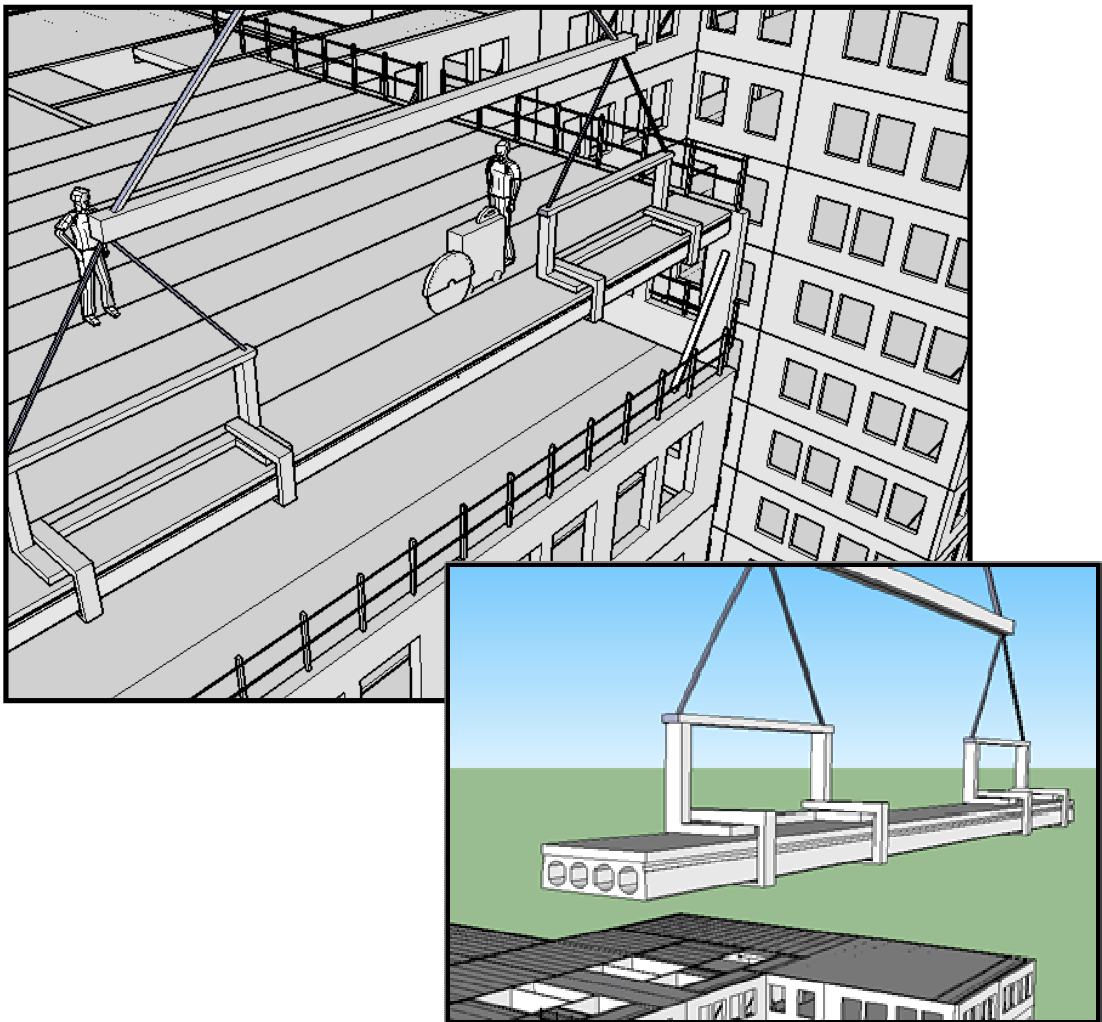


Master's Thesis

Reuse of hollow core slabs from office buildings to residential buildings



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I. Preface

The past nine months I have worked with great enthusiasm on this thesis that will finalize my master Civil Engineering at the TU Delft. The subject "Reuse of hollow core slabs from office buildings to residential buildings" turned out very interesting and many positive results were booked to really put this concept in the market. The interaction with all people I have interviewed and others with whom I have spoken with about my research have brought me to the final result. Everyone has contributed by pointing out new aspects and ideas I had not thought of before.

I would first of all like to thank my committee of being at least as enthusiastic about this research as I was. After each meeting they gave me so much energy and willingness to continue and achieve the best possible result. Secondly, I would like to thank the people I have interviewed. They were willing to give up their time to help me develop the concept and some even helped me through-out the rest of the research whenever I needed extra information or documents. I would also like to thank all people of DHV, which is at the moment of writing Royal HaskoningDHV, who have invested time and effort to help me. I had a great time working at the DHV office in The Hague. Finally, I would like to thank my family and friends, because they did not lose interest in listening to me when talking about my project over and over again.

I hope that by reading this report people in the building sector will start realizing the opportunities that lay in extending the life time of concrete elements. An attempt is made to let them become aware of the environmental drawbacks of the current building cycle, inevitable to be able to be receptive to innovations that lead to progression. I have noticed within almost all interviews held that there is reluctance against such large innovations mostly because the advantages are not clear. I hope that this research will contribute to the awareness of all these advantages and that it is the beginning of a shift within the building sector to reduce the large environmental impact of this sector.

Finally, I hope that someone will continue with the development of the process of reusing hollow core slabs. I am aware that much effort is needed from several individuals and companies to start up this change, but I am convinced that with this effort much gain is to be booked.

Nanda Naber,
Delft, August 2012

II. Abstract

The subject of this thesis is the reuse of hollow core slabs from office building to residential buildings. It was written as final part of the master Civil Engineering of the TU Delft. The occasion for this particular topic is the short functional lifetime of buildings compared to the technical lifetime of their concrete load bearing structure. By reusing instead of recycling concrete, a higher level on the waste management hierarchy is reached. This implies an environmental gain since less connections have to be broken within the concrete and less new ones have to be formed to build up the new construction. This fits well into the chain-aimed policies of the government that are partly drawn up to reduce the environmental impact of the building sector. The question that is attempted to be answered within this research is if it is feasible to reuse concrete elements present in buildings, both technically as well as on process level.

At this moment, especially the vacancy rate of office buildings is high which has resulted in a short functional lifetime of those type of buildings. It is first determined that *Component level* is the highest possible level of reuse when the building parts are supposed to be transported after disassembly to be reused in another building. Decomposing a building on a higher building level means less embodied energy gets lost which implies a higher level of sustainability. Hollow core slabs were particularly examined within this research because the connections these elements form with the rest of the construction are easy to break. On top of that, this type of elements is very common in office buildings as well as in residential buildings, of which there is a larger demand at this moment. Therefore, the focus is put on reuse from office buildings to residential buildings.

In order to reuse building elements, the building in which they are present has to be disassembled instead of demolished. These two processes differ from each other on several aspects and both bring along some negative effects. There is less dust production during the disassembling process because fewer connections within the concrete have to be broken and the process can be better controlled because of the different equipment used to break the connections with. Building workers, however, experience several negative effects from disassembling instead of demolishing since more is done manually and they therefore have to be closer to the work. Vibrations and noise nuisance are the biggest problems but also the fact that they stand inside the building during disassembling which brings along more risks.

To decide upon the possible type of reuse, the functional requirements of floors in residential buildings were examined. The fire safety requirements are stricter in high residential buildings than in office buildings of the same height and also the thickness of the concrete topping should be taken into account in deciding for what type of building the elements coming out of office buildings are suitable. The sound insulation requirements for floors are equal for office buildings and single-family dwellings but higher for apartment buildings. To realize a sufficient level of sound insulation with floors coming from office buildings, extra mass or a floating floor is needed on top of the second hand slabs. Block-outs and finishing of the slabs are also important. The amount of extra work needed to adapt the slabs partly determines the success of reuse.

To be able to determine the rate of success of reusing HCS from office buildings to residential buildings, a case study was performed. A standard office building (the PWC in Rotterdam) with several types of hollow core slabs was chosen. An investigation was made of all HCS present in this building and also in two other reference buildings: a single-family dwelling and an apartment building. With these data the possible percentage of reuse was determined. The disassembling process of the PWC was worked out with information of two projects executed in the past that were also disassembled and by making a visualization. Not a lot of research was done after the reassembling process since this is assumed to be the same as with new slabs. The only restriction of second hand slabs is that the cores are not all empty anymore and it is therefore not always possible to make new connections with the wall elements. The common construction type of residential buildings in which the floor slabs are put between wall elements is suitable for the second hand slabs.

To determine the difference in environmental impact between newly fabricated slabs and second hand slabs, an LCA study was performed with the earlier mentioned reference buildings. Within this LCA the disassembling process and demolition process were compared on basis of Carbon Footprint and Human Toxicity. Transport distances were varied to get insight in their impact on the whole process. With the data obtained in this part of the study, the Carbon Footprint of reusing the slabs as opposed to using newly fabricated slabs was mapped out. With the shadow prices of the NIBE a total shadow price per variant was determined by taking all environmental aspects present in the EcoInvent database of SimaPro into account. The results of the LCA study are very positive towards reuse of hollow core slabs.

Another aspect that is of importance of the feasibility of reuse of HCS are the costs. The costs of second hand slabs and new slabs were therefore also calculated within the case study. For the second hand slabs, the process of disassembling, transport, storage and preparation for reuse were taken into account. For the used HCS that were placed in an apartment building, the costs of the necessary floating floor were also calculated. With the assumption made, applying second hand slabs in a floor costs about 20% more than using newly fabricated slabs.

Demonstrating the feasibility of a concept does not necessarily mean it will be implemented in the building industry. One or more companies within the sector have to take the initiative to start up the process. In order to decide who should do this and how, several scenarios were sketched within the report. When the costs of second hand slabs are higher than of new slabs the government should use their means to level out the difference.

It can be concluded that reuse is very favourable for the environment. It is however slightly more expensive because of the disassembling process which also costs more time. The negative aspects that the building workers within this process encounter can also not be neglected.

The environmental gain that can be achieved is highly valued and it is therefore recommended to continue with this research. By optimizing the whole process, the costs can be brought down and by developing the disassembling process the negative effects for building workers can be minimized.

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1. Introduction

In this chapter, a motivation is given for the choice of the topic and the outline of the research will be presented. For the latter, a problem analysis is given with a problem definition. Consequently the goal of the research is stated and with that the main research question. Finally the scope is presented which frames the boundaries of the research. The used approach to come to this result is also explained.

1.1. Motivation

The functional lifetime of many buildings in the Netherlands is much shorter than the possible technical lifetime of its concrete structure. At this moment, this especially holds for office buildings in which a high vacancy rate can be found. There is still a market for new office buildings that are rented by users who leave an empty office building behind. Structural vacancy brings along all sorts of societal problems such as social and economic decay. Solutions to cope with these problems are transformation, redevelopment or demolition. In case the location of a building is not suitable for other functions and redevelopment is not an option either, the building should favourably be demolished. At his moment the amount of empty office buildings has even driven the government, investors and builders to come up with a plan to tackle this problem. This is stated in an article published on 27 July 2012 on the NOS website. Part of this plan is to grant a subsidy for the demolition of vacant buildings. (NOS, 2012)



Figure 1-1: Demolition of a building with concrete structure

The current method of demolishing is to nibble down the concrete load bearing structure until only a pile of concrete rubble is left. Consequently this concrete is recycled. The idea was born to do research after increasing the lifetime of concrete structural elements of buildings by reusing them in new buildings instead of down-grading them for recycling.

1.2. Problem analysis

A large part of the yearly consumed energy in the Netherlands and in the rest of the world is consumed in the building industry. Apart from the use of electricity during the lifespan of the buildings, a large part is used during the construction of the buildings, the manufacturing of the building materials and elements and the transport of both. Only a small part of the construction materials is being reused whereas at least 90% is being recycled. Recycling is better than taking the old construction of a building to a landfill, but the materials are most of the times downgraded, which means the quality of the materials goes down.

On top of the energy it costs to fabricate construction elements, it also has a negative influence on the environment in terms of the exhaustion of raw materials and the damage to the environment in areas where these raw materials are extracted from nature. For that reason, the government has already set restrictions on the extraction of some raw materials, such as marl.

Current construction methods only use a small percentage of the durability potential of building materials. This percentage tends to decrease even more since there is a new trend of shortening the lifetime of buildings due to the faster changes in their functional demands. Because of these ever changing demands in the building industry, there is a disproportion between the use and the technical lifecycle of building materials.

Although many components of a building are already separately demounted during the deconstruction of a building, this does not count for concrete elements. They are usually not designed to be demounted and will not stay intact during demolition. In the first phase of the demolition process, reusable components and parts other than the concrete skeleton are stripped from the building and transported to a sorting plant. Finally, the brickwork and concrete are cut up and taken to a crushing plant where it is downgraded to granules.

Recycling is thus based on decomposed crushed material instead of decomposition and integration at a higher level. This short service lifetime compared to the potentially long technical lifetime of concrete elements contributes to:

- More demand for energy
- A larger waste stream
- Exhaustion of raw materials
- Damage to the environment

This leads to the following problem definition:

“Instead of fully using the technical lifetime of concrete elements in buildings, the concrete elements are downgraded at the moment the building is at the end of its functional lifetime. This leads to a sub-optimum application of resources of raw material and energy.”

1.3. Objectives

1.3.1. Main research goal

The problem definition is aimed at the limited functional lifetime of buildings in which prefabricated concrete elements take care of distributing the applied loads to the foundation. There are several ways to expand the lifetime of a building, but in this research the focus lies on expanding the lifetime of the elements. The main goal of the research is therefore as follows:

“To develop a feasible concept at a high level for the reuse of concrete elements present in existing buildings, both technically as well as on process level.”

1.3.2. Main research question

To reach this goal, research questions are developed. The main research question is derived from the main goal.

“Is reusing prefabricated concrete elements from buildings to be demolished buildings in new buildings feasible and attractive on a technical, sustainable, logistic and financial level?”

1.3.3. Sub research questions

To come to the answer of the main research question, sub questions are formulated. These sub questions are categorized in three parts; the three stages of the research process. Those stages are set out in the research methodology.

Literature study

1. What is the current status of the reuse of concrete in general and of elements specifically and why?
2. What are the regulations of the government and the building industry on sustainability and reuse in the building sector?
3. What demolition methods are available and how do they influence the reuse?
4. What methods are available to determine the as-built-properties and the current quality of existing concrete elements?
5. What buildings are currently at the end of their service life and consist of elements suitable for reuse?
6. What elements are most suitable for reuse and what is the most favorable type of reuse?

Technical study

7. What are the negative and positive aspects of disassembling a building compared to demolishing a building?
8. How should the old elements be adapted to be able to be reused?

9. What are the characteristics of the building structure of the building used as case study?
10. Which of the existing demolition techniques can be used to separately take out concrete elements?
11. In what type of new building should the concrete elements from the case study building be applied?

Feasibility study

12. What percentage of the concrete elements could be reused?
13. What percentage of a new building can be constructed with old elements?
14. What is the environmental gain of reusing old elements?
15. What are the costs of second hand concrete elements compared to new elements?
16. Which concept (using new elements or reusing old elements) is most favourable when taking all criteria into account?
17. What is needed to put the concept of reuse of hollow core slabs in the market?

1.4. Scope

At the beginning of the research, it was not yet known what type of prefab concrete elements would be most suitable for reuse. During the literature study it became clear that hollow core slabs (HCS) are the most obvious choice for reuse. The rest of the research is concentrated on the reuse of this type of elements. Possibilities of reuse of other structural concrete parts are left out of the rest of the research. Furthermore, it was decided after the literature study to focus on the reuse of HCS from office buildings into residential buildings. Other possible functions in which HCS could be reused are left out of the research.

Within this research the aim lies on the current supply of building elements present in constructions. It is examined how the elements in these buildings can best be reused but does not contain a design for disassembly in future projects.

Within this study, many aspects of the whole process are taken into account. These aspects are discussed on quantitative level when data are available or on qualitative level when information is obtained in another form. By outlining the advantages and disadvantages a good vision is formed about all different facets. Combining them to one score to compare current methods with the new concept is not the aim. The goal is to demonstrate the feasibility of the new concept and indicate its restrictions and points of improvement. Therefore, the final conclusion has a qualitative character.

1.5. Research methodology

1.5.1. Process

The research is built up out of three main parts, namely:

1. Literature study
2. Technical study
3. Feasibility study

During phase 1, the literature study is executed to map out the current situation. Although it is called a literature study, also other means such as interviews are used to find the answers to the questions posed in this phase. The reason to make this literature study more interactive is that not all information can be found in literature. After this phase, there was a decision moment about what type of elements and what type of buildings the focus would be put on during the rest of the research.

Phase 2 consists of a technical study on the implementation of the concept. It first outlines the impact on the demolition process. Consequently, the functional requirements of a residential floor are examined to find out what adaptations are needed on the hollow core slabs coming from an office building. A suitable building for the case study is chosen and the type of floors and connections are mapped out. It is determined what type of equipment is needed to disassemble the building and what type of new connections can be formed when reusing these slabs. It is determined in what type of residential buildings the slabs of the reference project can best be reused. These new buildings are also included in the case study.

With all information obtained in the second phase, a feasibility study is performed. The first part is done with help of the case study and contains analyses and calculations to answer the research questions. Consequently, a market study on scenarios for the realization of the concept is done. This is executed with help of literature and conversations with parties involved in the building process. At the end, the collected data are used to evaluate on certain criteria that determine the total feasibility of the concept.

It should be remarked that throughout the research many assumptions have been made of which some could not be well-grounded. In those cases, information in the textboxes indicate what extra research needs to be done on the specific topics. In the chapter on the evaluation of the case study these textboxes are used to translate the results from the case study into meaningful information for the process in general. For the final chapter on the realization textboxes are used to outline the scenarios that could form an incentive for reusing hollow core slabs.

1.5.2. General approach

The general approach in this research is an interactive one in which many actors were involved. This has three main reasons. First of all, the research deals with an undeveloped concept of which not much is known in literature. Secondly, the subject is rather practically-oriented which calls for the knowledge of people from practice. A third reason to have a lot

of interaction with different participants of the building industry is that most concepts never get implemented in the building cycle because they lack a bridge between theory and practice. To make a new concept work, all parties involved have to see possibilities of making profit out of it. When they see too many bottlenecks, they do not want to invest. Making this concept as a basis for a new movement in the building industry implies listening to the participants and implementing their ideas into the concept.

1.5.3. Structure of the report

The report consists of ten chapters. They chronologically follow the outline as stated in the paragraph on the process.

In figure 1-2 the structure of the report is presented.

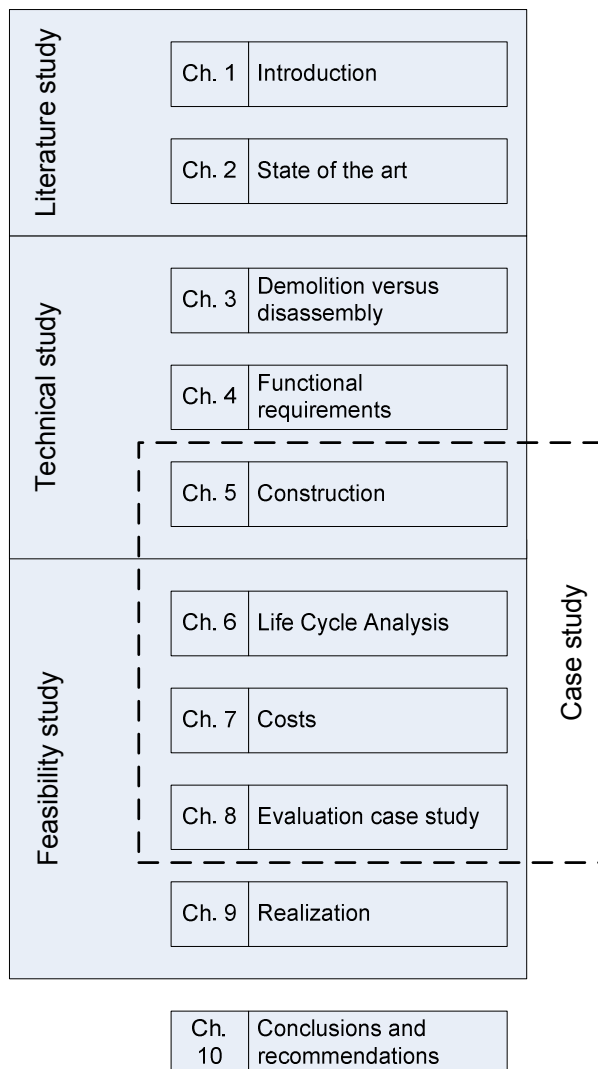


Figure 1-2: Overview of the structure of the report

2. State of the art

This chapter will give an overview of the sustainable objectives in the building industry and the developments of reusing concrete so far. It will also give insight into the possibilities and bottlenecks that can be encountered by carrying out the concept of reuse. Finally, the building level of disassembly is given as well as the type of buildings and elements most suitable for disassembly and reuse.

2.1. Sustainability objectives in the building industry

Within the three decades people have become aware of the impact of the building industry on the environment. This has led to the development of methods to judge the environmental impact of the life cycle of materials and building components. The government has also developed policies to prevent waste and reduce the emissions in the building industry. The sustainable objectives of the government as well as other influential parties will be outlined in this paragraph.

2.1.1. Waste management hierarchy

In 1980 the Dutch government published an order for waste treatment. This order is called the Ladder of Lansink and is fixed top-down approach:

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

This ladder shows the waste management hierarchy with a descending order of priority, wherein the desirable goal is waste prevention. Whenever prevention is not possible anymore, reuse is the next best option.

In 2000, the CIB also developed a waste management hierarchy. This hierarchy is more detailed than the ladder of Lansink since it makes a distinction between reuse and recycling. The highest priority for this method is also reduction because this produces the most beneficial effect for natural systems. Reuse is just below reduction and is

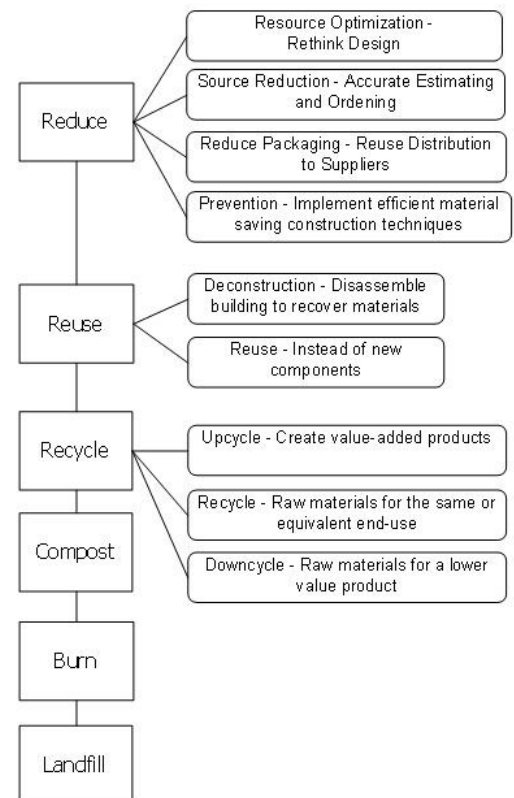


Figure 2-1: Waste Management Hierarchy (source: CIB)

considered to be a higher –level option compared to recycling. This is because reuse presents an opportunity to place recovered building components into direct use without processing. (TG39 CIB, 2000)

2.1.2. Regulations

European Guidelines (Europa Decentraal, 2012)

The national regulations and goals on sustainability in the building sector need to at least meet the European guidelines. The most important European guideline in the area of waste matters is the Framework Directive on Waste (2008/98/EG). This guideline was published in 2008 and was implemented in 2010.

For Non-Risky Build- and Demolition Waste (BDW) this guideline states that by 2020, reuse, recycling and other useful applications of material should be increased to a minimum of 70 per cent volume.

National Regulations (Overheid, 2009)

General goals

Within the national 'Wet Milieubeheer' it is stated that the Minister of VROM (currently: 'Infratructuur en Milieu') is obliged to lay down a Plan for Waste Control at least every 6 years. 'Het Landelijke Afvalbeheerplan 2' (LAP2) is the plan which is valid from 2009 until 2015.

The LAP2 consists of a policy framework as well as sector plans. The policy framework contains the main points of the waste policy whereas the sector plans contain the further details of this policy for specific waste products. For each sector plan, the minimum requirements for handling the waste stream are stated.

In the LAP2, it is stated that for Non-Risky Build and Demolition waste (Brick work and Concrete) the goal of reuse, recycling and other useful applications of material is 95%, which is much higher than the earlier mentioned 70% in the European guideline.

Apart from the quantitative goals, the LAP2 also gives among others the following qualitative goals which apply to BDW:

- The use of an integral chain-aimed approach (ketengericht afvalbeleid) to decrease the environmental impact of waste
- To stimulate the Cradle to Cradle concept
- Specific goals in line with the integral chain-aimed approach:
 - o The CO₂ emissions are in 2020 reduced by 30% compared to the emissions in 1990
 - o In 2020 there will be no danger for human and environment of hazardous materials
 - o In 2020 the loss of biodiversity has stopped

Chain-aimed waste policy

Up to the first LAP, the policy was mainly aimed at the end phase of the material chain; the waste stage. In the last decennia, a lot of progress was made with this policy. We come however, to the limit of possibilities to further decrease the environmental impact by waste through sector waste policies. Yet it is still necessary to further decrease this environmental impact because it is still too high to be able to speak of a sustainable society. We do not yet succeed sufficiently in driving back the exhaustion of energy sources and raw materials.

For those reasons, an approach in the perspective of the whole chain is desirable. With this new chain-aimed concept, there is a search for solutions earlier in the chain. This also contributes to the prevention that the environmental impact will manifest itself in another phase of the material chain. It is concluded that more is needed than an individual sustainable company strategy to realize a sustainable material chain. Cooperation within the chain is the key word which can produce new solutions and can bring about radical innovations.

Chain-aimed policy is more focused on the material side of the environmental policy: sustainable use of material hand in hand with a sustainable energy use. Within the new approach, seven priority industries are determined to apply this method on. These priority streams follow from the total environmental impact of these specific chains, the environmental impact of the waste stage and the costs of treatment of waste. One of the industries selected through above mentioned criteria for the chain approach is the waste policy of Build- and Demolition Waste.

Build- and Demolition Waste

BDW is a waste stream of large volume which exists of several components, such as stony material, plaster and glass. From studies it appears that the total environmental impact of stony materials (the largest component of BDW) is relatively high with an also high waste related environmental impact. Especially the beginning of the chain of stony material has a large negative impact on the environment. The current application of stony material as replacement of gravel compensates the environmental intensive pre-chains not sufficiently. Possible environmental advantage can be booked by looking with more detail at the difference in eminence between process options.

Quantity wise, this part of the chain-aimed program has a directional objective to increase the environmental profit with 20% in 2015. This objective holds for all seven priority streams separately. Along with the chain-aimed waste policy, the 'Meerjarenaafspraken energie-efficiency 2001-2020 (MJA's)' set standards for the decrease of energy use within the next decennia. The execution of the chain approach will at some points be in cooperation with the MJA-program. The general goal of this program is to have companies reach 30% energy-efficiency improvement in the period of 2005-2020. (Overheid, 2008)

As part of Corporate Responsibility the government asks the private enterprise to take on more responsibility for the environmental effects of his activities than he is obliged to by law and regulations.

Landfill taxes

To bring down the amount of waste brought to a landfill, many EU states have introduced landfill taxes. In 2008, the highest rate is found in the Netherlands who charges €88.21 per ton for low density waste and €14.56 per ton for non-combustible high density waste. (Oosterhuis, 2009)

The Netherlands were also one of the first to implement those landfill taxes and with that the country has the lowest dependency on landfill and the highest levels of waste recovery. (Univercity College Dublin, 2010)

The amount of waste sent to a landfill has strongly decreased since the introduction of the waste tax, but is also the result of other measures. The decrease was a continuation of a trend that began in 1995, the year the ban on land filling of recyclable and combustible waste came into operation. (Oosterhuis, 2009)

CIB

The International Council for Research and Innovation in Building and Construction (CIB) is an association established in 1953 with support of the United Nations. Their initial objectives were to stimulate and facilitate international collaboration and information exchange between governmental research institutes in the building and construction sector.

Currently about 500 organizations are member of CIB from whom about 5000 individual experts participate in over 50 CIB Commissions. These extend over the whole area of building and construction research and innovation. It could be said that it is the world's foremost platform for international cooperation and information exchange in the area of building and construction research and innovation. The general aim of CIB is the promotion of sustainable construction and development.

They currently have a committee (W115) Construction Materials Stewardship that published a report about Construction Waste Reduction around the World. The committee was formed in 2006 and built on the work carried out by CIB Task Group 39 (TG 39) that produced a series of five reports which culminated in CIB Publication 300 – Deconstruction and Materials Reuse - an International Overview, which is a state-of-the art report on deconstruction and materials reuse in ten countries. The mission of W115 is to drastically reduce the deployment and consumption of new non-renewable construction materials and to replace them with renewable ones whenever possible. (CIB, 2011)

Their objectives include:

- Develop systems to mitigate and ultimately avoid construction material waste
- Establish strategies to promote whole buildings, components and materials reuse
- Establish methods and strategies to enhance utilization of used construction materials.

2.2. Life cycle of concrete structures

2.2.1. Demolition phase

Most concrete buildings are nowadays constructed with prefabricated elements. The elements are transported from the fabricating plant to the construction site where they are carefully put in place. Wet connections are used to create a rigid construction.

At the end of the life span of those buildings they are usually being demolished. This demolition process takes place in several stages. First of all, reusable components are stripped from the building. These include glass elements, sanitary fixtures, wooden floor finishes and radiators. Consequently, stripping of all materials and components other than the concrete frame is executed and brought to a sorting plant. Part of it will be recycled while the other part is either burned or brought to a land fill in case it concerns non-burnable material. The last part of the demolition process concerns cutting up the concrete structure, which is usually done with breaker shears. The rubble that is left is taken to a crusher plant where it is crushed and the reinforcing steel is removed. At least 90% (2001) of this crushed concrete is recycled and used as secondary material. The majority of these granules are used as road base. A rather small part is used as granules in new concrete. (Durmisevic, 2006)

The article 'Cradle-to-cradle – A concept for the disposal of buildings at the end of their lives?' is one of the most recently released in the field of sustainable construction. It discusses alternative disposal methods of buildings at their end-of-life with respect to opportunities for cost saving and responsibility for reducing environmental burdens. It argues that significant improvements in the quality of disposal waste can be achieved by selective deconstruction. It can also be cost effective.

The concept of deconstruction is explained as the destruction of the material structure without separation of connections. It includes the partial or complete dismantling of a building in its components. It helps the separation of different building materials and contributes to the high quality reuse and recycling of materials. The following figure is presented with the article.

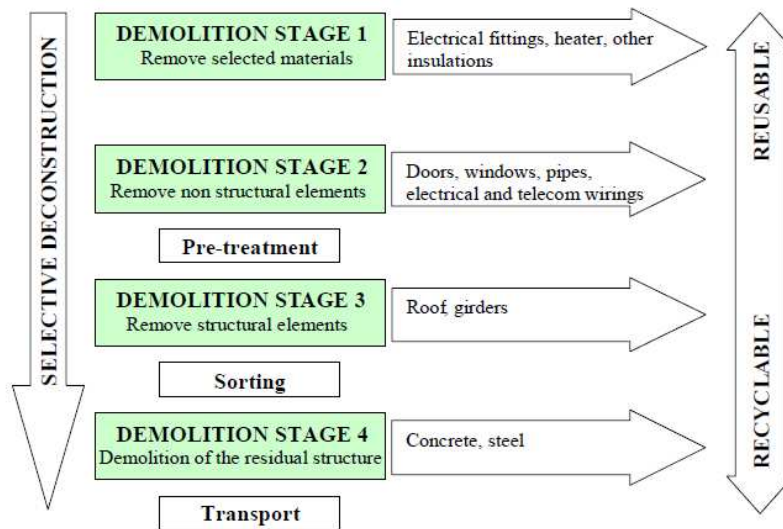


Figure 2-2: Demolition stages for selective deconstruction (Source: Simon et al., 2007)

The first and second stage of the process states the removal of all non-structural materials and elements. They should, according to the scheme, all be reused. When looking at a concrete structure, the structural elements exist for the large majority of concrete. The third stage is therefore not relevant. In stage 4, other than the removal of materials and elements in all other stages, the structure is demolished and will be recycled instead of reused. This shows the lack of total reuse and the arrears of the extent to which the load bearing structure is being reused as compared to the other parts of a building. The question that should be posed is: Why does this concept lack a total closure of the building cycle to fit the cradle-to-cradle principle?

The reason for not applying the method of disassembly instead of demolition is mostly an economic one. Contractors want to bring down the building in the cheapest way possible. A change in their demolition methods and level of recycling and reusing can only be effected when more is known about the profits of the stripped materials. Generally it can be said that demolition is a low technical process, since rapid destruction and disposal of structures are often the main aims of the contractor. (Simon, 2007) Maurice Lamber of demolition company M Heezen confirms that it is only a matter of money. It takes a lot more time to dismantle a building and also more people have to be involved. All the extra time spent on a project costs money and leads to less profit for the contractor.

Apart from the economic argument, it is also the conservativeness of the building industry that holds back the development in the demolition process. Innovations cost money and not many companies in the demolition industry are willing to invest in processes they will probably not gain from until many years later. Only if the government or the society calls for more sustainable processes, the processes are taken a step further towards sustainability.

2.2.2. Recycling phase

As mentioned before, concrete is recycled by making granules that are mostly used in road construction and as replacement of gravel in new concrete. This has some advantages and disadvantages which are outlined in this paragraph.

On the website www.granulaatbeton.nl assistance is given for the replacement of gravel by granules made of used concrete. The website was initiated by five parties of both governmental and private constitutions. The aim is to stimulate the reuse of concrete as granules in new concrete.

As mentioned before, at least 90% of the stony demolition waste is reused. The granules that are produced by crushing the concrete rubble have several applications. They are used as drainage material, ballast for seawalls, paving sand, road foundations and aggregate in concrete. This brings along a couple of advantages over dumping the debris on landfills.

These advantages of recycling are:

- It reduces the use of the primary raw materials that are replaced by the granules
- It prevents large quantities of stony Build and Demolition Waste, i.e. it prevents landfill piles

Regulations concerning the use of granules as replacement for gravel in concrete have become more extensive in the last decade as a result of more knowledge about the quality. 50% replacement of gravel by granules that satisfies the requirements laid down in CUR recommendations 85, does not change the properties of the concrete significantly. The quality stays within the margin of normal concrete and NEN 6720 can be applied. There are also recommendations for adapted calculations which should be applied when a volume percentage of granules of more than 50 in new concrete exist of reused concrete.

Apart from these positive points that can be mentioned about reusing the granules of concrete, there is still a lot to gain. First of all, the type of recycling most used is called down-cycling because the granules do not reach the same quality as the previous concrete they were part of. Only when using the granules as aggregate for new concrete, the new material can achieve nearly the same quality as its previous application. Secondly, crushing used concrete to usable granules costs a lot of energy. And finally, most energy within the process of fabricating concrete is used for the production of cement. By reusing crushed concrete, this cement is still needed for the production of this so-called 'second-hand' concrete. The reinforcement also has to be produced again.

In Switzerland, some life cycle assessments (LCA's) have shown that secondary concrete does not improve environmental impacts (especially for CO₂ emissions) much if at all, so that this incentive drops out for companies ("greener" products/production). The crucial points for CO₂ emissions in concrete production are the type and amount of cement. Furthermore, type and distance of transport have a big influence on environmental performance (CIB, 2011; Kytzia, 2010; Stengel, 2006)

1 m3/2445 kg concrete		Material	CO2 (kg)
		kg	
cement (CEM I)	13%	325	348
Gravel	53%	660	0,93
Sand	27%	1300	2,48
Water	7%	160	0,48
Total		2445	352

1 m3/2445 kg concrete		Material	CO2 (kg)
		kg	
cement (CEM II)	13%	325	243
Gravel	53%	660	0,93
Sand	27%	1300	2,48
Water	7%	160	0,48
Total		2445	247

1 m3/2445 kg concrete		Material	CO2 (kg)
		kg	
cement (CEM III)	13%	325	116
Gravel	53%	660	0,93
Sand	27%	1300	2,48
Water	7%	160	0,48
Total		2445	120

Table 2-1: CO₂ emissions in fabrication of concrete using different types of cements. (Source: Royal HaskoningDHV)

As can be seen in the tables above, using CEM III instead of CEM I can bring down the total CO₂ emissions by $100 - (120/348) \cdot 100 = 66\%$. Even though it depends a lot on the type of cement used, it also shows in the tables that the CO₂ emissions coming from the fabrication of cement accounts for at least $116/120 = 97\%$ of the fabrication of concrete.

2.2.3. Market situation in the Netherlands

In the Netherlands, about 20 million tons of debris becomes available each year of which almost the same amount of recycle granules can be produced. There is a slow shift from only using these granules as foundation material under a road, towards the use as aggregate for concrete.

Studies show that the market for recycled granules as foundation for roads is slightly getting exhausted. The volume of Build - and Demolition Waste (BDW) will however increase within the next two decennia. The amount of stony BDW is estimated at about 30 million tons in 2025. The share of concrete will also increase because of the change in material use in the building industry. About 22 million tons of all BDW will exist of concrete in 2025. This means that either the concrete industry has to start using a large amount to produce new concrete with or another solution has to be found to cope with all this waste.(Granulaat Insite, 2010)

2.3. Level of reuse

This research concentrates on the destination of the concrete structure at the end of the service life of a building. The highest level of the waste management hierarchy, prevention, is not reachable anymore since the concrete structure is already fabricated and built. The second highest level, reuse, is therefore examined. There are several building levels on which a building can be disassembled. The concept of demountable connections is also looked into as well as some reference projects that have reached a high level of reuse.

2.3.1. Building levels

As mentioned, reuse can take place on different levels. Eekhout has developed a pyramid in which these different levels are indicated. Every step higher in the hierarchy means that there has been an increasing value of: labour, energy, material and use of equipment. (Eekhout, 1997)

Durmisevic has also developed a top-down hierarchy of levels on which a building can be disassembled in her dissertation on transformable building structures in 2006. Van Westenbrugge has combined both methods in one figure to compare them.

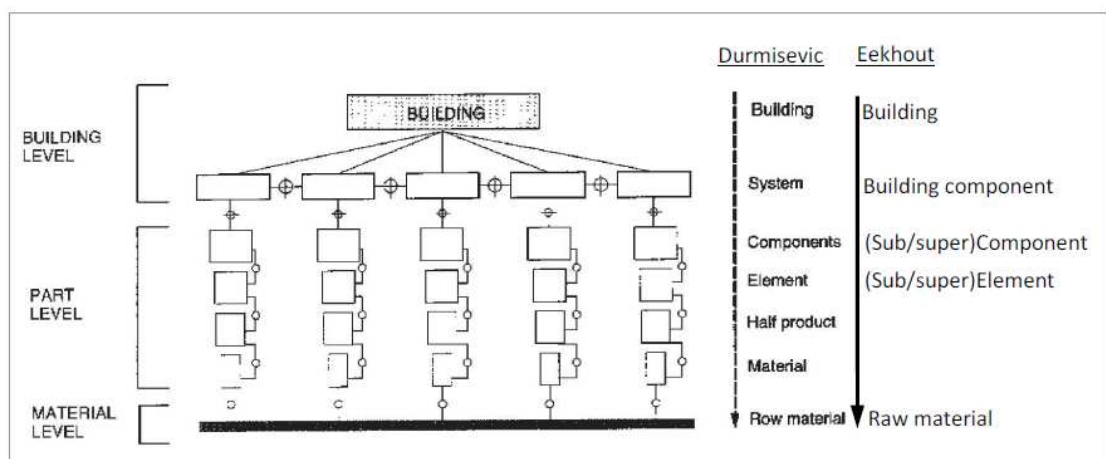


Figure 2-3: Different levels of according to Durmevic (2006) and Eekhout (1997)

The method of Durmisevic will be used for this research since her description of the level of *system* is considered a clearer representation of its content than the term *building component*. Furthermore more steps are defined which makes it easier to assign stages to the building that will be examined in this research.

For this research the reuse possibilities of a building with a concrete structure that is to be demolished will be examined. The construction of such a building can be classified with help of the phases in the top-down hierarchy. On the next page, this classification is shown.

Building: Whole building
 System: Whole floor, core or façade
 Component: Part of the floor, core or façade, such as columns, beams, facade elements and floor elements
 Element: Reinforcement
 Materials: Concrete, steel
 Raw materials: Sand, gravel, cement, water, iron ore, coal

The highest level of reuse is reuse of the whole building. The possibilities of this should always be examined first. How can the building be made attractive again? Renovating or changing its function could be the solution. If there are no opportunities for the location in combination with the structural part of the building, the building should be taken down. When transformation is not possible, the highest level of reuse of the concrete structure should be determined. The higher the level of reuse, the least energy is needed to break the connections and the least energy is needed to form new connections in the building in which the constructive parts are applied.

The different building levels are shown in figure 2-4. The higher the building level, the less embodied energy gets wasted and the least new energy needs to be added to construct a new building. A higher building level also means the level of integration is higher and thus the level of sustainability. As mentioned, when a building is transformed for another function the most embodied energy is kept. When a whole building is decomposed to the level of raw materials, the most energy is required and the most embodied energy gets lost.

