused are prefabricated elements and they were used in a braced system as simple supported. Since they are designed as simple supported they have the maximum moment in the middle section of the beam with the maximum tensile reinforcement. They have also a few rebars at the compression zone but they are used for practical reasons. As long as the reinforcement in the beam is known it is possible to calculate the maximum moment that can be received at the middle of the beam (where the maximum moment is located). The moment can be calculated from the following formula:

$$M_{Ed} = A_s \times f_{yd} \times 0,9 \times d$$

The next step after having the maximum moment is to calculate the maximum load that can be applied on the beam. Under the condition that the beam is used as simple supported the following formula can be used:

$$q_{max} = \frac{Mx8}{L^2th}$$

During the design phase the engineer can go through the elements and find out which one complies with the moment and the load that he needs for his design. In case that the beams are analyzed as simple supported but they are partial fixed at the supports, top reinforcement should be present and resist at least 15% of the maximum span moment. If the existing reinforcement is not enough, extra reinforcement can be added in the compression layer.

Shear reinforcement

The shear reinforcement (stirrups) of the beam depends on the maximum shear forces at the supports of the beam. Usually the stirrups at the edge of the beams are more dense and in the middle they become more sparse. The shear reinforcement of the old beam is already known and it is possible to calculate the maximum shear resistance ($V_{Rd,max}$). This can happen during the creation of the inventory. Attention should be paid at the fact that the edges of the beam are cut and as a result a number of shear reinforcement is lost.

Also it is possible to calculate the shear resistance of the concrete ($V_{Rd,c}$). If the shear forces are less then hypothetically no shear reinforcement is needed. According to Eurocode, a minimum amount of shear reinforcement must be provided in order to form a cage supporting the longitudinal reinforcement and to resist any tensile stresses due to factors such as thermal movement and shrinkage of the concrete. The minimum reinforcement is equal to:

$$\rho_{w,min} = \frac{0,08 \times \sqrt{f_{ck}}}{f_{yk}}$$

The detailed calculations of the shear reinforcement can be found in Appendix VI and the analytical procedure can be found in NEN-EN 1992-1-1, chapter 6.2 and 9 and in the Dutch National Annex.

Columns

Also the columns are made from prefabricated concrete and there are only rectangular sections. They were used in a braced system to transfer only vertical loads. They have to be used with the same way at the new design. The columns were used to support the beams and corbels were used for this reason. The corbels are not going to be used in the new design so they have to be cut. The columns will support the beams as simple supported. Similarly to the beams the properties of the columns have to be noted. They are the same with the beams with minor modifications. The detailed properties can be seen

The columns have to be assessed according to the following checks:

- Cover of reinforcement
- Slenderness ratio
- Main reinforcement
- Shear reinforcement
- Dowel(s) for the connection

Slenderness ratio

In order to check if the second order effects have to be taken into account the limiting slenderness ratio (λ_{\min}) of the column have to be calculated. If it is bigger than the slenderness ratio of a column (λ) then the column is short and second order effects can be ignored.

$$\lambda = \frac{l_o}{\sqrt{(I/A)}} \quad \text{and} \quad \lambda_{\min} = 20 \times A \times B \times C / \sqrt{n}$$

The analytical procedure can be found in NEN-EN 1992-1-1, chapter 5.8 and in the Dutch National Annex.

Longitudinal reinforcement

The main reinforcement of the column depends on the axial forces and the moments from eccentricity. In every case there is an eccentricity due to imperfection but it is possible that there is eccentricity from the axial load. Since the reinforcement depends on the axial forces and the moments it is difficult to calculate the maximum axial force and moment. The calculations will be made with tables from Eurocode. Besides calculating the amount of steel also the maximum distance between the rebars has to be checked.

Cover of reinforcement

The cover has the same functions like in beams. The detailed calculations of the cover can be found in Appendix VI and the analytical procedure can be found in NEN-EN 1992-1-1, chapter 4 and in the Dutch National Annex.

Detailing of column

The longitudinal and transverse reinforcement of the reused columns have to be assessed according to detailing demands of Eurocode. The details that have to be checked are:

- Maximum and maximum distance between main reinforcement
- Maximum center to center distance between stirrups
- Minimum reinforcement dimensions

The above properties can be found in NEN-EN 1992-1-1, chapter 9.5 and in the Dutch National Annex.

Besides the detailing of the main reinforcement and the stirrups it is important to check the effect of cutting the beam at the bottom or the top. The existing splitting reinforcement will be cut off and for this reason it has to be checked if the concrete can resist the lateral tensile forces or enhance the concrete either by adding a steel plate.

Walls

As the beams and the columns also the walls are prefabricated elements. They were used in a braced system to transfer vertical and lateral loads. As it was explained, their function in the new design will be the same.

There are walls with different dimensions and in order to be reused they have to be modified according to the needed dimensions. The checks that have to be made are the same with the columns and only the detailing is different. Like the columns, also the walls have to be checked for the lateral tensile reinforcement and if the concrete can resist these forces.

Slabs

The slabs that derive from the 2 office buildings are Hollow Core slabs and they have different dimensions. The most optimum is to use the slabs at their original size. If it is not possible to do that then they have to be sawn according to the needed dimensions.

Unfortunately, no specifications about the properties of the slabs were found during the inventory stage. This is happening because most of the times the manufacturers of the slabs have the drawings and the detailed properties. Nevertheless, it is possible to reuse them for the new design because they were previously used in office buildings where the loads are higher than in houses.

The only property of the slab that can be checked is the deflection according to the supporting system. It is suggested to avoid the fixed connections of the slabs at the supports due to the nature of the hollow core slab.

Assessment of elements

The sections of the new design in figures 5.5 and 5.6 shows the elements that were assessed. The analytical calculations and the detailed drawings of the elements can be found in Appendix VI In this section the examples of the EIDs of specific elements are presented which includes the results of the structural assessment.

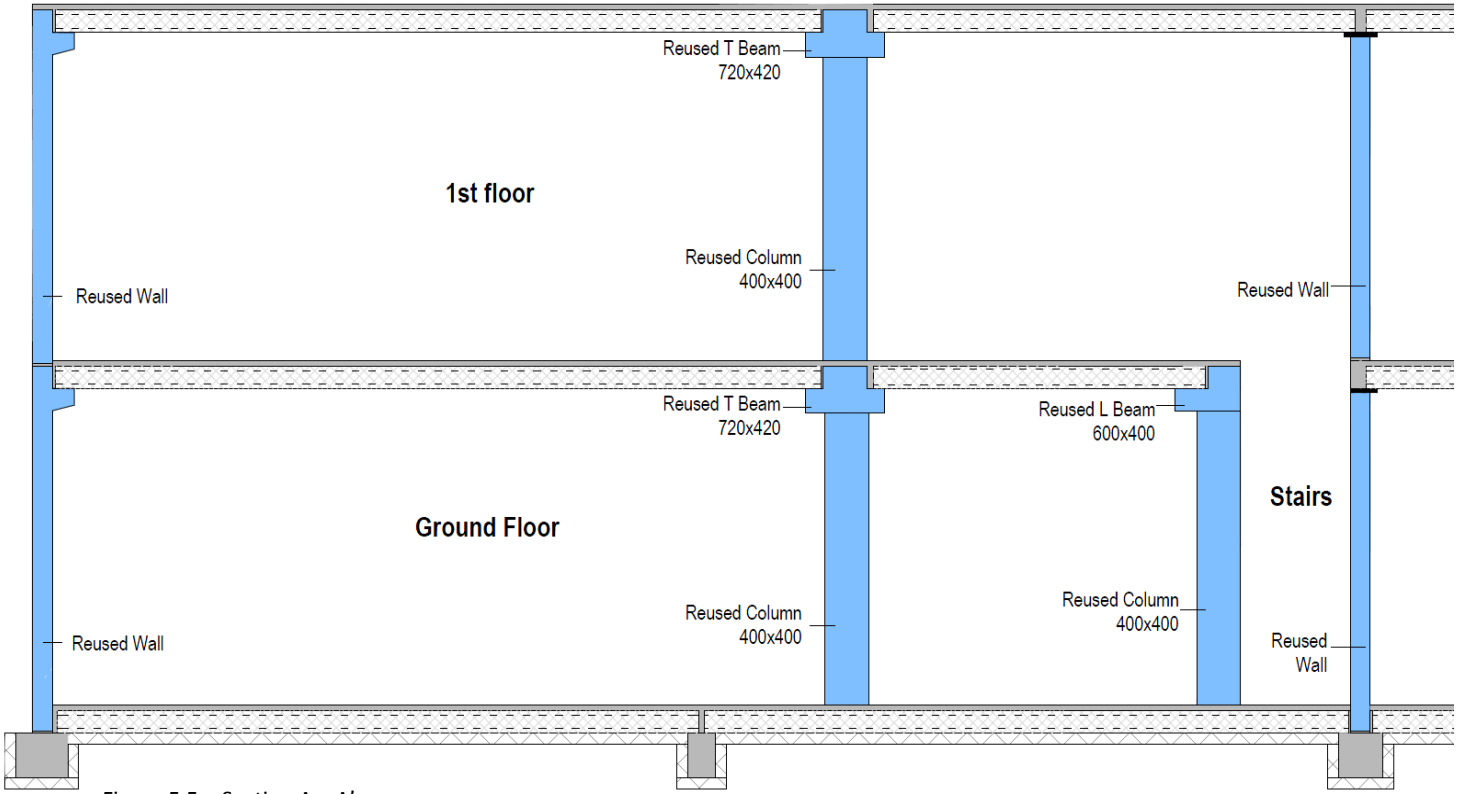


Figure 5.5 – Section A – A'

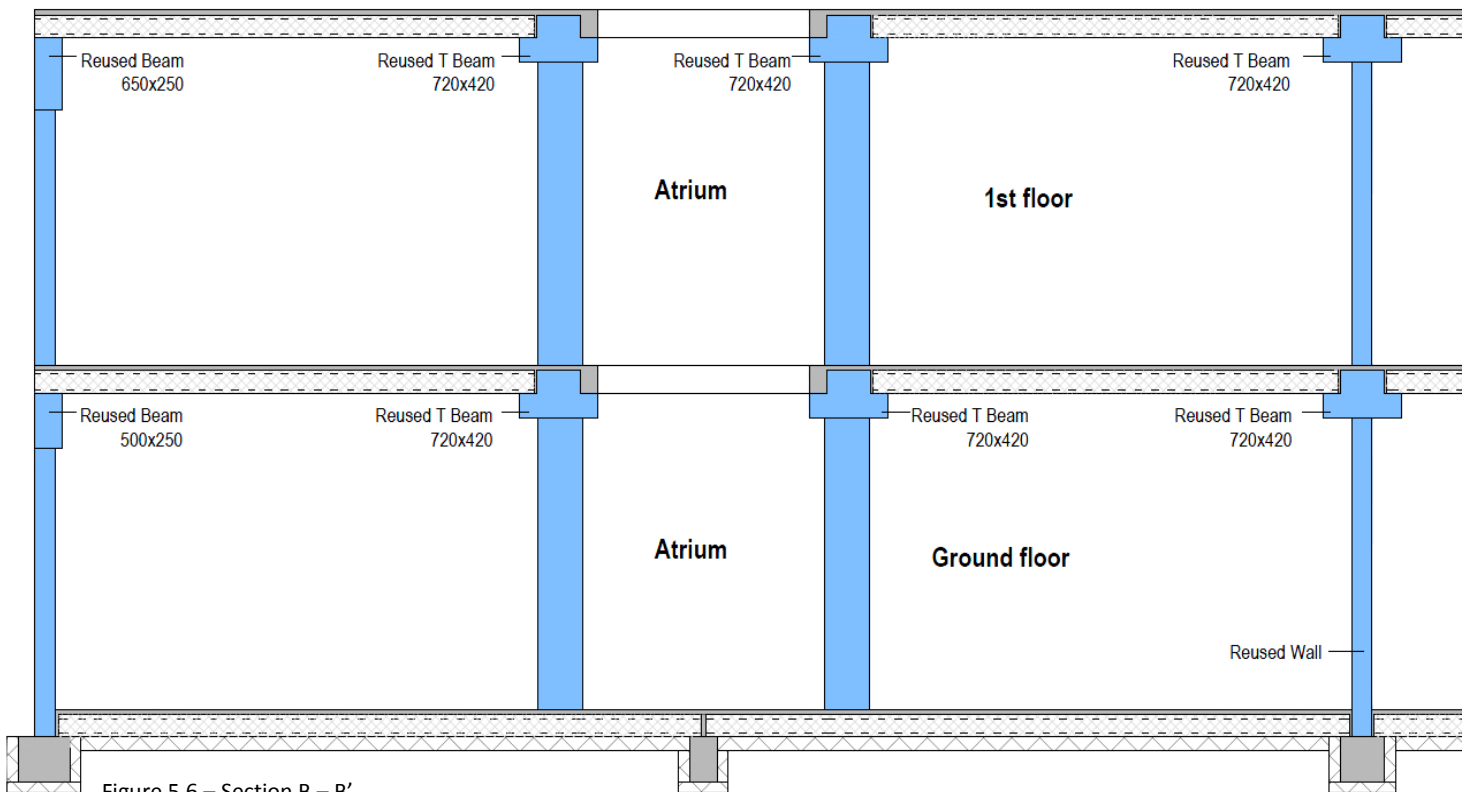


Figure 5.6 – Section B – B'

- L beam at the stairs

This beam is suitable for this position instead of reversed T beam because it does not insert in the space of the stair. It originates from the building in Karspeldref 2 and in the existing drawings it is labeled as L1. The total amount of the beams is 24. The detailed drawings of the beam can be found in Appendix III. The following table presents the EID of the element which includes the results of the structural assessment of the beam. As it can be seen from the results the beam fulfills all the checks. It is used at its maximum dimension after deconstruction.

Original properties													
Length (mm)	Section (mm)			Weight (kg)	Cover (mm)	Concrete quality	Steel quality	Longitudinal reinforcement				Shear reinforcement	
	h	b	d					Above	Area (mm ²)	Under	Area (mm ²)	Edges	Middle
3580	400	600	386	1805	30	B35/45	500 B	2 Φ 10 + 1 Φ 12	270	3 Φ 12 + 2 Φ 16	741	Φ 8/100	Φ 8/200

Properties after modification			
Length (mm)	Weight (kg)	Shear reinforcement	
		Edges	Middle
3240	1634	Φ 8/100	Φ 8/200

Total ultimate load	
New design	22,68 KN/m

Main reinforcement	
Existing reinforcement	741 mm ²
Max. Moment due to existing rebars	112 KNm
New design moment	26 KN/m
Required reinforcement	323 mm ²

Shear reinforcement	
Concrete resistance	55 KN
Existing middle stirrups	Φ 8/200
Resistance due to existing middle stirrups	76 KN
Existing edge stirrups	4 Φ 8 x 100
Resistance due to existing stirrups at the edges	151 KN
Design shear at the edge of the support	34 KN
Required reinforcement	Φ 8/250

Cover	
Existing	30 mm
Eurocode	13 mm

Anchorage length	
Design anchorage length	$l_{bd} = 339\text{mm}$
Reduced anchorage length	$l_{bd,red} = 148\text{mm}$
Min. anchorage length	$l_{b,min} = 160\text{mm}$

Reuse	
Original weight	1805 kg
Weight after modification	1634 kg
Reuse percentage	91 %
Debris	171 kg
Concrete for recycle	168 kg
Steel for recycle	3 kg

Table 5.2 – EID of L beam

- Rectangular beam at the sides

This beam is used at the external sides of the houses. It is preferred over a reversed T beam because it does not create any irregularities at the façade. It originates from the building in Karspeldreef 2 and in the existing drawings it is labeled as B11. The total amount of the beams is 6. The detailed drawings of the beam can be found in Appendix III. The following table is a part of the Element Identity and it presents the results of the structural assessment. As it can be seen from the results the beam fulfills all the checks.