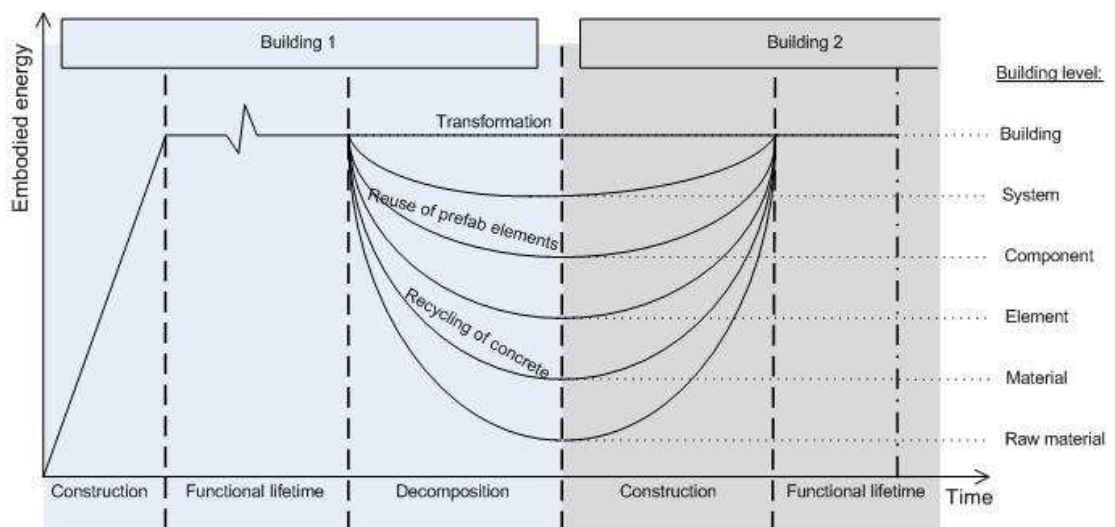


Figure 2-4: Embodied energy of different levels of reuse

A prefab construction is built up on component level. The components (prefab elements) are constructed in the prefab plant and are transported to the building site where they are assembled. The size and weight of the components are partly attuned to the maximum possible transportation and disassembly size. Disassembly is building in the opposite direction. The construction should favourable be disassembled on the level on which it was assembled. A higher level is harder to realize, because of transportation and equipment needed for disassembly. A lower level would not be favourable since this is less sustainable.

It should be noted that the building level to which the building is disassembled is called *component level* but that these components are also called *prefab elements*. This might be confusing, since the two expressions have in this case the same meaning. In the rest of the report the prefab elements are referred to as *elements*.

2.3.2. Demountable connections

The disadvantages of reusing materials instead of reaching a higher level of reuse was already known in 1976, when professor H.W. Reinhardt introduced the idea of Demountable Building in his inaugural speech. He recommended the application of demountable connections within precast concrete systems. (Van Dijk, 2000)

To try to reach a high level of reuse, the idea of demountable connections in precast concrete structures was further developed by the special committee D7 (a division of CUR-VB) that explored the possibilities for research and development of Demountable Building for concrete structures in the Netherlands. The committee was formed in 1986 and developed several types of demountable connections. To reduce the waste production, the Dutch government started promoting further development of the concept of Demountable Building. Governmental contributions were given to projects with precast concrete structures with demountable connections. In 2000, however, demountable building systems only had a market share of 1%. (Van Dijk, 2000)

One of the problems was that buildings designed with a demountable system were not always assembled as demountable. A poor collaboration between precast manufacturer, engineer and building contractor was usually the cause. In some cases the connections were fixed with cement-mortar and were in the end not much different from traditional precast concrete constructions. Of more influence, however, was probably that it is not yet known what will be the lifecycle of a building at the moment it is constructed. It is not known of a building with demountable connections during its construction if the elements can be reused later on. The company that will gain from these demountable connections is probably not the same as who invested money in them during the construction process. It is therefore not very likely that companies are willing to invest in such a concept if so much is still unknown.

2.3.3. Reference projects

Despite the low success booked by the use of demountable connections in precast concrete systems, two precast concrete buildings were successfully disassembled in the Netherlands. They were originally not constructed with the idea to disassemble them later on, but due to circumstances the possibility was examined. After some tests with the connections of the buildings, it turned out that they were not very strong and disassembling was possible.

Middelburg

In 1986, a residential building in Middelburg was levelled down by 7 floors. A large part of the used concrete elements were reused to build new apartments with. This was the first

time in the Netherlands that a concrete building was partly disassembled instead of completely demolished.

To meet the increasing demand for new apartments after the Second World War, construction company 'de Delta' developed the standard system BMB in 1965 for the construction of residential apartments. Many more of such construction systems were developed. In a short period of time (1950-1975) large amounts of them were built. (Van Nunen, 1999) Because of the high density of apartments in not very popular areas in the city, some of these buildings attracted high vacancy rates. This was also the case with the Schotteflat in Middelburg (built with the BMB system) of which the design changed in the last phase before construction started. This caused social problems from the beginning the flat was taken into use. After several failed attempts to attract tenants, it was decided in 1984 to level down the building to 5 storeys and renovate the remaining apartments to increase the level of comfort in the building. Because the elements had to be taken out carefully not to damage the lower construction, they stayed in good condition. This is why it was decided beforehand to reuse the elements that came out of the existing building; 114 new houses were built with those used elements. (Coenen, 1990)

Although the preparation for this project took about two years and the costs were higher because of special equipment and the time that was spent on the project, the project was successfully completed.



Figure 2-5: Residential building that was levelled down in Middelburg. (Source: De Delta)

Maassluis

In 2000, for the second time in the Netherlands, the levelling down of a residential building took place. In Maassluis the same kind of problems occurred with the after-world-war residential buildings built with a standard system, in this case the Elementumflats. Like in Middelburg, they had to make a choice between renovation and new buildings. Renovation was not suitable, which left them with the construction of new buildings. Contractor Panagro

and WSM (Woning Stichting Maassluis) initiated the plan to partly demount the residential flats down to the second floor and reuse the elements that would become available. In the end, they did not reuse the elements because of the following reasons:

- Logistically; the elements could not directly be lifted into a new building since it is difficult to synchronize the demounting of the existing building and the construction of the new building. To solve this problem a place to store the elements is necessary as well as a categorized system to make the reuse possible
- The levelling down turned out to be more difficult than expected
- The expected subsidy of the government for realizing housing with used elements was not granted



Figure 2-6: Residential building that was levelled down in Maassluis (source: Bouwwereld)

2.3.4. Constructions suitable for disassembling and reuse

As said before, the project in Middelburg (1986) of levelling down a residential building and reusing the elements can be seen as successful. It concerned a building built in the period of 1970-1972 with the construction system BMB (Baksteen Montage Bouw) which consists of large prefabricated concrete elements. (Köhne, 1986) The system is suitable for disassembly because of the size of the elements and the type of joints. The elements are attached to each other by poured concrete joints of which the quality is generally poor. This resulted in little bonding between the joints and the elements and makes it easy to take out the elements without damaging them too much. (Van Nunen, 2000) Onderdijk, project manager of the project, confirms in an interview that the project mainly succeeded because the joints gave away quite easily.

During a demolition project of a so-called 'Elementum flat' (also one of the assembly construction systems built after the Second World War) in Vlaardingen in 1999, it turned out that the elements could be taken out of the construction fairly easily without damaging the elements too much. (Van Nunen, 1999)

In 2000, the second levelling down project took place in the Netherlands. This time it concerned an Elementum flat in Maassluis. With the knowledge acquired a year ago in Vlaardingen, they knew it was possible to take out complete concrete elements. During the

disassembly of the construction there were however more difficulties than expected, because of which they abandoned the plan to reuse the elements in a new construction. (Luiken, 2000) The project booked some environmental profit and was cost neutral, so could be seen as practical experience to build on in the knowledge to reuse concrete elements (Bouwhelp Groep B.V. Eindhoven, 2001)

As a result of the high vacancy rate of the assembly construction system buildings together with the environmental aspects of demolishing them, Haico van Nunen and Ralph Luiken devoted their master theses on the subject a decade ago. They looked into disassembly and reuse of prefabricated concrete elements of this type of buildings and both drew positive conclusions about the disassembly and reuse of assembly construction system buildings built after the Second World War.

Ralph Luiken concludes in his thesis that only assembly construction systems are suitable for disassembly and reuse, because the large prefab elements are only attached at the joints. The smaller unreinforced concrete blocks used in the stacking systems are less suitable for disassembly, because they get damaged more easily. It is also too labour-intensive to disassemble all the small elements. The disassembling of poured systems and traditional constructions costs a lot of energy because of their monolith character which makes it too costly. (Luiken, 2001)



Figure 2-8: In-situ poured concrete system



Figure 2-7: Assembly construction system



Figure 2-9: Stacking construction system

It can be concluded that constructions with large prefab concrete elements are most suitable for disassembly and reuse. To what extent it is possible to disassemble the construction on element level, depends on the way it has been constructed. (Luiken, 2000). Important are also the possibilities of adaptation on the desired technical performance (constructive, nuisance resistance, capacity to host wires) and the possibilities of demolition. The current quality of the elements and technical properties also determine if reuse is a good option. (Bouw hulp Groep B.V. Eindhoven, 2001)

2.4. Developments in the disassembling process

The reference projects in Middelburg and Maassluis and the master theses of Van Nunen and Luiken can be used to map out the developments so far. This combined with the information acquired in the different interviews held can be the starting point for further research.

2.4.1. Demolition process

Disassembling a building is the same as constructing a building, but in the opposite direction. This means that it starts from the top and ends with the first level. Before the constructive elements are disassembled, all other parts should be removed. For the residential building in Middelburg, this was also the case. First the interior of the apartments and the light separation walls were taken out. Consequently, all other non-constructive parts were removed. This concerned parapets, windows, store-rooms and such. (Van Nunen, 1999)

Demolition methods

It depends on the type of construction what demolition techniques are most suitable. For the two reference projects the used techniques are represented in table 1.

	Middelburg	Maassluis
Stability construction	Shores	Shores
Detaching reinforcement joints	Diamond saw	Diamond saw
Detaching concrete joints	Electromechanical jackhammer	Pneumatic hammer
Lifting floors	- Hoisting jacks - Mobile crane with spreader beam and floor slab fork	Mobile crane with hoisting cables
Lifting walls	Mobile crane with hoisting cables	Mobile crane with hoisting cables

Table 2-2: Demolition techniques used in reference projects

Ralph Luiken made an investigation of all demolition techniques for disassembling concrete structures. His conclusions are:

- The diamond saw is very suitable for dismantling a concrete structure. The technique is accurate and can take an element out of the construction without many damages. Of the techniques which can compete with the diamond saw, the diamond saw is the most economical alternative. The only disadvantage is the production of noise. If the level of nuisance is unacceptable, the most economical alternative is probably the diamond cable saw.

- The jackhammer and chipping hammer are most appropriate for breaking unreinforced or slightly reinforced concrete. Disadvantages are high nuisance and dust production, but because of their low costs they are still favourable
- For buildings up to 5 to 6 floors, mobile cranes with telescope - or framework lever are most suitable. For higher buildings, tower cranes are the best alternative



Figure 2-9: Diamond saw



Figure 2-10: Pneumatic hammers project Middelburg

The choice of disassembling equipment depends on costs, speed and possible damage of the elements. (Luiken, 2000) Also the production of nuisance and dust is of influence on the choice of equipment. Since this could do harm to people nearby and could be annoying for people living or working close to the project, it should be restricted to a minimum.

During the project in Middelburg, it were especially the pneumatic Kangoo hammers that caused much nuisance. The noise production was higher than with a traditional demolition process. There was also no workman's shelter, so the executers of the project were constantly exposed to a lot of noise. The project even cost Onderdijk his sense of hearing on one side. (Onderdijk, 2012)

Maurice Lamber of demolition company M Heezen states that the disassembling techniques used in Middelburg and Maassluis are not different from the ones that would currently be used for such projects. There is a little more noise production using a diamond saw and a pneumatic hammer than there is with techniques used for the traditional demolition process. The dust that is produced can be minimized with water, which is also used in traditional techniques. The biggest problem with disassembling instead of flattening a building is the extra time it costs (Lamber, 2012)

More research needs to be done after techniques to disassemble a building. It is difficult to determine methods only on basis of literature. There is not much experience yet in this field but with help of pilot projects, this experience can be obtained. By disassembling a building in practice, ideas could more easily be developed about most suitable equipment and solutions for problems that occur can be found faster.

Points of particular interest

Safety

A very important issue during the disassembling process is the safety. The biggest problem is the size and weight of the elements. The stability of the construction is guaranteed by the coherence of the whole construction. When parts are taken out, this stability is no longer guaranteed and the construction needs to be shored. This combined with the vibrations caused by the execution works, especially because of the use of pneumatic hammers, leads to movements at the supports of the floors. Since the dimensions of these supports were very little, the work had to be stopped for a while during the execution of the project in Maassluis. (Bouwhulp Groep B.V. Eindhoven, 2001)

In Middelburg, also a lot of attention was paid to the safety and the stability during the dismantling process. A series of requirements were formed by the different parties involved in the project. (Coenen, 1990) "The safety regulations were very strict. Nobody was for example allowed to work beneath the parts that were taken out at that moment. We knew for 98% that the lifting hooks would hold the elements, but there is always a risk. The iron lifting hooks were embedded in the elements for the assembling when the construction was built. They were squashed but could be used again." (Onderdijk, 2012)

During the dismantling of both projects much was still unknown. It was difficult to predict the construction, so a lot of safety requirements were necessary. By carefully considering those requirements, no serious accidents occurred, but the process cost much more time than the traditional demolition process would have.

Maurice Lamber emphasizes that for the surroundings, it is safer to disassemble a building than to demolish it traditionally. Whenever there is a road next to the building for example, it is dangerous to use traditional techniques. For busy urban locations, it could therefore be required to demolish a building by taking out each element separately. Lamber even thinks that in 30 years everybody uses this method to take down a building. Ron van Schaaik, from demolition company Van Dijk, who has more experience with demolishing prefabricated construction, does indeed argue that it can be dangerous to demolish a prefabricated construction with techniques developed for in-situ poured concrete constructions which is why you have to know exactly how the building is constructed. You have to demolish the building in the opposite way. With a shear breaker you can demolish a prefabricated construction in a safe enough way. This does not have to be less safe than if you would disassemble the same building. This depends on the people, the machines and other factors.

Lifting out the elements

To decide upon the equipment used for lifting out the elements, the still present embedded anchors, lifting hooks and screw dowels need to be detected. It should be judged if they could be used again, because this could simplify the dismantling. If reuse is not possible, for example as a result of corrosion, there are several different techniques to attach elements to the lifting equipment. (Luiken, 2000)

For wall elements, it is possible that the present lifting hooks can be reused. This was the case in Middelburg. The elements were still of very good quality and so were the lifting hooks: "There was no rust visible; the grease was still ready for reuse in the screw dowels." (J. van de Woestijne, 1986) In Maassluis they did not reuse the still present anchor bolts, but made new holes for the chains of the hoisting crane.

For floor elements it is unlikely that present lifting hooks can be reused. Normally, a finishing floor is poured over the prefab elements, which makes it impossible to reuse them. This was the case in Middelburg as well as in Maassluis. In Middelburg, a floor slab fork was used to take out the floor elements. In Maassluis, four holes were cut in each hollow core slab to be able to attach the chains of the crane to take out the elements. (Luiken, 2000)

If the lifting hooks cannot be used again, there are a few other possibilities. (Luiken, 2000)

- Hoist chains, - cables and – bands can be used when new holes are made in the elements or to tie around the elements
- Bucket for hollow core slabs. If joints between the elements are cleared, these buckets can grip the slabs on the sides and lift them out of the construction.
- Floor slab forks. This fork is slid under the floor element until it passes the centre of gravity of the slab. Consequently it can be lifted out of the construction.

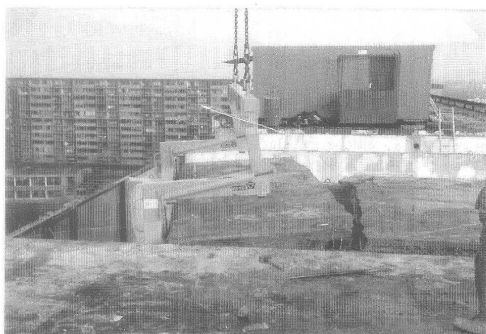


Figure 2-10: Floor slab fork project Middelburg



Figure 2-11: Bucket to clasp the hollow core slabs (source: BFBN)

According to Van Nunen, reuse of lifting hooks is not possible, because they are either folded over, sawed off or deformed. Van Nunen mentions some other possibilities to tackle this problem:

- Bore holes and attach a sling through the holes to attach the elements to the hoisting crane. Disadvantage: it takes time.
- Embed new lifting anchors in the elements. This also takes time, because the newly poured concrete needs time to dry.
- The easiest way is to take out the elements without any additional action. This can for example be done by using 'block shears' (in Dutch: blokschaar). These are available in different dimensions and tonnages. By using block shears, time can be spared in the dismantling phase but also in the reconstruction phase.

The choice of type of lifting equipment depends again on costs, speed and possible damage of the elements.

According to Lamber, embedding new lifting hooks in the elements to lift them out of the construction is technically too complicated. Boring holes to attach the teagle would be a more logical solution. There are special hooks that could be pulled through these holes. The best way to lift out the elements is probably to use the existing pin in the reinforcement that was used to assemble the construction. You can screw hooks in these pins and attach the lifting equipment to it. This is also possible for the floor slabs. If concrete is poured over the slabs, you can cut this out around the pins. You can also bore new holes but this will weaken your structural elements. Without holes it is difficult because the elements lie next to each other so there is no space to put the lifting equipment around the elements.

Changes made during the construction process

Problems during demolition works of the Elementum flat in Maassluis were partly caused by changes made during construction, which could not be found in the drawings. It is plausible that this problem occurs more often. Drawings give an indication of the situation, but it could not be said with certainty what could be expected of the construction. It is therefore difficult to give a systematic approach for levelling down a building. (Bouwhulp Groep B.V. Eindhoven, 2001)

Normally, a building is built according to its drawings. There is a chance, however, that contractors have changed the design at the last moment. Usually, revision drawings are made which indicate the final construction of the building. (Sterken, 2012) Nevertheless, there is a small chance that things are not well documented and that surprises may occur during the demolition process of the building, such as what happened during the levelling down of the residential building in Maassluis (Luiken, 2000) but also in Leeuwarden with the so-called Antillenflat where a balcony slab came down unexpectedly. The latter was an in-situ poured concrete building instead of prefab, but this does not exclude the possibility of anything like this happening with a prefab concrete structure. (Adema, 2012)

2.4.2. Reassembly

Reassembly highly depends on the type of elements that are reused. In Middelburg, the used elements were connected in the same way they were the first time. The only difference was that the reinforcement was sawn off. To compensate this, tie-bars were placed between the elements before concrete was poured to connect them again.

Nunen argues in favour of making the new connections demountable. Disadvantages of the current method of assembling elements are that it takes a lot of time for the concrete to dry and it is more difficult to disassemble the construction again.

The possibility to disassemble the construction again after reuse of elements is indeed a good starting point for the new construction. The reference projects have shown, however, that it is not necessary to use dry connections to be able to disassemble the construction. On top of that, the elements that are to be reused should be adapted the least possible to keep the costs low. The new building should therefore in the first place be easy to construct. The differences between second hand slabs and new slabs should be taken into account in choosing a suitable construction system.

2.4.3. Logistics

For the project in Middelburg, a code-system was developed from which one could derive the floor level and the apartment of the element. This made it possible to place the elements in the right order in the new construction. The elements that were taken out of the building were directly transported to a field nearby the location of the new building. More than 900 elements came out of the construction with a weight of 2500 up to 5000 kg each. (Coenen, 1990)

In Maassluis, they had also planned to reuse the elements that were taken out of the construction. Difficulties with the logistics was one of the reasons why they finally decided to reject this idea. (Luiken, 2000)

Van Nunen has set apart the different aspects that should be considered during the process from old building to new building. These aspects are:

- Transport
- Storage
- Sale
- Processing

These several aspects were worked out on a very basic level. He makes suggestions and gives his opinion, but not a lot of research is done.

According to René Sterken, head of construction and building methodology of BAM Utiliteitsbouw, elements that are taken out of a building should be stored and registered in a database. The best situation would be if you could call the 'second hand prefab elements supplier' to ask if a particular type of element is in store. If the elements meet the demands but have a different dimension, they could be sawn to size. The concept will not work if the elements are still in the old building when ordering them. The risk is too high that they could not be delivered in time. The most important condition is that it is uncomplicated and easily accessible. A disadvantage of this system is that there is a loss of interest when the elements lay in storage for a long time.

2.4.4. Changes in regulations

Office buildings constructed with prefab concrete elements are generally not constructed before 1980. The 'VB 1974/1984' is therefore the oldest norm that needs to be compared with the newest Eurocode to check the differences in regulations (for the same applications).

For the computable value of the load on floors, not a lot has changed over the years. The value for the live load of office buildings is between 2,5 kN/m² and 4 kN/m² and for residential buildings between 1,75 kN/m² and 2,5 kN/m². (NEN 6702:2007) This means that if you use the elements that come out of an office building for residential buildings, it should be ok. From office to office is probably also allowed. If the regulations have gone up, the span can be decreased in the new construction and the hollow core slabs can be sawn to size.

(Sterken, 2012) Another possibility to increase the load capacity of a hollow core slab is to glue strokes of carbon fibre to the bottom side of the slab. This is much easier than to add a net of reinforcement and spray extra concrete on the slab. (Adema, 2012) This solution, however, is too expensive and not sustainable. When the capacity of the slab is not sufficient either, it is best to buy another element.

What did change in the regulations is the concrete covering. In the VB 1974/1984 this was 15 cm for a concrete element placed in a dry environment. (Nederlandse Normalisatie Instituut, 1984) In the new regulations this is 30 cm. If the elements with a concrete covering of 15 cm are still of good quality after 25 years, it is not very likely that the quality is not sufficient for the next 25 years. The question is, however, what the regulations say about reusing old elements that do not meet the requirements of the new regulations. At this moment, the regulations do not say anything about this yet. (Sterken, 2012)

To make reuse of concrete elements possible, norms should be drawn up in the current Eurocodes. By following the regulations on constructing with reused elements, engineers can secure the required quality to the client.

2.4.5. Environmental gain

Van Nunen concludes in 1999 that a big environmental gain can be achieved by building with used materials as compared to the current construction methods. The LCA he made for his design shows that reusing the elements ones gives a gain of 35% per cent and reusing the elements twice shows a gain of 55% (CO₂). For this calculation the construction of the whole building was taken into account.

Luiken concludes in 2000 that the incentive for reusing elements is the environmental gain, but that this is only a small part of the cycle. The other phases of the lifecycle of a building also have to be looked into, such as applying energy efficient techniques, separating waste, use of less damaging materials etc. He also states that the environmental burden of a building is for 90% caused by the energy used during the use of the building and that the new building should be more energy efficient than the building of which the elements are reused. The whole cycle of course needs to be looked into, just like with any other building that is being built. The reused elements should not cause a higher energy use than when the building is built with new elements, but the gain of the reuse of the elements viewed apart can already be seen as a large progress.

2.5. Determining the properties of the used concrete elements

For contractors and all other parties that are involved in the reuse of prefab elements, it is important that the properties of the elements are known. As said before, it is possible that changes are made during the construction process that are not well documented. The quality usually does not go down during the use of a building, since the elements are not in an outside environment and are therefore not vulnerable to rust. (Adema, 2012) Koppenhol and Feenstra both agree that concrete slabs do not lose their strength over the years. The load

bearing capacity can only have gone down when the construction have been overloaded. In this case, cracks are visible. (Koppenhol, 2012) Holcon, manufacturer of concrete products, states in a presentation given in 2010 that "Prefab concrete lasts at least 200 years and we only use is 15 to 30 years on average. This can be improved. With demountable and standardized elements." (Bartels, 2010)

To make sure the properties of the elements are known, 'As-Built Documentation' should be drawn up at the end of the construction phase. This enables everyone to recall the properties of the structure in case another destination is found than was originally planned. This comes in handy in case of renovations, assigning a new function to a building or part of a building or in case the elements are reused such as in this research.

The As-Built-Documentation' shall be a reliable representation of the project as actually constructed. It shall include the results of the initial inspection of the completed work/project. An extract of the 'As-Built-Documentation', named Birth Certificate Document (BCD), will include the results of the initial inspection of a new structure. The content of the BCD is usually limited to the documentation of the direct input parameters for the future condition control of the structure, such as cover thickness to the reinforcement, diffusion coefficient for the concrete cover, etc. (fib, 2012)

The BCD (Birth Certificate Document) would provide a record of at least the following: (fib, 2012)

- verification of the as-built condition of the structure and a record of the standard of execution/variability achieved during construction;
- a known Benchmark for reference on service life design matters'
- initial data as required for the verification of the limit states (in particular limit states associated with durability)

Such documentation is not yet present for existing buildings. Suppliers of prefab concrete elements have documentation of the last 10 years of their delivered products. This documentation could also exist for older buildings, but suppliers are not obliged to keep those data in their database (Koppenhol, 2012). Owners of buildings or the municipality could also have documentation. As mentioned before, it is however not certain that everything is well documented. In this case, tests can be performed on the elements to determine their properties.

To determine the properties of a series of used prefab concrete elements, both destructive as well as non-destructive research should be performed. Destructive research is necessary to be able to accurately determine the quality of the concrete. The quality of the reinforcement also has to be determined with a destructive method. These methods need to be applied on a certain number of elements conform ISO 2859. With the knowledge of the properties of the fully tested elements, the properties of the rest of the elements can be determined non-destructively. Apart from the steel quality, the quantity and position of the reinforcement also needs to be determined. (Adema, 2012)

Information about the testing methods can be found in the appendix B.

2.6. Type of buildings and elements suitable for reuse

To determine what elements are most suitable for reuse it should first be examined from what type of buildings the elements come. At this moment, there is a high structural vacancy in the office market. With the ever increasing population there is still a need for residential buildings. It is therefore decided to aim this research concerning disassembling at the office market. After mapping out the type of office buildings that have the highest vacancy rates, the construction of this type of office buildings is examined. Consequently the concrete elements present in these office buildings are looked at.

The decision is made to focus on reusing the building structure of office buildings. This has to do with the current market and availability of second hand construction parts in these buildings. No research is however done after the availability of concrete in other types of buildings, such as parking garages, or in other sectors of the construction market, such as infrastructure. These types of constructions can also be examined to determine if their building structure allows for reuse.

2.6.1. Vacancy of office buildings

As a result of the economic growth in the Netherlands at the end of last century, many developers built new offices to answer the large demand in the office market. Most office buildings were built without having a buyer yet, in the persuasion that with the good economic situation, the buildings would be sold in no time.

In 2002 and 2003, however, the economic growth stagnated with a high vacancy rate as result. Even when the economy attracts again in 2005, the vacancy rate stayed high. Developers continued to develop offices because the requirements of the users changed more rapidly than in the past days. New offices were taken into use while the overcapacity of older office buildings grew. On top of that, more efficient use of space resulted in less demand. In 2008, the financial crisis hit the market even harder, with a disproportionate vacancy as result. (Zuidema, 2010)

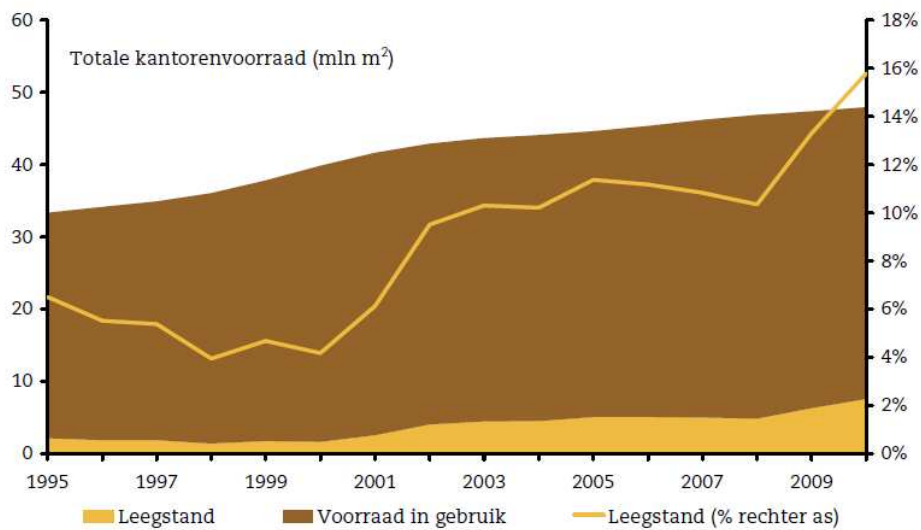


Figure 2-12: Office buildings in stock (Source: Bak, EIB)

In 2011, this vacancy rate has even reached a percentage of 16. Of the 48 million m² total supply of office space, 7.6 million m² is currently vacant. (DZT, 2012) The prospect is that, with no change in governmental policies, this vacancy rate will not significantly be decreased by 2020. (Zuidema, 2010)

Two causes for an even higher vacancy rate coming years is the proportional rise in the ageing population and decreasing amount of square meters necessary per employee because of 'Het Nieuwe Werken' which implies the indecency of location and time in the execution of work related activities. Another cause of this structural vacancy is that the ICT changes rapidly, what results in other demands for offices. (Sterken, 2012)

Normally, office buildings are rented for a period of 10 years. This is usually extended to 20 years and sometimes to 30 years, but that is about the maximum. The average economical life span of an office building is therefore about 25 years. Public Private Partnerships including maintenance and finance are also calculated over a period of 25 years. (Sterken, 2012)

Structural vacancy brings along all sorts of societal problems such as social and economic decay. Vacant buildings are target of vandalism and graffiti, break-ins and illegal occupancy. This results in unsafe areas and less attractive parts in the city. For an investor, a vacant building means less income and indirectly has a negative influence on the investors market as a whole. Solutions to cope with these problems are transformation of office buildings in residential buildings, renovation and upgrading, consolidation, redevelopment or demolition.

Not all vacant office buildings are suitable for either transformation, renovation, consolidation or redevelopment. This is mainly caused by their location. Among the problematic locations are the office - and industrial parks from the 1980s, situated along a highway or a ring road and not well accessible by public transport. (Remøy, 2012)

In the Real Estate Vision Report 2012, DTZ Zadelhoff argues that the supply of office space has to go down. It categorizes the total vacant space in office buildings into three categories,

i.e. favourable (in Dutch: kansrijk), optional (in Dutch: kanshebbend) and structural (in Dutch: kansarm). 18% of the vacant supply is favourable, which means it will probably be rented in the near future. 54% has potential to be rented as office building in the future. 28% is designated as structural and is already empty for at least 3 years. This last group concerns 1.9 million m². If nothing is done with these buildings, it is not likely that they will be rented in the future.

Some general characteristics of these vacant buildings:

- No or minimal distinguishing characteristics
- Are designed with a standard grid
- Mono functional location
- Many offices from construction period 1980-1999
- Large volumes
- Decrease in rent prices does not lead to more renters

Nederlandse kantorenmarkt

Aanbod naar bouwperiode per januari 2010

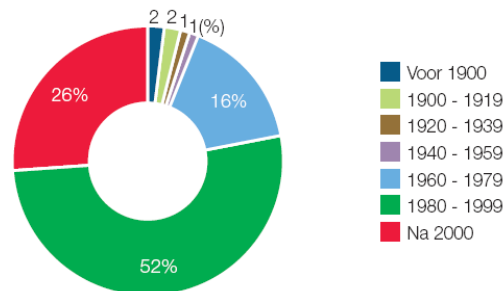


Figure 2-13: Vacancy per year of construction (Source: DTZ Zadelhoff)

If we look at the locations of structural vacant buildings, a pattern can be found. Focusing on the 4 largest cities of the Netherlands (Amsterdam, Rotterdam, Den Haag and Utrecht) the structural vacancy can usually not be found in the city centres; the further from the centre, the more structural vacancy. (DZT, 2010) Examples of areas with a large amount of prospectless office buildings: Rivium Capelle ad IJssel, Paasheuvelweggebied Amsterdam Zuidoost, Nieuwegein, Leidschendam-Voorburg, Zwolle Oostenk. (DZT, 2012)

The conclusion of the 'Kantorentop', a conference about offices, held on May 25th 2010 was the following: "The large scale of structural vacancy in office buildings in the Netherlands is starting to cause big problems for especially the owners and the government (as director of public space). This has to be tackled by joining forces!" (Dynamis, 2011) As a result of this conference, an action program vacancy offices (Actieprogramma Aanpak Leegstand Kantoren) was drawn up by the Ministry of Traffic and Environment (Schultz van Haegen, 2011) at the beginning of 2011 in which three main goals are stated:

1. Redevelopment, transformation and demolition
2. Measures to increase the functioning of the office market on the long term
3. Better regional environmental planning, programming and tuning

It can be concluded that most parties involved in the office market, including the government, recognize the large vacancy rates in office buildings as a problem that needs to be solved. The government gives as short-term solution to redevelop, transform and demolish office buildings that are currently vacant and have no potential in their current function.

2.6.2. Type of constructions

From in-situ concrete towards prefab concrete

Thirty years ago, almost 100% of all office buildings were built in in-situ concrete. In the eighties this changed rapidly towards buildings constructed with prefab concrete elements. At this moment, almost 100% of all office buildings are built in prefab concrete. Of these prefab concrete structures, almost all are constructed with hollow core slabs and load-bearing façade walls. (Dekkers, 2012)

"Of an increasing number of office buildings, the load bearing structure exists of prefab concrete floors - almost always hollow core slabs – and load bearing walls." (Van Paassen). The hollow core slabs are placed on the ridge of the inner leaf of the cavity wall. When the office building has more than one nave, columns and beams support the hollow core slabs.

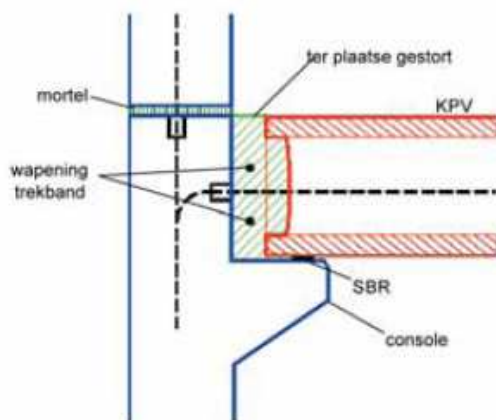


Figure 2-14: Standard connection inner leaf of



Figure 2-15: Hollow core slabs supported by steel THÇ beams (Source: BFBN)

Many buildings that are labelled by DZT as being structural vacant are built in the period of 1980-1999. Since the switch of in-situ to prefab also occurred within this period, it is not clear what the percentage prefab and in-situ is. An estimation is that about 60% of the structural vacant buildings is constructed with prefab concrete elements, because of the earlier mentioned characteristics of this type of buildings. This percentage will increase with time, since currently almost 100% of the office buildings are constructed in prefab concrete.

Components

In the Netherlands, about 200 to 300 million m² hollow core slabs are currently present in constructions. (Hordijk, 2011) For spans up to 8/9 meters, a height of 200 mm is sufficient.

For spans up to 12 meters, a height of 320 is most suitable and for spans up to 16 to 18 meters, the hollow core slab needs to have a height of 400 mm. (Van Paassen)



Figure 2-16: Stock of hollow core slabs in a storage hall (Source: BFBN)

On top of the hollow core slabs in office buildings either a concrete topping or a finishing layer is applied. According to Koppenhol (VBI) and Feenstra (Dycore) a concrete topping is used for about 40% of the surface. This concrete layer with reinforcement is applied to divide the loads and stresses equally and allows for cooperation between the slabs. (Adema, 2012) A concrete topping makes disassembly more difficult. It is best to leave the layer on the hollow core slabs. One probably has to saw through this layer near the joints. The disadvantage is that the layer is not continue anymore, so maybe a layer has to be poured on top of this one. This however increases the load, so maybe the function of the building in which the elements are used needs to change from office to residential. (Sterken, 2012)

If a concrete topping is not required, a sand/cement layer is used to create coherence between the slabs. Lamber argues that the finishing layer probably comes off during disassembly since the coherence between the slabs and this layer is very little.

As stated above, hollow core slabs are very common in office buildings. An advantage of this type of concrete elements is their standard width of 1.2 meters which maximizes their reuse possibilities. Also the fact that little energy is needed to take the elements out of a construction and keep them intact because of the poor bonding between the elements and the joints makes them suitable for reuse.

The other elements that are very often applied in office buildings are concrete load bearing wall elements. These concrete inner leaves of the cavity walls are usually unique per building. Reinforcement varies and also the block-outs for windows. (Dekkers, 2012) The thickness of the walls varies normally between 180 mm tot 220 mm. (Van Paassen) The variation in the wall elements restricts their reuse possibilities. The requirements on floor height that have increased over the years also makes it more difficult to reuse this type of elements. If wall elements are to be reused it is not practical when they are not high enough, since this would imply extra adaptations and thus more costs. The uniqueness would restrict the freedom in design for architects and engineers that want to use second hand wall elements for their design. Only if the height is correct and the architects and engineers are willing to design their building around existing wall elements, this concept could succeed.

Apart from hollow core slabs and load-bearing walls, there are other floor systems and supporting systems possible. As floor systems, the half prefab product precast wide plank flooring is sometimes used. Since a lot of in-situ poured concrete is used for this floor type it is less suitable for reuse. The connections are much stronger than in case of prefab concrete elements and thus more energy is needed to disassemble the building.

When an office building has more than one nave, columns and beams are applied to create supports between the façade walls. Beams used are either made of precast concrete or of steel. The hollow core slab basically never gets constructed in one span when a building exists of more than one nave. (Van Paassen) Columns and beams are also quite unique which makes them difficult to qualify for reuse. The amount of concrete in one building used in columns and beams is also significantly less than the amount of concrete of the floor. This makes it more urgent to develop a process of reusing the floor because more environmental gain per building can be booked by this.

From the decision of focusing on office buildings, their type of building structure leads logically to hollow core slabs as most suitable element for reuse. The possibility of reuse of the other elements is however not excluded. If the building is disassembled for the reuse of HCS, the other elements can also easily be taken out one by one. The next step is to also find a higher level in the waste management hierarchy for these elements. If success of reusing hollow core slabs is proven the possibilities for reuse of the other elements should also be looked into.

2.7. Results

The government has set out guidelines to decrease the environmental burden caused by the building industry. This should be reached by the chain-waste policy together with the 'Meerjarenaafspraken energie-efficiency 2001-2020 (MJA's)' which sets standards for the decrease of energy use within the next decennia. As part of Corporate Responsibility the government asks the private enterprise to take on more responsibility for the environmental effects of his activities than he is obliged to by law and regulations.

The highest possible level of disassembly in case a building is taken down is component level. This is therefore set as target because the least energy has to be used for breaking the existing connections and forming new connections in the new building.

From two reference projects and two master theses it can be concluded that it is technically possible to disassemble constructions of large prefab concrete elements. The methods and equipment used for the projects in Middelburg and Maassluis are probably also most suitable to disassemble a prefab concrete structure nowadays.

For reuse it is important to know the properties of the second hand slabs. If they are not well documented there are several methods to test them. For future buildings a Birth Certificate Document should be drawn up at the end of the construction phase in which all properties of the construction are recorded. The load bearing capacity of concrete does not decrease over time when it is held in a dry environment and the construction is not overloaded. It can be

assumed that prefab concrete elements have a technical life time of at least 200 years and are therefore very suitable for reuse after they have served as floor in a building with a lower life span.

The focus of the rest of the research is on hollow core slabs, because they are very common in office buildings and they are fairly easy to disassemble. HCS are also much applied in residential buildings where the design loads are lower than in office buildings. At this moment, there is a greater demand for residential buildings than for office buildings. It is therefore decided to concentrate on the concept of reusing hollow core slabs taken out of an office building into a residential building.

3. Demolition versus disassembly

Regulations concerning the safety of the surroundings and the prevention of dust-, noise- and vibration nuisance are included in 'Bouwbesluit 2012'. (VERAS, 2012) During demolition works, these aspects play a role and can have negative effects on the health of people. They should therefore be reduced as much as possible. The methods and equipment worked with during the demolition process determine the degree of nuisance. To establish a healthy work environment and few hindrance for the environment, devices can be used that are developed to reduce dust- noise and vibrations. Another option is to choose for a method or technique that in itself is not harmful for building workers and surroundings.

Apart from the noise, vibrations and dust that should be minimized, safety is also an important issue. Because of the change of in-situ concrete towards prefab concrete buildings, more attention needs to be paid to the way the building is demolished. A prefab concrete structure usually has hinged connections and can therefore collapse more easily when an unexpected load is applied on part of the structure.

To be able to make a judgment about what methods are safer and better for the well-being of both building workers as well as the surroundings, a comparison is made between traditional demolition methods and disassembling a construction. It is important to map out the differences to make a better decision on the feasibility of reuse of structural concrete elements.

3.1. Dust

3.1.1. Problem

During the demolition of stone and concrete materials, there is a high production of dust. The dust particles, in which quartz is found, can reach the lungs of people in the surrounding area and can do harm to their health. Quartz, the chemical compound of silicon dioxide (SiO_2) is one of the most presented minerals on earth. It can especially be found in sand and rock and thus in many construction materials such as concrete. (Lumens, 2009) As soon as connections within a material in which quartz can be found are broken, the quartz comes out in the air.

All participants in the field of demolition works are aware of the urge to diminish the amount of dust that building workers are faced with. In the framework of the ArboConvenant (2002 – 2006), which has partly been established on the initiative of the branch itself, an action plan was set up to decrease the dust production during demolition works. (Arbeidsinspectie, 2007) This action plan made at the end of 2007 has to promote and develop demolition devices which decrease the amount of dust that is released during demolition works. (Vereniging van Sloopaannemers & Babex, 2008)

Apart from the building workers on the demolition project, people living or working nearby can also experience inconvenience from dust. Some projects are even stopped for a while because of complaints of people in the neighbourhood. In such cases, project managers have

to take measures to decrease the amount of the dust flying around. Last year, at least two projects in the Netherlands had to be interrupted because of the production of dust, namely in Rijnsoude and in Enschede.

The municipality of Rijnsoude has stopped the demolition of the 'Veevoederfabriek' in April 2011 because people in the surroundings had justifiably complained about the amount of dust that was produced during the demolition. It has led to health problems and inconveniences under several neighbors. (Lokale omroep Rijnsoude, 2011)

A month earlier, the municipality of Enschede had stopped the demolition works on the Ramelebrink on request of the association 'Leefmilieu'. During the demolition works, there was visible dust spreading and the dust even descended in areas outside the building site. It turned out that the demolition company had not taken sufficient measures through for example sprinkling water to reduce the amount of dust. In Enschede, mobile breakers were used to break the concrete. This often happens in the area of dwellings and sometimes schools. Apart from the nuisance, the breakers also cause much unnecessary dust production. (Leefmilieu, 2011)



Figure 3-1: Breakers in Enschede (Source: Leefmilieu)

3.1.2. Comparison between different demolition methods

After society has become aware of the danger of dust, the development of devices made for demolition works that reduce dust spreading started. The first method is to moisturize the objects that are being demolished. The water catches the dust particles which consequently precipitate. The second method is based on an integrated suction device in the demolition equipment that extracts the dust by suction. These techniques are already used in devices such as saws, drills and cutters; equipment that is not only used during demolition processes. Devices that are only used in the demolition branch are not as developed yet, such as the pneumatic hammer. (Arbeidsinspectie, 2007)

During the demolition of prefabricated concrete structures, mostly buckets (in Dutch: grijpers) are used to pulverize the concrete. During this process, a humidifier can be placed next to the project to humidify the construction. Despite this measure that certainly helps, dust cannot be completely prevented. (Van Schaik, 2012)

By disassembling a construction instead of demolishing it, less quartz is released. When using for example a diamond saw there is no dust production, because the sawing is done under

water. Some dust is produced during cutting out the joints between the floor slabs, but this is very little compared to traditional techniques such as buckets. The pneumatic hammer, one of the tools that can be used during the disassembling process, also causes some dust nuisance. This can however easily be reduced by using humidifiers. During disassembling, other than during the traditional demolition process, the dust that is produced is locally. This is the reason why, for sure, it causes less inconvenience. It is easier to control the dust production and could therefore be less harmful for the surroundings. (Van Schaaik, 2012)

Apart from the ability to control the dust, the amount of hindrance also depends on the total production. This mainly depends on the amount of concrete surface that is broken. The higher the level of disassembling, the least connections are broken and so less energy is wasted. When the parts that come out of the building are larger, less new connections have to be formed for the new application, which saves energy for the production of materials to form these new connections. To create the least hindrance concerning dust, the concrete should be assembled to the highest building level possible. The building levels were already stated in the previous chapter. It was concluded that the component level is the highest level possible. A higher level would cause several problems. Taking out larger parts means more weight per part and therefore calls for other equipment that is necessary to take out the parts. Another important aspect is the ability to reuse the parts that come out of the building. This also depends on the possibility to transport the parts.

Building Level						
Building						X_a
(sub) System						X_b
Component						X_c
Element						X_d
Material						X_e
	Level specification	Mechanical properties	Geometry	Connections	Structural functions	Complete building structure

Table 3-1: Specifications of building levels within a structure (source: A. van Westenbrugge)

Demolition company Snellen BV is a company that finds sustainability an important aspect of the demolition process. On their website, one page is dedicated to the reduction of dust during demolition works. "Unfortunately, demolition of stone and concrete is often a dusty to very dusty activity. This can be inconvenient but also harmful for the human being and its surroundings." As a solution to the dust production a number of measures are mentioned on the website. The first one mentioned is the use of another demolition method that produces less dust. "You might ask yourself, another demolition method, is this possible? The answer is yes; in many circumstances there is an option to demolish an object in several ways. You can take as an example a reinforced concrete floor which has to be removed. You can use cutting devices and clean up the crushed concrete at the end. With this, you get dust

production during the cutting itself, but also during cleaning up the debris in a later stage. You can however also choose to saw up the floor slab in pieces after which you can take away the concrete lumps directly.” (Snellen BV, 2012)

3.2. Noise

3.2.1. Problem

During demolition processes very high levels of noise are reached. During drilling, sawing and cutting this level becomes too high. It is clear that during the demolition process the daily dose is higher than the legally allowed 85 dB and it is therefore obliged for building workers to wear ear muffs. (Arbeidsinspectie, 2007) People working and living in the surrounding area can also experience noise hindrance from demolition projects.

3.2.2. Comparison between different demolition methods

The opinions about the amount of noise that is produced through the use of several demolition and disassembling techniques are not unambiguous. According to Onderdijk of the project in Middelburg and Lamber of demolition company Heezen, disassembling techniques cause more noise nuisance than traditional techniques. Especially the pneumatic hammers have caused problems during the disassembling project in Middelburg. Van Schaaik also confirms that the pneumatic hammers produce a lot of noise. According to him, however, this is not much compared to the traditional way of cutting up concrete floors.

The different perspectives can be caused by the interpretation of noise nuisance. Do the different techniques cause hindrance for the building workers or for the surroundings? Pneumatic hammers and diamond saws are electrical machines of which building workers using them are within a small distance of the noise source. Someone operating a machine to cut up concrete is further removed from the noise source, so will experience less hindrance.

If we look at the average noise level the machines produce, it can be concluded that the diamond saw produces most noise. All other equipment produces about the same level of noise, so no conclusions can be drawn from this. It can only be said that building workers have the ability to wear protection against the noise while for the environment this is not a realistic option. For tools such as a pneumatic wrecking hammer and the diamond saw, there are already types that produce less noise.

Equipment	Level of noise
Pneumatic wrecking hammer	109 dB(A)
Pneumatic diamond drill	100 – 125 dB(A)
Diamond saw	133 dB(A)
Concrete- and debris breakers	107- 112 dB(A)

Table 3-2: Noise level used equipment during demolition works (Source: Arbouw)

It should be noted that there is an extra risk for building workers who wear ear muffs. They are well protected against the noise produced by the equipment, but also isolated from noise

around them. Machines that come too close and warnings that are given can often not be remarked. It is however possible to communicate with colleagues through the ear muffs, but it is still not as safe as when you hear where noise is coming from.

3.3. Vibrations

3.3.1. Problem

During many technical occupations, employees are confronted with vibrations. The amount and intensity of these vibrations depend on the type of machinery or equipment used. Vibrations can have negative effects on the health of building workers. Apart from that, they can cause damage to surrounding buildings or hindrance to people working or living nearby locations where vibrations are produced. For building workers, two types of vibrations are distinguished, namely body vibrations and hand- and arm vibrations. (Overheid, 2005)

To minimize the amount of vibrations produced during work activities, the European Parliament has set guidelines to state the maximum allowed level. These guidelines were put into operation in 2002 and give minimum requirements for protection against excessive exposure of vibrations on the workplace. Measures should be taken as much as possible at source because there are hardly any protection measures to restrict the vibration transfer. Often, the only solution is to make radical changes or replace a machine or vehicle. (Overheid, 2005)

	Work value	Limit value
Body vibrations	0,5 m/s ²	1,15 m/s ²
Hand- and arm vibrations	2,5 m/s ²	5 m/s ²

Table 3-3: Limit values (Source: Schuurmann)

The intensity of the vibrations and the percentage of people exposed to them are relatively constant. Despite the technical progress in the state-of-the-art technique, there is a very slow improvement on the working place.

Building workers

High percentages of building workers exposed to body vibrations can be found in technical occupations, especially in the building sector and the road- and hydraulics engineering sector. During demolishing and cutting with equipment such as a wrecking hammer or bucket attached to a crane, machinists are confronted with body vibrations. The limit value of 1,15 m/s² can be exceeded. 54% of people working in the demolition industry have complaints about body vibrations. (Arbocatalogus)

The exposure to hand- and arm vibrations is among others relatively high at demolition companies. (Overheid, 2005) This is especially a problem when working with electrical driven equipment. 51% of the demolishers have complaints about it. During the use of this type of equipment, especially the pneumatic hammer, the limit value is often exceeded. (Arbocatalogus)

Surroundings

Apart from the harm that vibrations can do to the health of people working with demolition equipment, vibrations caused by demolition works can also cause damage to buildings nearby. New buildings usually have a better resistance against vibrations, but for example for monumental buildings it could cause problems. The degree of nuisance also depends on the type of building. For residential- and office buildings, it usually stays restricted to hindrance, while for specific buildings such as computer centers and hospitals the consequences can be radical. For this reason it is advisable to do research after the potential risks of the demolition works. (Dijkstra, 2010)

3.3.2. Comparison between different demolition methods

SBR has published a few guidelines that can give practical assistance for the limit values of vibrations. The values give the expected safe work distances in meters.

SBR tabel sloopwerkzaamheden								
SBR A	Zagen	Vracht	Kangoo	Knabbelen	Shovelbewegingen	Mobiele sloophamers		
*		middel	20 kg	40 Ton	20 Ton	5 Ton	20 Ton	40 Ton
Bouwen en slopen met verwachte veilige werkafstanden in meter								
Cat III	0 - 1	8 - 16	7 - 16	20 - 48	20 - 48	15 - 30	25 - 50	30 - 70
Cat II	--	4 - 8	3 - 8	10 - 24	10 - 24	8 - 15	13 - 25	15 - 35
Cat I	--	1 - 3	1 - 3	3 - 8	3 - 8	2 - 5	4 - 8	5 - 11

* Cat I betonnen constructie, Cat II gemetselde constructie, Cat III monumenten.

Table 3-4: Limit values for vibrations (source: SBR)

The equipment causing most trouble for building workers when looking at vibrations is the pneumatic hammer. Disassembling techniques such as sawing (in Dutch: zagen) and using the Kangoo wrecking hammer cause less hindrance than traditional demolition techniques such as nibbling (in Dutch: knabbelen).

3.4. Safety

3.4.1. Building workers

In traditional demolition processes, the construction is stripped until only the structural part is left. Up till that point, there is no danger for building workers concerning the structural stability of the construction. Consequently, the building is demolished with help of machines during which the building workers are at least a few meters removed from the building.

The difference with disassembling the construction instead of demolishing it, is that during the disassembling process building workers need to be situated on top or inside the building which makes them more vulnerable. Another problem is the size and weight of the elements

that need to be disassembled and lifted out of the construction. The stability of the construction is guaranteed by the coherence of the whole construction. When parts are taken out, this stability is no longer guaranteed and the construction needs to be shored. (Bouwhulp Groep B.V. Eindhoven, 2001)

Another issue for disassembling projects is that there is not a lot of experience yet. During the dismantling of both reference projects much was still unknown. It was difficult to predict the construction, so a lot of safety requirements were necessary. In Middelburg, for example, building workers were not allowed to stand underneath an element while it was taken out. "We knew for 98% that the lifting hooks would hold the element, but there is always a risk." By carefully considering all safety requirements, no serious accidents occurred, but the process cost much more time than the traditional demolition process would have. (Onderdijk, 2012)

3.4.2. Surroundings

In 2006, the Rabobank in Utrecht collapsed like a house of cards when the ball breaker hit the building. Something similar happened in Middelburg in 1986 with a residential building built with the same type of construction as the building that was levelled down. Explosives were used to take down the prefab construction.

These incidents show that taking down a prefab building with a ball breaker or explosives brings along too much risk for the environment because the demolition process cannot be controlled.



Figure 3-2: Collapse like a house of cards after using explosives to demolish a prefab concrete building in Middelburg (1986)

Van Schaaik, who has experience with demolishing prefab concrete buildings, says it is a matter of knowing the construction of the building. This is the essence of demolishing prefab

structures. You have to know how the building was constructed and should demolish it in the opposite order. With a pulveriser (in Dutch: vergruizer) or sorting bucket (in Dutch: sorteergrijper) you can control the demolition process quite well. If you have less space around the building, it becomes more complicated. In any case, you have to make a demolition plan in which you state how the building will be demolished. This plan is submitted at Bouw- en Woningtoezicht who judges the safety. If your plan does not fulfil the requirements, it has to be revised. Van Schaaik thinks that the current way of demolishing is safe enough. If disassembling is safer, he judges, depends on the people, the equipment and some other factors.

3.5. Results

Dust

Disassembling a building instead of demolishing it in a traditional way causes less dust production, because less concrete surface has to be broken and the dust can be better controlled. For both building workers as well as the surroundings this means less harm is done to their health. Devices used during disassembling works should be equipped with dust reduction measures to reach a high dust reduction level.

Noise

The amount of noise produced during the traditional demolition process compared to a disassembling process does not differ very much. For the surroundings it does therefore not matter which method is used. Building workers stand closer to the noise source during disassembling a construction, however. This forces them to wear earmuffs in order to prevent hearing damage. The danger of this, is that they have a higher risk of not noticing danger in time.

Vibrations

More than half of the people working in the demolition branch have complaints about vibrations. This is therefore something that should not be ignored when looking into the differences between demolishing traditionally with machines and disassembling manually. The pneumatic hammer gives most problems for building workers. Use of this tool should therefore be avoided as much as possible and can be replaced by other techniques such as cutting or sawing.

Whenever a building is demolished in a densely populated area or with a vulnerable building nearby, the demolition techniques should also be carefully considered. Nibbling and using mobile demolition hammers produce more vibrations than disassembling techniques such as sawing or using a Kangoo hammer.

Safety

It can be concluded that a prefab building should not be demolished as if it were an in-situ poured concrete building. It is important to engineer the demolition process step by step, so

that it is at all times known how the construction will behave during the process. This requires more time and effort than when it concerns an in-situ poured concrete structure. A disassembling process also needs to be engineered in detail and even brings along more risks for building workers, because they are actually on top of - and inside the building. This is one of the reasons why the process takes even more time.

For the surroundings it could be favourable to choose for a disassembling process instead of demolishing the building, because less space is required for a disassembling process. When there is no space around a building, nothing may fall down from the building and nibbling off concrete is therefore not a good option.

4. Functional requirements

To decide upon the possibilities of reuse of hollow core slabs in residential buildings, the functional requirements of floors of these types of buildings are mapped out. It concerns the fire safety, sound insulation, block-outs in the slabs and finishing of the ceiling. The requirements in residential buildings are usually different from those in office buildings which could make adaptations necessary before reusing the slabs. In apartments buildings very often floor systems other than HCS are applied, such as wide floor planking. The reasons are sound insulation requirements and the ability to easily place wires in the floor. The aim of this chapter is to determine how a floor system with HCS can meet the same requirements as floor systems currently used.

4.1. Fire safety

4.1.1. Regulations

For residential buildings, the requirements with regard to fire resistance are higher than for office buildings because of the 'sleep function' it has. Bouwbesluit 2012 gives regulations about the minimum number of minutes the load bearing structure has to be secured in case of fire. For all office buildings and all residential buildings with a height of less than 7 meter, a reduction of 30 minutes may be applied when the permanent fire load of the load bearing structure is less than 500 MJ/m². This value corresponds with 26 kg pine wood. With incombustible building materials such as concrete and steel, the criteria for the reduction are almost always met. (Bouwen met staal, 2012) The reduction may not be applied for residential buildings higher than 7 meter, to create a safer situation for fire men who enter the building to search for people still in the building. (Overheid, 2012)

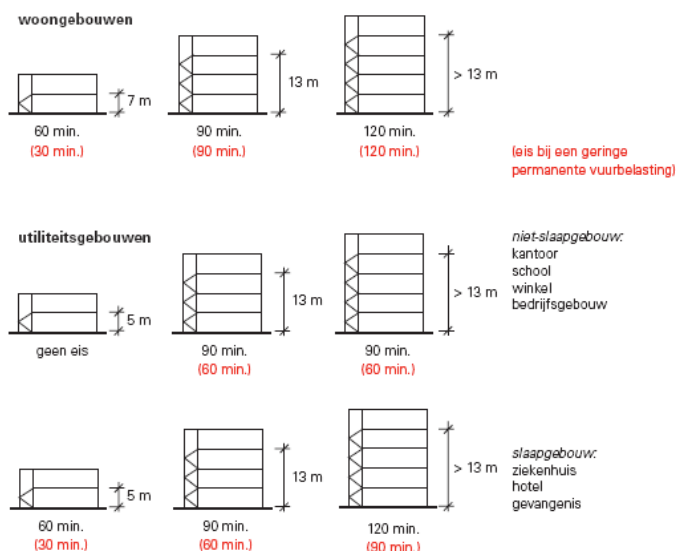


Figure 4-1: Fire resistant requirements in Bouwbesluit 2012 for the load bearing structure of residential building and commercial- and industrial buildings

In most prefab constructions with hollow core slabs, the floor slabs are part of the load bearing structure because they provide the slab action that partly assures the stability of the construction. Only when other parts of the floor provide this stability, such as horizontal cross bonds, the hollow core slabs do not have to fulfil the fire safety requirements that hold for the load bearing structure. (Klein-Holte, 2012)

To meet higher fire resistance requirements, the thickness of the hollow core slabs has to increase. An increase in fire resistance can also be obtained by increasing the concrete covering on the prestressing steel and/or by increasing the amount of prestressing steel. (Dycore, 2000a) The time resistance of the construction also depends on the load on the construction. For lower loads, the construction is resistant against fire for a longer period of time.

In the Netherlands, there are 3 major suppliers of hollow core slabs, namely VBI, Dycore and Beton Son. All three suppliers provide products developed by themselves with their own specific properties. In general, however, they do not differ much. The hollow core slabs all have a width of 1.2 m and standard thickness, but the amount of reinforcement and the form of the cores are different. The properties of the hollow core slabs used in office buildings are given in the table below.

Thickness (mm)	Type	Supplier	Strength class	Weight (kg/m ²)	Fire resistance (min)	Remarks
150	A150	VBI	C40/50	264	60 - 90	
	K150-8	Dycore	C53/65	240	up till 90	
	K150-11	Dycore	C40/50	250	up till 90	
	HVP150-8	Beton Son	C53/65	263	60 - 90	
200	A200	VBI	C45/55	303	60 - 120	
	K200-6	Dycore	C53/65	270	up till 120	before N200
	K200-11	Dycore	C40/50	310	up till 120	
	HVP 200-6	Beton Son	C53/65	312	60	
	HVP 200-11	Beton Son	C53/65	312	60	
260	A260	VBI	C45/55	376	90 - 120	
	K260-5	Dycore	C53/65	370	up till 120	before T260 (t = 255 mm)
	K260-11	Dycore	C40/50	432	up till 120	
	HVP260	Beton Son	C53/65	382	60 - 90	
320	A320	VBI	C45/55	443	90 - 120	
	K320-4	Dycore	C53/65	430	up till 120	before H320
	HVP320	Beton Son	C53/65	408	60 - 120	
400	A400	VBI	C45/55	548	120	
	K400-4	Dycore	C53/65	500	up till 120	
	HVP400	Beton Son	C53/65	467	60 - 120	

Table 4-1: Properties hollow core slabs for office buildings (Source: VBI, Dycore and Beton Son)

4.1.2. Behavior of hollow core slabs during fire

In the past few years, a lot of research has been done after the behaviour of hollow core slabs during fire. (Hordijk, 2011) The occasion for these researches was a fire in the parking garage of an apartment building in the Lloydstraat in Rotterdam in October 2007. This fire caused damage to the hollow core slabs in a way that was not predicted beforehand. (W. Welling, Paassen, A. van,, 2009)

In the past decennia it has been common in the Netherlands, more than in most other countries, to use a constructive concrete topping on the hollow core slab floor to guarantee the cohesion and the stability of a building in a practical and simple way. It is mostly this concrete topping that causes hollow core slabs to act differently in case of fire than was initially expected. If the upper shell is withheld from deformations when temperature differences occur, the thermal expansion of the lower shell could lead to shear in the webs and therefore the coming off of the lower shell. (Hordijk, 2011)

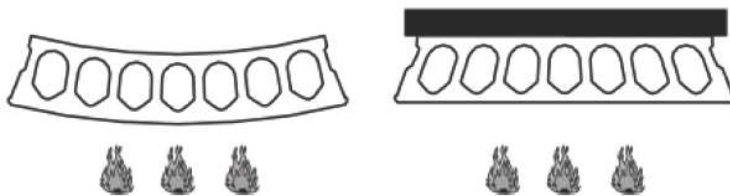


Figure 4-2: Prevention of deformation during fire because of top layer (Source: Cement)



Figure 4-3: Breaking off of webs of hollow core slabs because of shear stresses caused by unequal deformations in lower and upper shell (Source: Cement)

As a result of the damage of the construction in the Lloydstraat in 2007, BFBN has given commission in 2008 for further research to a consortium of TNO, Efectis Nederland bv and Stichting Expertisecentrum Regelgeving Bouw (ERB). At this moment, another research has been completed by TNO, Efectis Nederland bv, Adviesbureau ir. J.G. Hageman B.V., ERB and DGMR. (Pielkenrood, 2011)

Two of their conclusions are:

- If because of a thick concrete topping or finishing layer (combined top layer) with rise of temperature the upper side cannot sufficiently deform, horizontal cracks can occur in the piers of the hollow core slab because of which the lower shell can give away earlier than normal.
- Expectations are that for top layer thicknesses up to 50 mm, problems with the lower shell will hardly occur. It can be assumed that in that case, the lower shell will not give away. For a top layer above 70 mm there are indications that the horizontal crack forming in the piers can occur with as possible result breaking off of the lower shell. For a top layer between 50 mm and 70 mm, horizontal crack forming could also occur with the same consequences.

The conclusions lead to recommendations for existing buildings. It depends on the thickness of the top layer and the consequence class (in Dutch: gevolgklasse) if measures need to be taken. In the appendix, detailed information about recommended measures in relation to the top layer thickness and the consequence class can be found. Looking at dwellings and apartment buildings (relevant for this research) it can be summarized as:

- For all buildings with hollow core slabs with a top layer of less than 50 mm, no measures are necessary
- For top layers of 50 to 70 mm it depends on the consequence class if measures are necessary. For dwellings with a maximum of 5 floors and apartment buildings with a maximum of 4 floors the risks are sufficiently low. No measures are necessary. For higher apartment buildings measures need to be taken.
- For top layers with a thickness of more than 70 mm, measures are only not necessary for dwellings up to 4 floors. For all dwellings higher and all apartment buildings, measures are necessary.

In practice it is common to speak of a (constructive) concrete topping, whereas for drawing up measures it is purposely chosen to use the term 'top layer'. The reason is that not only the constructive concrete topping contributes to the prevention of deformation of the upper flange, but also the possible applied finishing layer. To determine the thickness of the top layer, the thickness of the finishing layer needs to be added to the thickness of the concrete topping unless measures are taken to keep the finishing layer separated from the concrete topping. When the quality of the finishing layer is very low, the contribution on the prevention of deformation is relatively limited. The stiffness (modulus of elasticity) is not directly proportional with the strength (for a low strength there can still be a high stiffness). The advice is therefore to take half of the height of the finishing layer into account when its strength is maximally D15 and whenever the strength is higher than D15, to take the whole thickness into account for the determination of the thickness of the top layer. (Hordijk, 2011)

Although the research of BFBN was aimed to map out the risks for existing buildings with hollow core slabs, it is assumed that the recommendations can also be used for new buildings. In the table below, it is indicated in what type of residential buildings hollow core slabs with a certain top layer can be reused. This holds for top layers that cannot easily be removed from the slabs, so in most cases constructive reinforced concrete toppings.

Tables on recommended measures concerning the thickness of the top layer can be found in appendix C.1.

Class	Type of building	Top layer thickness t		
		t ≤ 50 mm	50 mm < t ≤ 70 mm	t > 70 mm
1	Single-family dwelling ≤ 5 m	Y	Y	Y
2a	Single family-dwelling of max. 5 floors	Y	Y	N
2a	Apartment building of max. 4 floors	Y	Y	N
2b	Apartment building of max. 70 m	Y	N	N
3	Apartment building higher than 70 m	Y	N	N

Table 4-2: Possibilities of reuse of hollow core slabs with a certain top layer in residential buildings

According to Feenstra (Dycore) and Koppenhol (VBI) a concrete topping is applied in about 40% of the office buildings. This layer is either 50 or 70 mm. Usually the layer is automatically put in the construction because the engineer wants to stay on the safe side. Normally, the constructive concrete topping is not necessary. Koppenhol is of the opinion that it is only necessary to apply such a layer in about 10% of the office buildings. The layer is only indispensable when the floor needs to carry high loads. In such a case, the initial height of the floor is not sufficient.

4.2. Sound insulation

4.2.1. Regulations

In Bouwbesluit 2012 several requirements are stated on sound insulation. For precast slab floors these are especially for dwellings situated next to each other or above each other. Two different kinds of noise can be distinguished (VBI, 2003):

- airborne noise: radio, television, voices;
- impact sound: footsteps, drilling, slamming with doors

The requirements in Bouwbesluit 2012 can be found in appendix C.2 in which the characteristic airborne noise level difference is indicated with $D_{n;T;A,k}$ and the weighed impact sound level is indicated with $L_{n;T;A}$.

For a dwelling which is situated above another dwelling, $L_{n;T;A} \leq 54$ dB should be obtained (incl. the concrete top layer). To reach this level of impact sound insulation, a concrete floor should at least have a mass of 800 kg/m² (VBI, 2003). This can be done by applying a floor of 300 mm concrete and a top layer of 50 mm. For this sound insulation level, footsteps will be annoyingly noticeable if a hard floor covering, for example laminate, without springy under layer is applied. A safer construction to apply is the 'wet' floating floor of which the weighed impact sound level can be lowered to 49 dB. (Praktijkboek Bouwbesluit 2012) The requirement for a floor between two dwellings with regard to airborne sound is $D_{n;T;A,k} \geq 52$ dB, which can be reached with less mass than the requirement for impact sound.

For single-family dwellings, the requirement for the sound insulation level of the floor is lower than when different users live above each other. The requirement $D_{n;T;A,k} \geq 52$ still holds but the impact sound may be 5 dB higher, so maximally 59 dB.

For office buildings, the requirements are even lower. $L_{n;T;A} \leq 64$ dB and $D_{n;T;A,k} \geq 47$ is sufficient because they are not categorized as 'geluidgevoelige bouwwerken' in de Wet Geluidhinder (Overheid, 2012).

4.2.2. Suitable floor types

To meet the sound requirements for single-family dwellings for a story floor, all hollow core slab floors/ access flooring systems with a thickness of minimally 200 mm can be applied. If they are combined with a double parting wall of sand-lime brick or concrete, or with a massive parting wall, this leads to good results. (VBI, 2003)

In residential towers, usually precast wide plank floorings are used because of the sound insulation requirements. (Feenstra, 2012) This type of floor has more mass than the hollow core slabs for the same height. Feenstra mentions, however, that the apartment floor of VBI is an exception. This type of floors has smaller tubes, so the mass is higher than for the normal hollow core slabs with the same height. To fulfill the sound insulation requirements, a thick concrete topping could be a solution, but because of fire safety the thickness of the layer should be limited to 70 mm and in some cases to 50 mm. According to Koppenhol (VBI), the solution is a floating floor. In Germany, this is a standard floor used for residential buildings.

For floors that separate apartments, there are thus two basic options:

- A floor with more mass. A floor that weighs 800 kg/m^2 (incl. concrete top layer) fulfils the high requirements for impact sound. This is not feasible with hollow core slabs that are used in office buildings.
- A floor with a floating floor. By applying a floating floor, sound insulation can considerably be improved. This, however, asks for a more precise execution. To meet the requirements of $L_{n;T;A} \leq 54$ dB, a structural floor with a mass of minimally 500 kg/m^2 (incl. concrete top layer) with a floating floor with $\Delta L_{in} \geq 11$ dB (noise reduction that is achieved by applying the floating floor) is a solution. An alternative is a floating floor with $\Delta L_{in} \geq 14$ dB with a lighter floor of 400 kg/m^2 (incl. concrete top layer).

The floors described above satisfy the sound insulation requirements set by the government. By private law, requirements could be higher. For this, there is a so-called comfort class, which aims for the insulation values of $L_{n;T;A} \leq 49$ dB and $D_{n;T;A,k} \geq 57$ dB. To meet these requirements, a floating floor is inevitable. A floor with a mass of 500 kg/m^2 in combination with a high quality floating floor ($\Delta L_{in} \geq 14$ dB) up to a span of 9 m is possible. For larger spans up to 12 m, a floor with a mass of 700 kg/m^2 in combination with a floating floor ($\Delta L_{in} \geq 11$ dB) is a good solution. (VBI, 2003)

4.3. Block-outs

4.3.1. Wells of a staircase

Block-outs (in Dutch: sparingen) for wells of a staircase are realized in the plant when the concrete is still green. When the concrete has not yet reached its full strength, it costs less energy and effort to cut or saw block-outs. Block-outs for wells of staircases are realized by using a diamond saw or a certain kind of knife. (Feenstra, 2012) Normally, block-outs for wells of staircases are made in the grid. (Koppenhol, 2012) In this case, the hollow core slabs only have to be sawn width wise. This is no different from the normal cuts that are made at the beginning and end of a hollow core slab.

It happens sometimes that a block-out for a well of a staircase has been forgotten in the plant. The block-out should then be made afterwards on the building site with a diamond saw. It is possible to make these block-outs afterwards, but it costs extra money (Feenstra, 2012; Koppenhol, 2012) It also happens sometimes that block-outs need to be sawn in a construction after it has been used for several years because of a change in function.

Apart from the block-outs that have to be realized, stair trimmers are necessary to transfer the load to the floor slabs on both sides of the block-out. These stair trimmers are assembled on the building side. (Van Schaaik, 2012)

In residential buildings normally more wells for staircases are required than in office buildings. The reason for this is that in offices more people make use of the same staircases or elevators. When hollow core slabs are to be reused from office - to residential building, this would mean that these block-outs have to be made after the hollow core slabs have been taken out of the old building.

The condition under which a slab can be sawn in the longitudinal direction is however, that the position of reinforcement is known and that this is taken into account. Sawing between the stands is possible but prudence is called for when it concerns sawing through the strands because this would weaken the slab. (Feenstra, 2012) Another disadvantage of longitudinal cutting the strands is that it could damage the diamond saw. (Van Schaaik, 2012)



Figure 4-4: Stair trimmer

4.3.2. Pipes and wires

Apart from block-outs for staircases, pipes also sometimes have to pass floor slabs vertically. In case of office buildings, shafts are normally used to transport the installations from lower to higher floors. For residential buildings, these block-outs are usually smaller. They can be realized by using a diamond drill. It is possible to make those block-outs after the concrete has reached its full strength.

For horizontal pipes, there are several options. In office buildings, a system ceiling is usually applied. A lowered ceiling is placed a few decimetres below the floor slabs to create space for the wires and pipes. With this system, no horizontal block-outs are necessary in the floor slabs.

For residential buildings, several types of floors are developed to tackle the problem of wires and pipes. Most frequently used types are hollow core slabs and wide slab flooring. In wide slab flooring, the wires are usually placed in the poured top layer. For hollow core slabs, wires can be placed in the cores of the slabs or in the top layer. A condition for wires poured into the floor is that they should be continuous, because it is impossible to repair them. Most of the wires are placed in the walls and for the wires in the ceiling, pipe chases are usually milled. (Veldhuijs, 2012)

When wires are placed in the cores of the floor slab, block-outs are required. These are usually made when the concrete is still green. At VBI, these block-outs are made by cutting out the concrete and extracting it by suction. The slits can be made both in the direction of the cores as well as perpendicular to the cores. The block-outs in the direction of the cores can be made over the whole length by removing the upper shell of one core. In the other direction, this can only be done close to the supports, because in the middle of the slab the magnitude of the bending moment is at its highest and needs the whole height of the slab. (Koppenhol, 2012)

When wires are put on top of the slabs, they can be concealed by a top layer of 50 to 70 mm. Disadvantage is that there is only a small covering on top of the piping. A central box is sometimes used to cluster the electricity wires. (Dycore, 2000b)



Figure 4-5: Central box (In Dutch: centraaldoos) for wires placed in concrete top layer (Source: Dycore)

If hollow core slabs are reused for residential buildings, a solution has to be found to incorporate pipes for drainage in the floor. Because of the requirement to limit the top layer to maximally 70 mm, the pipes cannot be incorporated in this layer since they have a height that goes up to 110 mm (for toilet drainage). (Feenstra, 2012)

Block-outs for wires can very well be made on the building site with help of a hammer drill or a diamond drill with a diameter up to 25 mm. (Dycore, 2000b) Whenever this is done, the zones where drilling is not possible are indicated on the slab beforehand. Advantages of this method are:

- It limits the number of different slabs coming from the plant.
- The size of the drilled hole is correct and no further adaption is necessary.
- Size deviations in the construction do not lead to extra cut- or break work.
- One can determine the final location of the block-outs in a late stage which prevents extra costs for changes during the process. Especially for small block-outs it is economically attractive to make them on the building site.

Disadvantages are:

- You have to take the amount and location of the reinforcement into account. The block-outs should not cut the strands in the direction parallel to the cores. If you have to pay attention to this during the fabrication process, you might as well make the block-outs right away. (Feenstra, 2012)
- Costs could increase when large amount of slits have to be made on the building site.

To make horizontal block-outs perpendicular to the cores, however, is almost impossible after the concrete has reached its full strength. This is because you can hardly get out the concrete between the cores. There is a big chance that the slab would break if you would try. Therefore, you should try to put those wires above the slab. Pipe chases perpendicular to the cores could however be necessary. Smart architects try to cluster the slits so that not every slab needs them. (Feenstra, 2012)



Figure 4-6: Block-outs made at the building site (source: Dycore)

The best solution is to prevent as many block-outs as possible. It has already been concluded that a floating floor is the solution to reach enough sound insulation in residential buildings with more than one occupant in vertical direction. In this case, the piping should be placed in the layer on top of the slabs. Consequently, a springy layer is put on this layer and finally a

finishing layer is used, which is not connected to the constructive floor. This finishing layer is a sand/cement or anhydrite floor in which a floor heating system can be integrated.

Piping could also be totally kept out of the floor, except for some electricity wires in the ceiling for which slits can be milled. Wet areas should be situated around the vertical shaft that transports pipes and wires. A mixture of used and new floor slabs is another possibility. For floors with block-outs, new slabs can be fabricated while for the other part of the floor, used slabs can be used.

4.4. Finishing

4.4.1. Ceilings

Almost all office buildings have lowered ceilings above which pipes are located. The hollow core slabs cannot be seen from below, because of this lowered ceiling and do therefore not need a finishing layer. The pipes for the installations are attached to the hollow core slabs with mountings that are drilled into the slabs. When a building is at the end of its service lifetime, the concrete skeleton is stripped from all materials but metal. (Van Schaaik, 2012) This can be removed later, when the concrete has been crushed. A large magnet separates the reinforcement and other metal from the concrete after which both can be recycled.

In residential buildings, the bottom side of floor slabs is finished with a sprayed finishing layer to flatten the irregularities of the floor slabs and create a visually attractive ceiling. For a dwelling, this is an important aspect. (Feenstra, 2012)

When a hollow core slab coming from an office building has to be re-used in a dwelling, the mountings for pipes have to be removed. Consequently the holes that are present because of these mountings have to be stopped with help of a stopping knife and putty. Finally, the floor slabs can be finished in the same way as new slabs would be finished. Nothing will be visible anymore of the irregularities caused by installations ones attached to the slabs. (Feenstra, 2012)

The only disadvantage is that more time is needed to remove the mountings and to fill the holes in the slab.

4.4.2. Camber

If hollow core slabs are applied, one has to take into account that eccentric prestressing will cause a certain camber (in Dutch: zeeg). The magnitude of this camber is apart from the usual factors creep and shrinkage of the concrete, dependent on the reinforcement, the section of the slab (own weight) and the length of the slab. (VBI, 2003)

Apart from differences in camber of slabs of another length and percentage of reinforcement, the factor time and load on the slabs during their lifetime also has influence on the final shape of the slab. Hollow core slabs that initially had the same properties but were applied in different buildings can show significant differences in camber at the end of their service life in an office building.

In general it holds that for larger slabs with more reinforcement, the camber increases. To prevent extra finishing when large differences between neighbouring slabs occur, some restrictions should be taken into account. This holds for the amount of reinforcement and maximum length per slab thickness for slabs used for 'ceilings in sight'. (VBI, 2003)

Slabs that are not already used can also show large differences in camber when applied in residential building. An example is the camber differences that can occur around a well of a staircase. The slabs around the block-out are apart from the normal load, also loaded with an extra concentrated load coming from the trimming beam. To be able to carry this extra load, these slabs have more reinforcement. This leads to an extra camber that should be taken into account during execution of the work to prevent it from being visible. (Feenstra, 2012)

The magnitude of the camber should always be taken into account when using second hand slabs. If it turns out during construction that the cambers of adjacent hollow core slabs are not of the same order, something needs to be done to even them out. For this, there are two common solutions. One is to place shoring struts under the lower slab and place dead load on the highest slab. The maximum load of both slabs should be taken into account and should of course not be exceeded. At the moment the slabs are loaded, the joint should be poured. When the joint has reached its full strength, the auxiliary construction can be removed. Another option is to use brackets to even out the construction. When the joints have reached their strength, the brackets can be removed. (Adviesbureau ir. J.G. Hageman B.V., 2000)

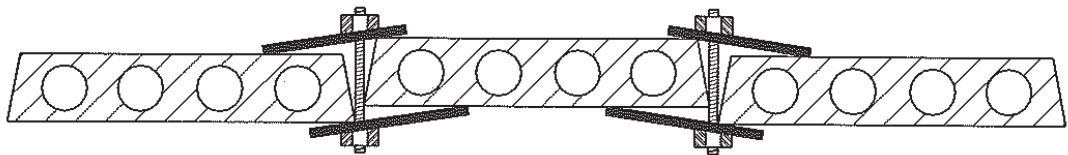


Figure 4-7: Brackets to even out the construction (Source: Dycore)

Maybe with a thicker layer of gypsum on the ceiling the differences can also be evened out or for example by varying the height of the supports under the slabs.

To reuse hollow core slabs that come out of one specific office building to one specific residential building will probably not cause many problems with camber differences because the properties of the slabs are equal and they have been in one building for the same amount of time with about the same load. When different slabs coming from different office buildings are piled up in the same storage and combined to be used for one new project, more differences in camber are probably visible.

More research is required to find out if this could form a serious problem and what other solutions can be found for this problem. The solutions can either be found on the side of finishing of the slabs in the new building, of which some options are already given, or on the side of logistics. If the solution is solved by good logistics, the process has to be managed in such a way that only slabs with small camber differences are used in the same new building. In case the solution is found in finishing of the reused slabs, more differences between the slabs are allowed. The extra costs that come along with this should be taken into account.

4.5. Results

Fire safety

Hollow core slabs are in most constructions part of the load bearing structure and therefore have to meet high fire safety requirements. For residential buildings, these requirements are even higher than for office buildings. The fire resistance of hollow core slab floors depends on their thickness, amount of reinforcement, covering on the reinforcement and load on the floor.

Apart from the parameters that are of influence on the fire resistance time of a construction, the thickness of the top layer also plays a role. A thick concrete top layer can have a negative influence on the fire safety because it restrains the slab from deforming during large temperature differences. For dwellings up to 4 floors a top layer of more than 70 mm is acceptable. For apartments up to 4 floors and dwellings up to 5 floors, the top layer may maximally be 70 mm and for apartment buildings higher than 4 floors, the thickness of the top layer should be limited to 50 mm.

Sound insulation

The hollow core slabs applied in office buildings meet the sound insulation requirements of the floors used in single-family dwellings. For apartment buildings with more than one dwelling vertically there are higher requirements for sound insulation. Floors used in office buildings do usually not meet these requirements.

When a normal hollow core slab floor is applied in an apartment building without floating floor, the floor has to have a weight of at least 800 kg/m² which means all frequently used floor types in office buildings (200 mm, 260 mm and 320 mm) are not heavy enough. A solution is either to fill up the hollow tubes of a 320 mm floor or to use a floating floor. The latter is more logical, because this would not limit the type of reusable floor slabs to 320 mm.

The 260 mm floor is also heavy enough to create a sufficient level of sound insulation when a common floating floor is applied. Apart from that, it is a more economical- and sustainable solution, because it requires less adaptations in order to reuse them.

To reach the comfort class level with regard to sound insulation, the office building floors are not heavy enough, except the 400 mm which is not very common in office buildings. The only solution in this case is to fill up the cores with concrete after disassembling the hollow core slabs, but again, this might be too laborious. In case a floor with a high comfort class is required, reusing floor slabs coming from office buildings is not a good option.