Original properties													
Length (mm)	Section (mm)			Weight (kg)	Cover (mm)	Concrete quality	Steel quality	Longitudinal reinforcement				Shear reinforcement	
	h	b	d					Above	Area (mm ²)	Under	Area (mm ²)	Edges	Middle
4460	500	250	454	1450	30	C35/45	500 B	2Ø10 + 2Ø12	383	1Ø12 + 2Ø16	515	2Ø6	Ø6/250

Properties after modification		
Length (mm)	Weight (kg)	Shear reinforcement Middle
2800	910	Ø6/250

Total ultimate load	
New design	31,48 KN/m

Main reinforcement	
Existing reinforcement	515 mm ²
Max. Moment due to existing rebars	122 KNm
New design moment	27 KN/m
Required reinforcement	323 mm ²

Shear reinforcement	
Concrete resistance	62 KN
Existing middle stirrups	Ø6/250
Resistance due to existing middle stirrups	72 KN
Design shear at the edge of the support	38 KN
Required reinforcement	Ø6/250

Cover	
Existing	30 mm
Eurocode	13 mm

Anchorage length	
Design anchorage length	$l_{bd} = 339\text{mm}$
Reduced anchorage length	$l_{bd,red} = 213\text{mm}$
Min. anchorage length	$l_{b,min} = 160\text{mm}$

Ultimate load (KN/m) vs Length (m)

Bending moment diagram [M]

Shear force diagram [V]

Reuse	
Original weight	1450 kg
Weight after modification	910 kg
Reuse percentage	63 %
Debris	540 kg
Concrete for recycle	529 kg
Steel for recycle	11 kg

Table 5.3 – EID of Rectangular beam

- Column at the atrium.

The column that is used in axis 2 at the atrium originates from Hogehilweg 18 and in the existing drawings is labeled as K1. The total amount of the columns is 6. Due to the large height of the column it is possible to divide it in 3 smaller columns. Since the column is high for a house function it is decided to cut the corbel. The main issues that derive from this is the absence of lateral tensile reinforcement at the edges and the larger distance between the stirrups compared to the requirements of the Eurocode. All the other requirements and especially the column is oversized and it can be used for higher loads. The table following table is part of the Element Identity.

Original properties											
Length (mm)	Section (mm)		Weight (kg)	Cover (mm)	Concrete quality	Steel quality	Longitudinal reinforcement		Shear reinforcement		
	h	b					Above	Area (mm ²)	Top	Middle	Low
10170	400	400	4250	35	C35/45	500 B	4 Φ 16 + 8 Φ 12	1708	Φ 8/250	Φ 8/250	Φ 8/250

Properties after modification				
Column	Length (mm)		Weight (kg)	
	Original	After modification	Original	After modification
Top	3820	2950	1597	1233
Middle	3400	2950	1421	1233

Slenderness	
λ	25,52
λ_{min}	213,92

Main reinforcement	
Existing reinforcement	1708 mm ²
Required reinforcement	342 mm ²

Shear reinforcement	
Distance between longitudinal rebars	86 mm
Max. distance between longitudinal rebars (EC2)	150 mm
Distance between existing stirrups	250 mm
Max. distance between stirrups outside overlapping length (EC2)	400 mm
Min. distance between stirrups inside overlapping length (EC2)	240 mm

Cover	
Existing	35 mm
Eurocode	13 mm

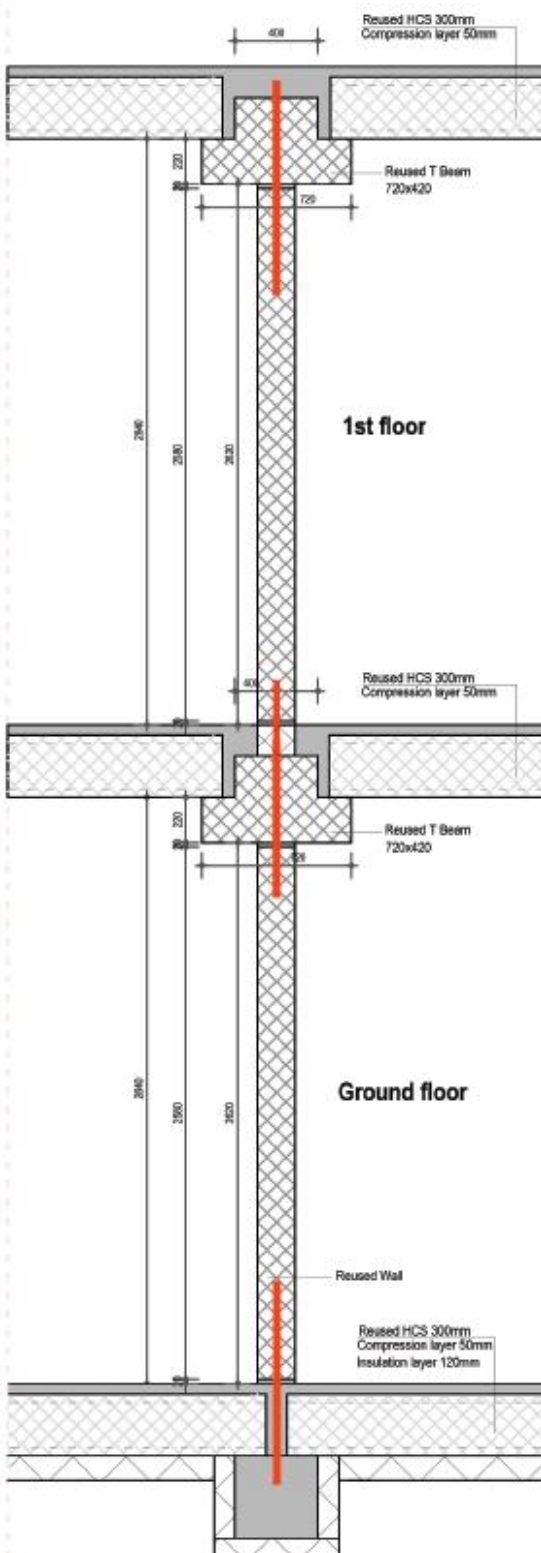
Connection beam-column	
1 Dowel in the center	R = 16 mm
Max. Moment capacity	26,19 KNm
Design moment	5,31 KNm

LOADS new design	
Axial (from beam)	56 KN
Moment due to eccentricity of the axial load	5,04 KNm
Moment due to imperfection eccentricity	0,27 KNm

Reuse	
Total original weight	3018 kg
Weight after modification	2466 kg
Reuse percentage	82 %
Debris	552 kg
Concrete for recycle (98%)	541 kg
Steel for recycle (2%)	11 kg

Table 5.4 – EID of column

Connections



The main goal of this case study in order to reconnect the elements was to use connections that are already known without using new elements. For this reason, an attempt was made to design connections that are used to connect prefabricated elements. Workers have to use a drilling machine and a diamond saw. The difference of creating connections for reused elements compared to new elements is that the connections have to be prepared on site. This means that extra attention and accuracy is needed in order to avoid unpleasant surprises during the construction process.

When designing with new elements the connections are calculated and designed later in the design phase. In case there is an issue with the element then it is easy to change its properties. On the other hand, when designing with reused elements it is important to design the connections in detail from the beginning of the design phase. This is happening again due to the restricted properties of the reused elements.

Due to the low loads of the construction the connections are designed with the minimum reinforcement that is used only for practical reasons. In order to connect the beams they were supported on top of columns and walls. An example of a typical connection can be seen in figure 5.7. It is a beam and wall connection at the middle walls. The loads of the slabs are the same from both sides of the beam and as a result there is no need to connect them. In case of eccentricity the slabs have to be connected with the beam. The rest of the connections can be found in Appendix V.

Figure 5.7 – Beam - Wall connection at middle wall

BEAMS**5.4. CONCLUSIONS****MAIN REINFORCEMENT**

The existing main bottom reinforcement in all the beams is more than the required. Extra loads can be added and as a result the elements can be used for different functions with higher loads. Top reinforcement is usually not needed. Nevertheless, top reinforcement is needed at the support of the beam on a column and when the beam is supported on a wall as a middle support due to partial rigid connection. When the beam is supported on walls it is possible to avoid connection with top walls and as a result no fixed moment is created. The reused beams do not have top reinforcement. It is assumed that 3Φ8 exist for construction purpose. The existence of these reinforcements has to be checked during the quality assessment. The extra top reinforcement can be added in the compression layer of the beam.

SHEAR REINFORCEMENT

The existing shear reinforcement fulfills in most of the cases the needed reinforcement. In certain cases the existing reinforcement fulfills the needed reinforcement due to the shear forces but it does not fulfill the minimum reinforcement demanded by the Eurocode. In this case it is suggested to use the element since it was being used for 25 years to support higher loads. It had proven its structural capacity. In case there are doubts, destructive tests can be performed in order to check the element.

LENGTH ANCHORAGE

The length anchorage depends on the diameter of the rebar. Since the edges of the elements are cut, the anchorage has to be straight and the support has to be equal to the length anchorage. Due to the low loads and the low moment it is possible to reduce the length anchorage and as result minimize the needed support. It can be concluded that the low loads of the beam allow reducing the anchorage length and using the same beam to cover larger openings.

COVER

The cover of the beams is sufficient for all the cases. Only the edges of the beam have to be protected due to the dismantling of the connections.

MAX. DISTANCE

All the beams except the rectangular beams from Karspeldreef 2 fulfill the requirements of the maximum and minimum spacing. The rectangular beams do not fulfill the requirements of the min. spacing. This does not mean that the beam cannot be used since it proved already that it works properly. As for shear reinforcement, tests can be conducted in order to check the element.

COLUMNS

MAIN REINFORCEMENT

As the beams, also the columns are oversized elements. The existing reinforcement is much larger than the required which means that extra floors can be added. In order to connect the columns one rebar is used in the middle of the column. An issue that derives from the way that the elements are cut is the loss of the lateral reinforcement at the edge of the column. It is possible to avoid that by choosing a different deconstruction method but it has to be further researched.

SHEAR REINFORCEMENT

Since there are no axial loads on the columns the shear reinforcement is sufficient. A check that should be made is the maximum spacing. At the middle of the column the requirements are fulfilled. On the other hand the requirements at the connection are not fulfilled since a distance of 240 mm between the stirrups is required and the existing distance is 250mm. Due to the small difference and the low loads of the construction this will not be an issue and the columns can be reused. In case of higher loads, this requirement has to be taken into account and it should be further researched.

LENGTH ANCHORAGE

The length of the anchorage is the length that is needed for the lapping joint. Due to the fact that the connection rebar is used in the middle of the column the anchorage length has to be doubled in order to transfer the forces at the main reinforcement of the bottom column.

COVER

The cover of the column is sufficient for all the cases. The part that is cut can be protected with special coating but it is possible to avoid extra coating since a beam will supported on the column.

WALLS

The walls are checked with the same way as the columns. They are large elements and they transfer vertical but also lateral loads. The existing reinforcement is sufficient and they can be used in higher constructions. As for the columns, the main issue for the walls is the loss of the lateral reinforcement at the edge of the elements due to the deconstruction method.

CHAPTER 6

COST ANALYSIS

One of the causes that deconstruction and consequently reuse of structural concrete elements are not common solutions until today is the uncertainty about the extra amount of costs. In order to have a clear view about the feasibility of reusing concrete elements, it is important to calculate these costs. A comparison between deconstruction and demolition will help to understand their differences and estimate the required budget for each process.

Besides the comparison between deconstruction and demolition it is essential to compare the costs of individual new and reused elements. The costs of the reused elements derive from the deconstruction costs plus the modification, the transportation, the storage and finally the construction costs. After calculating the total costs of each individual reused element it is possible to calculate the costs of a building made with reused elements and compare it with a building made with new elements. The building at Hogehilweg 18 from Amstel III area was used for the comparison of the deconstruction and demolition costs. The elements that derive from the hypothetical deconstruction of the building will be used for the calculation of the costs of each individual element and the construction of one block of residences of the housing project.

The actions before demolition or deconstruction (stripping, remove of asbestos, etc) are the same for both processes and they are not taken in account for the overall cost evaluation. The building is assumed to be fully stripped and only the structural elements are left standing. Furthermore, the foundations of the building are not meant to be reused and they are excluded from both calculations.

It should be mentioned that none of the buildings in Amstel III area are meant to be demolished or deconstructed. The buildings were used as a case study for the purposes of the thesis.

The calculation of the costs was made with the aid of demolition advisor Rene de Hoog and cost advisor Harrie van Horne from Brink Groep. Since the whole process of calculating the costs of reused elements is new, estimations were made for several matters especially for the required

working hours to complete a certain task of the process. The calculations were made excluding VAT. Through further research and during practice this numbers might change. The goal of the cost analysis is to examine the feasibility of the whole process and the estimations that were made are acceptable for this purpose.

6.1. DEMOLITION COSTS

The calculation of the demolition costs of a building is an already known and standard procedure. The general characteristics of the building in Hogehilweg 18 are presented in table 6.1 and the capacity of concrete debris is presented in table 6.2. As soon as the total amount of concrete debris is known it is possible to calculate the total costs of demolition according to the following cost categories:

Equipment & Workers

At first, the equipment and the workers that are needed for the demolition of the specific project are calculated. The estimated time for demolishing the office building in Hogehilweg 18 is 30 working days (6 weeks). In order to start the demolition, a placement cost is needed to set up all the machines. During the demolition only one worker is needed since all the work is made from machines. At the beginning of the process, a 40 ton crane with a long arm is needed in order to lower the building. After this, a 40 ton crane without the long arm is used for the lower floors. At the last two weeks of the process, a smaller crane (30 ton) is needed in order to remove all the remaining debris together with the 40 ton crane. It is assumed that 100% of the debris is sent for recycle. Before sending them to the recycle plant, concrete has to be crashed and steel has to be separated. For this process a crusher is needed.

Transportation & Storage

In Amsterdam there are a lot of recycle concrete plants for debris deposit. It is assumed that a recycle plant is located 20 Km from the construction site. The price per ton is estimated according to the distance that the track has to cover including potential delays. In order to deposit the debris at the recycle plant a fee has to be paid for the further modification of the debris in recycled concrete aggregates and for the storage at the site.

Various costs

For this project the various costs are the ramps placed for the movement of the heavy machines.

Projects costs

Project costs include a temporary fence in order to protect the pedestrians and keep away intruders together with a security plan. Also a site hut and toilets for the workers are necessary in every demolition site. Finally, a project leader will supervise the whole process and a foreman will ensure the execution of it.

General costs and Profit & Risk costs

All the costs are summed up and a 7% is added for the general costs that are not mentioned (e.g. permits). After adding the general costs, a 3% is added which is the profit and the risk of the contractor. From the overall costs the revenue from selling the steel, which is separated from the concrete, has to be deducted. It is estimated that 2% of the total debris is steel.

The total costs of the demolition process, divided in above categories, are presented in table 6.3. The detailed calculations of the demolition process can be found in Appendix VII. In chart 6.1 the influence at each stage of the demolition process can be noticed.