Block-outs

When the hollow core slabs of an office building are reused, some adaptations should be made to realize the necessary block-outs. For wells of staircases, slabs should be sawn to size crosswise. Since probably all slabs need to be sawn to size to make them ready for reuse, this is not an extra operation. If the staircases are not made in the grid the slab also has to be sawn in the direction parallel to the cores. In this case, attention should be paid to the location of the reinforcement to prevent cutting strands in this direction. For vertical transport of pipes and wires, holes can be drilled in the floor slabs with a diamond drill. This is not very laborious. More accuracy and time is required for horizontal block-outs to place wires or central boxes in the cores. Block-outs perpendicular to the cores are too difficult to make when concrete has its full strength.

Finishing

The appearance of the ceiling is very important in a residential building whereas in office buildings they are hidden behind a system ceiling. Some adaptations are required for slabs coming from office buildings to make them ready for reuse in dwellings. After adaptation a good result can be booked; irregularities caused by installations ones attached to the slabs will not be visible anymore. The only disadvantage is that more time is needed to remove the mountings and to fill the holes in the slab.

In office buildings with ceiling systems, the magnitude of the camber is not of considerable importance because the slabs are not visible. When reusing the slabs, attention needs to be paid to the differences in cambers of neighbouring slabs. The best solution is to use slabs with similar properties thus of the same initial length and with the same amount of reinforcement.

5. Construction

To bring the theoretical information into practice, a case study is performed. This allows for realization of the obtained information into a better impression of the concept. The building PriceWaterhouseCoopers in Brainpart III in Rotterdam (in the rest of the report called PWC) was particularly chosen because of its size, type of construction and different types of hollow core slabs. It is a fairly standard office building compared to offices built in the last decade and has common connections. On top of the different types of hollow core slabs, there are also two different top layers; a (non-constructive) finishing layer as well as a concrete topping. Because of this, different disassembling techniques need to be applied.

In this chapter, the construction is examined. The process of disassembling is determined with information from the previous part. This contains the equipment to break the connections but also the method to lift out the elements and the operations necessary in order to reuse the slabs. It is also determined in what type of buildings the slabs can be reused with help of the chapter on the functional requirements of floors in residential buildings.

The results of this chapter are used as input for the LCA study and the costs calculation.

5.1. General information

Name:	PriceWaterhouseCoopers, Brainpark III (PWC)
Location:	Rotterdam
Architect:	Rapp+Rapp; Prof. Hands Kolhoff Architekten
Engineer:	Imd Raadgevende Ingenieurs
Client:	Fortis Vastgoed Ontwikkeling
Completion:	November 2005
Size:	20.000 m ² offices; 12.000 m ² parking



Figure 5-1: Photo 1 PWC (Source: Hurks Beton)



Figure 5-2: Photo 2 PWC (Source: Hurks Beton)



Figure 5-3: Photo 2 constructie PWC (Source: Hurks Beton)



Figure 5-4: Photo 1 constructie PWC (Source: Hurks Beton)

5.2. Construction data

The construction consists of:

- A three layer split level parking garage of an in-situ concrete frame
- An office tower (16 floors, 65 m high) of precast concrete elements.

The inner leaves of the façade of the office tower are load bearing precast concrete elements as well as the construction of the core with elevator shafts and staircases in the middle of the building. The floors mainly consist of hollow core slabs with or without concrete topping. An inventory is made of the amount and type of used hollow core slabs in order to determine the possible reuse. The table with all slabs can be found in the appendix E.

The strength class of the hollow core slabs is B65 (C53/C65) and that of the reinforcement is Fcp1860. The strength class of the concrete topping is B25 (C20/C35) and that of the sand-cement finishing layer is D35. In residential buildings, normally no concrete topping is applied and the strength of the cement-bonded finishing layer is D15.

The main floor types used are the hollow core slabs are N200 with a finishing layer of 50 mm, the T260 with a finishing layer of 50 mm and the H320 with a finishing layer of 50 mm and with a concrete topping of 60 mm with finishing layer of 20 mm.

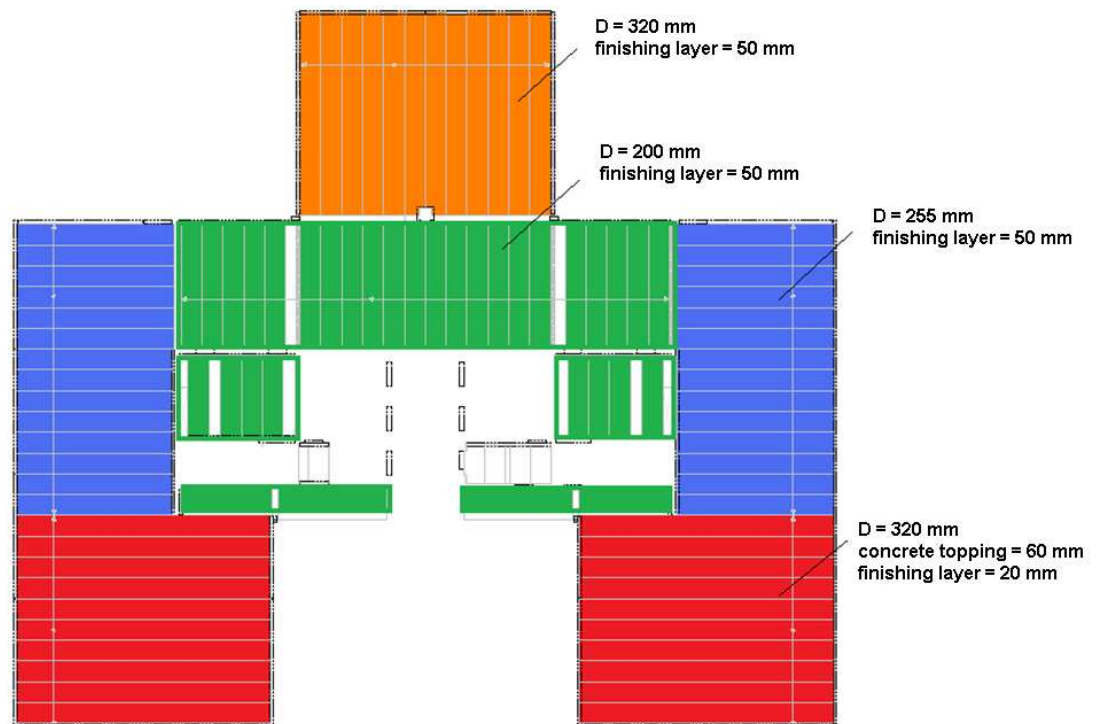


Figure 5-5: Hollow core slabs of floor 4 – 13 (10 floors)

The relevant floor plans of the PWC can be found in appendix D.1.

5.3. Connections

General

To create slab action of the floor, a tie-rod is placed around the floor bays and poured into the mortar of the joint. For extra interaction between the load bearing walls and the floor slabs tie-bars attached to the walls are placed in the joints between the hollow core slabs. In the longitudinal direction of the slabs, in almost all hollow core slabs 1 or 2 tie-rods are placed at the end of the cores and attached to the load bearing walls. In the direction perpendicular to the cores, at two places over the width of each floor bay, strips are anchored into the cores of the slabs as well as into the walls.

In appendix D the different floor bays with their connections can be found as well as the layout plans of the slabs with their connections to the rest of the construction.

N200 finishing layer 50 mm

The hollow core slabs are placed on consoles wherever they are adjacent to the load bearing wall. At places where they are next to another group of hollow core slabs, they are supported by THQ beams. Around a group of hollow core slabs, a tension rod is situated existing of two steel strands.

T260 finishing layer 50 mm

The A260 slabs are also placed on consoles when they are adjacent to a wall and placed on a THQ beam when they are adjacent to another floor field. Also a THQ-beam with one flange is used at one side where this beam is placed between the lower and upper wall. Around the whole floor, a tension rod is used of two or three strands.

H320 finishing layer 50 mm

Details are only indicated of the part where the hollow core slabs are supported by a THQ beam. In the middle of this beam, a column is located to transport the vertical forces. At this location, the slabs are placed on the console of the column, which means a block-out is required in the two adjacent slabs. The sides perpendicular to the THQ beam are load bearing walls with consoles which are attached to the long side of the outer slabs by means of a joint with tension rod. Of the third wall, no details are present, but it is assumed that the connections are similar as the previous ones, so also a console is used to support the ends of the hollow core slabs. There are also 4 strips present to create extra stability of the structure. These strips are attached to the hollow core slabs with dowels placed in the cut-open cores in which mortar is poured at the end.

H320 concrete topping 60 mm and finishing layer of 20 mm

On this part of the floor, a constructive concrete topping of 60 mm is applied. The regulations imply that for a concrete topping of more than 50 mm a two-way reinforcement is required of bars with a diameter of minimally 5 mm, a centre-to-centre distance of 250 mm and a steel quality of FeB 500. (Beton Son, 2012) In this case a minimum reinforcement of $78.54 \text{ mm}^2 \text{ per m}^1$ is applied in the concrete topping.

The hollow core slabs are supported by consoles of the surrounding walls. The longitudinal joint between the hollow core slab and the adjacent wall is established by making use of some formwork with which a joint of 20 cm with a tie-rod of two steel strands is created.

5.4. Disassembling process

5.4.1. General

For the safety of the building workers and the quality of the elements that are disassembled, the process of disassembly needs to be engineered in much detail. The division of forces needs to be known at all times and with this the order of disassembly.

From the research on negative effects from demolition processes it turned out that the pneumatic hammer causes many vibrations for building workers and should therefore be used limitedly. The diamond saw produces a high level of noise for which the use of ear muffs is inevitable. A good communication system is needed through these ear muffs to minimize the risks of signaling a dangerous situation.

The diamond saw is only necessary when reinforcement needs to be sawn in two. It could also be used to cut through the finishing layer, but using a pneumatic hammer is probably a better option for this. This is only for the first 50 mm until the top of the slabs is reached. For the rest of the joint a wedge (in Dutch: wig) and a normal hammer should be sufficient to cut out the joint.

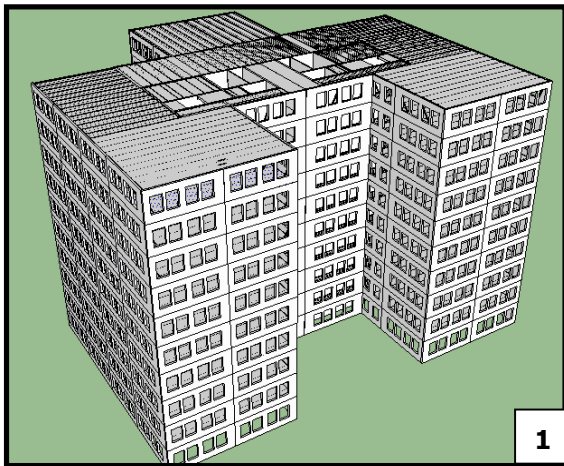
It can be assumed that because of the low strength of the finishing sand/cement layer, this layer can easily be removed from the slab. When the slab is taken out of the construction, this layer usually breaks off because of the forces created as a result of the change in camber in the slab.(Lamber, 2012) If the finishing layer is still intact after the slabs have been taken out, it should be removed afterwards by using a wig and a hammer.

Lifting out elements

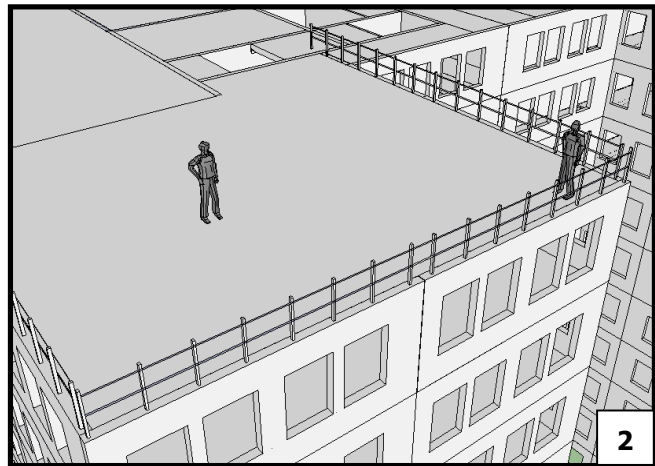
It was already concluded that the fastest and easiest way to take out a HCS is with help of a fork or a bucket. A hollow core slab bucket is not practical, because it should clasp in the joints, which cannot be done until the moment the joints are totally removed. A fork can already be put in position before the joint is removed. This gives extra safety during the disassembling process of the construction. This floor slab fork can only be used if one of the long sides of the hollow core slabs is accessible. The order of disassembly should therefore be to first take out one of the walls parallel to the hollow core slabs. Consequently the hollow core slab closest to the wall should be taken out, after that the neighbouring one and so on. To take out the wall elements, a lifting crane with hoisting cables that should be attached through the block-outs for the windows is used. To be able to place the cables through the holes, the wall elements that should be taken out first should come loose from the adjacent floor slab. After sawing the joint between the two elements, the wall element should be slightly tilted to the outside of the building by extending the shores that support the wall element a little bit. By doing this, the bottom side of the wall element should be well enough attached to the floor to secure that it will not fall out of the construction. This can be done by placing shorter shores near the bottom of the wall elements.

On the images on the next pages the process of taking out the elements is illustrated. It concern a floor bay with concrete topping. In case of a finishing layer, a pneumatic hammer instead of a diamond saw is used to cut through this layer. The process was developed with help of the reference projects and the people interviewed. Extra information on the images is given below. The image number is indicated.

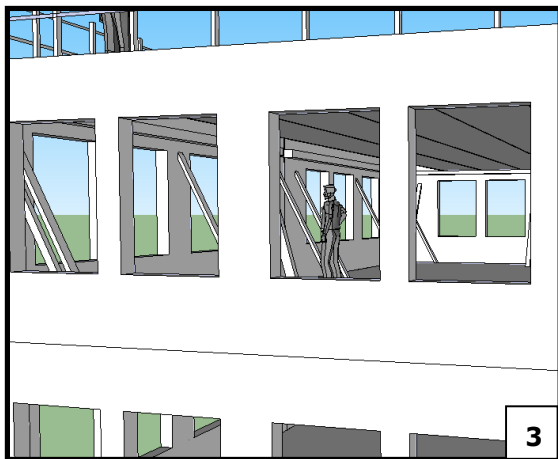
1. The ten standard floors of the PWC are modelled in Sketch-up.
3. The walls need to be shored because their connections are hinged and when the floor slabs are removed they lose their support.
4. Before the lines can be traced out, their location of the longitudinal joints between the slabs have to be indicated:
 - By measuring
 - By drilling at the location that is assumed to be the joint. If a harder layer is reached after the finishing layer is removed, the joint is situated on another location
18. After sawing the concrete topping the joint between the hollow core slabs can be removed by using a wig and a hammer.
24. The process can be continued by removing the next HCS and consequently the walls underneath these slabs.



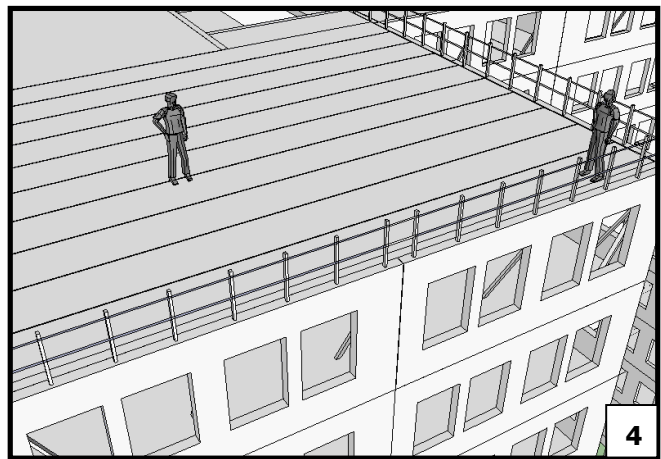
10 standard floors of PWC



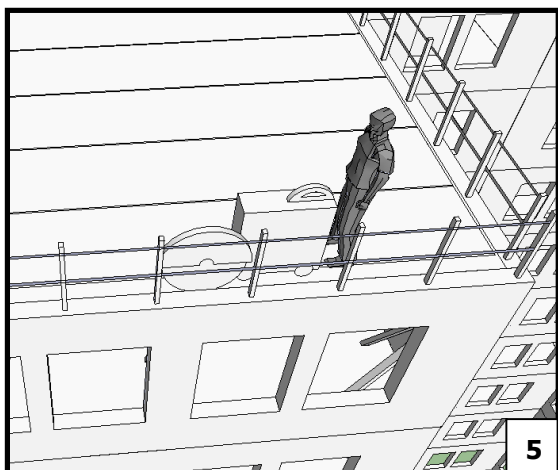
Step 1: place safety fences and attach the building workers to it



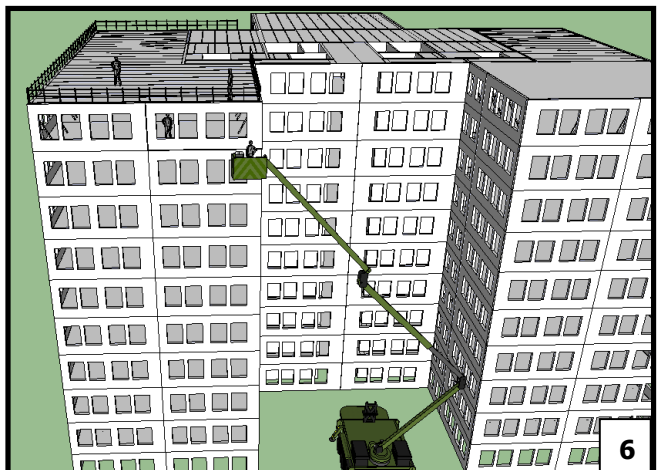
Step 2: place shores to support the wall elements



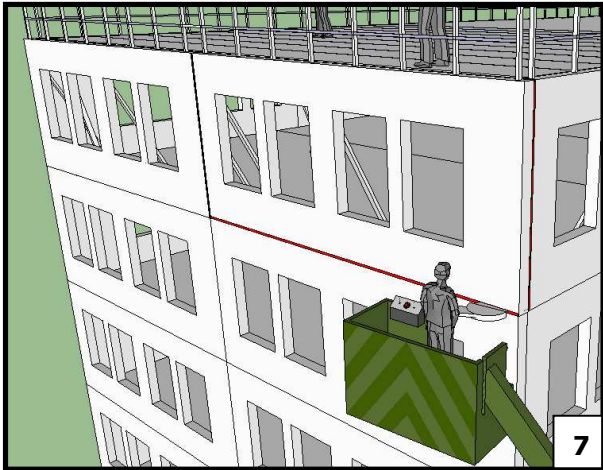
Step 3: Trace out the saw-cuts



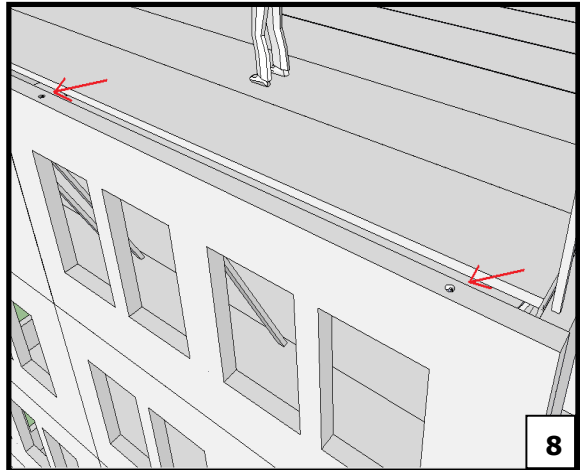
Step 4: Saw the longitudinal joint between wall elements and HCS with a diamond saw



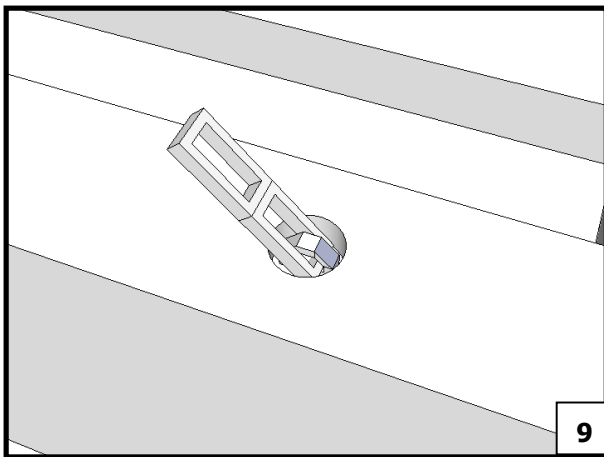
Use a cherry picker to saw the rest of the joints of the wall element



Step 5: Saw the other wall joints from the outside with a diamond saw



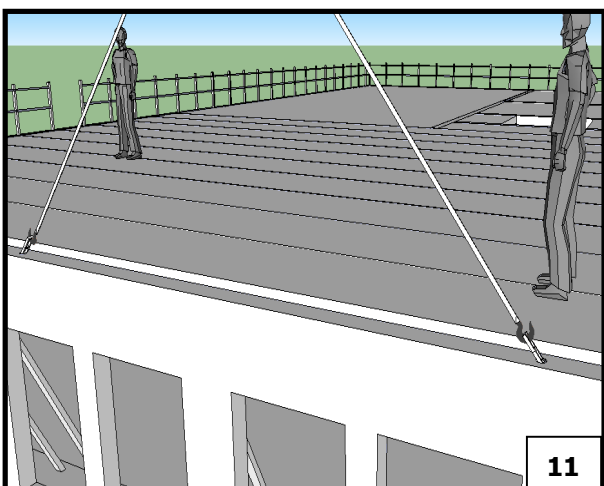
Step 6: Localise the lifting anchors with help of a compressor and pneumatic hammer



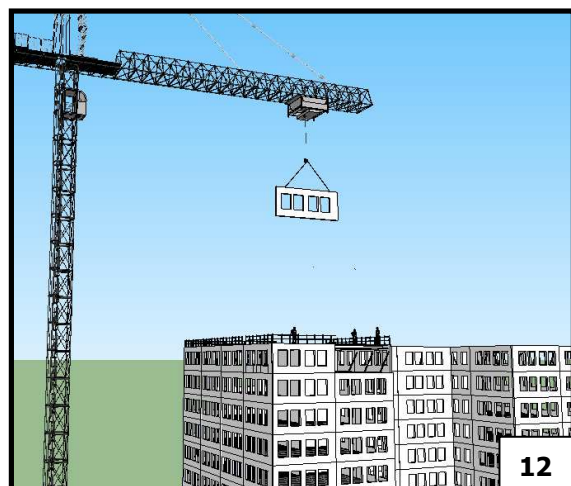
Step 7: Attach lifting brackets to the lifting anchors



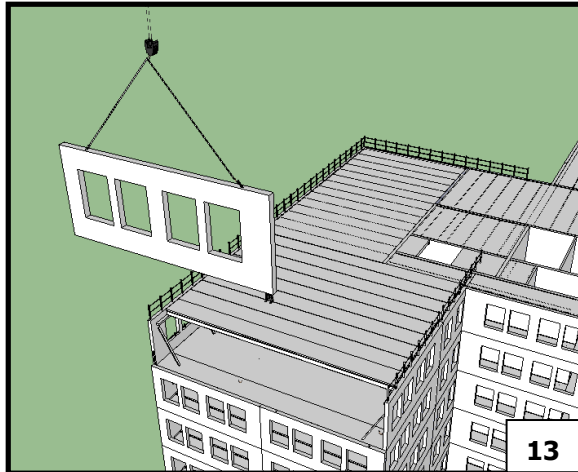
Use a building crane to take out the wall elements



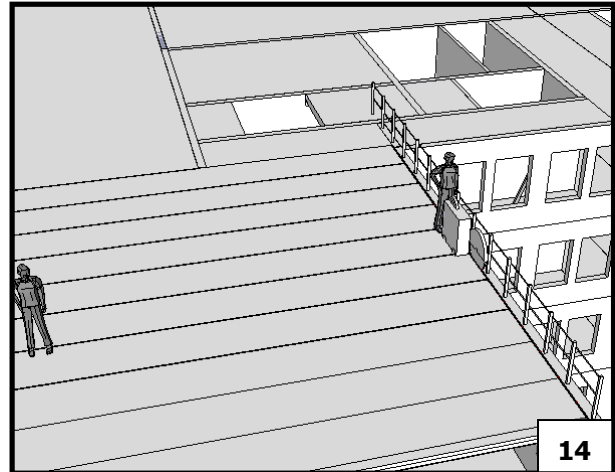
Step 8: Attach the lifting hooks to the lifting brackets and remove the shores



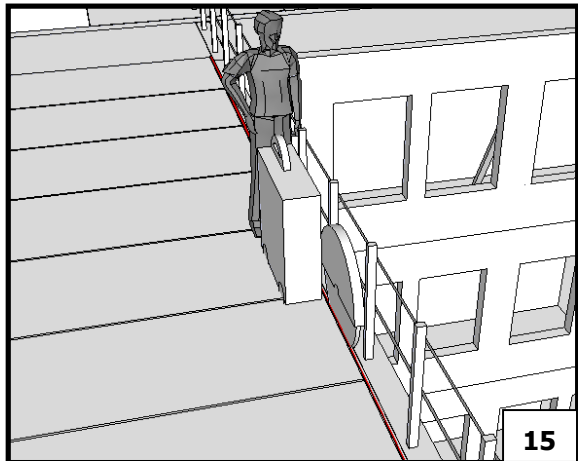
Step 9: Take out the first wall element



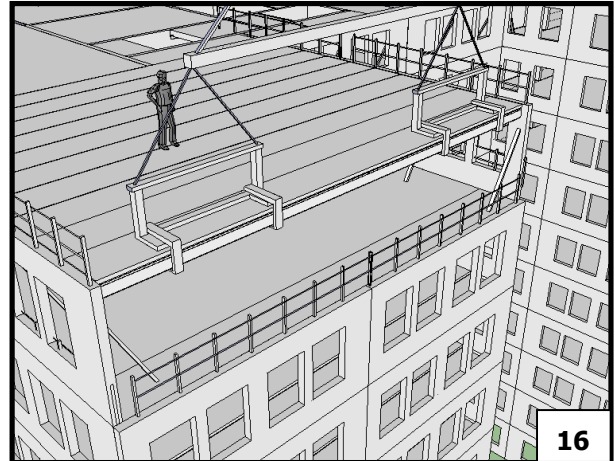
Step 10: Take out the second wall element in the same way



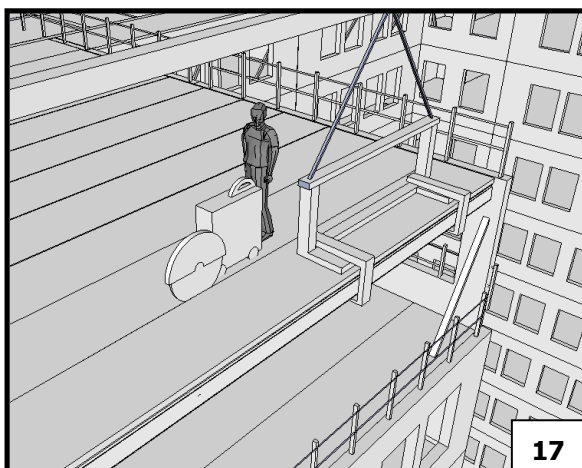
Step 11: Saw the joints between the short side of the HCS and the wall elements with a diamond saw



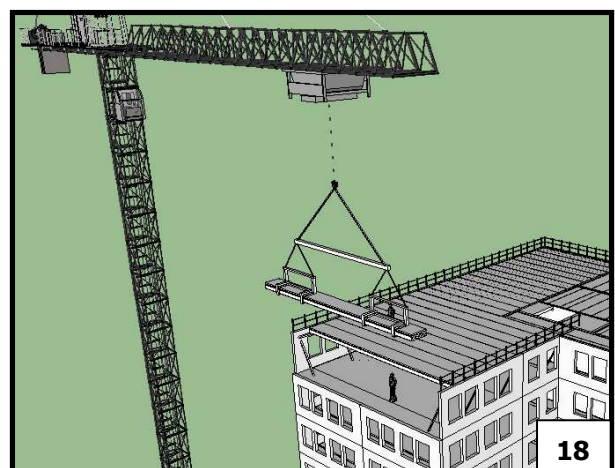
Sawing the joint



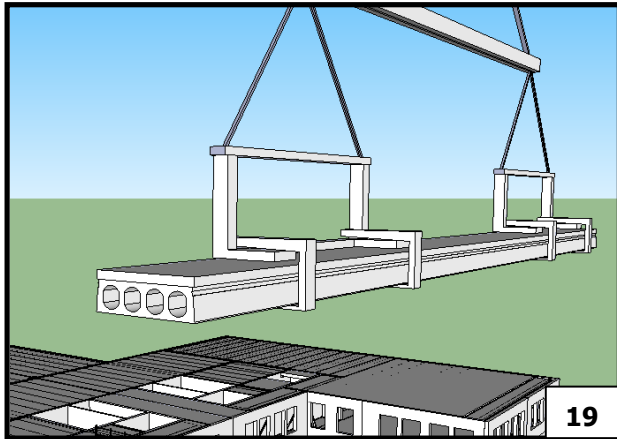
Step 12: Put the floor slab fork in place to



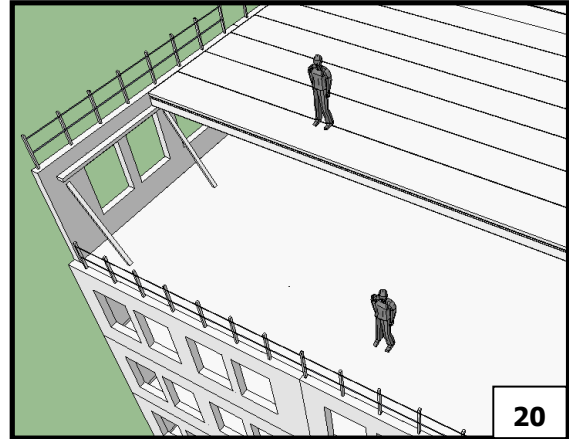
Step 13: Saw the concrete topping between the first and second HCS



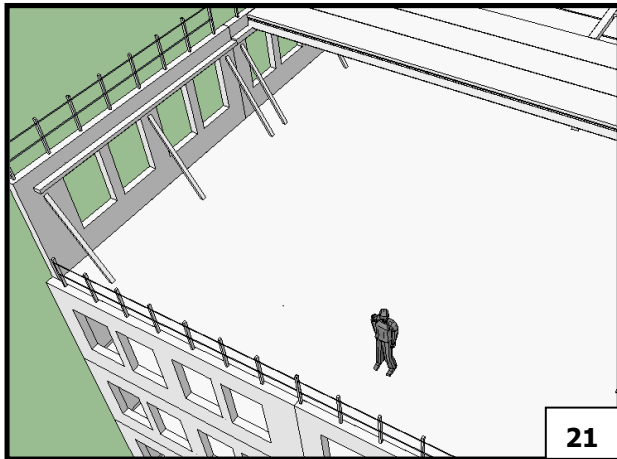
Step 14: Take out the first HCS



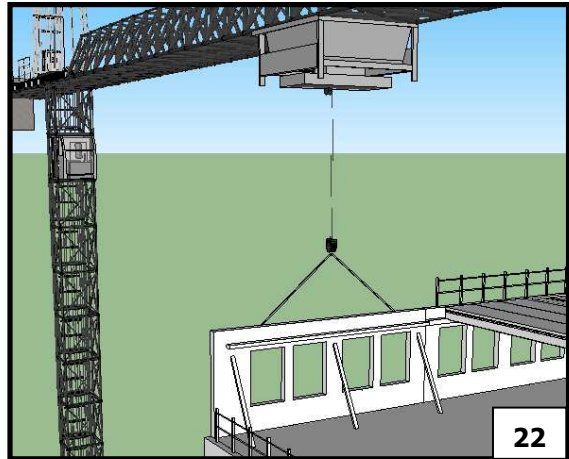
Impression of the HCS



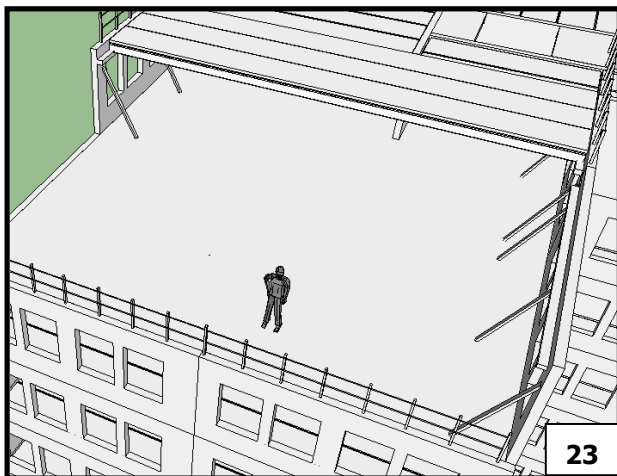
Step 15: Place a safety fence on the next floor and take out the second HCS in the same way



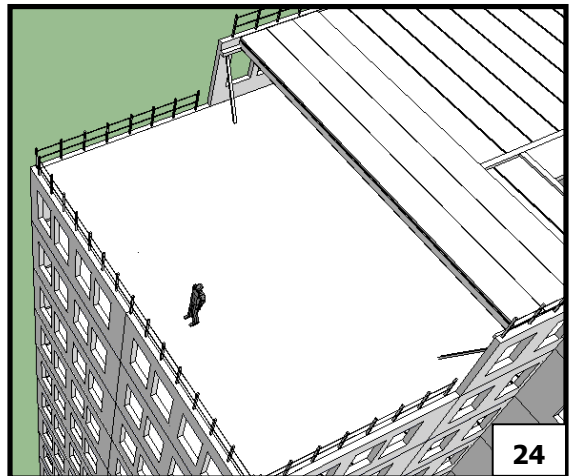
Step 16: Take out the next HCS's and remove the safety fence



Step 17: Put in place the hoisting cables and remove the wall shores



Step 18: Take out the wall element



Step 19: Take out the opposite wall element in the same way and place safety fences. Continue with the HCS's

5.4.2. Per floor bay

N200 finishing layer 50 mm

At some places between the walls or the beams and the HCS, there are tie-bars to attach them to each other. For these joint, a diamond saw should be used. There is no reinforcement between the slabs so these joints can be taken out by using a wedge and a hammer. To cut through the finishing layer, it is probably necessary to use a pneumatic hammer or a diamond saw.

T260 finishing layer 50 mm

Apart from the tie-rod around the floor bay, also for these floor bays tie-bars are placed between the hollow core slabs and attached to the adjacent walls to increase the stability of the construction. The joints around the floor bay are therefore sawn with a diamond saw. For the joints between the HCS the same method is used as for the N200 slabs.

H320 finishing layer 50 mm

Also for these floor bays, the joints between the HCS can be removed with pneumatic hammer and wedge and hammer, and the joints between HCS and walls are to be removed with a diamond saw.

H320 concrete topping 60 mm

The concrete topping has a reinforcement net with steel bars in two directions and should therefore be sawn between each slab. It is very important to indicate the location of the joints at first. This can be done by measuring the distance between the slabs when the layout plan (in Dutch: legplan) is known. After this indication drilling holes to verify it is also a good method. Apart from the concrete topping, tie-bars are used in every longitudinal joint which should also be sawn off near the wall elements.

For this disassembling process, the diamond saw and pneumatic hammer are much used. As concluded before, the pneumatic hammer has negative influence on the health of building workers because it produces much vibrations and noise. Either the pneumatic hammer should be improved or another method should be found to disassemble a building with. For the diamond saw it holds that the types that produce less noise should favourably be used. More research is needed after other disassembling equipment that can improve the disassembling process on health aspects for building workers.

5.5. Function reuse

5.5.1. Possibilities

For each floor type of the PWC, it should be determined if the slabs are suitable for reuse in a residential building and in what type of residential building. For reuse from office buildings to residential buildings, fire safety and sound insulation are the most important criteria. The following table is a summary of these requirements per type of residential building.

Class	Type of building	Fire safety		Sound insulation	
		Top layer thickness (t)	Time	Impact	Airborne
1	Single-family dwelling ≤ 7 m	no limit	30 min	≤ 59 dB	≥ 52 dB
1	Single family-dwelling 7 - 13 m	no limit	90 min	≤ 59 dB	≥ 52 dB
2a	Apartment building ≤ 7 m	0 - 70 mm	30 min	≤ 54 dB	≥ 52 dB
2a	Apartment building 7 - 13 m	0 - 70 mm	90 min	≤ 54 dB	≥ 52 dB
2b	Apartment building 13 - 70 m	0 - 50 mm	120 min	≤ 54 dB	≥ 52 dB
3	Apartment building >70 m	0 - 50 mm	120 min	≤ 54 dB	≥ 52 dB

Table 5-1: Fire safety and sound insulation requirements for hollow core slabs in residential buildings

With this table and the properties of the hollow core slabs of the PWC, it is per function indicated if reuse is possible and what type of floating floor is needed to fulfil the sound insulation requirements. (Y = yes, N = no)

Type	Concrete topping (mm)	Weight (kg)	Single-family dwelling	Single-family dwelling	Apartments	Apartments	Apartments
			≤ 7 m	7 - 13 m	≤ 7 m	7 - 13 m	≥ 13 m
N200	0	270	Y	Y	FF 2 (t ≥ 55 mm)	FF 2 (t ≥ 55 mm)	N
T260	0	370	Y	Y	FF 1 (t ≥ 55 mm)	FF 1 (t ≥ 55 mm)	FF 2 (t ≥ 15 mm)
H320	0	430	Y	Y	FF 1 (t ≥ 30 mm)	FF 1 (t ≥ 30 mm)	FF 1 (t ≥ 30 mm)
H320	60	574	Y	Y	FF 1	FF 1	N

Table 5-2: Type of floors WPC and their possible reuse

* FF 1 = Floating Floor 1: $\Delta L_{in} \geq 11\text{dB}$

The total weight of the hollow core slab floor incl. top layer should be at least 500 kg/m²

** FF 2 = Floating Floor 2: $\Delta L_{in} \geq 14\text{dB}$

The total weight of the hollow core slab floor incl. top layer should be at least 400 kg/m²

Fire safety

The requirement of a fire resistance time of 90 minutes is met for all floor types. 120 minutes is also mostly met in cases where they are reused in residential buildings, because the

computable value of the variable load is only 1,75 kN/m². For some slabs, however, this load should be increased by a concentrated load coming from a stair trimmer. It is therefore advisable to determine the fire resistance of a construction by taking a load of about 3,0 kN/m². Another factor that has influence on the fire resistance time of a slab is its span. For lower spans, the fire resistance time goes up. In residential buildings the span is usually small, so the slabs coming from the office building fulfil the 120 minutes requirements.

It is assumed that finishing layers come off easily, so they are not taken into account as top layer. The concrete toppings, however, are bonded strongly to the hollow core slabs and it will therefore require too much effort to remove them. The existing concrete topping will therefore also be present in the new construction and should be considered. For fire safety reasons the hollow core slabs with concrete topping are not suitable for all types of reuse. This is indicated in the table with an N.

By performing a pilot project it should become clear if the finishing layers indeed comes off as easily as assumed. The amount of effort needed should be evaluated to determine the type of equipment most suitable to break off this layer from the slabs. Also the different strengths of finishing layer and their differences in bonding with the hollow core slabs need to be investigated in further research.

Sound insulation

To determine the minimum mass and type of floating floor, the impact sound insulation is guiding. Only for single-family dwellings a floating floor is not required when reusing the slabs, because the sound requirements are not very high compared to apartment buildings. A floating floor on itself is for most hollow core slabs coming from an office building not enough to create a sufficient level of insulation. In those cases it is required to use a concrete layer with a certain thickness. This concrete layer should be placed directly on top of the hollow core slabs and wires can be placed in this layer. This is common practice, but attention has to be paid to sound leaks when wires go through the insulation between the slabs and floating floor.

It has become clear from literature that applying a floating floor does not always lead to the desired level of sound insulation. (VBI, 2003) In the previous chapter, it was outlined that there are two different levels of sound reduction that can be reached by applying a floating floor. In this case study, the floating floor that is applied on the second hand slabs is assumed to reach the lowest value of the two. By increasing the impact sound insulation of a floating floor to 14 dB instead of 11 dB however, the underlying floor only has to have a weight of 400 kg/m² instead of the 500 kg/m² assumed in the case study. With this weight reduction, the second hand slabs of office buildings are suitable for more types of residential buildings. It should therefore be examined more thoroughly what sound reduction can be reached with which layers of a floating floor. The amount of work required to place the floating floor and the chances on reaching the actual claimed quality are aspects that should be looked into.

5.5.2. Reuse per type of slab

N200

The N200 hollow core slabs without concrete topping are suitable for single-family dwellings but also for low apartments when a floating floor with $\Delta L_{\text{lin}} \geq 14\text{dB}$ and a top layer of 55 mm is applied. The quality of this floating floor has to be high and there is a fair chance that this level of insulation is not reached because of possible sound leaks. It is therefore determined to reuse this type of slabs in single-family dwellings.