Building details	
Project	Demolition
Location address	Hogehilweg 18
Levels (G.F., 1st, 2nd, 3rd, 4 th , Roof)	6,0
Height per floor (m)	3,4
Surface per floor (m ²)	660,0
Total height (m)	17,0
Volume (m ³)	11220,0

Table 6.1. – Building details

Elements		
Description	Debris (m ³)	Debris (tn)
Slabs (200 mm)	720,00	1800,00
Concrete finishing (30 mm)	108,00	216,00
Beams (whole building)	75,15	187,88
Columns (whole building)	70,82	177,05
Walls (whole building)	118,98	297,45
Facade beams	139,47	348,68
Total	1232,42	3027,06

Table 6.2. - Elements

Demolition costs	
Description	Costs (€)
Equipment & Workers	53.980,00
Storage & Transportation	19.675,89
Various	500,00
Project costs	7.120,00
General costs	5.689,31
Profit & Risk	2.608,96
Total costs	89.574,16
Revenues	- 12.108,24
Final contract price	77.465,92

Table 6.3. – Demolition costs

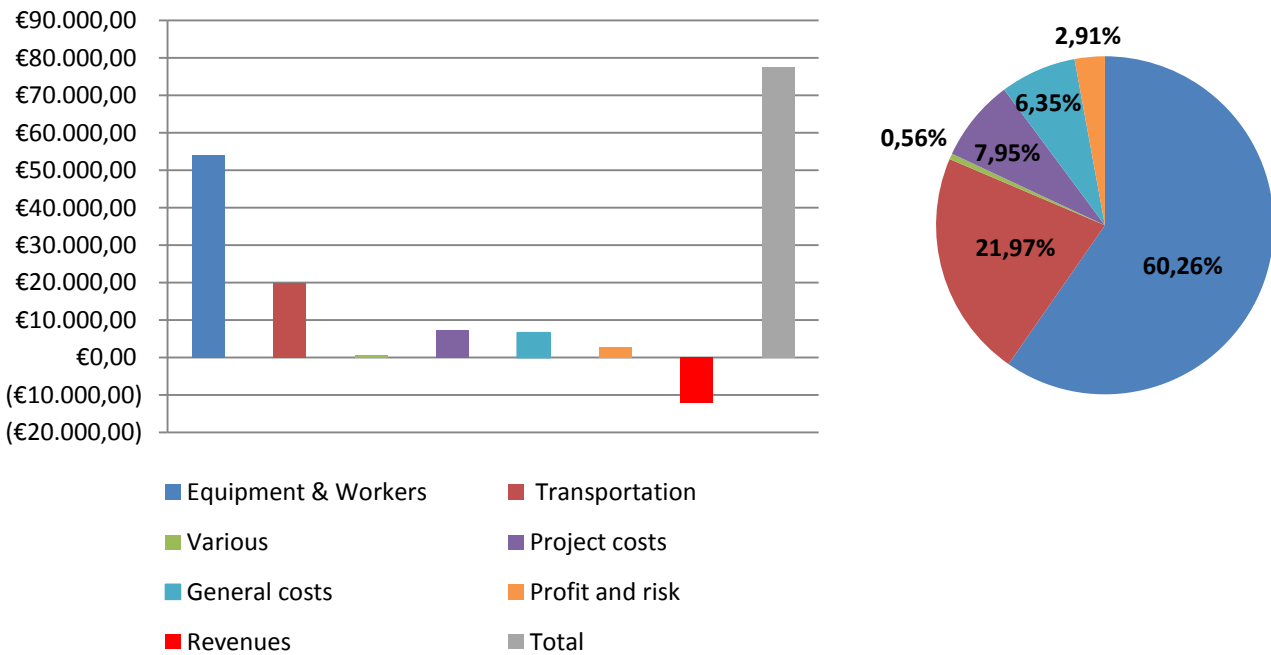


Chart 6.1. – Costs of demolition processes

6.2. DECONSTRUCTION COSTS The calculation of the deconstruction costs is not a known procedure so for this reason a lot of estimations were made. Before starting deconstruction, the elements of the building must be assessed on their reusability. The total costs of deconstruction will be distributed proportionally on the total amount of the reusable elements.

The procedure of deconstruction is the reversed procedure of construction. In order to calculate the deconstruction costs, the whole process was divided in stages and each stage has its own costs. This is helpful in order to assign the costs to each element according to the effort that is needed to remove it from the building and avoid equal distribution of the costs to the total amount of the elements. Specifically, the methods that are mentioned in chapter 3 will be used for the removal of the elements from each floor. The different stages of deconstruction are the following:

- Remove concrete topping
- Remove Hollow Core Slabs (HCS)
- Remove Façade Beams
- Remove Main Beams
- Remove Columns
- Remove Walls
- Various costs
- Project costs
- General costs
- Profit & Risk
- Revenues

The deconstruction costs of each element are the costs of removing it from the building plus the common costs (Various costs, Project costs, General costs, Profit and Risk) . All the common costs of deconstruction are divided by the total amount of reusable elements and they are equally distributed to each element. The percentage of reusable elements is important in order to minimize the total costs. For this deconstruction project the façade beams are characterized as not reusable because it will be difficult to use them in a new design. They are made specifically for an office building and their reuse potential is very low compared to the rest of the elements. At first the value of each element is calculated considering the façade beams as reusable elements and then as not reusable. In this section the final costs of the deconstruction process is presented. The detailed calculations can be found in Appendix VII.

Remove concrete topping

The first action is to remove the concrete topping from the floors. The thickness of the concrete topping in Hogeilweg is 30 mm and it has no structural function. As it was mentioned in chapter 3, a concrete topping that is functioning as finishing can be removed faster than a topping that functions as compression layer. The concrete topping will be removed with a compressor with hammers. It has to be removed in such a way that will not harm the HCS and it will leave intact the concrete layer above the beams. This layer will not be removed because it has reinforcement and it works as part of the beam. At the beginning of the process, the concrete topping has to be removed from the roof and the 4th floor. This is happening in order to place the shores of the walls and columns on the slabs and not on the concrete topping. The same procedure is repeated in every floor.

Remove Hollow Core Slabs

After removing the concrete topping from the roof, the HCS slabs can be removed. Before the removal, 4 actions have to be completed: i) decide the lifting method, ii) support the columns

and walls, iii) remove concrete between HCS, iv) saw joints that connects HCS with beams, façade beams and walls. According to chapter 3, there are several methods that can be used to lift the HCS. For this project chemical anchors will be used. The concrete between the HCS will be removed with a compressor with hammers. The columns and walls of the lower floor are supported with shores and their costs are added at the relevant stage. The costs of sawing the concrete join between HCS and beams/façade beams/walls will be added to the various costs since it concerns the removal of all the elements. All the 4 above actions can take place in the same time period. When all of them are completed, the lifting of the slabs can start.

Remove Façade Beams & Main Beams

The next elements to be removed after removing the HCS from the roof are the façade beams. The façade beams are characterized as non-reusable but they still have to be removed carefully in order not to damage the rest of the elements. Before removing the element, a steel rope has to be tied around it in order to lift it with a lifting crane. As it is already mentioned in chapter 3, there are several ways to disconnect a façade beam. For this project it is decided to drill out the reinforcement bar at the connection. The workers have to use scaffolding in order to reach the connections. Since scaffolding will be rent per week for the whole deconstruction process, the costs are included in the category of various costs.

After the façade beams, the main beams can be removed using the same method. The only difference here is that the cross section of the beam is larger and it creates extra costs.

Remove Columns & Walls

After removing the beams only the columns and the walls are left standing. The columns are already supported with shores. It is estimated that the total cost of a shore is €20/piece. In order to lift the columns several methods can be used. For this project, the method that is used is to drill a hole 1 meter from the top of the column and insert a rebar. The hole is drilled 1 meter from the top in order to be used for the new construction in case a part of the wall is cut. The method that will be used to dismantle the connection is to drill the steel rebars. As long as the connection reinforcements are drilled out the column can be lifted. The 2 cm mortar that is located at the connection between two columns will brake easily when the crane starts to lift the column. A wedge and a hammer can be used in case it is not broken.

The last elements to be removed from a floor are the walls. They are also already supported with shores. In order to lift the elements 2 holes will be drilled 1 meter from the top of the wall as was the case with the columns. After tying the element with the crane, the connection has to be dismantled. For this element the diamond saw is chosen as a deconstruction method because there are a lot of reinforcement bars in each wall to drill them out.

Various costs

Besides the removal costs there are various costs that need to be calculated. These costs are common for each stage and they are equally divided. Like in demolition, ramps are needed for the better circulation of the heavy machinery. In this project the ramps are more because the crane will be positioned in more than one places. Also the costs of sawing the connection between beams/walls/façade elements and HCS are part of this category. These costs are related to the removal of all the elements and as a consequence they are equally divided. The slabs will be sawn at their small dimension (1,2m) with a floor saw. Moreover, the costs of scaffolding belong in this category. The price to rent scaffolding is per week and since it can be used during all the stages except the removal of HCS their costs are equally divided. Finally, the costs of

renting a crusher crushing the debris and a demolition crane for the ground floor are included in the various costs.

Project costs

Like in demolition, the next step is to calculate the project costs of the deconstruction process. The project costs include a temporary fence in order to protect pedestrians and fend off intruders. Also a security plan is made in order to avoid accidents which will be more expensive than in a demolition process since there are more uncertainties. Site hut and toilets for the workers are also necessary. A project leader will supervise the whole process and an executor will ensure the smooth conduction of it. The costs are increased compared to the demolition process due to the extra amount of time that is needed to deconstruct a building. An extra cost is the building survey before deconstruction. This survey will reassure the quality and the condition of the elements and will confirm that the building is constructed according to the original drawings. The costs of the assessment are estimated by Joop Bovend’eerdt from BAS Research and Technology.

General costs & Profit and Risk

The final costs are the general costs (e.g. permits) and the profit and risk of the contractor. The general costs are the 7% of the total costs and the risk and profit costs are the 10% of the total costs plus the general costs. The percentage of profit and risk is increased compared to demolition process because there is no experience with deconstruction. The increased percentage will cover any unexpected situations and gives an extra motive to the contractor to deconstruct the building.

Revenues

During deconstruction process and in later stage during modification of the elements an amount of debris is produced. Like in demolition, this debris including the façade beams (non-reusable) can be crushed and separated into concrete and steel. The concrete will be send to a concrete recycle plant and the steel will be sold to a steel recycle plant. The revenues from selling the steel are subtracted from the contract price.

In table 6.4 the total costs of deconstruction process are presented. In chart 6.3 the costs influence of the removal of each individual element is shown. It is clear that the removal of the HCS has the biggest influence. The detailed calculations of the deconstruction process can be found in Appendix VII.

Deconstruction costs	
Description	Costs (€)
Remove concrete topping	20.280,00
Remove HCS	63.490,00
Remove façade beams	18.208,00
Remove beams	12.291,20
Remove columns	13.672,00
Remove walls	22.616,00
Various	31.748,80
Project costs	19.425,00
General costs	14.121,17
Profit and risk	21.585,22
Total costs	237.437,39
Revenues	- 2.940,00
Final contract price	234.497,39

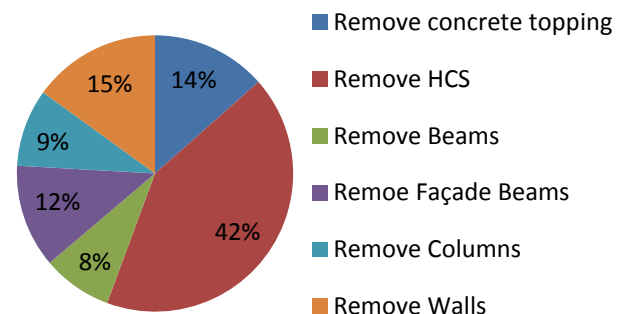


Chart 6.2 – Percentages of Deconstruction costs

Table 6.4 – Deconstruction costs

The costs of the removal process are different for each element but the rest of the costs of the deconstruction are equally allocated to the total amount of the elements. The common costs are calculated once considering the façade beams as reusable and once considering as non-reusable. In table 6.5 the final deconstruction costs of each element are presented including the removal costs and the common costs:

Deconstruction costs per element		
Element	Final price (€) (incl. Façade beams)	Final price (€) (excl. Façade beams)
HCS	296,54	385,38
Façade beams	307,22	0,00
Beams	422,02	510,86
Columns	376,75	465,59
Walls	601,21	690,04

Table 6.5 – Deconstruction costs per element

Modification costs are the costs that relate to the preparation of the element for reuse. The goal is to modify the element in a way that it can be used as a prefabricated element so that the construction process will be the same as a new element. The modification costs include only the costs that are necessary for the reuse of the element. For this case study the modification takes place at the deconstruction site. It is already known which elements are going to be reused so they are modified immediately after removal.

6.3. MODIFICATION COSTS

Modification of Beams

The following modification actions have to be done for each beam:

- Saw the beam. Both edges need to be removed so two cuts are needed. With this way the beam is sawn at the desired dimension.
- Drill 2 connection holes. Due to very low loads the connection is only for practical reasons. For this reason 1 hole of 40 mm per side is enough to create a connection.
- Protect the exposed reinforcement.

Modification of Columns

The following modification actions have to be done for each column:

- Saw the column. In order to remove the damaged edges and to saw the column on size 2 cuts have to be done. It is possible that only 1 cut is needed but it depends on the removal process.
- Drill 2 connection holes. Also in this case, the loads are very low and only vertical loads are transferred. For this reason the connection is only for practical reasons. One hole of 40 mm diameter will be drilled per side.
- Drill 1 hole of 20 mm diameter at the lower part of the column for the connection glue.
- Protect the exposed reinforcement.

Modifications of Walls

The actions that have to be done to modify a wall are the following:

- Saw the wall twice in order to remove the damaged connections. The wall is already sawn on size from the building so it is not needed.
- Saw the wall in order to create support for the beams. This depends on the size of the beam.
- Drill 4 holes for the connections. Also in this case the connections are used for practical reasons. Two holes of 40 cm will be drilled per side. More holes might be needed depending on the loads and the size.
- Drill 2 holes of 20 mm at the lower part of the wall for the connection glue.

- Protect the exposed reinforcement.
- Fill the holes. Depending on the size, the holes have to be filled either with masonry or insulation.
- Attach a non-structural wall in order to achieve sound insulation. This depends on the area of the wall.

Modification of Hollow Core Slabs

The actions that have to be done to modify a wall are the following:

- Saw the slab once in order to adjust the side. It is possible that no cutting is needed.
- Fill the holes. Depending on the size of the hole they have to be filled with concrete or masonry.
- Create openings in the slab. Depending on the position of the slab in the building.

The following table shows the modification costs per element:

Modification costs per element	
Element	Costs (€)
Beam	179,65
Column	135,14
Wall	311,58
HCS	36,79

Table 6.6 – Modification costs per element

6.4. TRANSPORTATION COSTS

When a building is demolished, the transportation costs are usually included in the final offer. In this case, in order to separate the different stages, the transportation costs are calculated separately from the deconstruction costs. While in a demolition project there is only 1 route, from the demolition site to the recycle site, in a deconstruction project there are more routes. The sum of the total routes will be equally divided on the amount of reusable elements. Estimations are made for the distances and the time that is needed to load and unload a truck.

Transport debris from deconstruction site to recycle plant

The debris is already crashed at the old construction site and the concrete is separated from steel. It is assumed that the recycle plant is located in a radius of less than 20 km from the deconstruction site. The costs are calculated for the case that the façade beams are reused as an element and for the case that the façade beams are crashed and send for recycle. Besides the transportation costs also the costs that are needed to deposit the debris at a recycle plant are calculated.

Transport elements from deconstruction site to new site

It is already known which elements are going to be reused in the housing project. The façade beams are completely excluded from these calculations because they are not meant to be reused.

Transport elements from deconstruction site to storage site

The only elements that are left to transport are the elements that are possible to be reused but not in the housing project. These elements will be transferred to a storage site which is located in a radius of less than 30 km. Also here the costs are calculated for the cases that the façade beams are send for storage and for the case that the façade beams are send for recycle.

Transport elements from storage site to another new site

Although these costs are not part of all the reusable elements, it is decided to divide them among all the elements in order to have elements with the same price even if they are stored. The maximum distance of the new construction site is 30 km. Above this distance the extra costs will charge only the stored elements. Again in this case two different calculations are made for the façade beams.

The company that is responsible for the demolition and consequently for the deconstruction is also responsible for the transportation of the elements and debris. In order to make the transportation costs part of the deconstruction process the general costs, the profit and risk of the contractor has to be added on the total amount. While for deconstruction the profit and risk is calculated as 10% due to increased uncertainty, in this case the profit will be 3% since transportation is an already known process. The total transportation costs are presented in table 6.7 for the case that the façade beams are crashed and for the case that they are reused. These amounts are equally divided to the reusable elements. When the façade beams are meant to be reused the total elements are 700 and while they are not going to be reused the total elements are 585.

Transportation costs		
Description	Façade beams are crashed (€)	Façade beams are reused (€)
From old site to recycle site	7.043,92	4.777,50
From old site to new site	17.850,00	17.850,00
From old site to storage site	1.955,00	4.675,00
From storage site to new site	1.955,00	4.675,00
General costs	2.016,27	2.238,43
Profit and Risk	924,61	1.026,48
Total	31.744,80	35.242,40
Transportation costs/ element	54,26	50,35

Table 6.7 – Transportation costs

The storage is an intermediate phase between deconstruction and reuse, for the elements that are possible to be reused but there is not an immediate client after removal. These costs include the costs for the storage area and the interest that is lost for having the elements in stock. According to Naber, it is estimated that the storage area costs € 5/m²/year and that the interest loss is assumed 3% per year. The interest is calculated on the value of the element which is a sum of the deconstruction and transportation costs. Modification, storage and construction are not included since no money is invested for these processes. It is assumed that the elements will be stored for 1 year and then they will be reused. The total storage costs of the 1st year will be equally distributed to all the elements in order to minimize the difference between stored elements and immediate reused. In case the elements have to be stored for more than a year the extra costs will be added only at the stored elements. The elements that are send for storage are: 70 slabs, 115 façade beams and 10 walls.