T260

The A260 floor without concrete topping can either be used in single-family houses or in apartment buildings. In this case there are two options. For apartment buildings up to 13 m a top layer of 70 mm is allowed, whereas for apartment buildings higher, the top layer may maximally be 50 mm. This means that for apartment buildings up to 13 m, a floating floor with $\Delta L_{\text{lin}} \geq 11\text{ dB}$ and a top layer of 55 mm is possible and for higher residential buildings a floating floor with $\Delta L_{\text{lin}} \geq 14\text{ dB}$ and a top layer of minimally 10 mm should be applied. When the top layer is uncoupled from the slab, it is however allowed to use a top layer of more than 50 mm and in this case the floating floor with $\Delta L_{\text{lin}} \geq 11\text{ dB}$ is also possible. A third option for apartment buildings higher than 13 m is to use a concrete top layer of a low strength up to D15. In this case, the top layer is only calculated for have the height, so the layer can maximally be 100 mm.

It is decided that the A260 floor will be reused in apartment buildings up to 13 m. A floating floor of $\Delta L_{\text{lin}} \geq 11\text{ dB}$ is applied with a finishing layer of 55 mm in which wires can be placed.

H320

The H320 floors without concrete topping can be used in all types of residential buildings. For apartment buildings they need a floating floor with $\Delta L_{\text{lin}} \geq 11\text{ dB}$ and a top layer of minimally 30 mm. For single-family dwellings the slabs are over-dimensioned, so it is best to reuse them in apartment buildings. For this case study, they are reused in apartments with a maximum height of 13 m.

The A320 floors with a concrete topping of 60 mm cannot be reused in apartment buildings with a height of more than 13 m because of the restrictions on thickness of the concrete topping. They can be reused in lower apartment buildings, but the extra finishing layer that might be necessary for wires has to be uncoupled from the concrete topping to keep the top layer below the maximum allowed 70 mm. With a floating floor of $\Delta L_{\text{lin}} \geq 11\text{ dB}$, the sound insulation requirements are largely met.

It should be remarked that the concrete topping present on used HCS will not provide for frame working anymore in the new floor because the reinforcement between the slabs have been cut. Since most lower apartment buildings do not need a concrete topping this will in most cases not form a problem. For floors in apartment buildings that do need a concrete

topping, in case of sloping walls or when extra load needs to be transferred, it is only possible to reuse HCS without concrete topping. The needed concrete topping can in that case be applied after the slabs have been put in place.

Slabs with a concrete topping of more than 70 mm

Although not present on the 10 floors that are looked into, these floor types are fairly common in office buildings built before 2007. The hollow core slabs with concrete topping of more than 70 mm, can functionally only be reused in single-family dwellings with a height of less than 13 m. The height of the floor of the residential buildings increases and has to be dimensioned on reusing this type of floor slabs. The extra weight of the elements also brings along extra costs for transport and assembly. This type of floors is therefore not very suitable in residential buildings and should probably best be used for recycling or in constructions with another function.

5.5.3. Adaptations for new buildings

Two other reference projects are chosen for reusing the slabs from the PWC. One is a standard single-family dwelling and the other a standard apartment building of 5 floors. More information on these projects will be given in the chapter on the LCA.

In order to reuse the slabs coming out of the PWC, the finishing layer has to be removed. This might have been happened already by taking out the slabs or else this layer, or the part that is left, should be removed with help of a wedge and a hammer afterwards. The bottom sides of the slabs have to be cleared from mountings for pipes and the holes that are consequently created have to be filled. The ceiling has to be sprayed with some sort of gypsum to create a smooth surface.

It is decided that in the reference projects the second hand slabs will only be reused as story floors and not as ground floor. In both reference projects the ground floors are not present on the drawings, probably because they were not made of hollow core slabs. Often, ground floors have an insulation layer attached to the bottom side of the slab because of higher temperature requirements. This is also possible with used slabs after they have been taken out of the old building but since it is not clear what block-outs are needed in the ground floor, this is left out of the calculation of reuse.

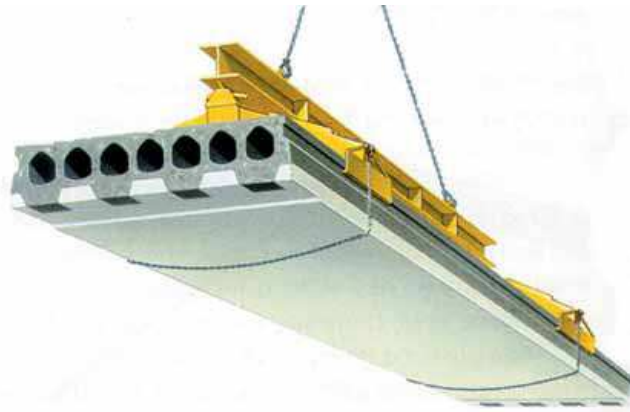


Figure 5-6: Insulated hollow core slab for ground floor (source: BFBN)

After the second hand slabs have been placed in the new buildings a finishing layer is poured on top of them just like with new slabs. For apartment buildings, first a floating floor needs to be placed to meet the sound insulation requirements. More about this floating floor can be found in the next chapter.

5.6. Reassembly

Second hand hollow core slabs differ from new slabs because not all cores are empty anymore. As explained before, most HCS in the PWC are in longitudinal direction at one or two places connected with the supporting wall. A steel bar is placed in the cores and the core is partly filled with mortar. The restriction when reusing these HCS in residential buildings is that not at the location of each core a new connection can be made between the slab and the wall. A construction system which does not require connections between the cores and the other elements is therefore most suitable.

5.6.1. Single-family dwellings

For single family dwellings a commonly used construction system is to place the hollow core slabs on top of the prefab concrete walls elements.(Van Paassen) In between a layer of mortar is used to form a solid construction. No concrete topping is needed in this type of constructions.



Figure 5-7: Construction single family-dwelling (Source: BFBN)

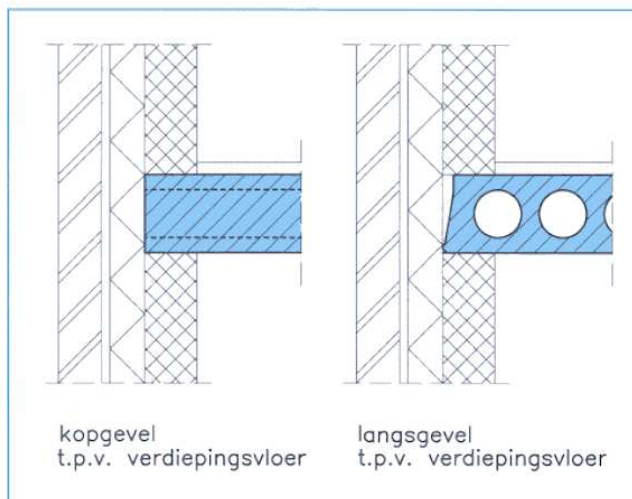


Figure 5-8: Details construction of HCS between the prefab concrete walls

5.6.2. Apartment buildings

For low apartment buildings, the HCS can also be placed between the wall elements. Martin Koppenhol of VBI states that this type of construction is used very often in residential buildings. It is possible to build up a building like this up to 6 floors. For more than 6 floors, it becomes impossible because the HCS cannot transfer the loads anymore. A solution for this is to fill up the holes with concrete.

For higher apartment buildings, often connections are made between the holes of the hollow core slabs and the load bearing walls to secure the stability of the building. It is therefore easier to reuse the hollow core slabs coming from office buildings only for low residential buildings.

5.6.3. Results

To disassemble the 10 standard floors of the PWC a diamond saw, pneumatic hammer and wig and hammer are used to break the connections between the building components. The wall elements and HCS are lifted out of the construction with a building crane; the wall elements with help of hoisting cables and the HCS with help of a floor slab fork. It is assumed that finishing layers come off easily by using a wig and a hammer. The concrete toppings are however assumed to be bonded strongly to the hollow core slabs and it will not be removed.

The hollow core slabs coming out of the PWC can best be reused for single-family dwellings and apartments buildings up to 13 meters. For both type of buildings a standard building is used to calculate the possible percentages of reuse.

The 200 mm slabs that are reused in a single-family dwelling do not need extra adaptation apart from sawing them to size in longitudinal direction, removing the mountings on the bottom side, filling the holes and spraying on a finishing layer. The other slabs also need a floating floor and in case no concrete topping is present also an extra concrete layer to meet the sound insulation requirements.

The process of reassembling is the same for old slabs as for new slabs. The only restriction of second hand slabs is that the cores are not all empty anymore and it is therefore not always possible to make new connections with the wall element. Therefore, a construction system should be chosen which does not require connections between the cores and the other elements. For residential building up to 6 layers, placing the hollow core slabs between the load bearing wall elements is a very common and suitable system.

6. Life Cycle Assessment

The aim of reusing hollow core slabs is to reduce the environmental impact over its whole life cycle. What the actual environmental impact of this concept is compared to the use of new HCS is reported in this chapter. First the concept of LCA is explained and the most suitable methods for this particular project are mapped out. Continuously the LCA study is performed and the results are presented in graphs and tables.

6.1. General

To make an environmental comparison between reuse of elements and the complete demolition and fabrication of new elements, an LCA (Life Cycle Assessment) method can be used. An LCA can be defined as the collection and assessment of all inflow and outflow and possible environmental effects of the product system during its lifecycle. This means that the LCA is a useful tool for the analysis of the environmental effect of a product during all its stages of its lifecycle including the extraction of raw materials, fabrication of materials, product components to the product itself, as well as the use of the product and the final processing after demolition by reuse, recycling, land filling or incineration. This lifecycle can be describes by 'from cradle to grave'. A product system exists of all processes that are involved in the lifecycle of the product. An environmental effect contains all influences on the environment, including depletion of raw materials, emissions of hazardous materials and different ways of land-use. (NIBE, 2012)

An LCA is, as far as possible, an analysis on a quantitative level. This is to create a clear image of all the environmental effects and to be able to compare different alternatives. To come to a simple indicator it is important to weigh and combine the different scores. There are several options to do this:

- Panel methods
- Distance to Target methods
- Technology methods
- Monetarisisation methods

Panel methods have a panel ascribe weighing factors to each effect category. Distance to Target methods normally use a distance to a policy goal as weighing factor. An example of a technology method is the Ecological Footprint in which the environmental load is expressed as necessary surface to undo this environmental load. The last option is to monetise the environmental load. This can for example be done with the shadow prize method. (TNO, 2004) In this environmental cost method, the equivalent environmental effects are multiplied by the monetising cost numbers per environmental effect. By adding up all the environmental costs, a total environmental cost overview is created, a weighed score in one number. The shadow prize of an emission is determined by the costs of the necessary measure to achieve the emission target, the so-called marginal costs. This shadow prize reflects the costs that society is willing to pay to achieve the environmental target. (NIBE, 2012)

According to TNO and CE Delft (CE Delft, 2010), this method has several advantages over the other methods such as:

- The shadow prize has a neutral unity with which the different environmental effects can be heaped together
- The different environmental effect categories can easily be weighed
- It is in line with the governmental instruments
- It is in line with the current economic reality in the business world because it reveals the external costs
- It supports integral analyses to provide transparent results with which the policy and business world can recognize their own activities and the relationship with environmental themes

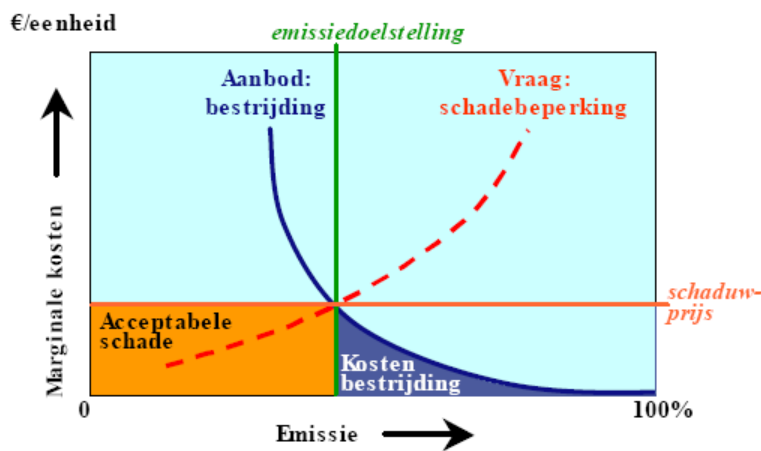


Figure 6-1: Shadow prices (source: Rijkswaterstaat)

6.2. Aspects

To make an LCA, the following three aspects are inevitable (STUTECH, 2012a):

- Classification method
- Database
- Instrument

6.2.1. Classification method

Several classification methods are drawn up to have the LCA come about in a uniform way. These definition methods are laid down in norms and describe the several parts and lifecycles of materials. They also state what parts do not have to be part of the quantification of a material. In the 'Bouwbesluit 2012' an article about sustainable construction is included that states that the emissions of greenhouse gasses and the depletion of raw materials needs to be quantified according to the "Bepalingsmethode Milieuprestaties Gebouwen en GWW-werken" (SBK). This classification method is in line with the European guidelines. (STUTECH, 2012a)

Stutech discusses, apart from the classification methods, the databases and instruments that can be used by concrete technologists, structural engineers and architectural and civil engineer designers. The aim is to support them in making well-considered choices in the design of a concrete building component and the type of concrete to use.

The TWIN2011 model is developed by NIBE which argues that it is a method most in line with the latest state-of-the-art. It uses the CML-2 method (Guinée et al., 2002) but combines it with the original TWIN-model (Haas, 1997) and the method of Müller-Wenk (1999) for the judgment of nuisance and road transport. The advantage of the combined method is that apart from the qualitative data also the less quantitative data are coped with to allow for a broader assessment.

A classification method should be determined on the basis of the system boundaries. What environmental processes and aspects should be taken into account in the calculation? For the calculation of the environmental impact of concrete elements at least the environmental impact of the extraction of bulk materials should be taken into account. The CML-2 method lacks this aspect (NIBE, 2012) and therefore the TWIN2011 model is preferred over this method.

6.2.2. Databases

According to Stutech, the three following databases are most qualified to be used for LCA calculations:

- Nationale milieudatabase (NMD)
This database is drawn up according to the classification method NEN-EN 15804 (NEN, 2011)
- Milieu Relevante Product Informatie (MRPI) bladen
The MRPI sheets are to fill the National Environmental Database
- European Life Cycle database (ELCD)
The LCI data that are included in ELCD are drawn up according to NEN-EN-ISO 14040 and NEN-EN-ISO 14044

The NMD is developed to create a uniform database so that everyone uses the same values for emissions. In such a way the output of environmental values is the same for one building calculated with different instruments. (STUTECH, 2012a, 2012b) This database is most used in the Netherlands and will also be used in the comparison of environmental impact between reusing elements and fabricating new ones.

6.2.3. Instruments

There are several instruments developed to perform an LCA study. There are general programs but also ones specially created for the building sector. They make it easier to perform an LCA to calculate the environmental impact of a building for example. (Enslin building, 2009)

The most widely used general tool in the Netherlands is SimaPro. It was not specifically designed to carry out LCA's for buildings but the complete databases combined with the flexibility of the impact assessment methodologies makes it suitable for this purpose. To calculate the environmental impact of the levelling down of the Elementum flat in Maassluis, this program was also used. Van Nunen also executed his calculations for his newly developed variant of reuse of elements in SimaPro.

Specific tools such as GPR Gebouw and Greencalc+ are developed to calculate the environmental impact of a building over its lifetime. Both programs are standardized and not designed for other processes such as disassembly of a building. It is possible that the programs allow for such inputs, but with SimaPro you can create your own process. This program has much more options and is therefore chosen to use for the LCA of reuse of elements.

6.2.4. Calculation

An LCA is carried out in four steps. (NIBE, 2012)

1. Determination of the goal and scope
Laying down the subject and profundity of the study, the central objective and research questions, the functional unity or comparison basis, to be evaluated product variants, definition of study and system boundaries.
2. Inventory of environmental data
Inputs such as energy and raw materials, outputs such as emissions, attribution inflows and outflows of products, intervention table of all inflows and outflows in the lifecycle.
3. Impact assessment
Selection of environmental effects, assign emission to environmental effects (classification), determination scores of environmental effects (characterization), normalization of the scores and possible weighing of the environmental effects
4. Interpretation
Analyses of all environmental effects and the qualifying factors, sensitivity analysis to determine the influence of assumptions and starting points.

6.3. Determination of the goal and scope

6.3.1. Central objective

The goal of this LCA is to make an environmental comparison between using newly fabricated hollow core slabs and using second hand slabs for a new residential building. Both a single-family dwelling as well as an apartment building are taken as reference projects to calculate the possible percentage reuse and the environmental impact of the reuse compared to using new slabs.

A second goal is to make an environmental comparison between the process of disassembling and demolishing a building. For this, an office building with 10 standard floors with different types of hollow core slabs is used.

6.3.2. Research questions

- What is the difference in environmental impact between demolishing and disassembling a building?
- What is the environmental gain by reusing hollow core slabs as opposed to recycling them?
- Does using second hand slabs bring along other negative effects that do not occur when recycling them and vice versa?

6.3.3. Functional units

Two different types of calculations with three different building are performed. Therefore, there are three different functional units. They will be described in this paragraph. The first concerns the demolition process versus the disassembling process, the second concerns new slabs versus second hand slabs in a single-family dwelling and the third new slabs versus second hand slabs in an apartment building.

Demolition phase

To give a total impression of the environmental gain of reusing old slabs coming from an office building in a residential building, the demolition phase also has to be taken into account. Part of the information obtained in this phase serves as input for the phase in which the slabs are actually being reused.

For the comparison between the demolition process and the disassembling process, the PWC in Brainpark III in Rotterdam that was built in 2005 is examined. This building has 14 floors of which 10 have the same floor plan with the same type of hollow core slabs. Other floors are either in-situ or only have a small percentage of hollow core slabs with deviated dimensions. More information on this building can be found in the previous chapter and in the appendices that present the floor plans of this building.

The functional unit is one standard floor including the walls that support the floor. The surface of one floor is 1161.9 m². The floor consists of fairly standard hollow core slabs that are used in office buildings. It concerns a combination of 200 mm, 260 mm and 320 mm slabs either with or without concrete topping. The connections between the floor elements and wall elements are mostly hinged with at some places steel rods that connect both.

All concrete parts of the construction of one storey are taken into account, because they all add to the emissions when taken down the building. This concerns the core walls and the walls of the façade that should be taken into consideration. The process in which the concrete of these elements is being prepared for recycling also has to be put on the balance of the disassembling or demolition process of one storey floor.

For the LCA calculation only the disassembling/demolition phase, the adaptation and the transportation are taken into account. The emissions in the disassembling/demolition phase come from the consumption of fossil fuels by running the machines that are used during both processes. The fabrication of the slabs before the building was built is not taken into account, because the environmental impact of it is subscribed to the existing building. It is not of influence of the environmental impact of reusing the hollow core slabs.

The method of disassembling is presented in the previous chapter with images made of the process. It concerns using a diamond saw to saw through the joints that are reinforced and a pneumatic hammer for the finishing floors above the joints. The joints without reinforcement are cut out by using a wig and a hammer. The elements are lifted out the construction with a lifting crane. They are transported by trucks to a storage place.

The method of demolition is bringing down the building with help of a demolition machine. The concrete is nibbled from the construction and crushed at site after it has come off the building. The crushed concrete is transported either to a local project where it is reused for road construction or to the prefab plant to replace gravel in new concrete.

At this moment, there are no plans to demolish the PWC, but the average service life of an office building of this type (with standard grids and surrounded by other office buildings) is about 30 years. The hollow core slabs have a service life of at least 200 years. Although there are no plans to demolish the building, it is taken as reference project and it is supposed to be dismantled within a year.

The environmental impact of disassembling versus demolishing one floor of the PWC will be converted to the impact of one m² floor slab. This way, the data can be used as input in the process of reusing the floor slabs in a new building.

Reuse of slabs coming from PWC in reference projects

It turned out earlier that the 200 mm slabs can best be reused for single-family dwellings and that the other slabs are most suitable for apartment buildings up to 13 m. Two standard buildings in both categories are therefore chosen to calculate the environmental impact of using new or second hand hollow core slabs.

Single-family dwelling

For the reuse of the 200 mm slabs coming from the 10 standard floors of the PWC, a standard single-family dwelling is chosen with a surface of 51 m² per floor. It concerns one of the dwellings of a project of 12 dwellings called IBBA that are to be built in Almere in 2012. In the dwelling 200 mm hollow core slabs will build up the floor. The supplier of the hollow core slabs is Dycore who also supplied the drawings of the project. The dwelling has 3 floors and thus a total surface of 153 m². 31% of the storey floor's area consists of slabs with large block-outs. The ground floor is not made with the same type of hollow core slabs because it needs to be insulated. It is therefore decided to only take the 1st up till the 3rd floor into account of which the 3rd floor is a flat roof. In the design, the roof is also constructed with 200 mm slabs and thus this type of reused slabs will also be used. Apart from hollow core

slabs, the finishing floor is also taken into account since this is part of the construction of the floor.

The requirements for this floor are the same as presented earlier in this report. For the sound insulation requirements it is assumed that the air noise difference $D_{n,T;A,k} \geq 52$ and that the impact sound $L_{n,T;A} \leq 59$ dB. 200 mm slabs fulfill these requirements. The highest storey floor of the dwelling lies at about 6 m above the ground which is lower than the limit of 7 m. For this type of construction, the fire load is low so the fire resistance time has to be at least 30 minutes. This requirement is met for all hollow core slabs with a thickness of at least 150 mm.

For the comparison of using second hand slabs and using new slabs, the fabrication process is taken into account. For second hand slabs, the fabrication is the process of disassembling the slabs and transporting them to the prefab plant. For new slabs it contains the extracting of raw materials, transportation and fabrication of the slabs. It is assumed that the construction method with reused hollow core slabs is the same as with new slabs. This part of the process is therefore not taken into account.

Comparisons are made on basis of the whole floor but also the environmental impact of each floor type per m².

At this moment, there are no plans to actually use second hand slabs in this dwelling, but this is the scenario that is examined. The time horizon is 75 years, since this is the normal design life of residential buildings. For this LCA study, the lifetime of the building is not taken into account. The calculation of the reuse of the HCS in the single-family dwelling is made for construction phase.

The floor plans of this building can be found in appendix D.3.

Apartment building

For the reuse of the 260 mm and 320 mm slabs coming from the 10 standard floors of the PWC, a standard apartment building with a floor surface of 220 m² per floor is examined. It concerns the 48 apartments Barones in Bennekom that are to be built in 2012 and for which VBI supplies the floor slabs. The actual building is 16 floors high, but it could have been an apartment building of 5 floors either (Van den Burg, VBI). Every floor consists of 3 apartments and a common staircase and elevator. 29% of the hollow core slabs have large block-outs. The type of floor slabs that are planned to be put in this building are AL320 slabs. These are especially designed for residential buildings and have more mass than normal 320 mm slabs used in office buildings.

The requirements for this floor are the same as presented earlier in this report. For the sound insulation requirements it is assumed that the air noise difference $D_{n,T;A,k} \geq 52$ and that the impact sound $L_{n,T;A} \leq 54$ dB. To fulfill these requirements floating floors are needed. The minimum thicknesses of the layers can be found in the Table 5-2: Type of floors WPC and their possible reuse. The highest storey floor of the apartment building lies at less than 13 m above the ground. For this type of construction the fire resistance time has to be at least 90 minutes. This requirement is generally met for all hollow core slabs with a thickness of at

least 260 mm. Only the 260 mm Beton Son floor does not always reach a fire resistance of 90 minutes Table 4-1: Properties hollow core slabs for office buildings (Source: VBI, Dycore and Beton Son). In this reference project, the floors come from Dycore, so the requirements are met.

Apart from the hollow core slabs, the extra materials that are placed on the slabs to create a floating floor are also taken into account in the LCA calculation. Since the extra materials that are needed for this floating floor are not used when the AL320 slabs are applied, the extra emissions caused by the fabrication of these extra layers are important for the comparison. The finishing layer that is needed for both floor types is also taken into account.

For the comparison of using second hand slabs and using new slabs the same stages in the process are taken into account as for the LCA of the single-family dwelling. Also for this building the calculations are made on basis of the whole floor but also per m²b of each floor type.

For this building, there are also no plans to use second hand slabs, but this is the scenario that is examined. The time horizon in this case is also 75 years. For this LCA study, the lifetime of the building is not taken into account. The calculation of the reuse of the HCS in the apartment building is made for construction phase.

The floor plan of this building can be found in the appendix D.4.

6.3.4. Effects

The effects that will be taken into account in this LCA are:

1. Abiotic depletion
2. Global Warming potential
3. Ozone layer depletion
4. Human toxicity
5. Fresh water aquatic ecotox
6. Marine aquatic ecotoxicity
7. Terrestrial ecotoxicity
8. Photochemical oxidation
9. Acidification
10. Eutrophication

6.3.5. To be evaluated product variants

For the demolition process 2 variants are examined:

1. Disassembling process
 - a. slabs and granules are transported to prefab plant
 - b. slabs are transported to local storage and granules to local project
2. Demolition process
 - a. granules are transported to prefab plant

- b. granules are transported to local project

For the single family dwelling 3 variants are examined:

1. Using totally new slabs
2. Partly using reused slabs (in case the building is not designed on reuse)
3. Using only reused slabs (in case the building is designed on reuse)

For the apartment building 5 variants are examined:

1. Using totally new slabs
2. Partly using reused slabs coming from the PWC (in case the building is not designed on reuse)
3. Using only reused slabs of 255 mm
4. Using only reused slabs of 320 mm
5. Using only reused slabs of 320 mm with a concrete topping of 60 mm

6.3.6. System boundaries

The system boundaries are very important, especially the boundary between the demolition process and the process of reusing the slabs.

The process of disassembling is taken into account as the 'fabrication process' of the second hand slabs. The emissions emitted during the process should be calculated per m² slab. The three stages of the disassembling/demolition process are:

- disassembly
- adaptation
- transport

In the disassembling process the emissions of the machines and tools used to take down the building are taken into account. For the adaptation, the sawing to size of the elements is taken into account. The transport is the transport from building site to prefab plant or to a local storage. Different variants are looked into because the transportation distance can have a large influence on the LCA and the distance is not fixed yet.

For the demolition also preparing the concrete for reuse as granules is taken into account and the transport of these granules to the prefab plant. There it will be reused for the fabrication of new concrete.

Not taken into account within this research are the transport of employees and the fabrication of the machines used for the process of demolition, transportation and construction.

6.4. Inventory environmental data

To be able to make an inventory, flowcharts of both disassembling and demolition processes are made. These processes are the input for the reuse or recycling of concrete coming from the demolished building. The flowcharts of disassembly and demolition can therefore also be

used for the different variants of reuse of hollow core slabs in a new single-family dwelling and an apartment building. For the apartment building a third flow chart is made to outline the process of adding a floating floor in case of reuse of HCS.

It is most conveniently arranged if stages are assigned to separate parts of the process to map out the inputs and outputs throughout the whole process.

Relevant stages are:

- Production
- Construction
- Demolition/disassembly
- Adaptation
- Transportation

The use stage is not taken into account because nothing happens with the hollow core slabs during this phase in the lifecycle of the slabs.

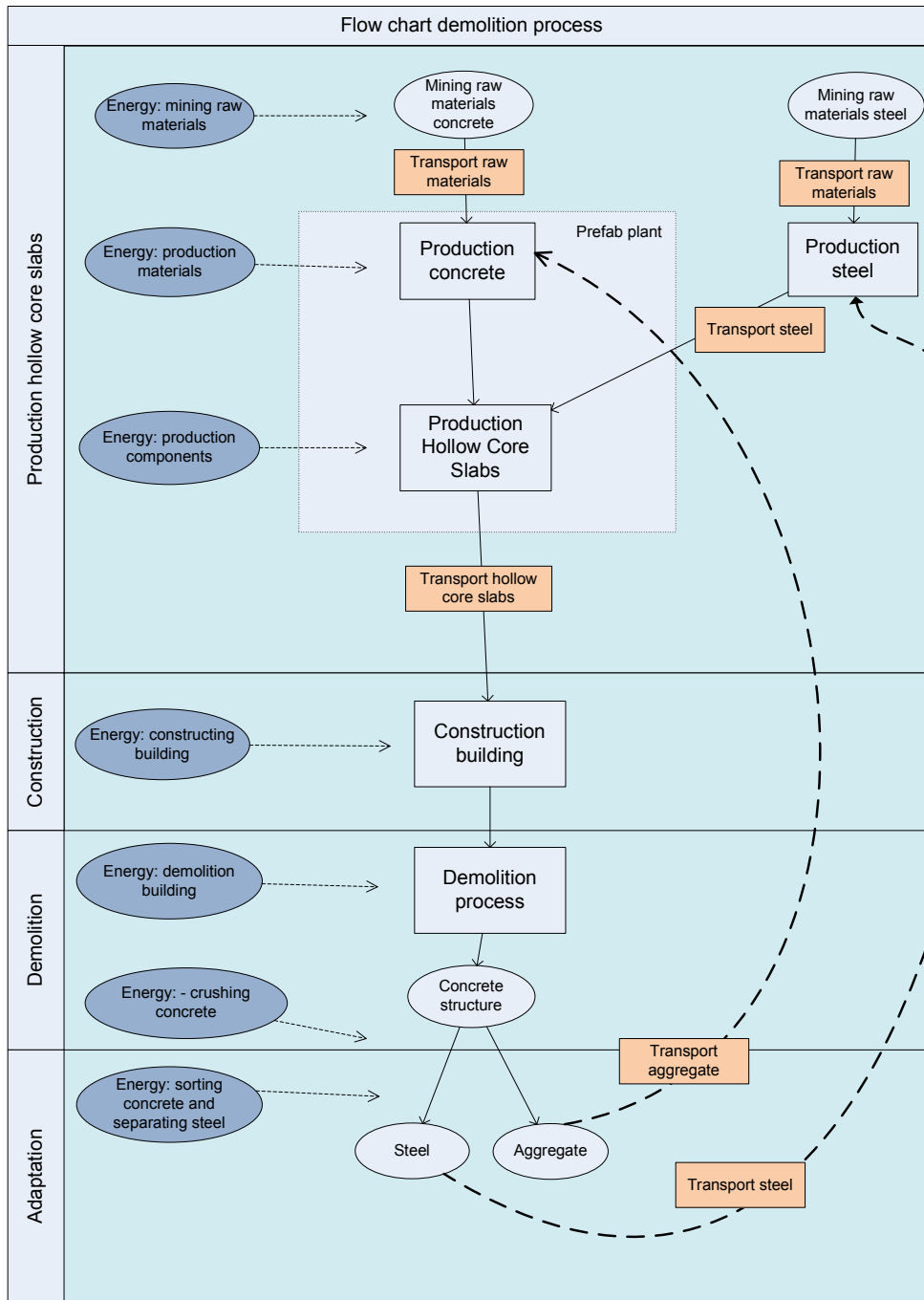


Figure 6-2: Flow chart demolition process

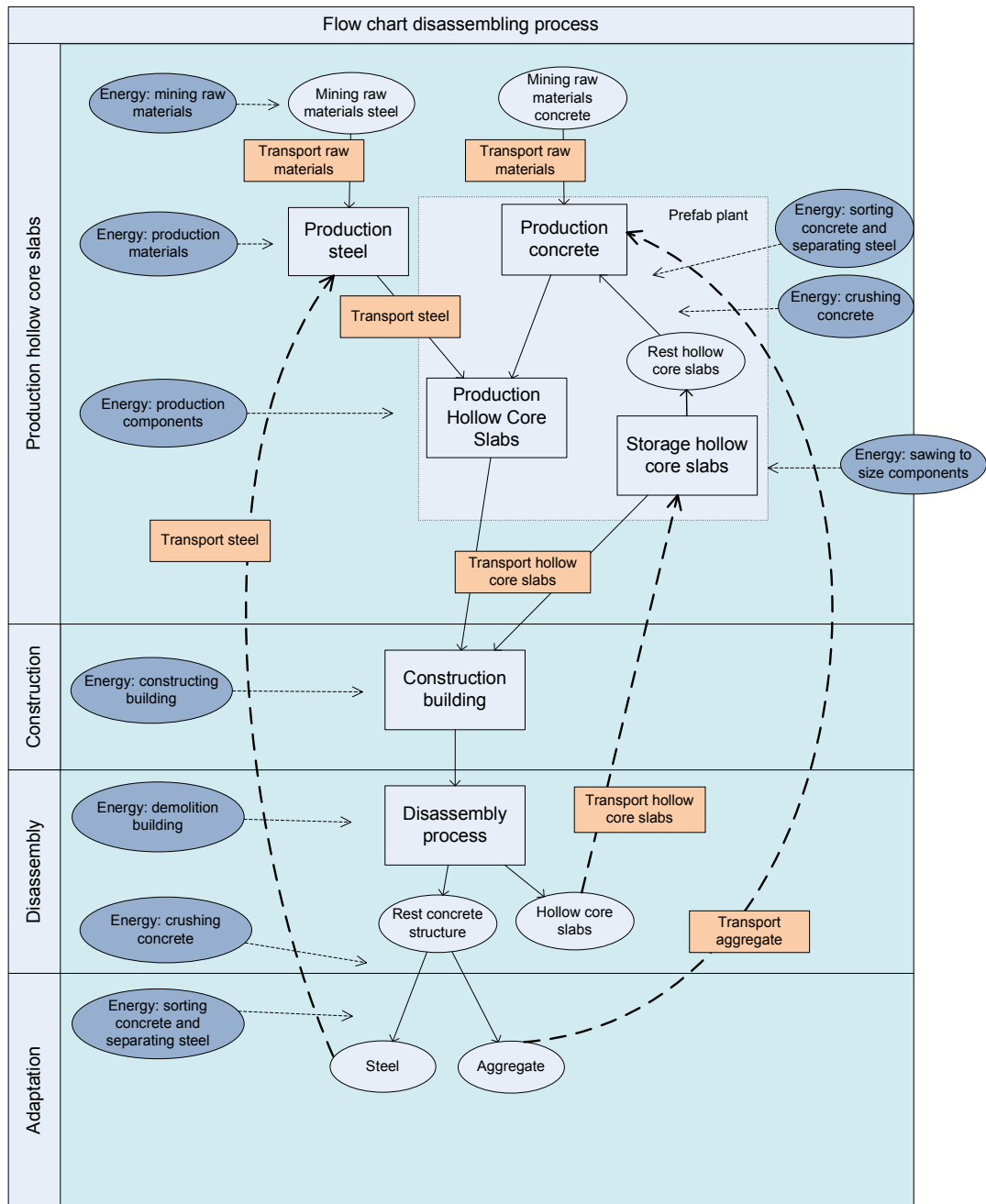


Figure 6-3: Flow chart disassembling process

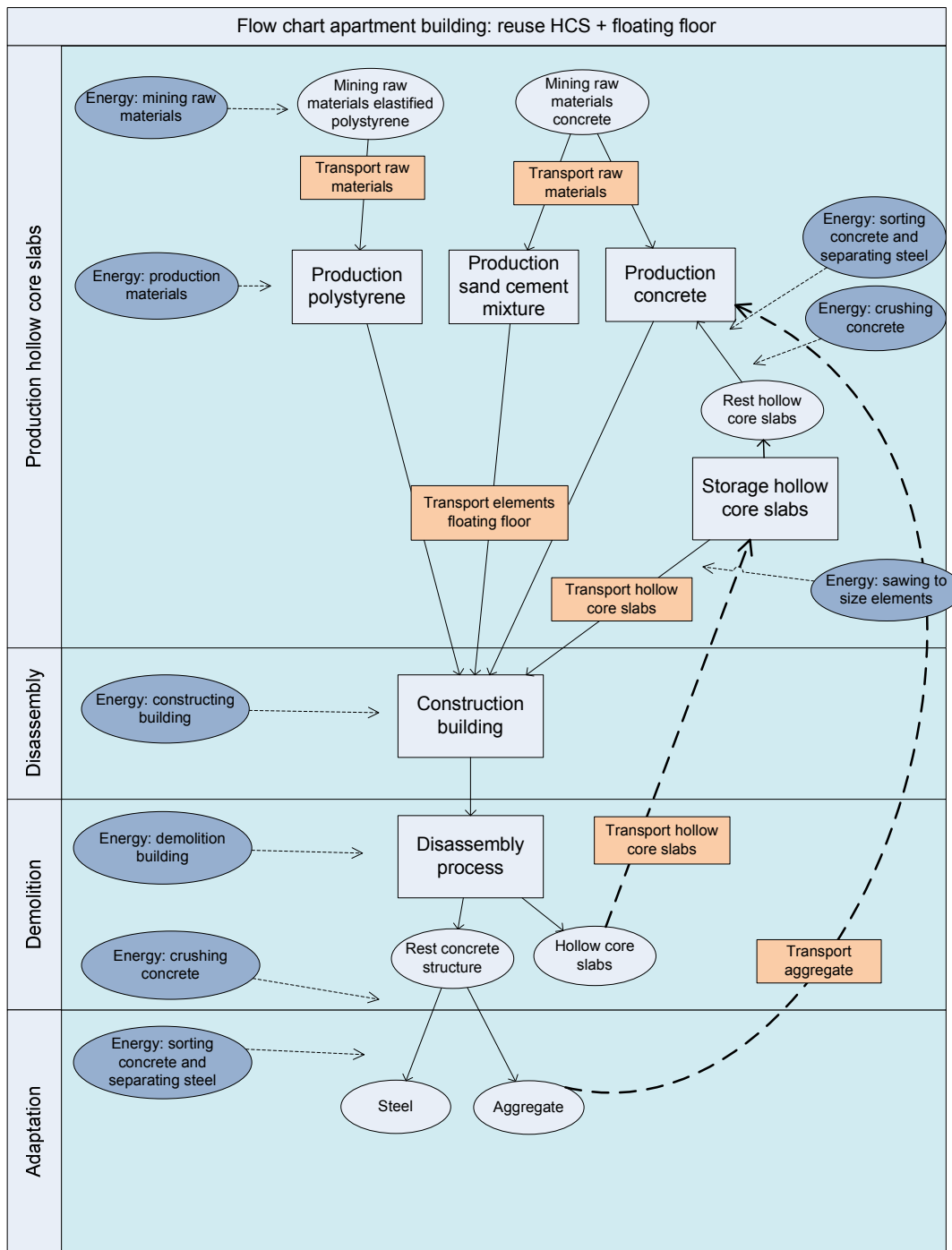


Figure 6-4: Flow chart of apartment building with reused HCS and a floating floor

Production

Raw materials for both concrete and steel for reinforcement need to be mined. Production of cement, one of the materials to make concrete with, is made in another factory than the concrete itself. Apart from the energy it costs to mine and fabricate the materials, they also need to be transported. This brings along emissions when fossil fuels are used for this transport. After the concrete and reinforcement have been fabricated they need to be combined in a formwork to form hollow core slabs. This also requires energy.

In case concrete granules are used to replace part of the gravel in new concrete, the depletion of gravel can be saved. Emissions are however produced because energy is needed to prepare the concrete for this recycle purpose. Other raw materials such as oil do need to be depleted for this process.

When hollow core slabs are reused, the whole process of fabricating new hollow core slabs is skipped. This saves both raw materials as well as energy, and with that emissions, that are needed to fabricate hollow core slabs.

Construction

Before the building with the hollow core slabs is constructed, the slabs need to be transported from factory to the building site. This is the same for new slabs as for reused slabs if they are stored at the supplier's storage area. The transport from plant to building site is therefore left out of the calculation. At the building site, the slabs are placed into the building. The amount of energy necessary is the same when it concerns new slabs or used slabs, because they are both placed into the construction with help of a hollow core slab bucket. It is assumed that both construction types are the same. The process of assembling can therefore also be left out of the calculation.

Demolition/disassembling process

The process of taking down the building is different when the building is demolished than when it is disassembled. The time it costs and equipment that is used are for example variables that influence the LCA. The amount of energy that is used in both processes is therefore different and with that their environmental impact.

Apart from the influence the demolition methods have on the environmental impact, the impact on the building workers and the environment is also different. This should also be taken into account.

Adaptation

The rest of the process of the used hollow core slabs depends on their type of recycling or reuse. For the building that is disassembled, the reusable hollow core slabs go directly to the storage. The wall elements and other rest parts go into the recycling process just like when the building is being demolished instead of disassembled. This concrete needs to be crushed, sorted and washed to be able to be recycled on a high level. The steel also has to be separated from the concrete.

When the project in which the hollow core slabs will be reused is known, the slabs have to be sawn to size and possibly some small block-outs need to be made. The sawing to size of the reusable slabs is also taken into account in the process of adaptation. The concrete that is left over after sawing the elements to size will be recycled. For this process, just like with the other part of the concrete, contains crushing, sorting and washing the concrete and separating the steel from the concrete.

Transportation

Transportation is a stage that comes back several times within the construction, demolition and recycling/reuse process of a building. For the comparison between different variants, it is only of importance what difference there is in transportation movements. If an extra transportation movement is made within one variant compared to the other it should be taken into account because it leads to different emissions just as when another distance is covered. If the same amount of cargo is transported with the same transportation system and over the same distance, however, it will not lead to a difference in the two processes and can therefore be left out.

The emissions of the fabrication of hollow core slabs are partly based on the transportation emissions of the materials. When reusing or recycling materials or components coming from a building, the transportation should also be taken into account since this is different from the transportation emissions of newly fabricated hollow core slabs. As said before, the transportation of second hand slabs or newly fabricated slabs from prefab plant to building site are equal when it is assumed that the second hand slabs are stored at the prefab plant. These emissions are therefore not taken into account. In case the second hand slabs are however stored nearby the project, the emissions of transportation between the two variants are different and need to be taken into account. These different scenarios are looked into in the demolition phase. As input for the reuse of second hand slabs in the two reference buildings, however, the distance of 50 km to the prefab plant is taken as assumption.