The maximum period that the elements can be exposed to the environment is 2 years (Joop Bovend'eerd, 2013). This is happening because the elements were in an indoor environment for 25 years and an extended exposure to outdoor environmental conditions might affect the elements. After 2 years the elements have to be stored in a protected area. The costs of the installation of the storage site are not taken into account. The storage site can be either an existing demolition company that has its own site, a company that produces prefabricated concrete elements or a new type of company that will store, modify and manage the reused

6.5. STORAGE COSTS

elements. Following the storage suggestions of Chapter 3, the slabs are stored in stacks of 10, the façade beams in stacks of 4 and the walls are stored vertically. The storage costs are presented in tables 6.8, 6.9:

Storage costs (excl. façade beams) – 585 elements			
Element	Storage Costs (€)	Interest (€)	Total (€)
Walls	30	223,30	253,30
Slabs	210	923,30	1133,30
Total			1386,60
Per element			2,37

Table 6.8– Storage costs excl. façade beams

Storage costs (incl. façade beams) – 700 elements			
Element	Storage Costs (€)	Interest (€)	Total (€)
Walls	30	195,50	225,50
Slabs	210	728,70	938,70
Façade beams	1555	1233,62	2.788,62
Total			3.952,82
Per element			5,65

Table 6.9 – Storage costs incl. façade beams

6.6. CONSTRUCTION COSTS

The final stage of the reuse process is the construction of the new structure using the existing elements. In order to calculate the construction costs estimations were made about the time needed and the various costs for the construction of 1 from the 3 housing blocks. When the elements arrive at the new construction site they are already modified and they are ready to be used in the construction. Minor modifications might be needed but with a good planning they can be avoided. The process of the construction was divided according to the different elements in order to have an idea of the different costs. Besides the costs of placing the elements (direct costs) there are also project and general costs plus the profit and risk of the contractor which are the common costs. It is estimated that these costs are 20% of the placing costs. The final price per element is the placement costs plus the equally division of the common costs. The final construction costs are:

Construction costs per element			
Element	Amount	Costs (€)	Per element (€)
HCS	240	34.845,60	173,15
Beams	62	6.368,00	130,67
Columns	72	10.840,00	178,51
Walls	28	4.144,00	175,96
Common costs	-	11.239,52	0,00
Total	402	67.437,12	

Table 6.10 – Construction costs per element

The total costs of the elements were calculated for two cases. In the first case the façade beams are considered as reusable and they are sent for storage (table 6.11) while at the second case the façade beams are considered as non-reusable and they are sent for recycle (table 6.12).

6.7. TOTAL COSTS OF REUSED ELEMENTS

Element	Deconstruction costs (€)	Modification costs (€)	Transportation costs (€)	Storage costs (€)	Construction costs (€)	Total costs (€)
HCS	296,54	36,79	50,35	5,65	173,15	562,48
Beam	422,02	179,65	50,35	5,65	130,67	788,34
Façade beam	307,22	0,00	50,35	5,65	0,00	363,22
Column	376,75	135,14	50,35	5,65	178,51	746,40
Wall	601,21	311,58	50,35	5,65	175,96	1.144,75

Table 6.11. – Total costs including facade beams

Element	Deconstruction costs (€)	Modification costs (€)	Transportation costs (€)	Storage costs (€)	Construction costs (€)	Total costs (€)
HCS	385,38	36,79	54,26	2,37	173,15	651,95
Beam	510,86	179,65	54,26	2,37	130,67	877,81
Column	465,59	135,14	54,26	2,37	178,51	835,87
Wall	690,04	311,58	54,26	2,37	175,96	1234,21

Table 6.12 – Total costs excluding facade beams

The previous mentioned values concern intact elements removed from the building. Among these, there are elements that are too large to be reused in a housing project. Especially there are columns that are 10 meters long, beams that are 7 meters long or walls that are 6 meters long. These elements are typical in office buildings and they are used in order to minimize the costs. When they are removed from the building their costs are the same compared to lower or shorter elements. Only when the section changes the deconstruction costs will change. In this building the sections are the same.

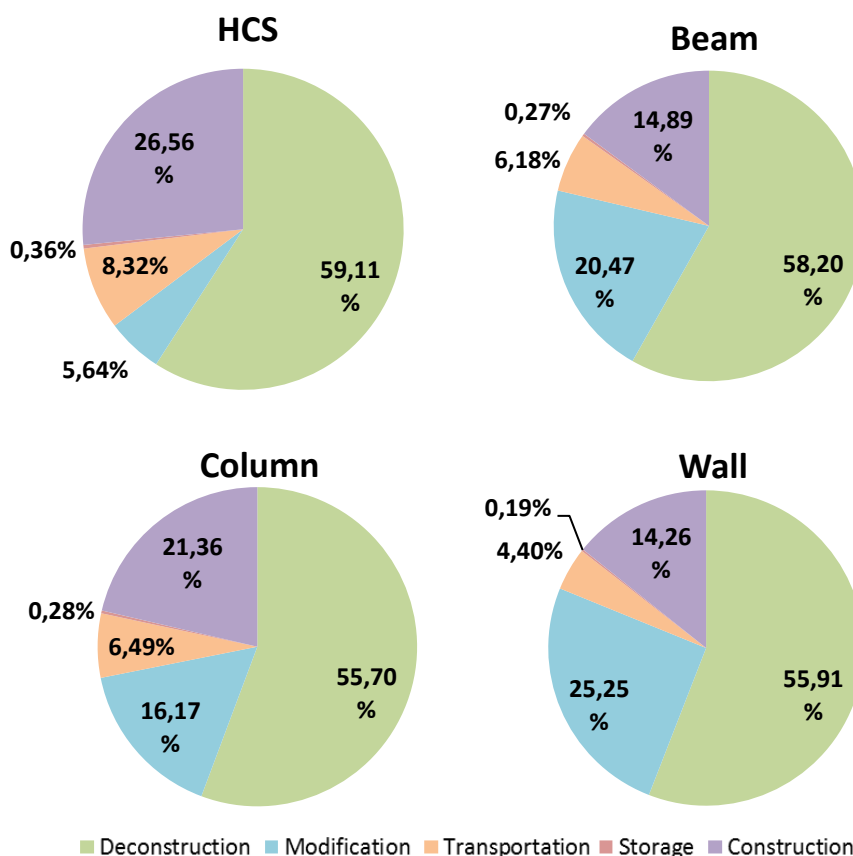


Chart 6.3 – Total costs percentages

The most cost efficient option would be to reuse these elements as a whole in a new design, with minor modifications. This is very difficult due to their large dimensions. For this reason, these elements have to be divided into elements with smaller dimensions. This option is still cost effective because the costs that concern the size of the building have to be divided according to the amount of elements. These costs are: Deconstruction costs, Transportation costs and Storage costs.

In order to understand the above, the column K1 from Hogehilweg 18 will be used as an example. The length of the column is 10,17 m. The deconstruction costs of this column are the same with the deconstruction costs of a column of 3 m. This is happening since the only difference between the elements is the weight which affects only the crane. A slight increase might be noticed due to extra time needed to carry the element or due to different lifting method. In this case this increase is neglected. The column with this height is not possible to be reused in the new housing project but it can be cut into 3 shorter columns. As a result the deconstruction costs, the transportation costs and the storage costs have to be divided by 3 in order to calculate their final price. The results of the above procedure are presented in table 6.13:

Element (m) 3 pieces	Deconstruction costs (€)	Modification costs (€)	Transportation costs (€)	Storage costs (€)	Construction costs (€)	Total costs (€)
2.95, 2.95, 2.78	155,20	135,14	18,09	0,79	178,51	487,73

Table 6.13 – Division of elements

It can be noticed that there is a significant difference in the final price of a column that derived straight from a building and the one that derives from the separation of one column. The same can happen with a large beam or a large wall. It is even possible to do the same with a large hollow core slab but the specific building does not contain large slabs.

Another issue that can be noticed from the final price of the reused elements is that the deconstruction costs have the biggest influence on the final price. When the façade beams are reused the deconstruction costs are approximately 53% the total costs and when the façade beams are not reused the deconstruction costs are approximately 57%. This means that in order to reduce the costs of reusing structural elements attention should be paid on the deconstruction process. Through practice and by gaining more experience on the field it is possible to reduce these costs and achieve lower final prices. The next category that affects the costs are the construction costs which ranges between 14-26%. The changes that can be applied on these costs are not significant since construction is an already known process and the room for improvement is limited. A category that can influence the final costs is the modification of the element. These costs vary from 5% to 25%. Again here with experience on the field it is possible to reduce the final costs. Especially in the case of hollow core slabs it is possible to eliminate them in case the slab is used at its original dimensions. Modification and construction costs are not influenced from the amount of elements.

Finally, it is essential to highlight the fact that the amount of reusable elements affects significantly the final price. In this case only the façade beams were characterized as non-reusable and sent for recycle. The difference between the final price when the façade beams are reused and when not is equal to 10%. This is a challenge for the engineers and the architects to achieve the highest possible percentage through smart solutions and designs.

6.8. NEW vs REUSED

The final price of a reused element is calculated and a comparison will be made between old and new individual elements together with a comparison of the entire construction build with new or old elements. It is important to make these comparisons in order to find out the feasibility of reusing structural elements in a new design.

Individual elements

The costs of reusing an element will be the same for each element regardless the dimensions. Two different comparisons will be made. The first will be between reused and new elements with the same dimensions and the second between reused and new with reduced dimensions. The reason of the second comparison is because in a new design the elements will be smaller. As it was proven in the structural analysis of the design, the reused elements are larger and have more capacity than it is needed. The comparison will be made for all the elements except the façade beams. The costs of the new elements include all the costs and they are presented in table 6.14, 6.15.

Same dimensions	Dimensions			Total Costs (€)
	H	b	L	
New prefabricated beam	400	700	2800	1065,12
New prefabricated column	400	400	2950	991,20
New prefabricated wall	2780	180	3600	1.765,41
New prefabricated HCS	200	1200	6960	661,48
New prefabricated HCS	200	1200	4250	403,92
New prefabricated HCS	200	1200	3060	290,82

Table 6.14 – Costs of new elements
(Same dimensions)

Reduced dimensions	Dimensions			Total Costs (€)
	H	b	L	
New prefabricated beam	400	400	2800	974,40
New prefabricated column	250	250	2950	665,52
New prefabricated wall	2780	200	3600	1.933,55

Table 6.15 – Costs of new elements
(Reduced dimensions)

All the elements except of the walls have reduced dimensions. This is happening because the walls must be thick enough for sound insulation. A new wall might be more expensive but in order to achieve sound insulation with reused elements, extra wall has to be added which will increase the cost. The dimensions of the slabs would be the same if the design was made with new elements.

By comparing the prices of tables 6.11, 6.12, 6.13, 6.14 the following can be concluded:

- i) Beams: The reused beams have a lower price even compared to a beam with reduced dimensions. This means that even in a construction that does not demand large beams the reused beams are most efficient to be used.
- ii) Columns: When a new column has the same dimensions with the reused column then the price of the reused column is higher. But when the new elements have lower dimensions they are cheaper than the reused elements. This is happening when a column is reused 1 to 1 from the original building. When a large column is separated in smaller columns then its cost are less than the new element with reduced dimensions.
- iii) Walls: Walls are the most costs efficient elements of all due to their volume. In fact, in a new construction the thickness of the new walls would be larger than the reused walls in order to achieve sound insulation. This leads to higher costs.
- iv) Slabs: They are the only elements that the when they are new the cost less than the reused elements. The reuse of slabs becomes cost efficient when slabs of 7 meters and above are reused.

Entire construction

The prices of the new elements include all the relevant costs: production, transportation, construction, profit. In order to calculate the total costs of the construction a sum of the different elements have to be made. The foundations are not included in this calculation since they will be new for both constructions. Tables 6.16 and 6.17 present the total construction costs of the housing project build with new elements:

Construction costs (same dimensions)	
Element	Costs (€)
Columns	57.870,40
Beams	60.256,80
Walls	40.170,62
HCS	104.732,49
Common costs	52.606,06
TOTAL	315.636,37

Table 6.16 – Construction costs - New (Same dimensions)

Construction costs (reduced dimensions)	
Element	Costs (€)
Columns	38.855,84
Beams	54.830,00
Walls	43.192,04
HCS	104.732,49
Common costs	48.322,07
TOTAL	289.932,44

Table 6.17 – Construction costs - New (Reduced dimensions)

As it was mentioned, it is possible to separate a large element in 2 or 3 segments. This means that the costs of deconstruction, transportation and storage of 1 element have to be allocated to the smaller segments. Also it is possible to reuse the elements without modification. This stands especially for slabs because the rest of the elements need modification due to the damaged connections. In order to see the influence of this, two calculations were made: i) the total costs of the construction were calculated assuming that each element is one unit so no separation of costs has to be made, ii) the total costs of the construction were calculated taking in account that some elements don't need modification or more elements derive from one.

Construction costs Reused elements (1 to 1)	
Element	Costs (€)
Columns	60.182,64
Beams	54.424,22
Walls	34.561,68
HCS	154.260,60
TOTAL	303.429,00

Table 6.18 – Construction costs – Reused (Same dimensions)

Construction costs Reused elements (divisions)	
Element	Costs (€)
Columns	36.857,26
Beams	54.424,22
Walls	34.557,88
HCS	154.641,40
TOTAL	280.480,76

Table 6.19 – Construction costs – Reused (Divisions)

Costs per m ² (Area 1807 m ²)	
Description	€/m ²
New elements (same dimensions)	175
New elements (reduced dimensions)	161
Reused elements (1 to 1)	168
Reused elements (Divided)	156

Table 6.20 – Total costs per m²

The above results show that when constructing a building with new elements with the same dimensions with the reused elements, the costs are the highest between all 4 categories. On the other hand when building with new elements but with normal dimensions (reduced) then the costs are lower than building with reused elements 1 to 1 but higher than building with reused elements with fewer modifications and with divisions of elements.

In order to achieve fewer costs when building with reused elements the following must apply:

- Reuse the elements in a way that they can contribute the maximum of their capacity..
- Reuse hollow core slabs without modifications.
- Reuse elements that derive from the division of larger elements.

6.9. DEMOLITION vs DECONSTRUCTION

One of the main reasons that contractors, demolition companies and engineers are hesitating to deconstruct a building are the extra amount of money that are needed. Both processes were analyzed and the amounts of money that are needed are known. In order to compare deconstruction with demolition, when mentioning the term deconstruction besides the costs of deconstruction process also the transportation costs are included. In this way both processes result at an empty plot.

The demolition of the building in Hogehilweg 18 costs €77.000. In exchange for this money the owner gets an empty plot. On the other hand, the deconstruction of the building costs €270.000 which is approximately 3,5 times the costs of demolition. In this case the owner gets an empty plot plus an amount of reusable structural concrete elements. This means that the extra costs that he needs to pay in order to remove the elements are €193.000 and not €270.000. The difference are the costs that are needed for the empty plot (See chart 6.4).

For the case study of this thesis, the total costs of deconstruction were divided on the elements and it was proven that even in this way it is possible to achieve a cost efficient construction. This means that the owner, can earn money from the construction but he also earns the money of demolition.

This scenario is valid only when there are no costs for the initial purchase of the elements. This means that the value of the building has to be depreciated and the owner’s demand is only an empty plot. In case the building is not fully depreciated then these costs have to be added at the total deconstruction costs. For this thesis it is assumed that the value of the building is fully depreciated so no initial costs are needed for the purchase of the elements. Also it is assumed that it is a project with restricted boundaries where an owner decides to reuse his own elements to build a new structure.