For the concrete granules the influence of different transportation distances are also compared. One scenario is that they are transported over 50 km to be reused as gravel for new concrete and one is that they are transported over 10 km to be reused in a local project of road construction.

6.4.1. Inventory of quantities per functional unit

Now that all processes with their inputs and outputs are known, quantitative data have to be assigned to the processes and materials that are used. To do this, some assumptions need to be made. The amount of kg concrete in the disassembling/demolition process comes from the amount of concrete that is present in the functional unit: one standard floor of the PWC.

First the type of floors present in the PWC and the type of floors suitable for the single-family dwelling and the apartment building were examined. The percentages of possible reuse of the floors coming out of the PWC and the percentages of possible second hand slabs in the new buildings are calculated to be used as input in the LCA.

Single-family dwellings

As indicated before, the slabs with a thickness of 200 mm are suitable to be reused for single-family dwellings. A standard single-family dwelling is used as a reference project to determine the percentage of reuse of both the slabs of the PWC as well as the percentage of reused slabs in the dwelling. In this dwelling, the first and second floor as well as the flat roof are made with 200 mm hollow core slabs. Floor plans of the single-family dwelling can be found in D.3.

To determine the percentage of reuse, all slabs present on floor 4 through 13 of the PWC are mapped out (since the lay-out of the hollow core slabs on these floors is similar). The 200 mm slabs coming from the PWC are separately put in a table as well as the slabs of the 1st through the 3rd floor of the new dwelling.

The tables with percentages reuse can be found in appendix E.

It is first calculated how many dwellings can be realized with the slabs of the PWC in case the percentage reused slabs in the new dwelling should be as high as possible. The outcome is 13 houses. For this amount of houses, 338 slabs are needed of which 52 should be newly fabricated because of their large block-outs, which is a surface percentage of 31. The other 286 slabs can all come from the PWC. In this case, however, only 59.8% of the 200 mm slabs of the PWC are used. One of the reasons of this low percentage is that the slabs of the PWC that are either too short or its width is too narrow. Of more influence, however, is the fact that the length of the slabs of the PWC does not correspond with the length of the slabs needed. This is why a lot of slabs are not used at all in case the dwellings have to exist of as much reused slabs as possible.

In case we want to reuse as much of the 200 mm slabs of the PWC as possible and argue that for the new dwellings part of the slabs can be newly fabricated, it becomes clear what the percentage of reuse of the PWC slabs can maximally be when they are reused for standard single-family dwellings. It turns out that 72.1% of the surface of the 200 mm slabs can be reused for the dwellings. In this case, 27 dwellings can be realized, but the percentage of reused slabs from the PWC in these 27 dwellings is only 30%. For the hollow core slab plan of the dwelling, part of the slabs of the PWC are not reusable because of their dimensions (too short or too narrow). Another part still has to be put in the crusher because the needed length of the slabs is not the same as the length of the slabs that come out of the PWC. When the slabs are to be reused in another dwelling, the percentage of reuse might go up when the dimensions of the slabs needed for the dwelling correspond more with the dimensions of the slabs that come out of the PWC.

On the next page the mentioned values are summarized in two tables.

	1 house	13 houses	27 houses
Surface (m2)	147	3754	5764
Total amount of slabs	26	338	702
Reused slabs		286	337
Reused surface		2594	1755
Percentage reuse in new buildings		69,1%	30,4%

Table 6-1: Percentages reuse in new buildings

	PWC	13 houses	27 houses
Surface (m2)	3169		
Total amount of slabs	530		
Reused slabs		325	418
Reused surface		1895	2286
Percentage reuse of PWC		59,8%	72,1%

Table 6-2: Percentages reuse of slabs present on the 10 standard floors of the PWC

To solve the problem of needing at least 31% new slabs in the single-family dwelling because of block-outs in the slabs, the architects and engineers could also design for reuse. In this case, they would place the tubes and wires outside the floor and 100% of the floor surface can be made of reused slabs.

Apartment buildings up to 13 m

The rest of the slabs of the 4th through the 13th floor of the PWC are suitable for apartment buildings up to 13 m. Only the slabs of 320 mm thick without a concrete topping may also be reused in higher apartment buildings but since this is a small percentage and they are also suitable for apartment buildings up to 13 m it is chosen to reuse them for this function.

A reference project is found to determine the percentage of reuse in a standard apartment building. 29.2% of the surface of the story floors of this apartment building exists of slabs with large block-outs. These slabs should therefore be fabricated in the plant and no second hand slabs can be used for this part because they would have to be adapted too much. With the 255 mm and 320 mm slabs without concrete topping, 25 floors can be realized. For all slabs without large block-outs, reused slabs can be used. A floor plan of the apartment building can be found in appendix D.4.

It should be noted that when the 255 mm slabs are reused, a floating floor with $\Delta_{L_{in}} \geq 11\text{dB}$ and a concrete layer of minimally 55 mm is needed to fulfill the sound insulation requirements. For the 320 mm floor, the same type of floating floor is required but to reach the sound insulation requirements only 30 mm of extra concrete is needed. Because of the different thicknesses of the slabs and the different thickness of additional concrete layer needed, it is easiest for the construction to place the different types of slabs on different floors; or even easier, in different buildings. This is not strictly necessary, but it might be cheaper if no solutions have to be found for such difficulties.

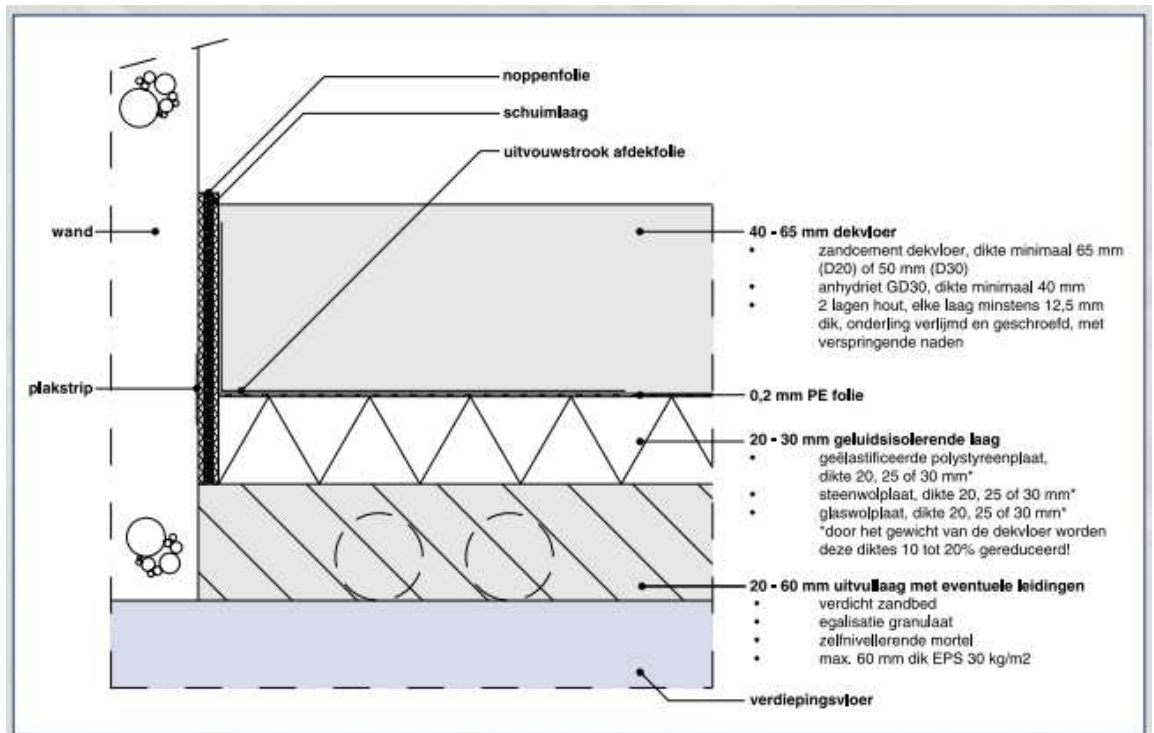


Figure 6-5: Cross-section floating floor (Source: VBI)

All slabs of 255 mm coming from the PWC are about 9 m long and the slabs of 320 mm almost 12 m. They all have a width of 1200 mm and are therefore all suitable for reuse. If 25 floors (which means 6 buildings with 5 floors and 1 building with 2 floors if the ground floor is not made with reused slabs) are realized with these slabs, 86.4% of their total surface in the PWC is reused. Almost all slabs are used and this is therefore about the maximum percentage of reuse. The percentage is again not 100% because the length of the slabs needed is different from the length of the available slabs. This could be different when the slabs are to be reused in another project. The tables with percentages reuse can be found in appendix E. In the tables below, the most important values are presented.

	1 floor	25 floors
Surface (m ²)	220	5664
Total amount of slabs	41	1025
Reused slabs		800
Reused surface		4011
Percentage reuse in new floors		70,8%

Table 6-3: Percentage reuse in apartment building

	PWC	25 floors
Surface (m ²)	4743	
Total amount of slabs	400	
Total weight slabs (tons)	1856	
Reused slabs		390
Reused surface		4068
Total weight reused slabs (kg)		1603
Percentage reuse of weight slabs PWC		86,4%

Table 6-4: Percentage reuse of weight of 255 and 320 mm slabs of PWC

For an apartment building the same holds as for a single-family dwelling: if architects and engineers design on using second hand slabs, the percentage of reused slabs in a new building can go up to 100%.

The 320 mm slabs with concrete topping can only be reused in residential buildings up to 13 m because of their concrete topping of 60 mm. This group of slabs is separated from the others although applied for the same type of buildings because of its different type of floating floor needed. No extra concrete is needed on top of the slabs but a layer of granules is applied to create a sufficient level of sound insulation. With all 320 mm slabs with concrete topping coming from the PWC, 20 new apartment floors (5 buildings with each 5 floors of which the ground floor exists of new slabs) can be realized. The maximum percentage of reused slabs in these apartment buildings is of course still 70.8%. The percentage of floor surface that is reused from the PWC is 86.4% which is coincidentally the same as the reuse percentage of the 255 mm and 320 mm slabs without concrete topping. The tables with percentages reuse can be found in appendix E.

A summary of the results is presented in the table below.

Type	Concrete topping	Weight (kg)	percentage	Percentage reuse	Reused for	Percentage second hand slabs
N200	0	270	27,3%	72,0%	Single-family dwelling	69%
T260	0	370	26,3%	86,4%	Apartment building	71%
H320	0	430	14,5%	86,4%	Apartment building	71%
H320	60	574	31,9%	86,4%	Apartment building	71%

Table 6-5: Input values percentages reuse

Demolition process

The amount of electricity and diesel needed to disassemble or demolish the building is estimated with help of the Slim Slopen Tool, the video of the reference project in Middelburg and producers of demolition equipment.

The Slim Slopen Tool was developed by the Gemeentewerken Rotterdam to calculate the environmental impact of the demolition process. This tool takes into account the influence of demolition machines and the influence of the process of adapting the concrete in order to make it ready for reuse. Also transportation of the materials is taken into account. The program only presents the values for CO₂ and NO_x emissions. With help of the CO₂ emissions in combination with the type of machine that is used, estimation can be made of the amount of litre diesel that is needed. In SimaPro, the values for the other effects are also given for the use of 1 litre diesel. With the combination of the two programs, the emissions in the demolition process were calculated. The values can be found in appendix F.1.

The transportation distance is assumed to be 50 km to the prefab plant, 10 km to a local project where the granules can be used and 10 km to a local storage area for the hollow core slabs.

Floating floor

The type and thickness of the layers of the floating floor are determined with help of the cross-section of a floating floor as represented in the handbook of VBI (2003). For the thickness and material of the finishing layer the most standard values are chosen. In the table below, the values of the materials that are possible to be used for the floating floor are presented. The values in green show the chosen materials because they are most environmental friendly.

		Density kg/m ³	Density kg/m ²	kg CO ₂ eq. per kg	kg CO ₂ eq./m ²
20 - 60 mm equalizing layer:					
40 mm equalizing granules	or	2100	84	0,0059	0,4956
40 mm mortar B25	or	1900	95	0,0602	5,719
20 - 30 mm sound insulating layer:					
25 mm elastified polystyrene plate	or	30	0,75	2,63	1,97
25 mm rock wool plate	or	150	3,75	1,41	5,29
25 mm glass wool plate		70	1,75	1,76	3,08
40-65 mm finishing layer:					
50 mm joint cement B35	or	1900	95	0,0634	6,02

Table 6-6: Options layers floating floor (values: SimaPro)

It should be noticed that for the finishing layer no alternatives are presented. The milieu-impact of this finishing layer cannot be neglected and will influence the total outcome of the LCA significantly. Alternative materials that can be used to create this finishing layer should therefore be examined to minimize the environmental impact of the total floor.

Reuse/recycling of concrete

By calculating the environmental impact of disassembling a building, the 'fabrication process' of the used slabs is calculated. This is namely the amount of emissions that is needed in order to prepare the slabs for reuse and can therefore be taken into account as fabrication of second hand slabs.

The part of the process that is needed to crush the remaining concrete that cannot be reused as hollow core slab in a new building has to be taken into account for the new material that is made with these granules. So if 20% of the gravel to make new concrete with is replaced by granules of the demolished building, the demolishing process is seen as the 'fabrication process' of the granules.

Only 660 kg of the 2445 kg of one cubic meter concrete is gravel. In this reference project, 20% is replaced by concrete granules, which is 132 kg because this is the standard percentage of replacement. This percentage can however already be increased to 50% and in some cases up to 100%. Apart from the LCA study on the variants, also a quick study is made of the environmental impact of both gravel and concrete granules. This is done to show the impact of recycling and to supply input values for the use of new HCS.

In case the hollow core slabs coming from an office building are to be reused in a residential building, a floating floor is needed to meet the sound insulation requirements. It is therefore necessary to take the environmental impact of a floating floor into account when reusing slabs. The CO₂ emissions produced during the production and transport of the products are found in the EcoInvent 2.0 database of SimaPro.

6.4.2. Selection of environmental effects

After comparing the programs DuboCalc, the database of NIBE and the databases in SimaPro, it was decided to use the values from SimaPro, because this is the only program in which the environmental impact of hollow core slabs is present. In the NIBE database only the emissions of the fabrication of concrete and steel separately can be found. It is not easy to calculate the environmental impact of the fabrication of hollow core slabs only with these values.

For the demolition process, the electricity and diesel use of the demolition machines and transportation are calculated. With the emission values per kWh electricity and per litre diesel, the total environmental impact of the demolition process can be determined. It was important to use the same effects for both the demolition process as well as the process of reusing the slabs because the demolition process provides input for the latter process.

The earlier mentioned effects, present in the data of SimaPro, will also be taken into account in the calculation.

The Global Warming Potential (GWP) is an important impact category in life-cycle-assessment modelling of waste management systems. It is therefore taken as basis to compare the variants with. For the demolition process a comparison between the variants is also made on basis of human toxicity. Human toxicity is a measure for the impact on the human health, which was earlier indicated as an important aspect to evaluate.

Classification of emissions of environmental effects

The emission values of the materials come from the SimaPro database EcoInvent version 2.0. Part comes from SimaPro version 5.1 (materials) while the other part of the values comes from SimaPro version 7.3 (electricity and diesel use). Both values are without the impact of the production of the machines that are used. In version 7.3 this can be taken into account, but was switched off. The method that is used for all values is CML 2 baseline 2000 / the Netherlands, 1997.

Weighing factors

To compare the different variants, one final indicator needs to be found. With the kg CO₂ eq. per variant a good indication can be given of the environmental impacts of the different options. If the other effects are also taken into account, it is hard to come to one final judgment though, because the different emissions cannot be added up. To solve this problem, shadow prices are invented. These shadow prices represent the costs for preventive measures which must be taken to reduce the emissions to a sustainable level. These environmental costs can be seen as virtual costs because the measures have not been taken

in reality. They are therefore not integrated in the production processes and thus not integrated in the real cost. The costs of a kilo emissions per impact category are shown in the table below. The shadow prices are obtained from the NIBE material database. Due to new insights and methods these shadow prices are not fixed but keep changing and developing.

Impact category	Unit	Shadow price
abiotic depletion	kg Sb eq	€ 0,16
global warming (GWP100)	kg CO ₂ eq	€ 0,05
ozone layer depletion (ODP)	kg CFC-11 eq	€ 30,00
human toxicity	kg 1,4-DB eq	€ 0,09
fresh water aquatic ecotox.	kg 1,4-DB eq	€ 0,03
marine aquatic ecotoxicity	kg 1,4-DB eq	€ -
terrestrial ecotoxicity	kg 1,4-DB eq	€ 0,06
photochemical oxidation	kg C ₂ H ₂	€ 2,00
acidification	kg SO ₂ eq	€ 4,00
eutrophication	kg PO ₄ --- eq	€ 9,00

Table 6-7: Impact categories with shadow prices (source: NIBE)

Of the above described effects, the shadow costs will be calculated for different variants. It is chosen not to calculate the shadow price for the demolition process.

6.5. Impact assessment

6.5.1. Carbon Footprint and Human toxicity

As mentioned before, the comparison between the disassembling and demolition process is made on the basis of the Carbon Footprint and the Human toxicity. For both processes, the three stages demolition/disassembly, adaptation and transport are taken into account. The values of both processes can be found in appendix F.2.

Disassembly versus demolition

First, the process of disassembly is examined. The whole structure is disassembled so also the prefab walls which are crushed afterwards to be reused as granules in new concrete. By comparing the process of the reusable slabs against the to be crushed walls, it becomes clear what the impact is of adapting the concrete to be prepared for reuse or recycling. The transportation and disassembly emissions are equal for both products. By presenting the kg CO₂ equivalent per kg concrete the graph has the most value because the tonnage of the recyclable part and reusable part are not equal.

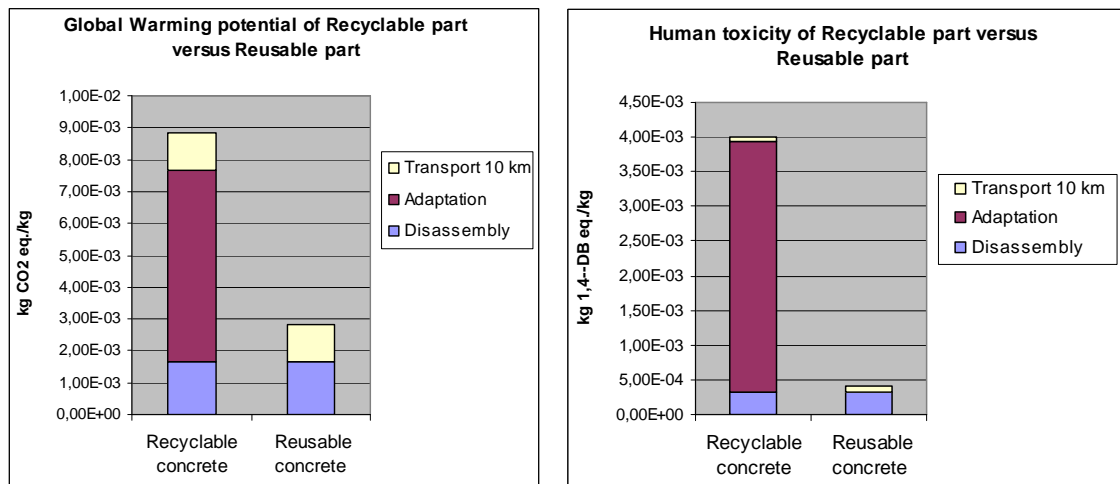


Figure 6-6: Comparison of recyclable versus reusable part for the construction in case the building is disassembled

It becomes clear from these comparisons that the emissions for the adaptation of the recyclable concrete are high in comparison to the emissions produced in the other phases of the process. The share of the adaptation process for the reusable concrete, which means the HCS, is very low. This is namely only the process of sawing the slabs to size. The human toxicity of the transport is also very low.

For the disassembling process also a comparison is made between different transportation distances of both the reusable slabs as well as the granules. Three variants are compared:

1. All concrete is transported to the prefab plant over a distance of 50 km
2. The reusable HCS are transported to the prefab plant (50 km) and the granules are transported to a local project at a distance of 10 km
3. All concrete is transported over a distance of 10 km. It is assumed that the hollow core slabs are stored at a local storage area and the granules used for a local project

The only variable in this calculation is the transportation distance. The disassembly and adaptation phase are equal for three variants.

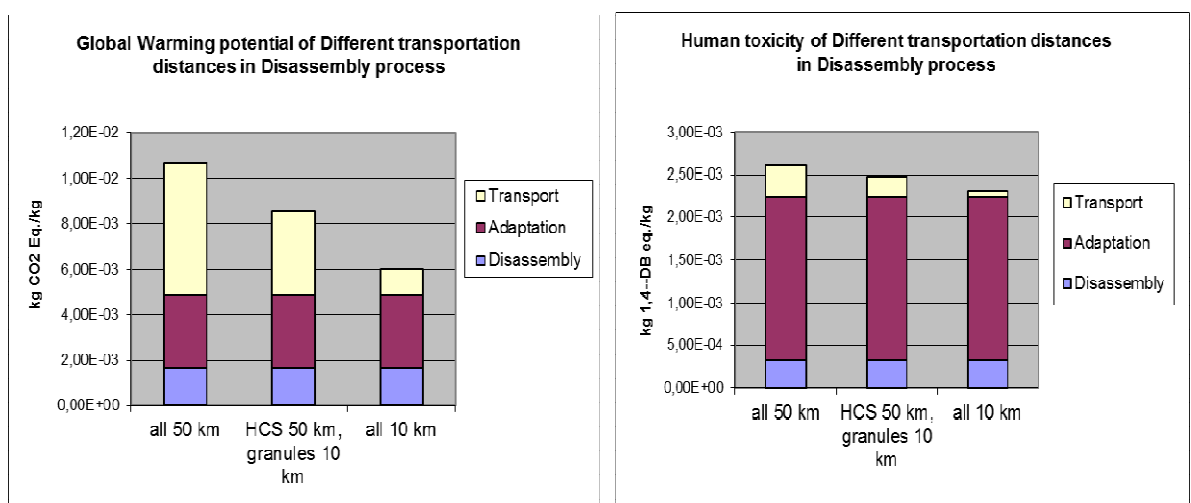


Figure 6-7: Comparison disassembling process on basis of different transportation distances

For the Global Warming Potential it shows that transport has a large share in the emissions. When the HCS and granules are transported over a distance of 50 km, the share of the CO₂ emissions caused by transport are even more than half of the total Global Warming Potential. As was also shown in the previous graph, for the human toxicity the transport distance only has a small share in the amount of emissions that are produced.

Disassembling versus demolition process

A comparison is made between the demolition and disassembling process. For the disassembling process the walls that are crushed and recycled after the building has been taken down are also taken into account since it is assumed that only the hollow core slabs will be reused. Also the emissions caused by crushing, sorting and washing the concrete part that is left after the HCS have been sawn to size is taken into account.

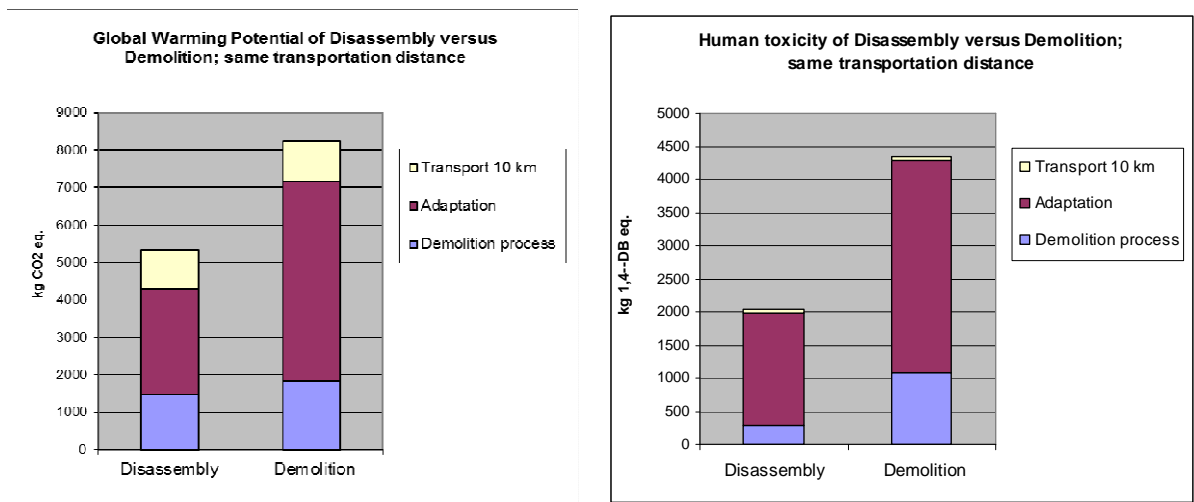


Figure 6-8: Emissions of the disassembly versus the demolition process

By comparing the disassembling and demolition process, it shows that demolishing the building has a slightly larger environmental impact on Global Warming potential than disassembling. The difference is a lot bigger for human toxicity. This is because for the demolition process more diesel was used whereas for the disassembling process much was done with electricity.

For the adaptation phase the same pattern shows, although the difference in Global Warming potential is higher than in the previous phase of the process. Crushing, washing and sorting the concrete has much more impact than adapting the HCS for reuse. That the emissions in this phase are only doubled for the demolition phase is because about half of the concrete coming from the disassembling phase is also assumed to be adapted for recycling instead of reuse. For transportation over 10 km, the Carbon Footprint is not very high and its share in human toxicity is negligible.

Finally the variant of transporting the hollow core slabs over a distance of 50 km and transporting the granules over a distance of 10 km is looked into. This comparison is made

because normally most concrete coming out of a demolished building is used in local road construction.

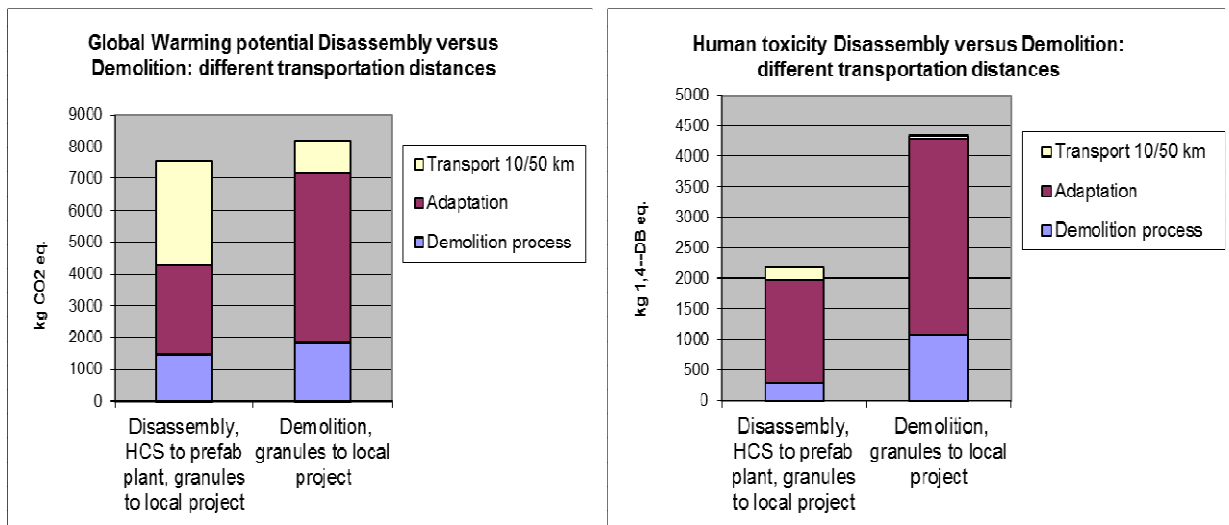


Figure 6-9: Emissions of the disassembly versus the demolition process when HCS are transported 50 km and granules 10 km

The only variable in this comparison is the transportation distance. The extra emissions caused by the longer transportation distance of the HCS makes the total emissions of assembling a building and demolishing it almost equal. The human toxicity is still a lot higher when a building is demolished, mainly because the emissions in the adaptation phase are very high and the transportation has few influence on the total human toxicity.

Granules versus gravel

The demolition process gives input values for the recycled concrete that is used to replace part of the gravel in new concrete HCS. With the results from the demolition process the influence on the environmental impact of replacing gravel by concrete granules can be determined. The emissions produced for the extraction of both materials are therefore compared.

For the extraction and transport of 1 kg gravel 0.00952 kg CO₂ eq. is emitted. The extraction of granules from the PWC incl. transport to concrete plant costs 0.0138 kg CO eq. when it concerns road transport over 50 km and 0.00923 kg CO₂ eq. when it concerns road transport over 10 km. Looking at CO₂ emissions it is thus not favourable to recycle granules for concrete. It should be noted that the demolition process of the building is also included, which would also be carried out if the concrete would not be recycled. This is however a fairly small part compared to making the concrete ready for recycling by breaking, sorting and washing. In appendix F.3 a table with all effects can be found including the comparison of the effects and the shadow prices of both gravel as well as granules.

With these results it can be concluded that the only advantage of reusing granules is that the used concrete is cleaned-up and does not have to be brought to the landfill. The raw

material gravel is saved out, but the depletion of raw materials in general is also taken into account in the LCA calculation. Other raw materials are needed to recycle the granules, mainly oil for diesel. More of this raw material is needed to recycle concrete than to extract and transport gravel. From the results it is especially remarkable that the emissions of Human toxicity are much higher for granules than for gravel.

Taking the 20% recycling of granules into account in the Carbon Footprint does not make a significant difference in the total production of hollow core slabs since 97% of the CO₂ emissions come from the fabrication of cement (presented earlier in this report). Using part of the recycled concrete as gravel does therefore not show in the total CO₂ emissions per kg hollow core slab.

The results of the comparison of the environmental impact of granules versus gravel are remarkable. The whole concrete industry is convinced of the large environmental gain that is booked by recycling concrete to replace gravel in new concrete, while this case study shows the opposite. The argument to clean up the concrete by recycling is understandable, but the amount of energy, and with that emissions, it costs that go along with this process plead for another form of recycling or reuse. For this research, the comparison between using granules or gravel was only made to calculate the environmental impact of new concrete. Therefore, not much attention will be paid to the results in the rest of the research. It is, however, recommended to further look into this problem. In case reuse of the concrete is not possible, other ways of recycling that are less environmentally-intensive should be found.

Single-family dwelling

For the comparison between the different floor types in the new buildings an evaluation is made on basis of Global Warming potential. Data on the comparison between all variants can be found in appendix F.4. The environmental impact of the finishing floor is also taken into account. For both new slabs and reused slabs this layer is poured in-situ after the slabs have been put in position.

In the first graph the following variants are compared:

1. 100% new HCS
2. 31% new HCS and 69% reused slabs (in case the dwelling is not designed on reusing second hand slabs)
3. 100% reused HCS (in case the dwelling is designed on reuse)

The second graph shows a comparison of CO₂ emissions between new HCS and reused HCS per m² floor surface.

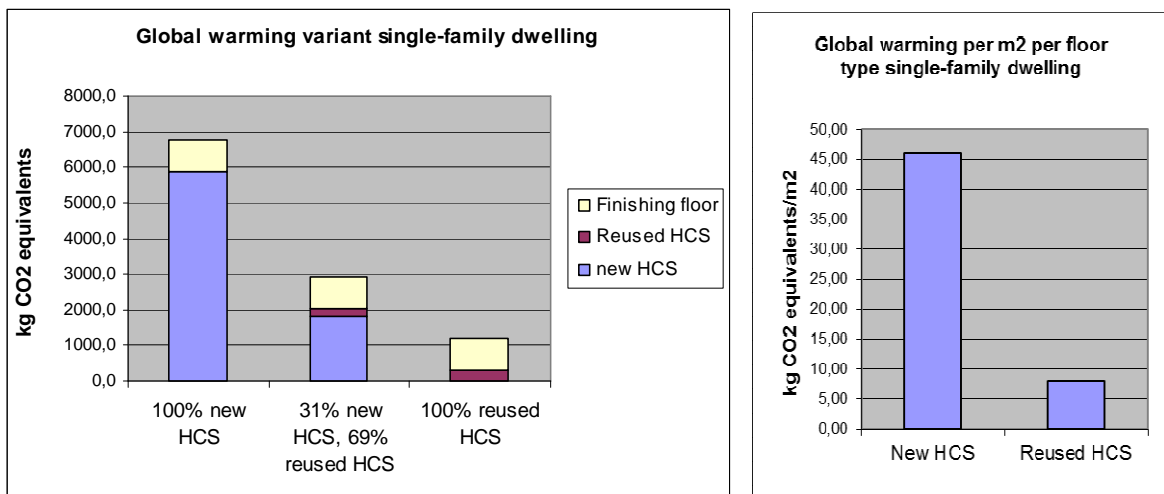


Figure 6-10: Comparison global warming potential of different types of floors in single-family dwellings

It can first be noted that the CO₂ emissions of the 'fabrication' of a second hand HCS are only about 5% of that of the fabrication of new slabs. As earlier mentioned, the fabrication of a second hand slabs consists of the emissions produced during the disassembling process and the transportation over 50 km to the prefab plant. If a dwelling is not designed on reuse of hollow core slabs, which means 31% of the slabs have to be newly fabricated, the Carbon Footprint is still less than half of the Carbon Footprint of the building in case 100% of the slabs are new.

Using second hand HCS as opposed to new HCS (both including a finishing layer of 50 mm sand/cement) provides a saving of more than 80% of the Global Warming potential in this project. It should be noted that the finishing layer accounts for about 3/4 of the CO₂ emissions of the total floor when second hand slabs are reused.

Apartment building

When an apartment building is not designed on constructing with reused slabs, the percentage of reuse can be about 71% percent of the floor area of the new building. A floating floor is needed to take care of the sound insulation requirements which is an extra entry on the environmental balance.

In the first graph the following variants are compared:

1. 100% new HCS
2. 29% new HCS and 71% reused slabs (in case the dwelling is not designed on reusing second hand slabs)
3. 100% reused HCS 255 mm incl. floating floor and 55 mm extra concrete
4. 100% reused HCS 320 mm incl. floating floor and 30 mm extra concrete
5. 100% reused HCS 320 mm including 60 mm concrete topping and floating floor

The finishing layer on top of a floating floor is 70 mm instead of 50 mm.

The CO₂ emissions of the different types of hollow core slabs coming from the PWC are compared to judge which floor slabs provide most environmental gain. Also for this type of building the amount of kg CO₂ equivalents are compared per type of floor slab per m² floor surface.

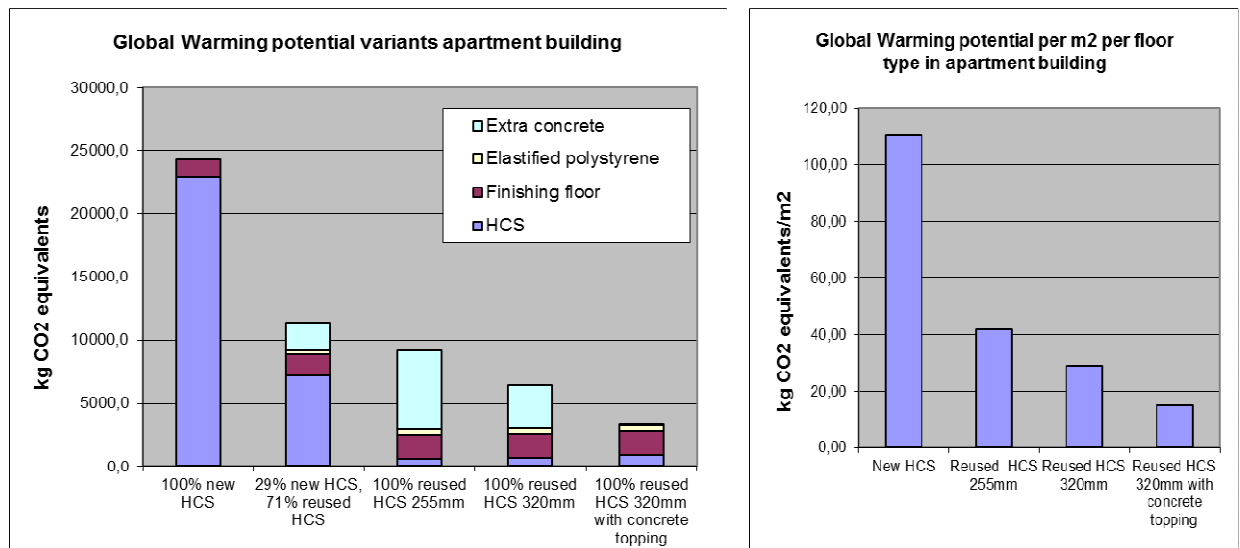


Figure 6-11: Comparison global warming potential of different types of floors in apartment buildings

It is clear that also in apartment buildings a lot of improvement can be made on reducing CO₂ emissions by using second hand HCS. In this case, an environmental gain of 2 up to 8 times can be reached. The extra concrete needed to meet the sound insulation requirements is the largest component in the Global Warming potential of using second hand slabs. When second hand HCS initially already have a large thickness, less extra concrete is needed and the CO₂ emissions can therefore be kept lower. Thus when the slabs coming from the office building already have a concrete topping, this will have a positive influence on the environmental impact of the new floor. In the second graph this is shown very clearly.

6.5.2. Shadow prices

With help of the EcoInvent database from the program SimaPro, the earlier mentioned effects can be examined per variant. By assigning the shadow prices coming from the NIBE database to each effect, a total shadow price can be calculated per variant. Tables with data that are used to make the comparison can be found in appendix F.5.

Single-family dwelling

For the single-family dwelling, the total shadow price of three different variants is calculated showing all effects. These variants are:

1. 100% new HCS
2. 29% new HCS, 71% reused HCS
3. 100% reused HCS

The calculations take a finishing floor of 50 mm into account.

Consequently the shadow price per floor type per m² floor surface is calculated. Also by taking all effects into account, but showing it as one column.

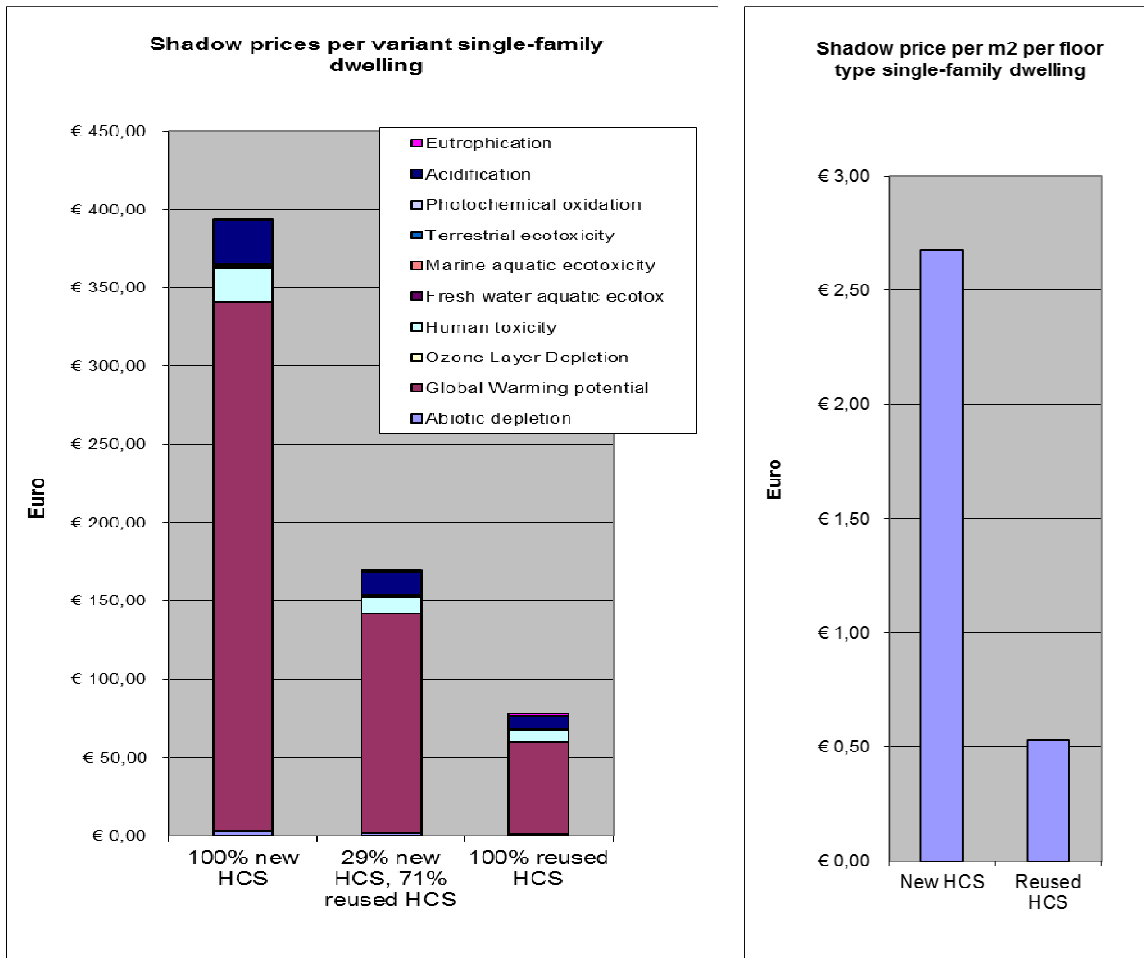


Figure 6-12: Shadow prices per type of floor in single-family dwelling

It shows that the shadow price of the whole floor (147 m²) is almost €400,- when new slabs are used while it is less than half when 71% second hand slabs are used. When the whole floor is made with reused slabs, the shadow price is only about €80,-. Global warming potential has by far the largest share in this price. For new slabs the CO₂ emissions are about 5 times higher than for reused slabs. The share of Human toxicity is about equal for all

variants while the Acidification is about twice as much when new slabs are used compared to second hand slabs. This impact category gives an indication of the decreased biodiversity over time. Eutrophication, which includes all impacts due to excessive levels of macronutrients in the environment caused by emissions of nutrients to air, water and soil is only emitted in case second hand slabs are used. This mainly comes from the diesel used to disassemble and transport the used HCS.