When deconstruction becomes an accepted procedure for the removal of the buildings it is possible that the owners will demand an amount of money for the purchase of the elements even if the building is fully depreciated. This will happen because the buildings as a whole might not have any value but the elements itself still have monetary value.

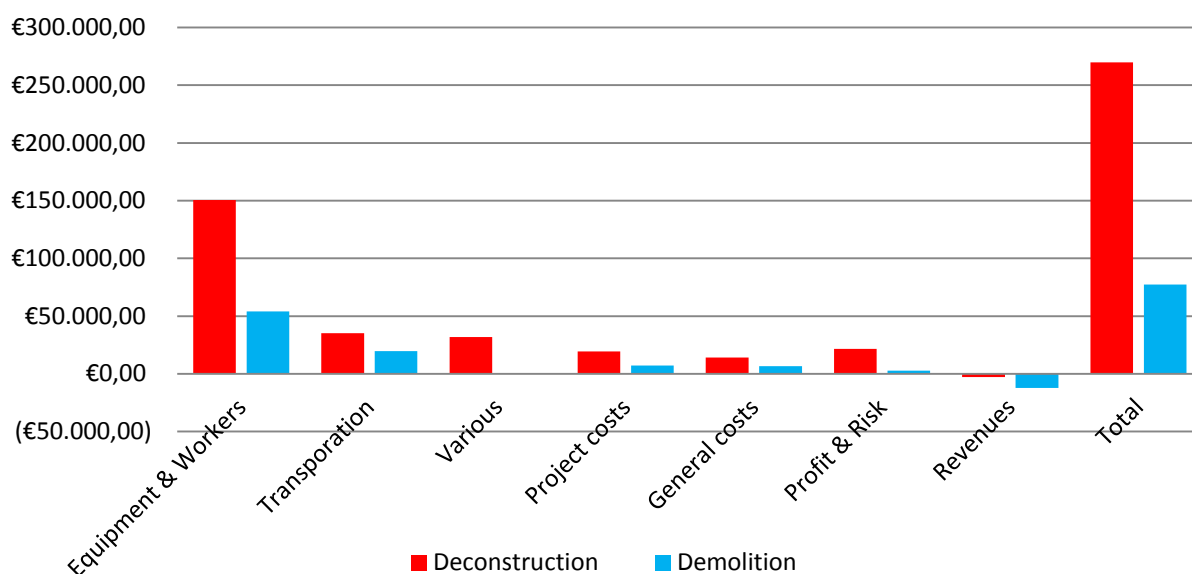


Chart 6.4 – Demolition costs vs Deconstruction costs

6.10. CONCLUSIONS

In order to calculate the costs of building with reused elements versus building with new elements the costs of the reuse process were divided in the following categories:

- 1) Deconstruction costs
- 2) Modification costs
- 3) Transportation costs
- 4) Storage costs
- 5) Construction costs

From the preceded calculations it can be concluded that the phase with the biggest influence on the reuse process is the deconstruction of the building. These costs can be further reduced through practice. In order to reduce the costs of the reuse process without changing the deconstruction phase, the elements have to be used at their original dimensions. With this way the modification costs will be avoided. It is very difficult to avoid them completely since most of the elements need to be cut on size due to the damage of the old connection or because they are too big to be reused in a new construction. The ideal solution for beams, walls and columns would be to cut the element on size during their removal from the building. The only elements that can have zero modification costs are the HCS since they can be reused immediately after being removed from the building. Especially slabs less than 7 meters should be avoided to be reused since the new ones are cheaper than the deconstructed.

Another way to reduce the costs of the reuse process is to use elements that are segments of larger elements. Office buildings contain usually a large amount of elements that can be divided in segments. This is happening because the deconstruction costs of an element do not depend on the weight but on the cross section. By using these elements it is possible to reduce the costs or cover the difference that is created between new and old elements.

Another conclusion is that In order to achieve maximum efficiency of the concrete beams, columns and walls they have to be used in structures that their dimensions and capacity are almost equally to what it is demanded. Consequently they have to be used in higher constructions or with longer spans.

Houses with more stories than one are more cost efficient for the reuse process due to the large structural capacity of the elements and the large difference between the value of a new and old element.

On the other hand hollow core slabs are efficient to be reused either when a large slab is divided in smaller slabs or when the length of the slab is bigger than 7 meters. In case that this is not possible, in order to reduce the costs the slabs have to be used at their original dimensions. With this way the modification costs will be reduced.

Walls are the most cost effective elements. By using them it is possible to cover the differences that occur from other elements. In this thesis walls were used as stability elements in order to stand all the horizontal loads. Due to the low height of the houses, only a few walls were enough. Since the walls are existing elements it is important to use the maximum amount possible. Even they are not needed for structural elements, they can be used to fill the gaps. The best option would be to use only walls in order to construct the new houses but this is not possible to happen since there are not so many walls in the existing office building. Their structural system is braced and they contain a large amount of columns and beams together with a few walls.

For the comparison between Deconstruction and Demolition the costs were divided in 7 categories, namely:

- i) Equipment & Workers costs
- ii) Transportation costs
- iii) Various costs
- iv) Project costs
- v) General costs
- vi) Profit & Risk costs
- vii) Revenues

From this comparison can be concluded that deconstruction might need more money than demolition but the actual amount of money that are needed for the removal of the elements is the difference between deconstruction and demolition. By dividing the total amount of deconstruction to the reusable elements the owner earns the money of demolition.

Also the contractor has the opportunity to gain more money due to the increased profit. This may stimulate for the demolition companies to consider deconstruction as a profitable solution and invest more time on optimizing the process.

CHAPTER 7

ENVIRONMENTAL IMPACT ANALYSIS

The idea of reusing existing structural concrete elements is based on the environmental benefits of the reuse process compared to the new elements. In order to identify these benefits an analysis of the environmental impacts of reused elements and new elements has to be conducted. This chapter presents the methodology of the analysis followed by the results and their interpretation.

7.1. METHODOLOGY

The method that will be used for the calculation of the environmental burden of the reused structural concrete elements is Life Cycle Assessment (LCA). With the aid of this tool it is possible to evaluate the environmental performance of a product by considering the potential impacts from all the stages of its lifecycle namely manufacture, product use and end-of-life stages [World Steel Association, 2011]. In order to simplify the comparison between reused and new elements shadow prices will be used which are estimates of the value of environmental goods. There are two different methods to calculate the shadow prices [CE Delft, 2010]:

- Abatement costs: the costs that should be paid in order to achieve the environmental targets.
- Damage costs: the costs that society is willing to pay in order not to damage the environment.

When a project is leading to changes in the environmental quality the damage costs should be used and when it leads to changes in the efforts required to secure environmental targets the abatement costs should be used [CE delft, 2010]. For the comparison of the reused elements with new elements the shadow prices calculated with the abatement costs method will be used. The environmental impacts taken into account in the LCA and their shadow costs are presented in table 7.1 [www.nibe.org,2013].

Environmental impacts	Unit	Shadow Prices (€)
Global Warming (GWP)	kg CO ₂ eq	0,05
Ozone Layer Depletion (ODP)	kg CFC-11 eq	30,00
Human Toxicity (HT)	kg 1,4-DB eq	0,09
Ecotoxicity, Fresh Water (FAETP)	kg 1,4-DB eq	0,03
Ecotoxicity, Marine Water (MAETP)	kg 1,4-DB eq	-
Ecotoxicity, Terrestrial (TETP)	kg 1,4-DB eq	0,06
Photochemical Oxidation (POCP)	kg C ₂ H ₄	2,00
Acidification (AP)	kg SO ₂ eq	4,00
Eutrophication (EP)	kg PO ₄ eq	9,00
Abiotic Depletion Factor (ADF)	kg Sb eq	0,16

Table 7.1 – Shadow prices of the environmental impacts

The classification method that will be used for the calculations is the TWIN2011 model developed by NIBE. This method is taking into consideration the environmental impacts of the extraction of raw materials which is not included in other methods, e.g. CML -2 [www.nibe.org, 2013]. The database that will be used is the Nationale milieudatabase (NMD) which is the most common database in the Netherlands. The software that will be used to perform the LCA is SimaPro.

The basic steps of a LCA analysis are the following:

- 1) Establish the Goal and the Scope of the analysis
- 2) Establish the System, Functional Unit and System Boundaries
- 3) Life Cycle Inventory (LCI)
- 4) Impact assessment
- 5) Interpretation of the results.

7.2. LCA

Goal and Scope

Naber already proved in her thesis that the reuse of HCS is beneficial for the environment. In this thesis the total environmental impacts of all the elements will be calculated. The primary goal of the LCA is to compare the environmental impacts of the total structural elements of the housing project in Amstel III constructed with reused elements and with new elements.

System

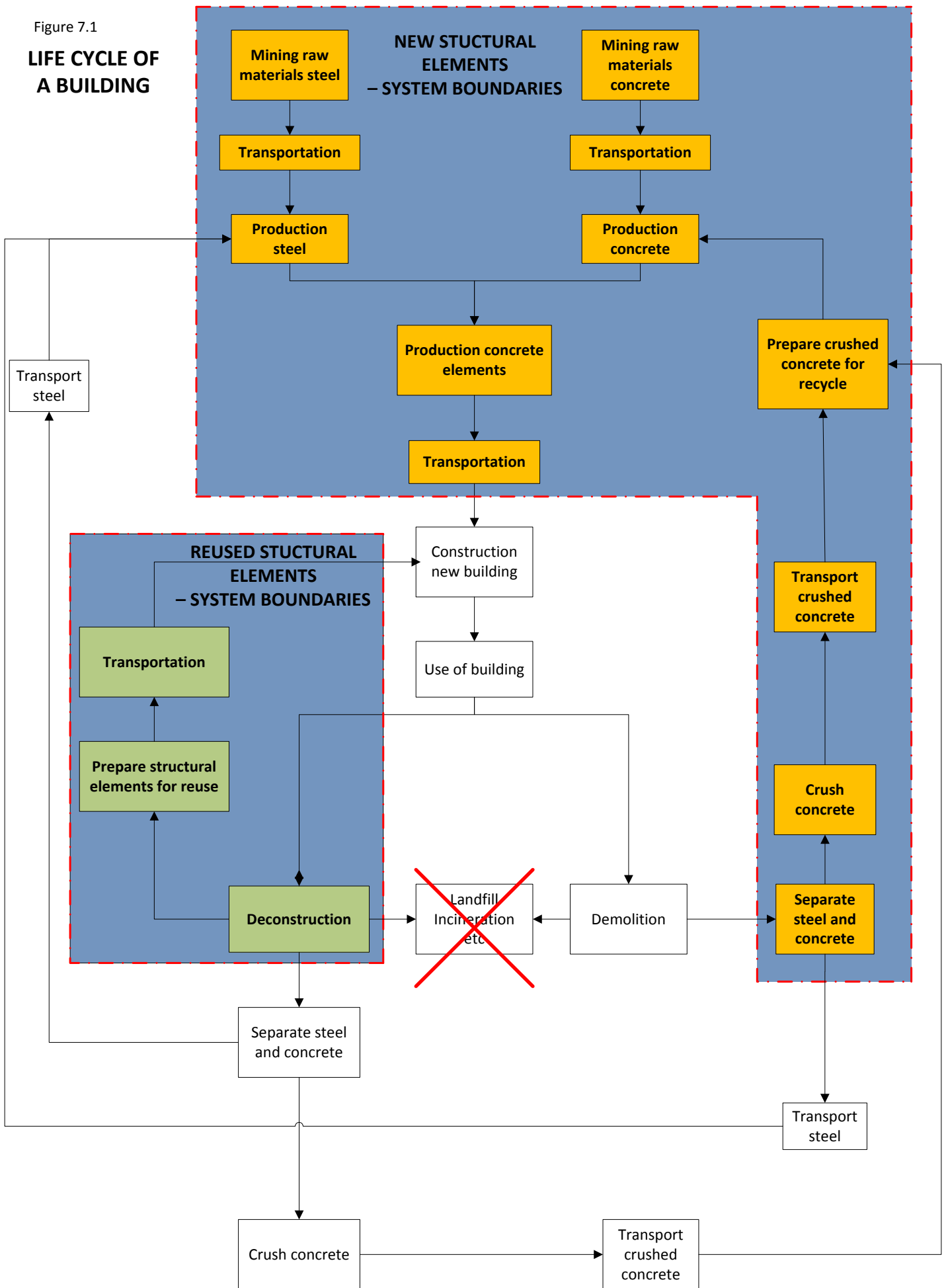
The system that is used to compare the reused elements with the new elements is part of the life cycle of a building. A system includes different processes that can be divided in sub-systems with the use of system boundaries. These are presented later in the report. The basic steps of the system of a building are the following:

- Production of the elements
- Construction of the building
- Use
- End of life

The system of the life cycle of a building and the system boundaries are presented in fig. 7.1.

Figure 7.1

LIFE CYCLE OF A BUILDING



Functional Unit

The functional unit for the comparison is the total square meters of the housing project. The total area is 5432 m². The environmental impact of the new elements and the reused elements will be calculated per m². The floor plans and the structural elements are the same either if the housing project is made with reused elements or with new elements.

System Boundaries

Every system is included in another system and in order to determine what is included in each system and what is left out, the system boundaries of the LCA have to be set. For the comparison of the reused elements with the new elements the use and the end of life stage are not included in the calculations since they are not affected from the type of the element. For the construction process the factor that will be taken in account is the transportation distance. The construction method is the same either when building with reused or with new elements. Therefore, it is not included in the calculations.

New elements

Production: The production stage of a new structural concrete element starts with the extraction and transportation of the raw materials that are needed to produce steel and concrete. Both the extraction and the transportation of the raw materials demand energy. Then steel and concrete are used in order to manufacture the new elements at a prefab plant. It is possible to replace an amount of natural aggregates with recycled aggregates. The energy that is needed to prepare the aggregates for reuse and the energy that is needed to manufacture an element has to be taken into account.

Transportation: The transportation distance of the prefab plant from the construction site is assumed to be 50 km.

Reused elements

Production: The production of the reused elements is the deconstruction and the modification process. With this way the whole production process of a new structural concrete element is avoided which means less raw materials and energy are required. In order to calculate the environmental impacts of the deconstruction process the guidance presented in Chapter 3 is followed. The process that will be calculated will concern only the removal of the elements. The machines that will be used in this phase are a diamond saw, a compressor with hammers, a compressor with drilling cores and a lifting crane. More machines are used during the deconstruction process, like a demolition crane and a crusher but they will not be included in the calculations since they are not part of the removal process of the elements.

During this modification phase the elements that are going to be reused in the housing project in Amstel III are prepared for the new construction. The machines that will be used are a diamond saw and a compressor with drilling cores. The diamond saw will be used to saw on size the elements and the compressor will be used to drill holes for the new connections.

- Transportation: The transportation of the elements is the only phase that can affect the emissions of the reused elements since modification and deconstruction are standard processes. The amounts of concrete in kg that will be transported are the same as with the new elements.

The reused elements will be used in Amstel III area. The distance between the deconstruction site and the site of the new housing project is 2km. The elements that will not be used will be transported at a storage site and the elements that are not possible to be reused the will be crashed and transported at a recycle plant. These are not included in the calculations since they don't affect the reused elements.

Life Cycle Inventory

The next step after having determined the system and the system boundaries is to calculate the inputs and outputs of the processes. In order to do that, the amount of concrete that was calculated for the whole housing project will be used. Table 7.2 shows the amount of concrete in kg per element that was calculated in chapter 4.

Mass (kg)	Main beams	Columns	Walls	H.C.S.	All	Recycle
Total	359664	291594	422560	1572045	2645863	330784
Reused	279169	246190	359156	1430563	2315079	
Percentage	78%	84%	85%	91%	87%	13%

Table 7.2 – Reused kg concrete per element

Amount of concrete

For both new and reused elements the amount of concrete needed is the same. The calculations of the environmental impact of the production of the new elements were made by using the database of NIBE. The existing database includes the extraction of raw materials and the process of recycled concrete, the transportation to the production site and the production process. In order to calculate the environmental impacts of new concrete different recycled percentages were used. The results can be found in Appendix VIII.