Apartment building

For the apartment building, the total shadow price of five different variants is calculated showing all effects. These variants are:

1. 100% new HCS
2. 29% new HCS and 71% reused slabs (in case the dwelling is not designed on reusing second hand slabs)
3. 100% reused HCS 255 mm
4. 100% reused HCS 320 mm
5. 100% reused HCS 320 mm including 60 mm concrete topping

The floors include the same top layers as mentioned before.

Consequently the shadow price per floor type per m² floor surface is calculated. Also by taking all effects into account, but showing it as one column.

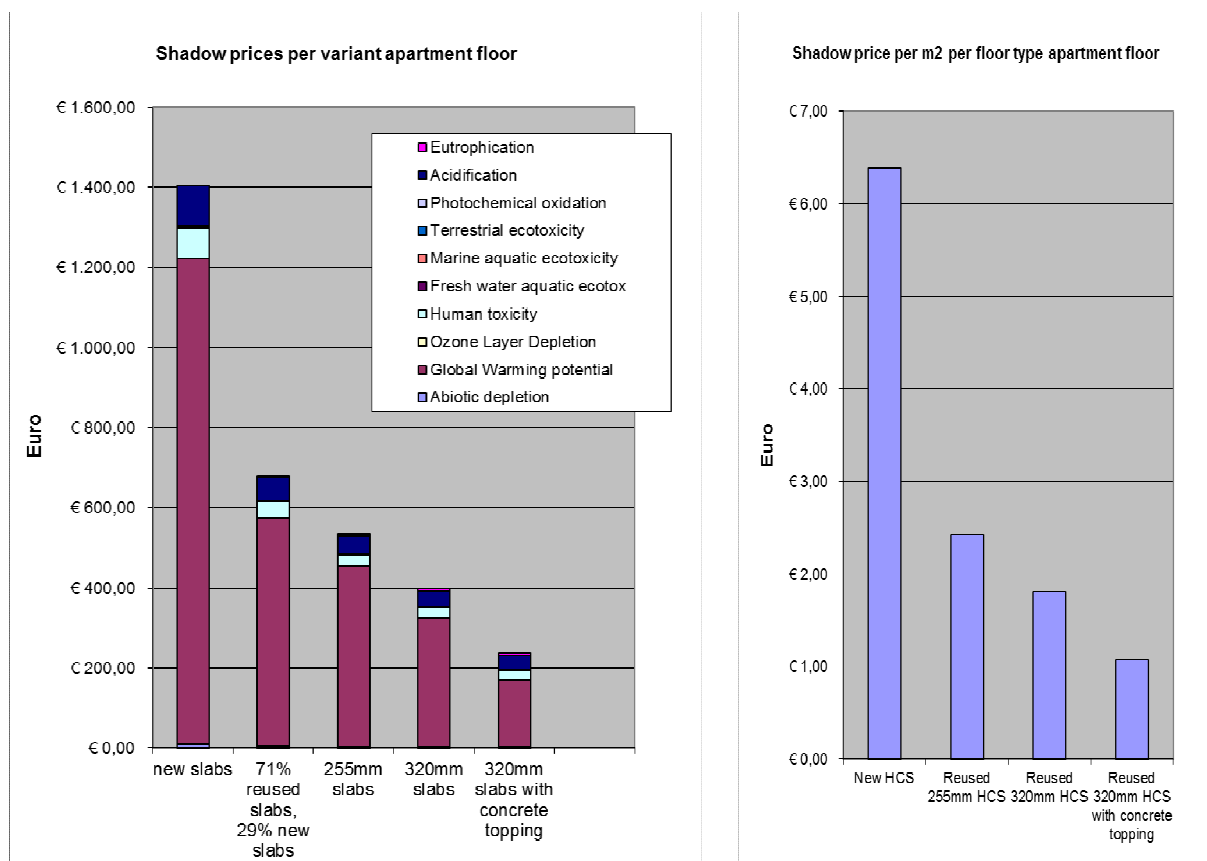


Figure 6-13: Shadow prices per type of floor in apartment building

apartment building are second hand slabs and the rest are new slabs, the shadow price is about halve of the shadow price when only new slabs are used. This can decrease to 17% when only 320 mm HCS with concrete topping are reused.

6.6. Interpretation

6.6.1. Analyses of the results

First a comparison was made between demolishing a building and disassembling the same building (in this case 10 standard floors of the PWC). This was done on basis of the emissions that the machines and tools produce during the process. It turns out that the process of demolition produces slightly more Global Warming potential and much more Human toxicity than disassembling the same building. The next phase, adapting the concrete to make it ready for reuse, is favourable when elements are reused instead of recycled. During the process to make concrete ready for recycling, it has to be crushed and sorted and also washed in case it is reused as gravel in new concrete. These processes produce much CO₂ emissions and human toxicity. The reusable slabs only have to be sawn to size which does not produce many emissions. When the transportation distance of the recyclable and reusable concrete is equal, the total process of disassembling the PWC produces 2/3 of the CO₂ emissions that are produced in the total demolition process. For human toxicity it is even more favourable to disassemble this building and reuse its slabs since only halve of these emissions are produced compared to demolishing the building and recycling the concrete.

The transportation distance of the concrete coming out of the building, however, plays a key role in the total CO₂ emissions of this process. When the transportation distance of the HCS of the PWC is kept below 60 km, the total disassembling process has a smaller Global Footprint than the demolition process in case the granules are transported over a distance of 10 km. In case the second hand HCS are transported 60 km after they have been disassembled from the building, this accounts for about 50% of the total environmental impact of the disassembling process and thus the 'fabrication' of second hand slabs. This is still a very small influence compared to the fabrication of new HCS. By increasing this transportation distance (but keeping the HCS within the Netherlands), the total environmental score of reused slabs will of course go down but will by far not lead to a worse outcome compared to new slabs. The transportation distance does not have a large influence on the total emissions of the Human toxicity.

In both the single-family dwelling as well as the apartment building, reusing hollow core slabs is very favourable when it concerns Global Warming. In the tables below the total CO₂ emissions per floor type and the percentage of Global Warming potential compared to using new slabs are presented.

Variants single-family dwelling	Total CO ₂ eq.	percentage
100% new HCS	6760	100,0%
31% new HCS, 69% reused HCS	2910	43,0%
100% reused HCS	1180	17,5%

Table 6-8: Total kg CO₂ eq. different floor types in single-family dwelling

For single-family dwellings, the finishing floor that is applied on the second hand slabs has about 3 times as much influence on the Global Warming potential than the slabs itself.

Variants	Total kg CO ₂ eq.	percentage
100% new HCS	24280	100,0%
29% new HCS, 71% reused HCS	11385	46,9%
100% reused HCS 255 mm	9166	37,8%
100% reused HCS 320 mm	6413	26,4%
100% reused HCS 320 mm with concrete topping	3336	13,7%

Table 6-9: Total kg CO₂ eq. different floor types in apartment building

For apartment buildings the Global Warming potential depends most on the amount of extra concrete that is needed on top of the slabs to meet the sound insulation requirements. The slabs that initially have most mass need less extra concrete and reusing these slabs in apartment buildings has therefore a lower impact on the environment.

By taking all effects into account, the shadow prices are calculated per variant. The CO₂ emissions have by far most influence on the price. The total shadow prices are therefore pretty much directly proportional to the Global Warming potential. Exact prices are presented in the tables below. By reusing HCS much benefit to the environment can be booked.

Variants single-family dwelling	Total shadow price	shadow price/m ²
100% new HCS	€ 393,29	€ 2,68
31% new HCS, 69% reused HCS	€ 169,34	€ 1,15
100% reused HCS	€ 77,78	€ 0,53

Table 6-10: Shadow prices per floor type in single-family dwelling

Variants apartment building	Total shadow price	shadow price/m ²
100% new HCS	€ 1.403,84	€ 6,38
29% new HCS, 71% reused HCS	€ 680,26	€ 3,09
100% reused HCS 255 mm	€ 533,75	€ 2,43
100% reused HCS 320 mm	€ 398,19	€ 1,81
100% reused HCS 320 mm with concrete topping	€ 237,34	€ 1,08

Table 6-11: Shadow prices per floor type in apartment building

6.6.2. Sensitivity analysis

To calculate the environmental impact of disassembling a building, most values were estimated. The types of demolition equipment that are used for the process (diamond saw

and pneumatic hammer) were determined with help of reference projects, 2 master theses and some people working in the field of demolition branch. The amount of time these tools have to run before the building is disassembled were estimated with help of data of suppliers. The amount of diesel the lifting crane uses is estimated with help of the video of the reference project in Middelburg. In this video it can be seen in what amount of time the crane takes out an element. The amount of elements that have to be taken out are known which enables the total time the crane has to run to take down all the elements. It is estimated that the values in the disassembling process could differ from reality by about 50%. The values for the demolition process are pretty accurate, since they were all obtained from the Slim Slopen Tool. The environmental impact of reused hollow core slabs does also depend for a large part on the transportation distance. Emissions for the assumed distances are accurate, but whenever the transportation distance doubles, for example, the values should also be altered.

For the part of reusing slabs in single-family dwellings and apartments buildings, assumptions had to be made about what type of finishing and floating floor are applied. With help of the VBI documentation the layers of the finishing floor are determined. There are many other materials on the market that could be used. In this LCA study, environmental friendly materials were chosen. The values for the emissions were found in the EcoInvent database in SimaPro and are assumed to be accurate. When actually reusing hollow core slabs, the type of floating floor should definitely be taken into account in trying to produce the least amount of emissions.

7. Costs

One of the criteria that is determining for the feasibility of reuse of hollow core slabs are the costs. In the end, no participant in the building sector wants to change their process if it will not bring in as much money as the old process. They might be willing to invest in an innovation but over time they need to gain from it. Therefore, a cost indication of second hand hollow core slabs is executed.

To calculate the costs of reused HCS the stages that are passed through from the moment the HCS are still in the old building up till the moment where they are in the new building have to be taken into account. In each stage costs are made which adds up to a cost indication per m² of reused HCS. This can be compared to the price of new HCS which maps out the difference between both.

7.1. Functional unit

The three buildings that were used before as reference projects are also used to make the cost calculation. It is assumed that part of the slabs that come out of the PWC are reused in the single-family dwelling and the other part in the apartment building.

For the process of disassembling, the 10 standard floors of the PWC are examined. These contain 11619 m² hollow core slabs of which it is assumed that about 86% will be reused (see chapter 6). This leaves us with 9992 m² hollow core slabs that can be placed in the new single-family dwelling or apartment building. With the extra costs needed for disassembling against demolition, the costs per slabs can be calculated. Transport is included in this price. Adaptation of the slabs and storage are added separately.

7.1.1. Disassembling/demolition

For the calculation of the costs of the reused slabs the disassembling process versus the demolition process has to be calculated. The additional costs of disassembling a building to be able to reuse the hollow core slabs compared to demolishing it to recycle the concrete can be seen as part of the costs of reused HCS. In cooperation with demolition company Anton Van Dijk a cost comparison was made between disassembling and demolishing the 10 standard floors of the PWC. The rest of the building can be demolished in an equal way and does therefore not have to be taken into account.

7.1.2. Storage

For storage it is assumed that the storage area costs € 5,- per m² per year. (Van Appeldoorn, 2012) The time the slabs are in storage before they are purchased is assumed to be 1 year. The losses exist of the costs of the storage area and the capital loss of the slabs. If they are sold one year later, the money that could have been earned one year earlier could not have been invested that year. The interest rate is assumed to be 3%.

7.1.3. Adaptation

It is assumed that adaptation of the slabs exist of sawing them to size, removing the mountings and filling the holes on the bottom side of the slabs. The costs per m² of sawing the slabs to size depend on the dimensions of the slabs. The thicker the slab, the more surface needs to be sawn. The longer the slab, the less sawing to length per m² has to be done. To give a good estimation it is therefore decided to calculate the costs of an average slab for the reference single-family dwelling and an average slab for the reference apartment building.

For the single-family dwelling it concerns a slab with a length of 5.2 m and a thickness of 200 mm. The width of a slab is almost for all slabs 1.2 m. For the slab that is calculated it is therefore assumed that it does not have to be sawn to size width wise.

For the apartment building, the slab with a thickness of 320 mm without concrete topping is calculated. The average length of a slab needed in this building is 4.2 m, which is therefore chosen as length of the calculated slab. For this slab also 1.2 m is chosen as width. When the 320 mm slabs are reused in an apartment building, a floating floor is needed to meet the sound insulation requirements. The costs of the materials and the construction of this floating floor are also taken into account.

The unit prices for sawing the HCS to size lengthwise come from the interview held with Ron van Schaaik of demolition company Anton van Dijk. The costs for removing the mountings and filling the holes on the bottom side of the slabs are estimated with the cost of one hour of labour (calculation van Dijk) multiplied by the amount of hours needed per m² (estimated).

7.1.4. Construction

The costs for the construction of the new building are not taken into account because they are assumed to be equal for using new slabs or using second hand slabs. On top of the HCS a finishing layer needs to be applied. The costs for this layer are taken into account because its thickness is not equal in all cases. When it concerns reusing HCS in an apartment building, a floating floor needs to be applied for sound insulation requirements. On this floating floor, the finishing layer needs to be 70 mm instead of the usual 50 mm to prevent cracks in the floor (Van Appeldoorn, 2012)

The floating floor itself also has to be calculated as costs for reusing hollow core slabs. A floating floor is not needed in case new slabs are used and thus the costs only have to be made in case old slabs are used. Gert van Appeldoorn, construction costs specialist at BAM – Advice and Engineering, has given a cost estimation for the layers of the floating floor as well as the finishing floor.

7.1.5. New slabs

The costs of the second hand slabs are compared to the costs of new HCS. Fabrication of new HCS of 200 mm are assumed to be €35,- per m² and costs for HCS for apartment buildings (AL320) are assumed to be €45,- per m² (Koppenhol, 2012). These mentioned costs are only for fabrication. Transportation to the building site and assembling are not taken into account.

It is assumed that the second hand HCS are stored at the same location as the new slabs. The costs for transport to the building site are equal for both type of slabs and are therefore left out of the calculation. It is also assumed that the slabs are placed in the same type of construction and assembling costs are therefore also equal and left out of the calculation.

7.2. Cost calculation

A large part of the costs of reused HCS come from the extra costs made during the disassembling process. As said before, construction company Anton van Dijk has given unit values for the cost calculation of the different demolition processes of the 10 standard floors of the PWC. With these prices per unit and amounts of materials or surfaces the estimations are made.

7.2.1. Starting points

The following starting points were used for the calculation:

- Each transportation load consists of 30 tons concrete
- The costs of the walls of the casco, the ceilings and the facades are based on disassembling and transportation
- The concrete that is not reused is crushed on site and offered on the local market as foundation of roads. It is directly taken to the location of the new project.
- The costs for the removal of building- and demolition waste, timber and synthetic building materials of the disassembling process is included in the m² costs of the walls of the casco, the ceilings and the facades.
- The final costs are based on the costs per unit including the realization costs, profit, risk and general costs.

7.2.2. Results

The cost calculation of the different demolition methods can be found on the next page.

DISCRIPTION OF WORKS DISASSEMBLY (4868 tons HCS, 4022 tons w walls)						
Discription:	Amount	Unit	Price/unit	Incl. perc.	Total	Remarks
Set up building site	1,00		€ 5.800,00	€ 6.206,00	€ 6.20600	
Site hut	30,00	week	€ 250,00	€ 267,50	€ 8.025,00	
Toilets	30,00	week	€ 90,00	€ 96,30	€ 2.889,00	
Preparation activities	1,00		€ 750,00	€ 802,50	€ 802,50	
Work plan and Safety- and Health plan	1,00		€ 450,00	€ 481,50	€ 481,50	
Supply of building crane	1,00		€ 3.360,00	€ 3.595,20	€ 3595,20	
Crane 100 tons	30,00	week	€ 3.920,00	€ 4.194,40	€ 125.820,00	
Building workers	4800,00	hour	€ 38,50	€ 41,20	€ 197.76000	
Compressor	17,00	hour	€ 12,50	€ 13,38	€ 227,46	
Cutting floors	7408,00	m1	€ 42,64	€ 45,62	€ 337.952,96	Diamond saw
Inner walls casco	3571,20	m2	€ 12,00	€ 12,84	€ 45.854,21	Demolition and transport
Ceilings	11619,00	m2	€ 3,00	€ 3,21	€ 37.296,99	Demolition and transport
Facades	6412,80	m2	€ 9,55	€ 10,22	€ 65.538,82	Demolition and transport
Transport HCS 50 km	17	cargo	€ 150,00	€ 160,50	€ 2.728,50	30 Tons per cargo
				Total:	€ 835.190,14	

DISCRIPTION OF WORKS DEMOLITION (8869 tons concrete)						
Description	Amount	Unit	Price/unit	incl.perc.	Total	Remarks
Set up building site	1,00		€ 5.800,00	€ 6.206,00	€ 6.20600	
Site hut	22,00	week	€ 250,00	€ 267,50	€ 5.885,00	
Toilets	22,00	week	€ 90,00	€ 96,30	€ 2.118,60	
Preparation activities	1,00		€ 750,00	€ 802,50	€ 802,50	
Work plan and Safety- and Health plan	1,00		€ 450,00	€ 481,50	€ 481,50	
Supply of building crane	2,00		€ 3.360,00	€ 3.595,20	€ 7190,40	
Crane 85 tons	22,00	week	€ 7.000,00	€ 7.490,00	€ 164.78000	
Crane 40 tons	22,00	week	€ 4.000,00	€ 4.280,00	€ 94.16000	
Building workers	3520,00	hour	€ 38,50	€ 41,20	€ 145.02400	
Build- and Demolition Waste	40,00	load	€ 900,00	€ 963,00	€ 38.520,00	
Timber-B	22,00	load	€ 540,00	€ 577,80	€ 12.711,60	
Synthetics	3,00	load	€ 400,00	€ 428,00	€ 1.284,00	
Rubble	8869,00	ton	€ 4,25	€ 4,55	€ 40.353,95	
Transport rubble	30	cargo	€ 150,00	€ 160,50	€ 4.744,92	Tolocal project
				Total:	€ 519.517,55	
Difference:					€ 315.672,59	

Table 7-1: Costs disassembly versus demolition of the 10 standard floors of the PWC

The difference between the costs of disassembling and demolishing is € 315.672,59. This amount is divided over the 9992 m² HCS that can probably be sold from the 11619 m² that come out of the building. This means the disassembly costs € 31,59 per useable m² HCS.

For both the single-family dwelling as well as for the apartment building the costs of a standard floor slab are calculated to be compared to new slabs. The calculation of the different floor types can be seen in the tables below.

Floor for single family dwelling				
Variant 1: new slabs	Costs/m³	Thickness (mm)	Costs/m²	Source
New slabs		200	€ 35,00	VBI
Finishing floor	200,00	50	€ 10,00	BAM
Total costs			€ 45,00	
Variant 2: second hand slabs (200 mm)				
	Length (mm)	Width (mm)	Surface (m²)	
Dimensions reused HCS	5200	1200	6,2	Reference project
	Costs	Surface (m²)	Costs/m²	
Disassembling	€ 315.672,59	9992	€ 31,59	Calculation van Dijk
Adaptation	Costs cm/m¹	Costs/slab		
Saw ing to size	€ 1,44	€ 34,56	€ 5,54	Interview van dijk
	Costs/h	Speed (m²/h)		
Removing fixings	€ 38,50	15	€ 2,57	Estimation
Filling holes	€ 38,50	60	€ 0,64	Estimation
Finishing floor	200,00	50	€ 10,00	BAM
		Costs m²	€ 50,34	
Storage 1 year	Costs/year/m²	Plates stacked		
Area	5,00	4	€ 1,25	BAM
	Interest loss/year	Value slab/m²		
Time	3,00%	€ 35,00	€ 1,05	VBI
Total cost m² reused HCS incl. storage 1 year			€ 52,64	

Table 7-2: Costs/m² for new slabs and for reused HCS slabs of 200 mm

New floor slabs of 200 mm including the materials and construction of the finishing floor cost about € 45,- per m². When old slabs coming from an office building are to be reused it costs about € 52,64 per m² floor including the materials and construction of the finishing floor. This is 17% more expensive than when new floor slabs are used.

Floor for apartment building				
Variant 3: new slabs (AL320)	Costs/m3	Thickness (mm)	Costs/m2	Source
New slabs		320	€ 45,00	VBI
Finishing floor	200,00	50	€ 10,00	BAM
Total costs m2 new slabs			€ 55,00	
slabs (320 mm)				
	Length (mm)	Width (mm)	Surface (m2)	Source
Dimensions reused HCS	4200	1200	5	Reference project
Disassembling	Costs	Surface (m2)	Costs/m2	
	€ 315.672,59	9992	€ 31,59	Calculation van Dijk
Adaptation	Costs cm/m1	Costs/slab		
Sawing to size	€ 1,44	€ 55,30	€ 10,97	Interview van dijk
	Costs/h	Speed (m2/h)		
Removing fixings	€ 38,50	15	€ 2,57	Estimation
Filling holes	€ 38,50	60	€ 0,64	Estimation
Floating floor	Costs/m3	Thickness (mm)		
Concrete B35 (35 mm)	120,00	35	€ 4,20	BAM
Elastified polystyrene 25 mm	160,00	25	€ 4,00	BAM
Sand cement finishing floor	200,00	70	€ 14,00	BAM
		Costs m2 HCS	€ 67,97	
Storage	Costs/year/m2	Stacked slabs		
Area	€ 5,00	4	€ 1,25	BAM
	Costs/m2/year	Value slab/m2		
Time	3,00%	€ 45,00	€ 1,35	VBI
Total costs m2 reused HCS incl. storage 1 year			€ 70,57	

Table 7-3: Costs/m² for new slabs and for reused HCS slabs of 320 mm

New VBI apartment floors of 320 mm cost about € 45,- per m². Including the materials and construction of the finishing floor it costs € 55,- per m². When old 320 mm HCS coming from an office building are to be reused for this specific apartment it costs about € 70,57 per m² floor including the materials and construction of the floating- and finishing floor. This is 28% more than when new floor slabs are used.

7.2.3. Discussion

For single-family dwellings the floor plans are fairly standard with the same length slabs. For apartment buildings, however, this varies very much. The reference apartment building has HCS with an average length of 4,2 m which makes the costs for sawing the slabs to size €10,97 per m². If the required length of the HCS increases, less sawing is needed per m² which has a large influence on the total costs. The lay-out of the apartment buildings therefore has a significant impact on the price of the second hand slabs and can be optimized to keep the costs low. This impact is further examined by looking at the changes in

costs when the length of the hollow core slabs increases. The influence of different lengths is shown in the table and the two graphs below.

Length of slab (m)	Costs sawing to size	Total costs	Percentage price difference
4 m	€ 11,52	€ 71,12	29,3%
5 m	€ 9,22	€ 68,82	25,1%
6 m	€ 7,68	€ 67,28	22,3%
7 m	€ 6,58	€ 66,18	20,3%
8 m	€ 5,76	€ 65,36	18,8%
9 m	€ 5,12	€ 64,72	17,7%

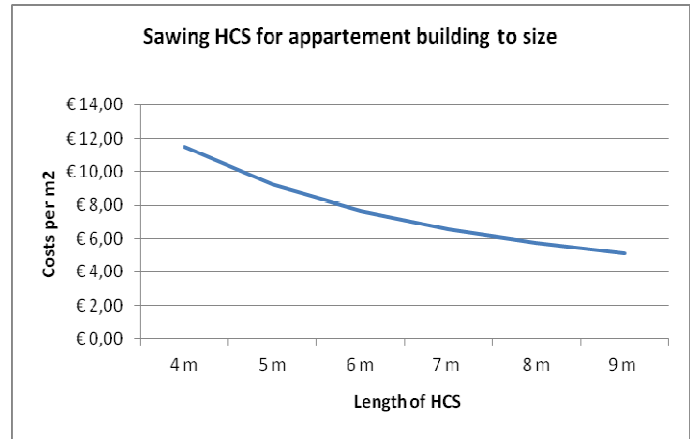


Table 7-4: Difference in costs for different lengths of HCS

Figure 7-1: Costs per m² for sawing HCS to size

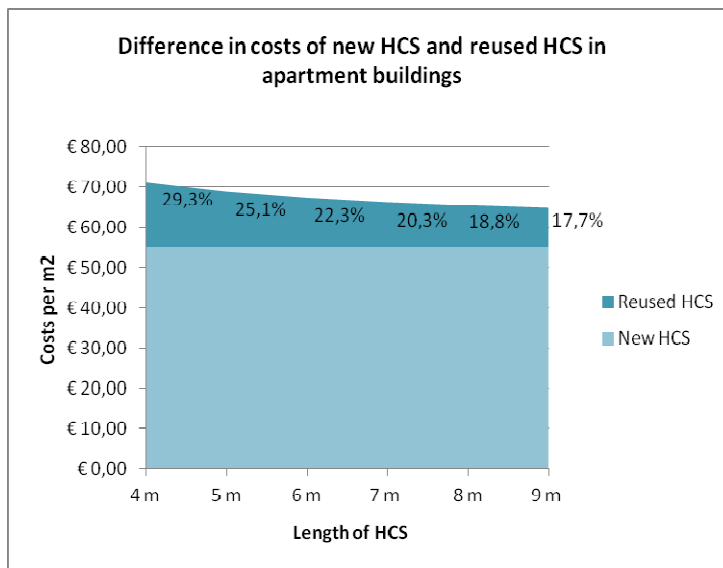


Figure 7-2: Difference in costs of new HCS and reused HCS in apartment buildings

The large influence of the length of second hand slabs in new apartment buildings becomes very clear from these graphs. The extra costs could decrease from 29% to 18% compared to the costs of new slabs.

The outcome of the graphs show a clear relation between the costs of second hand slabs and the lengths needed in new apartments. This could imply that the length of the HCS is leading for designing on reuse. It is interesting to do further research after the optimal design for reuse of HCS in apartment buildings.

It should however be noted that the average costs for new HCS were estimated on an average length, but will probably also decrease when the length of the slabs increases. It is assumed that this influence is not as large as for second hand slabs, because sawing them to size afterwards requires more effort. This should however also be examined.

7.2.4. Sensitivity analysis

The 'costs' indicated by external companies are actually prices they ask for their products or work. If the work is done by the same company that sells the slabs, the costs can probably be lowered. The costs also highly depend on how developed the process is.

Gert van Appeldoorn has evaluated the cost calculation of demolition company van Dijk as being realistic. He did remark that the costs of the demolition as well as the disassembling process seemed slightly high. Most important is however the differences in costs between both processes which will probably stay equal if some costs in the calculation are lowered. The cost estimation of the disassembling process has the most influence on the total costs because it has the biggest share in the total costs. The percentage of uncertainty in this calculation is estimated at 20%. The indicated costs of sawing elements to size is the price that has to be paid to the external company to do the work. The actual costs might be up to about 30% lower when the company selling the slabs also adapt the slabs. For the other adaptation the costs also highly depend on how everything is organized. If the process is highly developed, this can also make a difference of about 30% in the costs. The costs might also be about 30% more in case it turns out more time is needed to make the slabs ready for reuse. The costs for sawing block-outs in the slabs are not taken into account because it is assumed that not many of them are needed. The costs of the floating floor depend on the type of floor chosen. When the type that is chosen is used, the costs could probably differ from the estimated costs by about 20%.

In total it can be concluded that the costs of using second hand slabs can differ about 25% from the estimated costs. The price of new slabs is accurate but highly depends on the type of project. If more surface is needed, the price goes down but with more complexity of block-outs the price can go up. The estimated price probably differs maximally about 10% from the actual price.

8. Evaluation case study

To be able to determine the rate of success of reuse of hollow core slabs, the different criteria examined within the case study are evaluated. This is done by presenting the results obtained in the previous chapters and consequently by analysing the value of these results by looking at the whole concept of reuse of hollow core slabs. In the text boxes the bottlenecks for the process of reuse are outlined with their possible solutions. Also the positive points with suggestions to fully profit from them. At the end of the chapter conclusions are drawn about the rate of success of reusing hollow core slabs compared to using newly fabricated slabs.

8.1. Time

From the cost calculation in chapter 8, it can be seen that the disassembling time of the 10 standard floors of the PWC is 30 weeks. To demolish the same part of the building costs only 22 weeks. This means that the disassembling time is 36% longer than the demolition time. This brings along extra costs of having the equipment and people for a longer period of time, which can be seen in the difference in costs of both methods.

The slabs coming out of the PWC will be used for the reference new single-family dwellings and apartment buildings. The part that is used in apartment buildings needs a floating floor while in case the new AL320 HCS are used no floating floor needs to be applied. Placing a floating floor costs extra time because the concrete layer that is firstly poured over the hollow core slabs has to reach a sufficient strength before the elastic polystyrene layer can be applied. It is supposed that it costs 2 days to reach this strength. The polystyrene layer can be placed in one day before the concrete finishing layer can be poured. The latter layer is also applied when new slabs are used. It is therefore supposed that it takes 3 days extra per layer to place a floating floor. For an apartment building of 5 floors of which the ground floor is constructed as usual, it takes 12 days extra to construct the entire building when second hand HCS are used instead of new slabs.

The extra demolition time is not considered a problem, since the time needed to pass through the whole design cycle before the actual start of construction of the new building surpasses the demolition time. With concurrent engineering the old building can be disassembled at the same moment as the construction of the new building is designed and engineered.

The extra time needed to construct an apartment building with second hand slabs because of the floating floor, however, does influence the costs for the client. This should therefore be considered in the design and should be compensated with price or the value that is added by using these second hand slabs.

8.2. Percentage reuse

To calculate the possible percentage of reuse, an inventory was made of all HCS present on the 10 standard floors of the PWC. The slabs present in the standard single-family dwelling and apartment building were also mapped out. It is determined what percentage of each floor type present in the PWC can be used for the reference projects and what floor surface percentage in these new buildings can exist of the second hand slabs coming from the PWC. The results are presented in the table below.

Type	Concrete topping	Weight (kg)	percentage	Percentage reuse	Reused for:	Percentage second hand slabs
N200	0	270	27,3%	72,0%	Single-family dwelling	69%
T260	0	370	26,3%	86,4%	Apartment building	71%
H320	0	430	14,5%	86,4%	Apartment building	71%
H320	60	574	31,9%	86,4%	Apartment building	71%

Table 8-1: Percentages reuse

The reason that not 100% of the floor surface of the PWC can be reused for the new buildings is that some of the original slabs are too short or their width is too narrow. Another loss comes from the difference in needed length of the slabs. The slabs have to be sawn to size lengthwise to fit into the reference buildings. If the parts that are left of the slabs after sawing are too short, they cannot be reused. The percentage of reuse of the slabs that come out of the PWC is evaluated as very high. Only reusing the 200 mm slabs is limited because of the small dimensions of some slabs. The other loss of leftovers of the slabs after sawing them to size can in this case be seen as very low.

The possible percentage of second hand slabs in the reference buildings is limited because about 30% of the floor surface exists of slabs with large block-outs. For this part new slabs can be ordered in which the block-outs are made when the concrete is still green. 70% second hand slabs is already a large improvement compared to all new slabs. The 30% of slabs that still need to be newly fabricated brings down the environmental score of the new building. Apart from this, it could bring along logistic problems if part of the slabs are newly fabricated and part are second hand.

The reuse percentage of this case study in which HCS of one office building are reused in two specific residential buildings is considered high. The aim of the concept of reuse of HCS is to eventually have a large supply or used HCS divided over several storage areas to minimize the transportation distance. When a new building is built with second hand slabs they can be ordered from a database in which the properties and storage location of all second hand HCS can be found. With a large stock, the lengths of the old slabs can fit well to the needed lengths of the new slabs and not much is lost after sawing the elements to size. This means the percentages of reuse of hollow core slabs from office buildings might even be higher when largely applied. On the other hand, demand and supply could also be unbalanced, which could have a large influence on the percentage of reuse. It is assumed that because almost all HCS present in office buildings qualify for reuse in most low residential buildings, it is easy to attune demand and supply and a high percentage of reuse of all slabs coming out of office buildings can be reached.

In this case study, the residential buildings were not designed on reuse which limited the maximum percentage of second hand slabs to 70%. The solution for this problem is to design on reuse. When the new buildings are designed on reuse and block-outs are left out of the HCS, the percentage of second hand slabs can go up to 100%, which is of course even more favourable than the possible percentage of reuse for this case. The feasibility of design on reuse will be further discussed in the next chapter.

8.3. Costs

To compare the costs of new slabs and second hand slabs, the costs of both processes to 'fabricate' the slabs were calculated. For the second hand slabs this is the process of taking the slabs out of the old building, store them, making them ready for reuse and finishing them off.

It turns out that the second hand 200 mm HCS coming from the PWC cost € 52,64 per m² instead of € 45,- per m² that has to be paid for new slabs. This means 17% extra costs for the second hand slabs. This price difference is somewhat larger for the reference apartment floors because a floating floor needs to be applied when second hand slabs are used. Using new slabs costs € 55,- per m² while it costs € 70,57 per m² to use the second hand slabs coming from the PWC, which means 28% extra. 24% of the surface of the HCS coming from the PWC is reused for single-family dwellings and 76% for apartment buildings. This brings the average price of a m² reused slab from the PWC for single-family dwellings and apartments buildings to € 66,27 and the average price of a m² new slab for these buildings to € 52,60.

The difference in costs between second hands and new slabs, based on the case study, is considered small but still too much to make reusing the slabs feasible. The disassembling process has the highest influence on the price of second hand slabs. To bring down the costs this process should therefore be further developed to make it more efficient. The costs of keeping the slabs in storage are considered small, but by developing the logistics well, could also be brought down. For apartment buildings a considerable part of the costs comes from the floating floor. It is not yet clear if the chosen layers are the cheapest option to create a sufficient level of sound insulation. By optimizing the floating floor also an economization can be booked.

8.4. Environmental impact

For the case study the environmental impact of the disassembling/demolition process of the 10 standard floors of the PWC was calculated as well as the environmental impact of using second hand slabs and new slabs in the reference single-family dwelling and the apartment building. The following results were already presented in paragraph 6.6.

It turned out that the process of demolishing produces slightly more Global Warming potential than disassembling the same building. The next phase, adapting the concrete to make it ready for reuse, is favourable when elements are reused instead of recycled. During the process to make concrete ready for recycling much CO₂ emissions are produced. The reusable slabs only have to be sawn to size which does not produce much emissions. When the transportation distance of the recyclable and reusable concrete is equal, the total process of disassembling produces 2/3 of the CO₂ emissions of a total demolition process. It is however noticed that the transportation distance plays a key role in the total CO₂ emissions of the disassembling and demolition process.

In both the single-family dwelling as well as the apartment building, reusing hollow core slabs is very favourable when it concerns Global Warming. In the tables below the total CO₂ emissions per floor type and the percentage of Global Warming potential compared to using new slabs are presented.

Variants single-family dwelling	Total CO ₂ eq.	percentage
100% new HCS	6760	100,0%
31% new HCS, 69% reused HCS	2910	43,0%
100% reused HCS	1180	17,5%

Table 8-2: Total kg CO₂ eq. different floor types in single-family dwelling

For single-family dwellings, the finishing floor that is applied on the second hand slabs has about 3 times as much influence on the Global Warming potential as the slabs itself.

Variants	Total kg CO ₂ eq.	percentage
100% new HCS	24280	100,0%
29% new HCS, 71% reused HCS	11385	46,9%
100% reused HCS 255 mm	9166	37,8%
100% reused HCS 320 mm	6413	26,4%
100% reused HCS 320 mm with concrete topping	3336	13,7%

Table 8-3: Total kg CO₂ eq. different floor types in apartment building

For apartment buildings the Global Warming potential depends mostly on the amount of extra concrete that is needed on top of the slabs to meet the sound insulation requirements. The slabs that initially have most mass need less extra concrete and reusing these slabs in apartment buildings has therefore a lower impact on the environment.

The largest variable component when it concerns CO₂ emissions in the process of disassembling and demolition is the transportation distance of the materials and elements that come out of the building. Often concrete granules do not have to be transported over a large distance since they can be used in local projects. The transportation distance of the used HCS should therefore be kept as small as possible to make the disassembling process attractive. This impact is however small compared to the CO₂ emissions produced during the production of new hollow core slabs.

It can be concluded that for this case study, reusing hollow core slabs is very favourable for the reduction of CO₂ emissions. Since the values used in the calculation are considered accurate and many different variants were compared it can be said in general that using second hand HCS reduces the CO₂ emissions of a floor in a new building significantly.

It turns out from the case study that when 200 mm slabs are reused in single-family dwellings, 3 times as much CO₂ emissions are produced through the fabrication of the finishing floor than the second hand slabs itself. To further reduce the environmental impact of using second hand slabs in general, it is therefore most efficient to reduce the emissions coming from the production of the finishing floor. The different alternatives for finishing floors should be compared on basis of environmental impact to be able to decide what gain can be booked by applying another type of finishing floor.

For apartment buildings it holds that the extra concrete layer placed for the sound reduction has most influence on the CO₂ emissions. It should be looked into if the thickness of the concrete layer can also be compensated by applying another type of floating floor.

8.5. Social- and health aspects

The case study should also be evaluated on basis of social- and health aspects since these are an important measure for the success of the project. In the chapter ‘Disassembling versus Demolition’ the different negative aspects of both methods were outlined. These aspects are now taken into account in assessing the reuse of HCS of the PWC in the two residential buildings.

8.5.1. Demolition methods

To disassemble the 10 standard floors of the PWC a diamond saw, pneumatic hammer and wig and hammer are used to break the connections between the building components. It was earlier concluded that the pneumatic hammer is not good for the health of the building workers because of the vibrations and noise they produce and that the diamond saw can bring along extra risks because of the high level of noise that it produces. On this point, the reuse of hollow core slabs is therefore evaluated negatively for this case study.

When looking at the amount of dust production, the disassembling process is favourable for building workers as well as its surroundings. By breaking fewer connections within the concrete less dust is produced and the methods used for disassembling can keep the dust production more locally.

For the safety of building workers, the disassembling process is somewhat less favourable because the people disassembling the building have to stand inside, on top or very close to the building.

8.5.2. Human toxicity

Human toxicity is a measure for the impact on the human health and was calculated within the LCA study for the disassembling versus the demolition process.

It turns out that the process of demolishing produces much more human toxicity than disassembling the building in case of the PWC. In the adaption phase, also much more human toxicity is produced for recycling than for reusing the elements. By varying the transportation distances, it has turned out that transportation does not have much influence on the human toxicity. In total it can be concluded that the process of disassembling was very favourable compared to demolishing.

The disassembling process in the case study is not well enough developed yet to apply on other buildings. Although there are some positive effects such as less dust production, the methods used for disassembling PWC have some negative influences on the health of building workers. These effects should be minimized to make the disassembling process feasible. This could be either with other equipment, the same equipment that is improved to reduce the negative effects or with a well-developed process to minimize the risks while using the same equipment. With the latter, maximizing the ability of communication between building workers and well-considered safety regulations are meant.

The Human toxicity produced during the disassembling process of the PWC compared to the demolition process is much lower. The biggest difference lies in the adaptation phase. The values of adaptation of the concrete to be recycled are general and are only influenced by the amount of concrete and type of reuse. For a higher level of recycling, to replace gravel in new concrete instead of foundations of roads, more processes are required and therefore more emissions are produced. The adaptation phase of the concrete that is reused accounts for very little in the total amount of Human toxicity produced. In reality this might be slightly more, because only sawing the elements to size is taken into account. Other adaptations needed to make the elements ready for reuse are not taken into account because they are considered to have very little influence on the total emissions. It is assumed that the outcomes of the values of Human toxicity correspond very well with the actual outcome whenever the process is executed on other buildings than this single case study.

8.6. Conclusions

Taking all criteria into account, the reuse of hollow core slabs is evaluated positively for this case study because of the great environmental gain that can be reached with this innovation. Although these results are based on reusing the HCS of the PWC into two reference residential buildings, the outcome of the criterion 'environmental impact' does not depend much on the types of buildings chosen. In general it can be concluded that the environmental impact of reusing hollow core slabs is much lower than that of using newly fabricated slabs. The outcomes of the criteria 'time', 'costs' and 'social- and health aspects' do not plead in favour of disassembling the PWC instead of demolishing it. This is however not a reason to conclude that reuse has too many disadvantages, but rather to develop the process on these aspects. With good logistics, the criterion 'percentage reuse' could be kept positive when large quantities of hollow core slabs are reused.