Transportation

The transportation of the raw materials to the production plant is already taken into account in the calculations of the production of new concrete. The transportation of the new elements from the production site to the new construction site is assumed to be 50 km. The transportation is made with trucks that can carry 25 tn net cargo. The calculation unit is tkm.

The transportation distance of the reused elements from the deconstruction site to the new construction site is assumed to be 2 km since the housing project will be constructed in the Amstel III area. The trucks that will be used are the same with the transportation trucks of the new elements.

Deconstruction

The deconstruction process is assumed to be the “production” process of the reused elements. The time that is needed to operate the diamond saw, the compressor and the lifting crane are calculated. The energy that each machine needs to operate was found through research on the manufacturer’s website of the machines. The values are presented in table 7.3.

Machine	Power (KW)	Fuel (l/h)
Diamond saw	5,50	-
Compressor Hammer	1,45	-
Compressor drilling	2,50	-
Lifting crane	-	35

Table 7.3 – Energy of the dismantling machines

In order to calculate the time that is needed to operate each machine, estimations were made. The deconstruction process is calculated for the building in Hogehilweg 18. It is assumed that the same time is needed for the deconstruction of the each element from the building in Karspeldreef 2. Table 7.4 presents the energy that is needed to dismantle each element. It should be mentioned that the energy that is needed to remove the concrete topping and to saw the concrete between the elements is equally divided on the amount of elements. The detailed calculations can be found in Appendix VIII.

Element	Energy use (KWh) / element	Fuel use (lt)/element
HCS	1,23	5,86
Beam	1,49	6,22
Column	1,48	5,83
Wall	0,88	9,10

Table 7.4 – Energy for dismantling

From the deconstruction process are excluded the fuels that are needed to transfer the machines and the workers at the deconstruction site.

Modification

The modification of the reused elements will take place at the deconstruction site. The modifications process that consumes energy are sawing the element on size with a diamond saw and drilling of holes for new connections with a compression drilling machine. The fuel needed to bring these machines at the deconstruction site are excluded. Table 7.5 presents the energy that is needed to modify each element. It is possible that a number of slabs do not need further modification and can be used immediately at the new construction. The slabs that do not need modifications are 180. The modification energy for these elements is 0.

Element	Energy use (KWh) / element
HCS	0,05
Beam	0,83
Column	0,42
Wall	0,83

Table 7.5 – Energy for element modification

Impact assessment

The different environmental impacts of the housing project made with new and with reused elements were calculated with the aid of SimaPro. The results of the calculations can be found in Appendix VIII. The concrete that will be used for the production of the new elements is a concrete that includes 100% recycled concrete aggregates. The environmental impacts of 1 kWh and 1 liter diesel were taken from the thesis of Nanda Naber.

The comparison between reused and new elements will be made with the Global Warming Potential (GWP) which is related to the climate change and with the Abiotic depletion Factor (ADF) which is related to the extraction of minerals and fossil fuels due to inputs in the system. (Wrap, 2011). Moreover in order to take in account all the environmental impacts they are converted into shadow costs (table 7.1). A comparison of the shadow costs is also made.

The reused elements include the processes of deconstruction, modification and transportation while the new elements include the processes of production and transportation. The factor that can affect the emission of the reused elements is the transportation. In charts 7.1 and 7.2 are

presented the global warming potentials of reused elements for a distance of 2 km and 650 km and of new elements for a standard distance of 50 km. In charts 7.3 and 7.4 the Abiotic depletion potentials of reused elements for a distance of 2km and 650 km and of new elements for a standard distance of 50 km are presented. It can be concluded that while for a distance of 2 km the impact of reused elements for both factors compared to new elements is insignificant, for a distance above 500 km the impact of the reused elements is higher than the new elements. Especially for a distance above 500 km the Abiotic depletion factor of the reused elements is larger than the new elements while above 650 km the Global Warming potential of the reused elements is larger than the new elements. The distance of 500 km is the limit for the transportation of the reused elements. This distance is 1,5 times the size of the Netherlands so it will not be a problem for transportation inside the Netherlands. On the other hand, it shows that reused elements can be transported for large distances, even from other countries, which is an advantage for the expansion of the market.

Chart 7.1 **Global warming potential for 2km transportation**

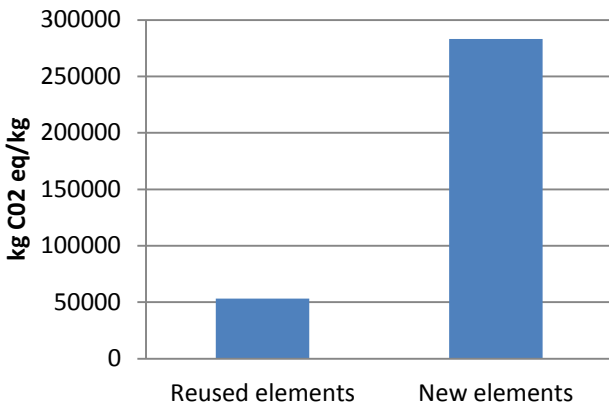


Chart 7.2 **Global warming potential for 650 km transportation**

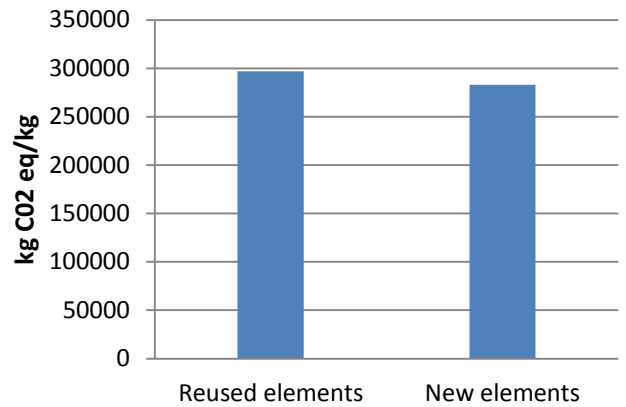


Chart 7.3 **Abiotic depletion for 2km transportation**

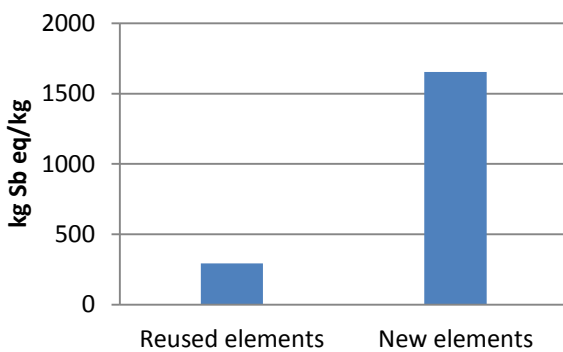
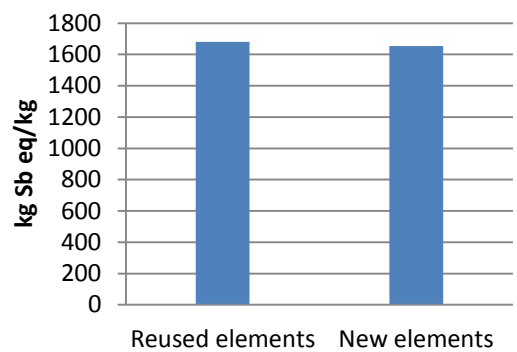


Chart 7.4 **Abiotic depletion for 500 km transportation**



In charts 7.5 and 7.6 the Global Warming Potentials and the Abiotic Depletion Potentials of the different process of the reused elements are presented. It is clear that the deconstruction has the greatest impact for all the elements while the impact of transportation and modification is negligible. The effect of transportation can increase if the distance increases while the effect of modification can only be reduced since it is a standard procedure. The impact of the compression layer is not included in this comparison since it is a new element.

Chart 7.5

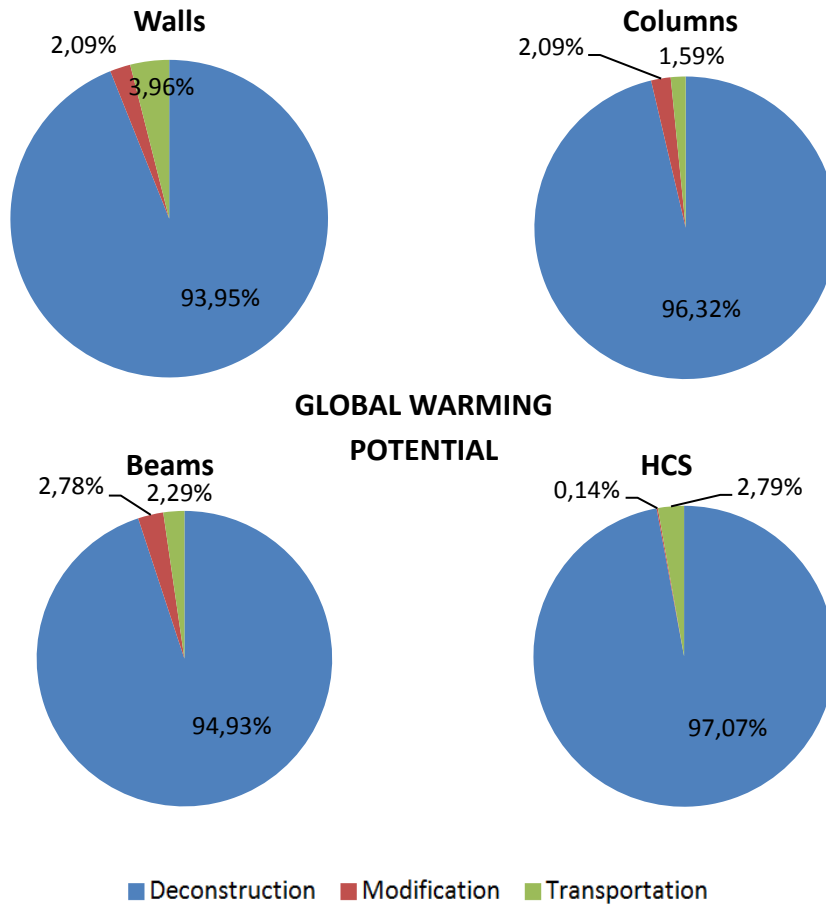
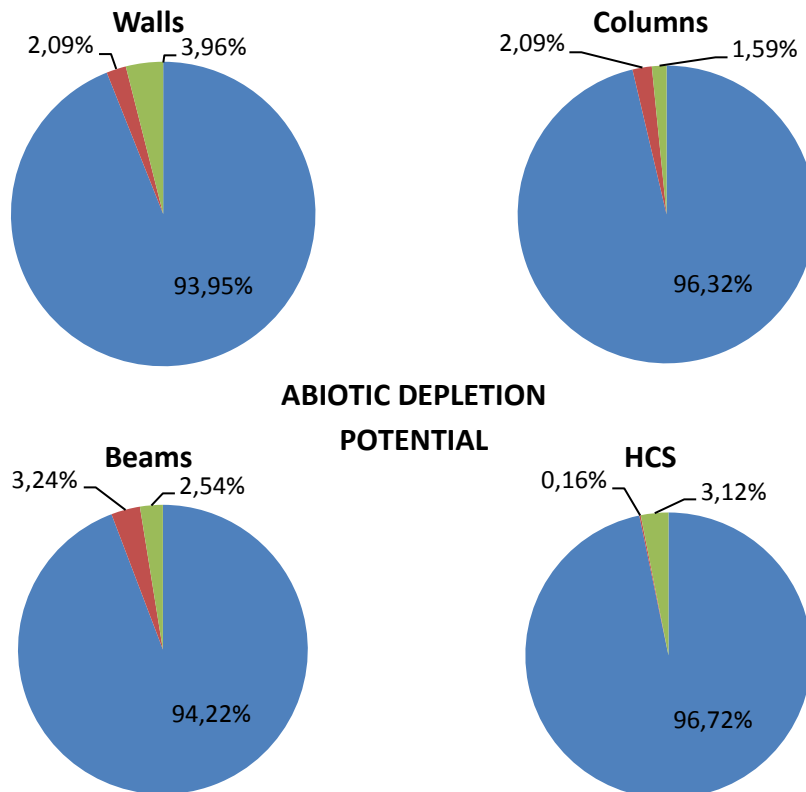


Chart 7.6



Finally the shadow costs of the structural system constructed with new elements and with reused elements are presented in chart 7.7. In both cases the compression layer is part of the calculation. The shadow costs are calculated for the total construction and per m². As it was expected the shadow costs of the reused elements are much lower than the new elements. These costs are not real costs but are the costs that should be paid in order to achieve the environmental targets.

Since 1st January 2013 it is obligated to deliver at the municipality a report for the Environmental Performance of new office or residential buildings larger than 100 m². In Dutch it is called MPG (MilieuPrestatie Gebouw) and it focuses on the environmental impact of the materials used in the buildings. All the environmental impacts are translated in shadow costs and the MPG is expressed in € per m² per year. For the time being, there are no limits for the MPG but it is certain that they will be set in the future (GPRGebouw, 2013). Buildings with an MPG that exceed those limits might have additional costs (e.g. fines). The reuse of structural elements showed that reduces the shadow costs significantly. As a result the Environmental Performance (MPG) of a building is improved and additional costs can be avoided.

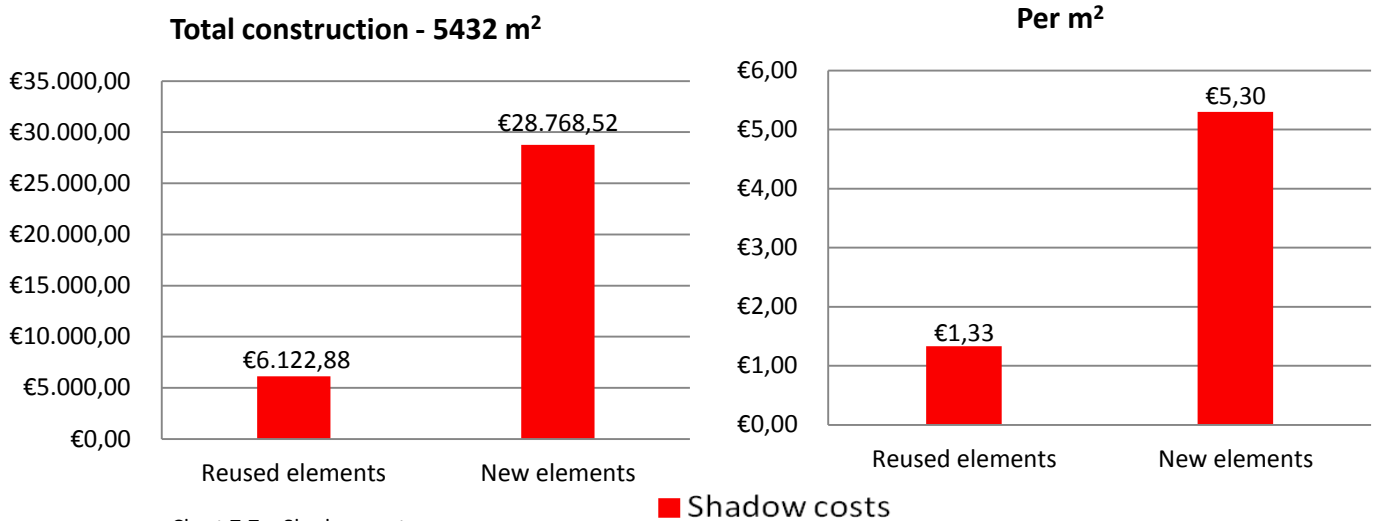


Chart 7.7 – Shadow costs

Interpretation

In this phase the results of the calculations will be analyzed. Before starting the analysis it should be mentioned that the new elements are considered as the first life of the product and the reused elements as the second life of the product. The impacts of the extraction of raw materials, manufacture and transportation are taken into account 100% in the first life. An alternative is to divide these impacts over the number of anticipated lives of the elements but this is not possible to happen since the number of the reused lives of the elements is not known.

Charts 7.1 and 7.2 compare the Global Warming Potentials of the reused elements and the new elements. Chart 7.1 shows that the impact of new elements is much higher compared to reused elements. The impact of the reused elements is 19% of the new elements. Since transportation is the only factor that can change the impact of the reused elements it was calculated that above 650 km the Global Warming Potential of the reused elements is higher (chart 7.2).

One remark from the calculations is that when using 100% recycled concrete aggregates in a mix the Global Warming is higher than the 0% recycle concrete aggregate. This is happening because the energy that is needed to crush the concrete is more than the energy that is needed to extract the raw materials. On the other hand, the total shadow costs of the concrete with 100% recycled aggregates are less than the 0% recycled aggregates. As a result the 100% recycled concrete will be used for the comparison.

Charts 7.3 and 7.4 compare the Abiotic Depletion Potential. Again in this case the impact of the reused elements is 18% of the new elements. When the elements are transported above 500 km the impact of the reused elements is higher. From the comparison of the Global impact and the Abiotic Depletion it can be assumed that the elements can be transferred for 500 km and the impact of the reused elements will be lower than the new elements.

The second comparison was between the different processes of the reused elements. It can be noticed that the dominate process is deconstruction. For all the elements, deconstruction is responsible for the 90% of the Global Warming potential and Abiotic Depletion potential. In this case transportation is insignificant due to the fact that the elements are transferred only for 2 km. In case the elements have to be transferred for a longer distance then the impact will be increased.

Finally the shadow costs of the reused elements are reduced 75% compared to the shadow costs of the new elements. Shadow costs are hypothetical costs and they do not have financial status. The only effect that shadow costs can have on real costs is the potential additional costs in case the MPG is above a certain limit. Nevertheless, in order to depict the effect of reusing structural concrete elements in a new construction the shadow costs can be added at the total costs. Table 7.6 shows the influence of the shadow costs on the total costs.

Costs per m ² (Area 1807 m ²)			
Description	€ Construction costs /m ²	€ Shadow costs/ m ²	Total costs (€)
New elements (same dimensions)	175	5,30	180,30
New elements (reduced dimensions)	161	5,15	166,15
Reused elements (1 to 1)	168	1,33	169,33
Reused elements (Divided)	156	1,33	157,33

Table 7.6 – Construction costs plus shadow costs

The shadow costs of the reduced dimensions have lower shadow costs due to less amount of concrete. The difference between new elements with reduced dimensions and reused elements that are used 1 to 1 without the shadow costs is 4,2 %. When the shadow costs are added at the total costs then this difference is reduced to 1,9%. It is possible to further reduce the margin by optimizing the deconstruction process since it is the process with the highest emissions. This can happen through practice.

With this LCA it was proven that the reused structural concrete elements have less environmental impacts compared to new elements. Moreover, potential future costs can be avoided due to the reduced shadow costs of the reused elements.

CHAPTER 8

CONCLUSIONS & RECOMMENDATIONS

This chapter presents the conclusions and the recommendations of the thesis. The conclusions are presented as answers to the research questions of Chapter 1. The recommendations are suggestions for further research in order to realize and promote the reuse of structural concrete elements.

8.1. CONCLUSIONS Main research questions

1) Which are the technical obstacles that prevent the reuse of reclaimed structural elements in new buildings?

and

2) Can these obstacles be solved?

In order to identify the technical obstacles, the reuse process was separated in stages. These are:

- Inventory
- Quality check
- Deconstruction
- Modification
- Design process

Inventory

The existence of an inventory is the most substantial phase of the reuse process. Through this phase it is decided if the building is suitable for deconstruction depending on the type and amount of elements. The inventories of the offices in Amstel III showed that buildings with pre-stressed slabs are not suitable for deconstruction due to the limited amount of reusable elements (only walls and columns). On the other hand buildings with prefabricated elements are

suitable for deconstruction due to the increased amount of reusable elements. The inventory includes all the properties of each individual element that are necessary for the reuse process. The obstacle of creating an inventory for existing office buildings is that it has to be made manually since all the drawings are in plans not accessible from a computer. This demands many working hours in order to review all the drawings. Apart from that it is possible that a number or even all of the drawings are missing so in that case on-site inspection is needed which increases the cost of the whole process. It is obvious that the obstacles of the inventory can be overcome with extra working hours and relative increase of project costs

Quality check

Before deconstructing a building it is important to assess the quality and the condition of the structural elements. Through this assessment the information of the existing drawings will be verified. As long as the condition of the elements is suitable for reuse and the building is constructed according to the old drawings then it can be disassembled. The results of the assessment will be part of the inventory and more specifically, every element will have its own certificate, the EID. This certifies that the quality and condition of the element is acceptable for reuse. No obstacles were identified in this process.

Deconstruction

The elements are removed from the building with the deconstruction process. It is a process that happened only a few times due to the increased costs. As a result there is no experience on how to conduct a deconstruction of a concrete building. On the other hand the sub-processes that constitute deconstruction are already known methods. There are different methods that can be used. The criteria for the selection are the final quality of the element, the costs and the safety. It has to be planned in great detail because the rate of success of the deconstruction process determines the amount of the reusable elements. The obstacle in this phase is that the buildings are not meant to be deconstructed so a lot of effort is needed to dismantle the connections. This creates extra working time and as a result extra costs.

Modification

Modification is the phase where the elements are prepared to be reused. Due to the fact that the existing office buildings are not meant to be deconstructed the connections had to be destroyed. In order to reuse them in the housing project new connections have to be created. Again here there are already known methods that are used to add a new part or modify an existing part of a building but never used for an individual element. In order to minimize the costs of modification elements like beams, columns and walls have to be cut straight from the old building according to the needed dimensions. In the case study, the columns, walls and beams are too long to be used in a housing project. For this reason they have to be sawn on size. Besides sawing on size and creating new connection, modification includes other important actions like protection of the exposed reinforcement and filling of holes. As far as it concerns the slabs, in order to achieve lower costs they should be used at their original size. This depends a lot at the design process. The place of the modification depends on the existence of a new project. For the housing project it is assumed that the elements are modified at the deconstruction site. The technical obstacles in this phase are the effort that is needed to modify each element and the accuracy to create the correct connection.

Design process

This step is important for the success of the reuse process. Designing with reused structural elements besides the structural design affects also the architectural design. It is important that the engineer and the architect collaborate from the beginning of the design. It has to be taken in

account that the elements have restricted dimensions that can only be reduced. This demands extra money so the most effective way is to reuse the elements at their original dimensions. The only elements that can be reused with 0% modifications are the Hollow Core Slabs since they are simple supported and a new connection is not needed. All the rest of the elements need a new connection since the old one was dismantled during the deconstruction phase. Due to the structural capacity of the elements and the low loads the connections are used only for practical reasons. For this case the simplest connections have to be made. Therefore the obstacle during the design phase is the need to prepare a detailed structural analysis of the construction from the beginning of the design. It is known that for a conventional design the detailing comes at a later stage after a preliminary design is completed.

Besides the already mentioned phases there are also transportation, storage and construction. These phases have no technical obstacles since there is a lot of experience. Good management and planning is needed in all the three process in order to reduce the costs and avoid damages.

It can be concluded that the technical obstacles of reusing structural concrete elements can be solved with already known methods. Processes like deconstruction and modification for reuse demand extra attention and effort but the research showed that they are technically feasible.

Sub-Research questions

1) What are the advantages of the reuse of building components and why it is not widespread like recycling?

The main advantage of reuse is the shorter lifecycle scenario compared to recycle which leads to less energy demands since the whole stage of production is avoided. The result of the thesis showed that the environmental impacts of reusing structural elements compared to elements made with 100% recycled concrete aggregate are reduced 75%.

The main reason that reuse of structural elements is not widespread like recycle is the fact that although there is a large amount of elements “stored” in existing vacant buildings, the buildings are not meant to be deconstructed. Furthermore, there is no market at the moment for reused elements while there is a well-established market for recycled concrete aggregates. This is a result of the disbelief of potential users against reused elements. For this reason demolition contractors prefer to completely demolish a building, crush the concrete and send it for recycle. In order to reassure potential users that the elements of the office buildings are safe for reuse a certificate was created. Another reason that reuse is not so widespread is because it demands close collaboration of all the participants. Engineers, demolition contractors, architects and contractors have to collaborate from the first phase in order to create the most efficient design with reused elements. On the other hand the use of recycle concrete aggregates does not affect the rest of the phases since new elements are produced.

2) Which are the existing deconstruction procedures? and

3) What are the advantages and disadvantages of deconstruction compared to demolition?

The methods and machines that are used for the deconstruction process are already known from demolition projects. The machines used are a lifting crane, a diamond saw, a compressor with hammers and core drillers. The method to deconstruct a building is a floor-to-floor deconstruction where each element is carefully removed. The advantage of using already known methods and machines is that workers are familiar with them but extra planning and attention is needed in order not to harm the elements, prevent accidents and avoid delays. One solution to

avoid damaging of the elements during deconstruction is to use the same workers for disassembly and reassembly of the elements [Eklund M. et al, 2003]. In this way, the workers will be more careful when removing the elements and as a result they will have to solve less problems during reassembly.

The main disadvantage of deconstruction is that the existing buildings are not meant to be deconstructed and there are no suitable machines for deconstruction. The fact that the buildings are not meant to be deconstructed demands extra time in order to safely dismantle the rigid connections without damaging the elements which leads to higher costs compared to demolition. The time needed for the deconstruction of the office buildings in Amstel III is 2,5 times more than demolition and the costs are 3,5 times higher. In addition to the extra time needed, demolition contractors have no experience with deconstruction and this creates higher risks. On the other hand, deconstruction leads to reusable elements. Their use in a new project reduces the environmental burden of removing raw materials and consuming energy for the production of new elements. Furthermore, the results of the case study showed that deconstruction has cost benefits. The total deconstruction costs of the office building in Hogehilweg 18 were covered since the new elements cost more than the reused elements. As a result, removing a building with deconstruction costs less than removing it with demolition as long as the elements are reused in a new project.

Furthermore, deconstruction has to be considered as an extra solution when the end of the functional life of a building is reached. Transformation of the building is the first solution that has to be examined and if it is not possible then deconstruction is the second solution due to the economical and environmental advantages compared to demolition. While demolition is considered as the end-of-life of a building, deconstruction can be considered as the beginning of the life of a new building.

**4) With respect to their function, which buildings are suitable for reuse in the Netherlands? and
5) Which areas in the Netherlands are the most urgent for solutions against structural vacancy?**

The criterion to choose the suitable building function for reusing its structural elements is the vacancy rate. Between the 4 main building functions namely offices, retails, industries and houses the office buildings have the largest vacancy rate. At the first half of 2013 the office market had a vacancy rate of 14,70%. Immediate solutions are needed for solving the problem of the high vacancy. Deconstruction and consequently reuse of structural elements can be considered as an extra solution. The areas that are most urgent for solutions are the mono-functional areas around the cities that where build in 1980's. For the case study it was decided to use the area in Amstel III which has 188.660 m² (25,80%) empty office buildings. Especially 50% are facing structural vacancy. In order to create the element inventory eight vacant buildings were used.

6) Which methods can be used for the structural assessment of an existing concrete element?

The structural integrity of an existing structural element is one important issue that has to be assessed before reusing any element in a new project. A quality check method was developed in order to assess the elements. It includes processes that are already used for the assessment of whole buildings and they can easily be used for assessing individual elements meant to be reused. These processes are the inspection of existing structural drawings, visual inspection of the elements and non-destructive tests. The goal of the quality check is to verify that the properties mentioned in the existing drawings match with the real project, detect any potential damages and assess the structural integrity of the elements. The outcome of the quality check is a certificate, the Element Identity (EID), which includes all the properties of the element and the

results of the structural assessment. The EID can be used in order to reassure all the potential users of the elements that they are suitable and safe to be reused.

7) Which properties of the structural elements will be contained in the inventory? and 8) What are the types and the quantity of the structural elements found in the empty buildings?

The inventory is created during the inspection of the existing drawings of the vacant buildings. The main properties that have to be part of an inventory are the following:

- General properties of the building
- Material properties
- Type of the element
- Dimensions of the element
- Structural properties of the element
- Reuse percentage
- Costs
- Environmental impacts

There are 3 buildings that contain columns, walls and slabs made from cast-in-situ concrete, 3 buildings that contain precast concrete elements and 2 buildings that contain precast and cast-in-situ concrete elements. From these buildings only 2 buildings containing prefabricated elements are suitable for deconstruction because the rest have either limited amount of elements or the existing drawings are not enough.

9) Which is a suitable function for the design of a new building with reused elements? and 10) Which elements from the inventory are more suitable for reuse?

The criteria for the new function designed with reused elements are the demands of the area, the loads of the different functions and the available structural elements. In order to avoid storage of the elements and extra transportation it was decided to use the elements in Amstel III. The main goal for the area is to add houses in order to convert Amstel III from a mono-functional to a multifunctional area. Furthermore, the existing elements derived from office buildings are suitable for reuse in a housing project due to the reduced loads.

The elements for the housing project in Amstel III derived from the buildings in Hogehilweg 18 and Karspeldref 2. The type and amount of elements determined the new construction. Usually, houses in the Netherlands are constructed only with walls and slabs. On the other hand, the office buildings include a large amount of columns, beams, walls, slabs and facade beams. As a result, it is essential to use the elements in the same structural system in order to achieve the highest efficiency. A 20% of the original grid, and as a result of the original area, is lost due to deconstruction and the new way of connecting the elements. For the housing project almost all the columns (95%), beams (86%) and walls (83%) were reused while a smaller but still efficient amount of slabs (65%) was reused. None of the facade beams were reused since they are not suitable for a housing project. The total reuse percentage of the original area was 65%. This percentage can be increased when a new design is started with the condition that existing elements with restricted dimensions will be used. Moreover, it can be increased by using a different support method and by choosing a different deconstruction method with fewer losses.

It has to be noted that the design process demanded extra time than it was originally planned due to the different changes. Especially, the choice of the elements for each position needed a lot of analysis because all the properties of the elements had to be checked before being used.

This delay would not occur at a conventional design process because the properties of the elements can change easily according to the design.

11) Which types of connections from the prefabricated elements can be applied on the reclaimed structural elements? and

12) Which are the technical problems derived from the connections and the structural assessment?

Usually, the connections of a conventional project are designed at a later stage of the design phase. On the other hand, the connections of the reused elements have to be analyzed from the beginning of the design process due to the restricted dimensions and structural properties of the elements. The goal of this case study was to create connections that will allow reusing the elements as prefabricated. The technical issue of this type of connections is the high accuracy that is needed during the drilling process in order to avoid mismatches during the construction process. Nevertheless, the connections that were designed fulfill the purposes of the thesis and is recommended to further research different types of connections for reused elements. Due to the low loads of the construction it was possible to use the minimum amount of rebars which reduced the modification costs.

The structural assessment of the elements showed that the elements are oversized for the housing project. Moreover, the majority of the elements fulfill the requirements of the Eurocode with some exceptions. The elements that don't fulfill the requirements of the Eurocode can be tested to prove that they are suitable for reuse or they are discarded. Technical problems that derive from the structural assessment are the absence of top reinforcement in the prefabricated beams and the loss of the lateral tensile reinforcement at the edges of the columns and the walls due to deconstruction.

13) What are the costs of reused elements compared to new elements?

The costs of a new element are the costs of production, transportation and construction while the costs of reused elements are the costs of deconstruction, modification, transportation, storage and construction. The highest costs of the reused elements are the deconstruction costs which are approximately 57% of the total costs. These costs depend on the section of the element and not on the length. A thicker section needs extra time to be sawn which increases the costs. On the other hand a crane can lift elements with a wide range of weight so no extra costs are needed. The total costs of the housing project designed with reused elements are 10% lower compared to new elements with the same dimensions. Even if new elements with smaller dimensions are used the total costs can be 3% less when large elements are divided. The dimensions of beam, walls and columns enable them to be cheaper compared to new elements while the HCS are cheaper when they are larger than 7 m. The profit in construction costs can be achieved only when the building has zero value. For this reason it is suggested to deconstruct a building when it has fully depreciated its value and it is meant to be demolished.

14) Which is the contribution of the reuse of structural elements to the reduction of greenhouse gas emissions?

In order to calculate the environmental impacts of the housing project constructed with reused elements, a Life Cycle Assessment (LCA) was used. The system boundaries of a new element are the extraction of raw materials, the process of crushed concrete, production and transportation. The system boundaries for reused elements are the deconstruction, the preparation for reuse and the transportation. The results of the LCA show that the greenhouse gas emissions (CO₂) of the housing project constructed with reused elements are reduced by 90% compared to new elements with 100% recycled concrete aggregates. In order to calculate the total environmental

impacts the shadow costs are used. The shadow costs of housing project with reused elements are reduced by 75% compared to the shadow costs of new elements. These results prove the high environmental gains of reusing structural concrete elements.

The results of this case study showed that it is technically feasible to reuse structural concrete elements by applying existing methods for deconstruction and reconnection. The greatest advantages of designing a house with reused elements are the large environmental gains and the reduced construction costs compared to new elements. It is possible to achieve even higher gains with further research. Finally, this thesis proved that deconstruction and reuse has to be considered as an extra solution against the vacancy of office buildings. With closer collaboration of the relevant actors and further knowledge on the subject it will be possible to realize a project with reused structural concrete elements in the foreseeable future.

8.2.

RECOMMENDATIONS

This thesis project researched the feasibility of reusing structural concrete elements from office buildings into housing project. Through the research different issues arose that demand further investigation and development in order to assist the realization of the reuse process. This section presents the recommendations for the actors involved in the reuse process.

Architects

For this research only the structural design of the housing project in Amstel III was analyzed. It is recommended that further research should be made on the design possibilities of reusing structural elements for different building types. Besides the structural requirements, other restrictions that have to be investigated are the different designs due to different grid, the effects of the larger elements in the interior design, the location of the installations and the openings. It would be interesting to create a "toolbox" of the different architectural building types and show in what way the previous mentioned criteria work in the most efficient way.

Urban planners

The goal of this thesis was to design a housing project with elements from existing office buildings without taking in account the implementation of the houses in the area. Using a redevelopment concept for a bigger area, it is recommended to look at the effects of changing building functions which will influence the area. Examples are the mobility system in terms of daytime/nighttime use, the different services that need to be added (shops, kindergarden, etc), and the new design of the plot itself.

Software developers

The reuse process is based on the creation of a building inventory which contains all the necessary information of the available elements for reuse. All the inventories from different buildings can be combined in a database. For the purpose of this thesis, excel files were created but only the main properties were included. In order to assist the reuse process it is essential to develop a user friendly database that will include all the detailed information of the elements. The time consuming process of investigating old drawings cannot be avoided but significant time can be saved when all the elements are organized in a large database and their properties are easily accessed. Furthermore, a software can be developed that contains the database and can calculate the reuse percentage of the elements of a specific building together with the maximum area that can be constructed. Moreover, it can calculate the costs and the environmental impacts of a construction made with reused elements compared to new elements. A possible source for the filling of the database is structural offices that are specializing in the transformation of existing buildings. They research and assess the structural system of a building for transformation

but many times the project is not realized. In order not to lose the knowledge for the existing building they can register it in the database.

Engineers

This thesis proved that it is technically possible to reuse structural concrete prefabricated elements from office buildings to 2-story high houses. For further research it would be interesting to investigate the reuse of elements to design buildings with more than 2 floors and with different function. Moreover, it would be interesting to investigate the suitability of reusing elements from buildings with different construction types like cast-in-situ concrete and from buildings with different function like industrial buildings.

For this thesis it was decided to reconnect the elements with connections that are not meant to be deconstructed in the future. It would be interesting to investigate the design of connections that are possible to be deconstructed for further reuse. Furthermore, it would be interesting to investigate the effects of using new and old elements in a design and their connections. Another recommendation is to research the different structural building systems typologies of existing buildings and classify them according to their suitability to be deconstructed. An attempt was made to perform this research in this thesis but it was not possible due to limited information in the literature. This type of research demands combination of the knowledge that structural engineering offices like IMd already have.

University

The university should become the initiator for promoting the deconstruction and reuse of elements. Through projects and workshops, civil engineer and architect students can collaborate and design different building types with a specific inventory of elements. Reusing structural elements is a new way of designing where the presence of an engineer is important from the beginning of the design phase. With this way students can get familiar with the reuse process.

Government

An attempt is already made with the masterplan from the municipality of Amsterdam to change the rules for Amstel III and implement different functions beside offices. A recommendation for the government to promote the reuse of structural elements is to subsidize deconstruction and reuse process. With this way it can become the first municipality that solves the problem of the vacant office buildings by reusing the existing elements. Furthermore, the owners of the buildings have to be informed for this extra solution, besides transformation and demolition, against vacancy. This can be done through events organized by the government. Another recommendation is to develop a building code for reusing structural elements similar to the code for reusing existing buildings. The results of the research showed that when the elements are assessed with Eurocode a number of requirements are not fulfilled. This does not mean that the elements cannot be reused since they were used for more than 25 years in a real construction.

Demolition companies

Deconstruction is the process that creates the highest costs and environmental impacts. Demolition companies should further research the most efficient ways of removing an element from a building with the less damage possible.

Pilot project

In order to better understand the deconstruction and reuse process of structural elements it is recommended to realize a pilot project. This can be promoted and sponsored by the government and the university with close collaboration of all the actors. With this pilot project potential risks

and unknown issues can be identified. Furthermore, through the pilot project it would be interesting to investigate the differences in the collaboration between the different actors compared to a conventional project with new elements.

CHAPTER 9

REFERENCES

ACI Committee 437, Strength Evaluation of Existing Concrete Buildings, American Concrete Institute, 2003

American Heritage Dictionary, 'Inventory', www.answers.com/topic/inventory#ixzz2OHeLK1fA, retrieved 21-03-2013

Architectural Service Department, 'Code of Practice for Demolition of Buildings', Government of Hong Kong, 2004

Asam C.; 'Recycling Prefabricated Building Components for Future Generations', in: IEMB, 1, 2006

Asam C.; 'Recycling Prefabricated Concrete Components – a Contribution to Sustainable Construction', IEMB, 3, 2007

Asam C.; 'Urban Renewal in Large Eastern German Residential Settlements with Regard to the Reuse Possibilities of the Dismantled Building Elements from Large Format Prefabricated Concrete Buildings', in: IEMB, 3, 2006

ASCE Standard, Guideline for Structural Condition Assessment of Existing Buildings, USA, 2000

Bluestone D.; 'Constructing Chicago', Yale University Press, New Haven, 1991

Brewer G, Mooney J.; 'A best practice policy for recycling and reuse in building', Proceedings of the Institution of Civil Engineering – Engineering Sustainability, No. 161, Issue ES3, 2008 (173-180)

Britannica Encyclopedia, 'Database', www.answers.com/topic/database#ixzz2OHetD4YT, retrieved 21-03-2013

Burton Car Company, <http://www.burtoncar.com/>

- CBRE; 'Dutch residential market in transition-A new perspective on residential real estate investment', June 2012
- CBRE; 'What Users Want – The Influence of the Innovative Workplace on the Office Environment', June 2011
- CCAA (Cement Concrete & Aggregates Australia); 'Use of Recycled Aggregates in Construction', Australia, May 2008
- Compendium voor de leefomgeving; 'Bouw- en sloopafval: vrijkomen en verwerking, 1985-2008', <http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl0147-Bouw--en-sloopafval.html?i=1-4>, (retrieved 16-5-2013)
- Comstock Maggie, Garrigan Curt, Pouffary Stéphane; 'Building Design and Construction – Forging Resources Efficiency and Sustainable Development'; UNEP - Sustainable Buildings and Climate Initiative, 2012
- Coolrec – Van Gansewinkel Groep; 'Scarcity of raw materials', on website: <http://www.coolrec.eu/duurzaamheid/grondstoffenschaarste.aspx>, retrieved 27-2-2013
- De Graaf M.; 'Interview with the demolition manager of Lekekkerkerker Rotterdam b.v.', 2013
- De Hoog R.; 'Interview with the manager of the demolition company Oranje b.v.', 2013
- De Schepper; 'Volledig recycleerbaar beton voor een meer milieuvriendelijke bouwsector', Technical University of Gent, Gent, 2009
- Dienst Ruimtelijke Ordening; 'Empty offices-Transformation for new functions – Summary', in: PLAN Amsterdam Edition 1, 2012 (30)
- Dijk van K., Boedianto P., Dorsthorst te B.J.H., Kowalczyk T.; 'Strategy for Reuse of Construction and Demolition Waste Role of Authorities', in: HERON, Vol. 46, No. 2, 2001 (89-94)
- Dijk van K., Boedianto P., Dorsthorst te B.J.H., Kowalczyk T.; 'State of the Art Deconstruction in the Netherlands', in: TG39 CIB – Overview of Deconstruction in Selected Countries, Publication 252, The Netherlands, 2000 (95-143)
- Diven R. J., Shaurette M.; 'Demolition – Practices, Technology and managements', Purdue University Press, Indiana, 2010
- Dorsthorst te B.J.H., Kowalczyk T.; 'Reuse of Apartment Buildings: a Case Study',
- DTZ Zadelhoff; 'Nederland Compleet – Factsheets Kantoren en Bedrijfsruimte market', DTZ Zadelhof v.o.f., January 2013
- DutchNews.nl; 'Office Vacancy Rate hits 16%', on website: http://www.dutchnews.nl/news/archives/2013/02/office_vacancy_rate_hits_16.php, retrieved 21-02-2013

- EIONET (European Topic Centre on Sustainable Consumption and Production); 'Waste policies 2009 – Factsheets for Netherland', on website:
http://scp.eionet.europa.eu/facts/factsheets_waste/2009_edition/factsheet?country=NL,
 retrieved on 14-05-2013
- Eklund M., Dahlgren S., Dagersten A., Sundbaum G.; 'The Conditions and Constraints for Reusing Materials in Building Projects', in: Chini A. R., Proceedings of the 11th Rinker International Conference 2003, CIB 287, Florida, 2003
- Eklund M., Dahlgren S., Dagersten A., Sundbaum G.; 'The Conditions and Constraints for Using Reused Materials in Building Projects',
- Fujita M., Iwata M.; 'Reuse system of building steel structures', in: Structural and Infrastructure Engineering: Maintenance, Management, Life-Cycle Design and Performance, Vol. 4, No. 3, 2008 (207-220)
- Gorgolewski M., Straka V., Edmonds J., Dzoutzidis C.S.; 'Designing Buildings Using Reclaimed Steel Components', in: Journal of Green Building, Vol. 3, No. 3, 2008 (97-107)
- Gorgolewski M., Straka V., Edmonds J., Sergio C.; 'Facilitating Greater Reuse and Recycling of Structural Steel in the Construction and Demolition Process', Department of Architectural Science – Ryerson University, Canada, 2006
- Gorgolewski M.; 'Designing with reused building components: some challenges', in: Building Research & Information, Vol, 36, No. 2, 2008 (175 – 188)
- Guy B., ;'Building Deconstruction Assessment tool', in: Proceedings International Conference Sustainable Building 2000 (125-137)
- Haritos N., Lam N. T. K.; 'Reuse – Issues and Challenges in Structural Engineering Applications'; International Conference on Sustainable Built Environmnet 2010 (267-273), Kandy, 2010
- Hendriks Ch.F., Jansen G.M.T.;' Reuse of construction and demolition waste in the Netherlands for road construction', in: HERON, Vol. 46, No. 2, 2001 (109-117)
- Hof Andries, Brink Corjan, Beltran Angelica Mendoza, Elzen Michel den; 'Greenhouse Gas Emission Reduction Targets for 2030 – Conditions for an EU target of 40%'; PBL Netherlands Environmental Assessment Agency, The Hague, 2012
- IenM (Ministerie van Infrastructuur en Milieu); 'Green Deal Verduurzaming Nuttige Toepassing AEC-bodema', March 2012
- Jones Lang LaSalle-On.pont; Dutch Real Estate Market Bulletin – On. point; 2012
- Jones Lang LaSalle-Pulse; 'Impact of the Covenant on the Approach to Vacant Office Space', 2012
- Keith James; 'A methodology for quantifying the environmental and economic impacts of reuse'; Wrap, UK, 2011

- Kibert C.; 'Deconstruction: The Start of a Sustainable Materials Strategy for the Built Environment', in: UNEP-Industry and environment, April – September 2003 (84-88)
- Korteweg P.J.; 'Veroudering van Kantoorgebouwen: Probleem of Uitdaging?', KNAG, Utrecht, 2002
- Macozoma D.S. ;'Report – Building deconstruction', International Council for Research and Innovation in Building and Construction (CIB), Pretoria, 2001
- Ministry of Housing, Spatial Planning and the Environment; 'Het Landelijke Afvalbeheerplan 2 (LAP 2) VROM', Den Hague, 2009
- Ministry of Housing, Spatial Planning and the Environment; 'National Waste Management Plan: Part 1 Policy Framework VROM', Den Hague, 2003
- Naber N.; 'Reuse of Hollow Core Slabs from Office Buildings to Residential Buildings', Master Thesis, Technical University of Delft, Delft, 2012
- NAHB Research Center; 'Deconstruction – Building Disassembly and Material Salvage', USA, 1998
- Paul S. C.; 'Mechanical Behavior and Durability Performance of Concrete Containing Recycled Concrete Aggregate', Master Thesis, Civil Engineering Department, Stellenbosch University, December 2011
- PCA (Portland Cement Association); 'Concrete technology – Frequently asked questions', on website: http://www.cement.org/tech/faq_recycled.asp, retrieved on 08-05-2013
- PCA (Portland Cement Association); 'Concrete technology – Materials: Aggregates', on website: http://www.cement.org/tech/cct_aggregates_recycled.asp, retrieved 08-05-2013
- Projectbureau Zuidoostlob, 'Strategiebesluit Amstel II van monofunctioneel werkgebied naad multifunctionele stadswijk', Gemeente Amsterdam, Amsterdam, 2011
- Regeer W.; '300 thousand dwellings vacant', CBS, <http://www.cbs.nl/en-GB/menu/themas/bouwen-wonen/publicaties/artikelen/archief/2012/2012-3687-wm.htm>; Published online 19 September, 2012
- Remøy H., de Jonge H.; 'Transformation of monofunctional office areas', In: Van den Dobbelen, A., M. van Dorst en A. van Timmeren (eds.), Smart Building in a Changing Climate, Techne Press, Amsterdam, 2009.
- Remøy H.; 'Out of Office – A Study on the Cause of Office Vacancy and Transformation as a Means to Cope and Prevent', IOS Press, Amsterdam, 2010
- Rijkswaterstaat Ministerie van Infrastructuur en Milieu; 'Ketenaanpak bouw- en sloopafval', on website: www.rwsleefomgeving.nl/onderwerpen/duurzaam_produceren/ketenaanpak/bouw-sloopafval/, retrieved on 14-05-2013

- Rijkswaterstaat Ministerie van Infrastructuur en Milieu; 'Nederlands afval in cijfers, gegevens 2006-2010', 2013
- Sebus J.; 'Conversion Gains Ground – Slowly'; in: Property EU Magazine, No 4, 2012 (38-45)
- Simon M., El-Haram M., Horner R.M.W.; 'Cradle-to-cradle – A concept for the disposal of building at the end of their lives?'; In: Horner M., Hardcastle C., Price A., Bebbington J., Proceedings International Conference on Whole Life Urban Sustainability and its Assessment, Glasgow, 2007
- The Royal Academy of Engineering; 'Engineering a low carbon built environment – The discipline of Building Engineering Physics', The Royal Academy of Engineering, London, 2010
- Thomsen A., Schultmann F., Kohler N.; 'Deconstruction, Demolition and Destruction', in: Building Research & Information, vol: 39, no:4, 2011 (327-332)
- Turpijn I.; 'Interview with the architect of Kantorenloods Amsterdam – Public company for empty buildings', 2013
- Valdivia Sonia, Sonnemann Guido; 'Life Cycle Perspective of Building Materials'; UNEP - Sustainable Buildings and Climate Initiative, Paris, 2010
- WCED (World Commission on Environment and Development); 'Our Common Future', Oxford University Press, UK, 1987
- Wikipedia; 'Downcycling', <http://en.wikipedia.org/wiki/Downcycling>, retrieved 14-5-2013
- Worldometers; 'Current World Population', www.worldometers.info/world-population/, retrieved 20-5-2013
- Wouters Huib, Derk Bol; 'Material Scarcity'; M2i – Materials Innovation Institute, Delft, 2009

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