The presented values outline the status quo of the concept. With no experience in the field of disassembling it is not more than logical that this process costs more time and money in the beginning. When the disassembling process is developed, these criteria will however become more positive step by step. Also the social- and health aspects have to be taken into account during the development of the disassembling process to minimize the negative effects for building workers. Taking these current disadvantages into account, it cannot be concluded that the concept will automatically sweep the market. The current differences on several

criteria between demolition and recycling on one hand and disassembling and reuse on the other hand make clear that the concept of reuse of HCS comes very close to being advantageous by itself already. The created value on the side of sustainability should be enough reason to make the concept profitable on each criterion. It will not only be favourable on the aspect of sustainability but will most likely be profitable overall within a few years when experience has been gained and repetition has brought down the costs and required time.

The figure below shows the optimization process of disassembling and reusing hollow core slabs. For the demolition and recycling process one value is taken as starting point for all criteria. For the process of disassembling and reuse the different criteria are compared with this value. In the beginning the optimization process goes fast and the negative value of the criteria will decrease quickly. The optimization process will continue when the concept is executed a couple of times but each time with smaller steps. The process of demolition and recycling will also develop over time but since this process already exists for a long time the optimization will go very slowly. The graph shows that in time all aspects of the disassembling process can become more positive than the current demolition and recycling process.

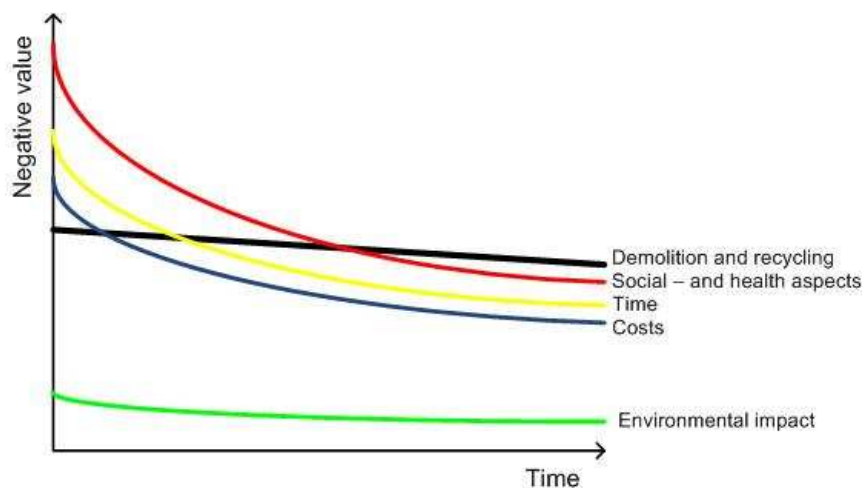


Figure 8-1: Optimization process of reusing hollow core slabs

9. Realization

9.1. Introduction

There have been many researches about sustainability concepts that can all contribute to a more sustainable society. Most concepts, however, are never put into practice. The reason is that participants in the building industry often not see how they can gain from it. The investment costs are mostly high and there is no evidence that the market is willing to buy the new products. This is why, for example, the concept of demountable building with concrete elements still has a market share of less than 1% (Van Dijk, 2000) This concept was based upon the idea that the prefab concrete elements (columns and floors slabs) could be reused after the building did not fulfil its function anymore. The problem was that it could not be predicted if these elements were indeed useful for buildings in the future. Contractors do not want to invest into something that lies so far in the future that they cannot be sure to gain from it. But even with other innovations that could be put into practice and could lower the CO₂ emissions, there is always an investment needed while there is usually the uncertainty about if the concept will indeed succeed. This is why innovations go so slow and need a trigger to succeed.

What could be the trigger that is needed to make reuse of hollow core slabs a success? Which participants within the process should initiate this concept and what could be their gain? There has to be 'something in it' for all parties involved. (W. Welling, 2012) It is a chain process and if one party objects, it will most likely not succeed. The advantages and disadvantages of each participant should therefore be analysed. What should be done to tempt the involved companies and individuals to make a contribution to this innovation? What will they gain or lose by participating?

These are important questions to answer to be able to make the first step in the realization of the concept. In the following chapter the participants in the process will be described and the scenarios that could lead to an initiative and finally a change in the lifecycle of hollow core slabs.

9.2. Government

9.2.1. Role of the government

As described earlier, the government has largely contributed to the developments of a more sustainable building sector the past few decades. To reduce the building waste they introduced a landfill ban in 1995 for recycle and combustible waste, still with many exceptions. In the same year the government introduced a landfill tax. Since 1998 there is a high rate for combustible waste and a lower rate for non-combustible waste. (IVM, 2005) With these regulations on waste, the demolition branch started with stripping buildings before demolishing them to separate the waste streams.

The goals of the government became higher and higher when it concerns the environment and the reduction of CO₂. These goals are stated in their policy plans and are reached by regulations, implying taxes and granting subsidies. Companies are usually willing to adapt their processes to make them more sustainable, but only if more profit can be gained. This could be because non-sustainable processes become too expensive (because of taxes implied by the government) or because more sustainability becomes more attractive (because of subsidies given by the government or clients who are willing to pay more for sustainable products). In an extensive survey held by TNS-NIPO in 2004 about social orientated values a restricted part of the Dutch population say to do something about sustainability or to be able to do something about it. 70%, however, is of the opinion that the government should take action. Sustainable issues are seen as a social dilemma; citizens are only willing to change their behaviour if others do the same. (Planbureau voor de Leefomgeving, 2004)

It is therefore important that the government initiates the next step in sustainability. There are also some other arguments why the government should support this particular concept and at the same time gain from it. At this moment, there are a couple of governmental policies to stimulate sustainability in the building sector, such as granting a project on the basis of 'EMVI' and the sustainable procurement policy. These policies will be discussed as well as the arguments that show the necessity for extra governmental action.

9.2.2. Means

Sustainable procurement policy (in Dutch: Duurzaam inkoopbeleid)

With this policy, the government wants to give the right example. To purchase sustainable, the market for sustainable products gets a substantial impulse. Different authorities have set standards for themselves with regard to sustainable procurement. To reach the objectives, sustainable criteria are developed for a large part of the products, meant to serve as a handle for sustainable procurement. (Ministerie van Infrastructuur en Milieu, 2011)

One of these product groups is demolition of buildings (in Dutch: sloop van gebouwen) which contains demolition works and related excavated activities and soil displacement. The regulations for sustainable procurement when it concerns concrete are that 20% of the aggregate in this concrete have to come from concrete granules. It is also stated that from several studies it has become clear that the amount of concrete granules will double in the coming years, while the traditional projects in raisings of soil and foundations stagnates. This should according to the sustainable procurement policy be solved by replacing 50% of the gravel by concrete granules. In this case, however, still 50% should come from primary raw materials and much energy is needed to crush the old concrete and fabricate new concrete.

At this moment, suppliers of hollow core slabs such as VBI, replace 20% of the aggregates by concrete granules because this is the percentage required by the government. The sustainable procurement policy does not stimulate the market enough to come with other solutions and is therefore not sufficient to radically change the processes to reach the objectives of the government about cradle-to-cradle and CO₂ emissions.

EMVI

Another policy to stimulate sustainability in the building sector is EMVI. EMVI (Economisch meest voordelige inschrijving) or Economic Most Favourable Tender is a method that is used to evaluate tenders. The government has come up with this method that evaluates tenders not only on the basis of price, but also looks at qualitative criteria, such as sustainability. This way, engineering companies and contractors can win a project by giving value to their concept. In the building industry this is called 'award on value' (in Dutch: gunnen op waarde). In the tender, an evaluation form is added in which the EMVI-approach is explained for that specific project. It contains the goals of the client, the criteria on which the project will be evaluated and the maximum value (expressed in money) that can be added by these criteria. (Rijkswaterstaat, 2012)

This calls for a little bit more creativity and innovations than the sustainable procurement policy, but the client still specifies the project and the exact criteria on which the designer or contractor can score points. The architect or contractor has not enough freedom to really innovate and come up with another, more sustainable, solution. (De Ridder, 2012)

Another problem is that the government is mostly client of GWW works and not of residential and office building projects. For the GWW sector about 80 to 90% of all projects is purchased or tendered by the government. Because of the dominant role of the government, there is a direct relation between the way of tendering and the developments in this sector. (Pianoo, 2012) For the building sector, the government has Rijksgebouwendienst who develops and maintains buildings that are state-property. This is however a small part of all residential and office building projects. The majority of the clients is private and has fewer motives to tender on EMVI.

Even though the government claims to use EMVI, GWW projects are still very often tendered on basis of lowest price. Only 20 to 25 percent of the projects are tendered on EMVI. Allowing for variants is not common either. According to Stichting Aanbestedingsinstituut Bouw&Infra only 3% of the tendering services allows for variants. One of the reasons is that it is difficult to tender on the basis of value criteria. EMVI calls for expertise for the formulation of criteria, the judgment of the tenders and the control on the delivered work in relation with these criteria. (Pianoo, 2012)

A third problem is that more than one company within the building sector has influence on the possible success of the concept of reuse. This is a perfect example of a chain-aimed innovation, but is hard to realize if the different stages in the chain do not work together and do not have the same interest. To reuse hollow core slabs:

- the initiator of a demolition project needs to invest more
- the demolition company has to be able to disassemble the building which asks for a lot of effort and specialism
- the prefab supplier, or another party, needs to be willing to take back the slabs and adapt them for new use
- the constructor and building company need to be willing to use the used slabs
- the client of the new building needs to invest in the reused slabs

An incentive as awarding a tender on value is probably not enough to change a process as drastically as this one needs to be changed. Besides, de Ridder argues, the EMVI method in the way it is applied by the government is too indirect. The costs of a building should actually be based on their whole lifecycle. Down cycling in tons after demolition of a building, for example, is a negative value. The amount of tons CO₂ over the lifecycle of a building can also determine who gets the tender. Materials that can be sold at the end of the lifecycle of a building can be subtracted from the price. This way, value is directly asked for. This requires much freedom for the designer. Since a couple of years, there is already the trend in the GWW sector to challenge the market more by not specifying the project and thus creating freedom for the designers. (Pianoo, 2012) This trend should continue and also extend towards the office buildings and residential building market to allow for more innovations.

It can be concluded that EMVI is a trigger for sustainability and can stimulate a concept such as reuse of hollow core slabs, but only if the EMVI is kept more abstract. The goal can for example be stated as 'realizing a sustainable construction'. Minimizing raw materials or CO₂ emissions can be aspects on which the construction is evaluated. Another EMVI value can be the time within which a building has to be realized. By using building elements that are already in store, a reduction could be possible. These three aspects can specifically stimulate the reuse of hollow core slabs.

Subsidies

Another way the government tries to stimulate innovations in sustainable building projects is in granting subsidies. With the current national financial crises, it is mainly the European Union that invests in research and innovation.

The EU Framework Program for Research and Innovation, called Horizon 2020, is the financial instrument that aims at securing Europe's global competitiveness. Running from 2014 to 2020 with an €80 billion budget, the EU's new program for research and innovation is part of the drive to create new growth and jobs in Europe. This program will combine all programs that are currently charged with a part of the funding. One of the goals of the program is to strengthen industrial leadership in innovation, including major investment in key technologies. Another part of the subsidy is meant to help address major concerns shared by all Europeans such as climate change. Horizon 2020 wants to "tackle societal challenges by helping to bridge the gap between research and the market by, for example, helping innovative enterprises to develop their technological breakthroughs into viable products with real commercial potential". (European Commission, 2012)

With this European program a project such as reuse of hollow core slabs could qualify for a subsidy, but it is definitely not sure since there are so many sustainable innovative initiatives that are in need of money to launch their product. But in case it is granted for the development of reuse of hollow core slabs, it could be used for more research and a pilot project after which the rate of success should be evaluated. The results, if positive, could be an incentive for companies in the building sector to invest in the project themselves. They need to experience the feasibility and see possible gains for their company in the future.

The companies that are involved in the project should definitely not stay dependent on this type of support of the government. With subsidizing companies the government makes them

lazy while instead they should be mobilized. (De Ridder, 2012) At the same time, subsidies are cut down to such an extent that it is not smart for companies to rely on them. (W. Welling, 2012)

Taxes

The European parliament has decided that tax has to be levied on polluting and wasting valuable resources instead of on incomes. This is a proposal to deal with raw materials more efficiently. According to Bas Eickhout, member of the European parliament and GroenLinks, it is a smart economic policy to tax what you have few of. If you lower the tax on labour at the same time, it also increases the amount of jobs. (iNSnet, 2012)

Hennes de Ridder also thinks the solution lies in taxes that should be levied on non-renewable materials and CO₂. By making new products with depleted new raw materials more expensive, it will stimulate reuse. When looking at disassembly, the costs of the total lifecycle of the products and materials and their environmental impact should be taken into account. The costs of reused products might be a bit more expensive at this moment, but if you take into account the environmental impact and you levy taxes on new products, it may be cheaper. If it turns out in the end that reuse is this more expensive, the government should again make new materials more expensive until there is a positive balance for reused products. (De Ridder, 2012)

The low prices of raw materials are also a problem for renewable energy. Because oil and gas are still cheap, the development of clean energy does not get off the ground. Fossil fuels should get taxed higher to enable the development of other forms of energy.

Not only new materials can be taxed but also the processing of the products at the end of the service life of the building. For some products, such as electronic products, the purchaser pays a certain standard amount per product for its processing after it has been used. If consumers pay for the disassembling of the building, this could definitely give an incentive for reuse.

9.2.3. Advantages and disadvantages of reusing hollow core slabs

As said before, the government could eventually gain from it themselves. At least two aspects should be mentioned in this case, namely their competitive position in relation to other countries and the possibility to create employment. The disadvantage for the government is that it either costs money, in case of subsidies, or that it is not clear what the economic consequences will be, in case of taxing on raw materials. This could lead to economic decline but if at the same time labour is taxed less, it will probably only stimulate reuse and help more people to work.

Competitive position

As also mentioned as one of the European goals, the national government could benefit from sustainable innovations because it strengthens their competitive position. There are private initiatives that make the building sector more sustainable but these are not sufficient to meet the sustainability goals of 2020.

The report of the 'Planbureau voor Leefomgeving' shows that the feasibility of these goals is very low. The 100 million Euros on subsidies that the national government grants every year do not support sustainability in the building sector. At this moment, these subsidies will even decrease because of the financial crises. Investigation of the WWF shows that investors even run away to other countries, because in the Netherlands there are not enough pilot projects. While our neighbouring countries invest 55% more in sustainability, the sustainable investments in the Netherlands decreased in 2009 by 34% per cent. (van der Sluis, 2009) Ewout van der Sluis, chairman of the management of Hevo, a consultancy company for accommodation and real estate in Den Bosch who has wrote the letter published in the financial daily magazine (in Dutch: Financieel Dagblad) with the title 'Government has to force', argues that a forcing and leading role of the government is necessary. She has to take her responsibility and take Germany as an example. The government in Germany has integrated the environmental goals in the building regulations which has led to a self-evidence of sustainability in the German building sector. Apart from meeting the sustainability goals when increasing the role of the government, it has another advantage. The Netherlands can claim to be the pioneer on the domain of sustainability. This way sustainability can become our export product.

This is more an argument why the government should be the initiator of sustainability in the building sector in general and not specifically for the project of reusing hollow core slabs. It does show however that we are not moving forward if the sustainability goals are supposed to be met by the market without interference of the government.

Creating employment

Gemeentewerken Rotterdam and consultancy bureau IVAM have developed a 'smart demolition tool' which is the outcome of 2 years of research. One of the conclusions of the research is that demolishing manually reduces the CO₂ emissions as compared to demolishing with machines. An important social aspect of 'Slim slopen' is the amount of employers that is needed for a project. This can decrease the unemployment among building workers. The chairman of the executive committee of sustainability in Rotterdam, Alexandra van Huffelen, argues that with disassembling a building as much as possible, two birds are killed with one stone. It contributes to the objective to cut in half the CO₂ emissions and at the same time creates employment. The idea is not to replace all machines by manpower, says Cor Luijten, project engineer of the engineering company and member of the 'Central Board of Specialists Demolition', but only where it can be done in a safe way and if it leads to a better result, technically as well as socially. It may also not stand in the way of existing jobs.

With the high rate of unemployment at this moment, especially among building workers because of the situation in the building sector, this is a good opportunity. In January 2012,

the amount of new unemployment benefits (In Dutch: WW uitkeringen) was more than 5000 that month (Source: UWV), which again shows an increase compared to the years before. (FNV Bouw, 2012) The FNV Bouw is concerned about the state of the building sector at this moment. They want a fast introduction of regulations to help recovering the sector. The high rate of unemployment among building workers could be one of the incentives for the government to invest in the reuse of hollow core slabs. The manpower it costs to disassemble a prefab concrete structure is much more than when it is demolished. According to Willem Welling (AB-FAB) however, this is not the solution to solve the economic crises. "You have to go forward instead of backwards." There are people who argue that in times of crises people should be supplied with this type of jobs. In the crisis years of the thirties, such employment projects were carried out. The future, however, is to make everything cheaper and use less manpower. (W. Welling, 2012)

If the government would grant a subsidy for a project that creates employment they would cut costs on social security because the people that needed an allowance now make their own money. The reason why the government would not grant a subsidy for a disassembling project in the name of creating employment is according to Welling that they do not look at macro level. Everyone working at the authorities is occupied with their own budget. It could be handy to use unemployed people in the disassembling project where more manpower is needed, but politically seen this is very difficult. Something has to be initiated to get it going, but as soon as things get large-scaled, machines should be used to make everything go faster and cheaper. The factor labour will be minimized because otherwise it would be too expensive. (W. Welling, 2012)

De Ridder also thinks it is not a good argument that more manpower is needed to get a subsidy from the government. It would be a step back when we should be looking forward. It has to be formulated differently because by saying the project is to get the unemployed back to work, it gets such a negative tone. It is better to focus on the total lifecycle and the environmental impact of the products and materials.

SCENARIO 1: Government as stimulator

From the role of the government and all the means they have it should be clear that the government as initiator of reuse of hollow core slabs is a very likely scenario. From analyzing their current policies and their rate of success it can be concluded that big innovations need more than the 'sustainable purchase policy' or tendering on standard EMVI procedures. EMVI could be a trigger but only if more freedom is given in the tender. Subsidies could give a first incentive but will in the end not allow for a real transformation in the market. When subsidies are cut, the concept of reuse should still be profitable or else companies will not be willing to participate in the process. A good way for the government to stimulate the reuse of hollow core slabs is to tax new raw materials that are needed to fabricate new hollow core slabs. To reduce CO2 emissions, fossil fuels should also be taxed more. By making new products more expensive, reused products will win ground and get a fair change in the market.

9.3. Supplier

9.3.1. Role of the supplier of hollow core slabs

The role of the supplier of hollow core slabs is to sell as much slabs as possible. To do so, the supplier needs to keep his price down and thus make the process of fabrication as cheap as possible. His delivery time should also be kept as short as possible in order to serve his clients the best he can. Another way to attract clients is to make the slabs more attractive for them by innovating them in order to integrate more functions in the slabs.

9.3.2. Advantages and disadvantages of reusing hollow core slabs

The supplier of hollow core slabs could be a key player in the process of reusing the slabs. He knows most about the properties and has documentation of the slabs that are currently present in buildings (at least of the last 10 years).

If second hand slabs will be used instead of new ones, this means the producer of hollow core slabs will sell less new slabs and his turnover will go down if the price is not driven up. To compensate this loss, he could stay involved over the whole lifecycle of the slabs. Advantages besides having knowledge about properties and being in possession of documentation are that he knows how to sell the slabs and what the requirements are in each building. Besides, the supplier of the slabs knows how to cut them to size and make block-outs. The producers usually also have a large area around their factory for storage. At this moment, the storage is used for new slabs that lay there before they are transported to the project. It is however at most locations possible to expand the storage area in order to store up old slabs.

A problem in the process of the reuse of hollow core slabs is the storage of capital. A large area is needed to store the slabs because it is not certain on forehand when the slabs are purchased. By having the second hand slabs in stock for a long time, a large storage space is needed. On top of that, the money that is earned by selling the slabs coming in later which is coupled to a loss of interest. If the concept is carried out successfully and many buildings are disassembled instead of demolished, a lot of slabs will become available. To stimulate the process of reuse this is also what it takes for the company that offers second hand slabs. The buyer wants to be certain that whenever he needs the second hand slabs they are available. If different buyers need the same type of slabs at the same moment, enough of them need to be in store to be able to supply them in time. An advantage when the producer of hollow core slabs is also responsible for reselling the old slabs is that whenever something is not available, he could always solve the problem by fabricating new slabs instead of giving out the second hand slabs.

Disadvantage of putting all knowledge about the slabs in hands of the supplier is that information could get lost if the company changes its current form, for example if it is taken over by another company. Another disadvantage is that the information is not public and gives power to the company that is in possession of the data. Instead of keeping the information about the slabs in their own database, there is also the possibility to store the data in the building elements themselves. By creating a micro-chip with all relevant

information about the properties and pouring it into each element, the information is stored in the building. It can be read with equipment that can be in possession of everyone that is interested in information about the building elements.

The disadvantage for the supplier to enable the reuse of slabs is that they could sell less new slabs. This can be a reason for prefab element suppliers to hinder the reuse by making the slabs in such a way that reuse is not possible. They would however put themselves offside by doing this. If the market demands second hand slabs, they should go along with the developments that make this possible. The market is very powerful and if they do not participate, another company will take over and they will lose ground.

9.3.3. Supplying load bearing capacity

Besides the possibilities of having the producer take back the slabs after they have been reused, it is also a likely scenario from the point of view of Corporate Social Responsibility (in Dutch: MVO). The producer has depleted raw materials and produced CO₂ emissions for the production of his product. It should be his task to make the lifecycle of these products as long as possible and make sure the environment will not be harmed even more.

For many products, the responsibility of reuse is put in the hands of the consumer. Judith Merkies, PvdA, member of the European Parliament, pleads for a lease-construction in which the producer becomes responsible for the whole lifecycle of his product. According to her, this will decrease the addiction to raw materials and import dependency. Valuable raw materials stay in the hands of the producer. (Merkies, 2012)

This could also be an option for hollow core slabs. In the auto-industry this concept started to develop in the late eighties in the Netherlands. Besides some big existing companies that started to invest in this market, a few new companies specialized in leasing cars were also born.

VBI already wants to take back the concrete of old hollow core slabs they have produced in the past. They do not stay owner of the slabs but they try to take the concrete back because they can use it to produce concrete with 20% recycled granules. The government demands this percentage of reuse and from the point of view of Corporate Social Responsibility it is also attractive to do so. (Koppenhol, 2012)

De Ridder thinks it is possible to lay the reuse of hollow core slabs in the hands of the producer. There are, however, certain conditions. The producers should get a saying in the assembly of the slabs to make it easier to take them out. They should actually install their own slabs, just like with the plumber who installs and maintains his own boiler. If the producer should take back its own slabs it is best if no one else has something to do with the assembly and disassembly. Building workers often damage the slabs and it is not realistic to force the producers to repair them and resell them for a very low price.

Producers themselves see also some disadvantages. The biggest disadvantage according to Koppenhol of VBI is that fewer new floors can be sold. Besides, their concepts go towards

selling performance. With reused slabs you have restrictions. You can for example not make a climate floor out of them.

Another disadvantage is the large storage area needed and the logistics around it. The slabs should be delivered on the building site in the order that they are needed. To realize this, they should be put in the reverse order on the storage area and with reused slabs of which you do not know yet for what project and in what order they will be needed, it is hard to realize. Besides, a whole database with second hand slabs is needed. It is just a very big organization to realize this. (Feenstra, 2012)

Both producers also think it is hard to get a financial gain from reselling the slabs. By increasing the price of new slabs it could however be evened out. (De Ridder, 2012)

SCENARIO 2: Supplier of hollow core slabs stays responsible for the slabs

Because of their knowledge on hollow core slabs and their means to store and prepare the slabs for reuse, the supplier could be made responsible for the process of taking back and reselling the slabs. On top of that, it is the supplier that has caused the negative impact on the environment by the fabrication of the slabs and it should therefore be his task to increase the lifetime of the slabs.

It is also possible that another party becomes responsibility for the logistics of reselling the hollow core slabs. A condition is that they are in possession of all data on the properties of the slabs. This could be arranged by storing the information in the prefab elements by implanting chips during production that possess this information.

9.4. Client

9.4.1. Role of the client

The client usually wants the project to have a maximum value against the lowest price. He could wish for sustainability if this is important for his image or if he could eventually financially gain from it, for example because the energy use in his new building will be low. A fast realization of the project is another important factor because it brings the interest rate down.

9.4.2. Advantages and disadvantages of reusing hollow core slabs

The client wants to be assured of the quality of the building he buys. It is therefore important that all products in the building are of good quality. The properties of the reused floor need to be documented and a guarantee of good quality is required.

For the process of reused slabs this means that of all buildings that are built with new slabs, their properties should be carefully documented in a Birth Certificate before the building is delivered to the client. This way, when the building is disassembled and slabs are taken out

one by one, it is directly clear what the properties of these slabs are. No tests need to be done afterwards to determine the properties. This saves out a lot in costs.

An advantage for the client could be that reused slabs do not have to be fabricated which in most cases means time is saved. More about this will be outlined in the paragraph 'Construction company'.

9.5. Architect/engineer

9.5.1. Role of the architect/engineer

The architect and engineer want to create as much value as possible for the client to make as much money as possible. To be able to create value, architects want to have as much design freedom as possible.

9.5.2. Advantages and disadvantages of reusing hollow core slabs

To be able to use second hand slabs it is best to design a floor with the least possible amount of block-outs. If the architect and engineer do not design on the reuse of old slabs, about 70% of the floor surface can be made with reused slabs. (CASE study) When they would, however, take the reuse of slabs into account and find another solution to locate the pipes and wires, 100% of the floor could be made with reused slabs. It is also profitable to take the width of standard hollow core slabs into account during the design stage. If the staircases and other dimensions are made in the grid, fewer slabs have to be sawn to size width wise.

Disadvantage for the architects is that this leaves them with less design freedom. On the other hand, they can create more value for the client with used second hand slabs and could therefore financially gain from it.

Another advantage for the architect and engineer by putting reused slabs in their design can be obtaining a leading position in sustainability. From the point of view of Corporate Responsibility it is favourable to invest in such concepts. The market asks for sustainability and has a big influence on the economy. Participating in sustainable innovations will ensure the market position of the architects and engineers and will probably bring in more projects. By getting involved early, an investment in the future is made.

9.6. Construction company

9.6.1. Role of the construction company

A construction company tries to build the work as cheap as possible after they have won the tender. To win the tender, they have to create as much value as possible against the lowest price.

9.6.2. Advantages and disadvantages of reusing hollow core slabs

Important for the construction company is the quality of the product. In order to choose second hand slabs, they would have to be guaranteed that the quality of these slabs is sufficient. On top of that, they would not have to be more expensive than new slabs, unless it is agreed upon to get more money from the client by using second hand slabs.

An advantage could be the faster delivery of reused slabs. In case this would cut down the construction time it could save money.

Another advantage is, just like for architects and engineers, the increase in their sustainable image and meeting their Corporate Responsibility goals.

9.6.3. Hollow core slabs in stock

By reselling used hollow core slabs, they should be stored somewhere and information about the available slabs should be put in a database. An advantage on the side of the contractor that purchases the second hand slabs and the client for whom the building is being built could be the shorter delivery time. No time is getting lost by waiting for the fabrication of new slabs. Old slabs that are found in a database can be sawn to size immediately after they have been ordered.

Reducing wastages is defined by LEAN management. Waste is for example the unnecessary time that is lost during the process of ordering hollow core slabs. If time can be shortened and will actually increase the pace of the construction time, profit can be gained. The building can be delivered earlier. This is an advantage for the client who can start making money from the building earlier and for the building company because it will be rewarded by the client for its fast delivery.

Normally, the process from ordering slabs and actually receiving them is about 10/11 weeks. (Feenstra, Dycore) Within these weeks, drawings are sent back and forth from the contractor to the supplier. In case the slabs are already present, a few weeks will still be needed to make the right HCS lay-out, to adapt the present slabs in such a way that the dimensions are correct and to locate them practically to be able to take them away easily and in the right order. Actually making the slabs and having time to plan them in is however saved.

According to Martin Koppenhol of VBI, this is however a non-argument. He states that the delivery time could be 8 weeks but is usually about 12 to 13 weeks because of the process of sending drawings back and forth. He states that only about 1% of all building companies ordering slabs actually need them within 8 weeks. The delivery time is not a bottleneck and using this as an argument in favour of reused slabs is not valid.

To validate this argument, a few employees of building companies that work in the preparation phase were asked to give their point of view.

Remko Bentvelsen, planner engineer at Dura Vermeer, does not totally agree with the argument of Koppenhol. He says that at this moment, their preparation- and purchase process is attuned to the delivery time of the slabs. One way to economize is a shorter preparation time because the work preparer has to put in fewer hours for the project which brings down the costs. Also shortening the time of fabrication could generate profit for the client because the start of constructing a dwelling can be brought forward which brings down the interest rates of the ground. According to Bentvelsen the hollow core slabs lay on the critical path in the planning. The preparation time is however about as much as that of the prefab skeleton. In case the rest of the construction is of sand-lime brick, the path becomes more critical because the delivery time of sand-lime brick blocks is shorter.

According to Cees-Jan Verhoeff of Ballast Nedam Bouw, the fabrication time of hollow core slabs is 5 to 6 weeks if it concerns about 1200 m² HCS. The slabs are just-in-time assembled and are not needed before the load carrying wall elements are assembled. The total construction time of the project can be shortened if also the walls are delivered earlier. The slabs do not necessarily have to be on site earlier. Time can especially be gained in the preparation phase of coordinating the block-outs. If this time can be shortened this can definitely be a profit for us.

Zivana Obrenovic of Heijmans agrees with the necessity of good information distribution of the drawings and coordination of the documents. She states that short delivery times could have a positive influence on the construction time of the building, but it is mostly the preparation phase that influences the length of the process. She thinks that the production time itself does not often hold up the construction process. With help of new methods such as 3D models, the drawings can already be better attuned to each other to shorten the preparation time.

SCENARIO 3: Construction companies and clients want reused slabs because of their shorter delivery time

It seems like a logic conclusion that profit can be obtained by shortening the delivery time of slabs. This could be a reason for construction companies to prefer slabs in stock over slabs that still have to be fabricated. The bottleneck in ordering HCS however lies usually in the preparation phase in which drawings are sent back and forth between supplier and construction company. If the coordination between the involved parties is improved, profit can be gained. The place and the amount of block-outs is usually the problem. If as much block-outs as possible are left out of the floor, this could be profitable.

Another argument why a shorter production time is not necessarily the solution for a faster construction process is that the delivery of HCS does not always lie on the critical path in the construction process or at least not by itself. The prefab walls also need to be fabricated which takes about as much time as the delivery of HCS

The argument of gaining from a faster delivery of HCS is therefore very unstable and depends on different factors. It can however be an advantage that it is known on forehand what the delivery time of the slabs is. If they only have to be sawn to size, the slabs can be delivered in about one week. Another order will not foul up the planned delivery date which could be the case if the slabs still have to be produced. If another order has priority it can lengthen the delivery time of the slabs for the project. By using second hand slabs there is more certainty about the delivery time which makes the preparation path of the HCS less critical and will in less cases lead to extension of the construction time.

To profit from this shorter delivery time it is however important to use only second hand slabs in a new building. If part of the slabs still have to be newly fabricated, this will probably counterbalance the advantage of the shorter delivery time of the second hand slabs. Partly because the new slabs will have a longer delivery time but also because of the more complicated logistics that are required when two different types of slabs from two different locations are used in one project.

9.7. Demolition company

9.7.1. Role of the demolition company

After having granted a project, a demolition company wants to demolish a building against a price as low as possible. By stripping a building, less money needs to be paid for the removal of waste and useful materials can be resold for reuse or for recycling.

9.7.2. Advantages and disadvantages of reusing hollow core slabs

Disassembling a project costs about 60% more than demolishing it. (CASE study) This increase in price needs to be compensated by the higher profit of selling hollow core slabs as opposed to granules. Another scenario to compensate part of the price is by increasing the

tax on fossil fuels. Demolishing a building costs more than twice as much fossil fuels as disassembling the same building. The CO₂ emissions are therefore more than twice as high. (CASE study)

When the costs of the extra hours and manpower needed to demolish a building are compensated, the construction company gains because their turnover increases.

Instead of making the supplier of hollow core slabs responsible for the old slabs, it could also be the demolition company that puts the second hand slabs into the market. They could find the cheapest way to disassemble the building and carefully take out the slabs so not much repair has to be done to the old slabs. They would have to set up the database and arrange one or more storage areas. Disadvantage of this concept is that they do not have as much knowledge of the properties of the slabs as the supplier has. By implementing a chip in the slabs during production, this problem can be solved.

If a demolition company invests in developing a disassembling process, they could gain from it later on. When the concept becomes a success they are leading in knowledge about disassembling a building and will therefore be hired for more projects. Because they have been involved from the beginning, their process is further developed than that of the other companies and therefore probably cheaper. This means the price of second hand slabs can go down and they become economically more attractive. This stimulates the reuse even further and will lead to more orders for the demolition company.

9.8. User

9.8.1. Role of the user

The user wants to live in a building for a price as low as possible. Part of the users also wants to give a positive contribution to the environment and is willing to invest a small percentage on this.

9.8.2. Advantages and disadvantages of reusing hollow core slabs

By buying or renting an apartment with reused slabs, the user is acting environmental friendly and might see this as a value. Most people, however, are not willing to pay more for the environment. They see that as a task of the government. (Planbureau voor de Leefomgeving, 2004) The reused slabs should therefore not lead to a significant increase in price for the users.

It should also not lead to less quality for the users. It is important that the quality is guaranteed or else the user is not willing to buy or rent a house with reused slabs.

SCENARIO 4: Striving for a better image or caring for the environment will drive companies and individuals towards sustainability

With the current knowledge about the impact of CO2 emissions and the exhaustibility of our natural resources, more and more people are willing to invest in a more sustainable world. Investing in sustainability means for companies a better image and therefore more clients that grant them projects. They give meaning to the Corporate Responsibility which is valued high by society. Individuals favor sustainable products if the price does not increase. For companies this is a trigger to innovate their products towards sustainability.

9.9. Steps to be taken

The current governmental policies do not sufficiently stimulate sustainable innovations such as reuse of building elements. Companies are willing to invest but only if they are rewarded more than others for taking Corporate Responsibility that will in the long run bring them profit. Within this study the large environmental gain that is reached by reusing hollow core slabs has been proven. Some negative sides of this concept compared to the current recycling of concrete were also outlined, but with effort of the participants that are willing to put the concept into the market, these can be turned into advantages. As shown in the previous chapter on the evaluation of the case study it takes time to develop the process to being feasible on all aspects. It also shows that we are not far from reaching this point and that repetition and experience will lead to this goal. It is clear that the next step needs to be taken in the realization of the concept.

From the analysis done in this chapter, the most logical first step is to set up a pilot project. Different companies that have a function in the process should form a committee that will set up the research. The government should support the execution of the pilot project by subsidizing the companies that invest in this project. With this pilot project the advantages and disadvantages of disassembling and reusing the slabs becomes clear and the process should be developed towards a profitable concept. Who has to be leading and will be responsible for storing and reselling the elements will follow from the experience acquired during the pilot project.

The government and other clients should apply EMVI more often. It is important to allow for more freedom within the EMVI criteria to stimulate innovations. By focussing more directly on maximizing environmental value, designs that use second hand building elements have an advantage and have more chance of winning the tender.

Another important step to be taken is to change the registration of the properties of the elements. Instead of putting the information of the building structure in hands of the owner and supplier of the building elements, the information should be stored in the building. This should be done by placing a micro-chip in the elements during fabrication containing information on their properties. It is also important to draw up requirements for reuse of second hand slabs in the Eurocode.

10. Conclusions and recommendations

10.1. Conclusions

At this moment, the concrete of building structures is crushed during the demolition process and recycling is the highest level that is reached in the waste management hierarchy. Since the environmental impact of the fabrication of concrete is mainly influenced by the production of cement, much environmental gain can be booked by keeping the concrete intact in order to reuse it. This fits perfectly into the governmental goals with respect to sustainability.

The highest possible level of reuse is component level, since larger parts of the building can physically not be taken out and transported at ones. A lower level of reuse would mean more energy is required to break old - and form new connections. Most favourable type of components to reuse are prefab elements since their connections are weaker and thus easier to break than those of an in-situ poured concrete structure.

The office vacancy rate is currently very high in the Netherlands and there is a call for demolishing such buildings in case they are not suitable for redevelopment or transformation. At the same time, there is a need for residential buildings. In both constructions, hollow core slab floors are the most common type of prefab concrete floor systems and are therefore valued as most favourable for reuse. An advantage of hollow core slabs (HCS) over other floor systems is their standard width.

With earlier executed projects it has been proven that disassembling a structure with prefab concrete elements is technically possible. The disassembling methods used during these projects combined with further research done in this field has led to the disassembling process of the PWC. The different demolition methods used during this disassembling process have some positive effects on the surroundings, such as less dust production, but also some negative effects on the building workers, such as more vibrations and high levels of noise. A positive effect in general is that less connections within the concrete have to be broken with the result that less energy is needed to take down the buildings and CO₂ emissions are reduced.

Functionally it is possible to reuse hollow core slabs coming out of office buildings for residential buildings. An advantage is that the design load in residential buildings is lower. Fire safety and noise insulation requirements are leading in the choice for what type of residential buildings the slabs are most suitable. The fire safety requirements are higher for high residential buildings than for office buildings which makes the second hand slabs more suitable for single-family dwellings and low apartment buildings. To meet the higher noise insulations requirements in apartment buildings, a floating floor should be applied. The thickness of the concrete top layer can restrict the possibility of reuse to lower residential buildings. The necessity of block-outs (in Dutch: sparingen) and the finishing of the ceiling determine the amount of adaptations necessary and the maximum percentage of reuse in new buildings.

The percentage of reuse of hollow core slabs from office buildings can be very high when the slabs have a sufficient length. What percentage is finally reused depends on the required dimensions in a new building. The percentage of reuse in new residential buildings highly depends on the block-outs necessary in the floors. Since not all block-outs can be made in slabs that have reached their full strength, for that part new slabs should favourably be used. A solution for this problem is to design on reuse and keep large block-outs out of the floor slabs. This way, the use of second hand slabs in new buildings can go up to 100 per cent.

From the LCA study it turns out that reusing HCS provides for a large environmental gain. Second hand slabs coming from the PWC have a very low carbon footprint compared to newly fabricated slabs (not even 5%). The total environmental gain that is booked by reusing second hand slabs depends on the percentage of reused slabs in the new building. The type of floating floor that is needed in case of apartment buildings is also of influence of the environmental impact of reusing HCS.

The costs of making a floor with reused slabs are about 20% higher than with new slabs. These conclusions are drawn from the case study for which a cost calculation was made for second hand slabs and new slabs. Taking out HCS and making them ready for reuse is only a little bit more expensive than the fabrication of new slabs. The costs for the storage and in case of apartment buildings of the floating floor should, however, be added to the costs of the second hand slabs. The largest influence on the costs of second hand slabs is the disassembling process which is more expensive than the demolition process.

Combining all results, the reuse of hollow core slabs is evaluated positively because of the great environmental gain that can be reached with this innovation. On other aspects some disadvantages need to be overcome but with experience and repetition at least the same level as with demolition and recycling can be reached. The next step is to put the concept in the market. Most important is that it becomes economically attractive to use second hand slabs instead of new slabs. To accomplish this, an incentive from the government is needed to prime the process. The current governmental policies, however, do not sufficiently stimulate sustainable innovations such as reuse of building elements. With a pilot project, in which a building is disassembled and its HCS are reused in new buildings, the participants in the building sector can obtain knowledge about the whole process. Consequently, companies can take over the leading role and make the reuse of hollow core slabs attractive.

10.2. Discussion

The results in this research concerning the environmental impact of reused slabs compared to new slabs have turned out more positive than expected. Although the results are based on only one case study, the comparison of many different variants and taking the whole floor into account, make them very reliable.

Keep in mind that another part of the conclusions are also based on this single case study. Standard buildings were chosen to make the results as realistic as possible. It should be remarked, however, that there is some variance in construction types of office buildings and the results do therefore not automatically apply to each office building. The same holds for the layout plan of the hollow core slabs of the chosen single-family dwelling and apartment

building. They are assumed to be representative for the newly built buildings with this function, but in reality there are also other plans with more and less block-outs and other floor types, especially in apartment buildings.

10.3. Recommendations

First of all, the results for the case study were positive regarding the environmental gain that can be booked by reusing hollow core slabs. There are also some negative aspects which can be minimized by optimization and development of the concept. Furthermore, there are still some uncertainties about the process of reusing hollow core slabs. It is therefore recommended to continue with research on this concept. In this paragraph recommendations for further research are given.

For the case study a 'standard' office building was chosen. It should be investigated if the types of hollow core slabs present in this building are indeed representative for the whole office market and if there are many offices with a concrete topping of at least 70 mm that limits the possibilities for reuse.

The chosen disassembling methods bring along negative aspects for building workers because they produce much vibrations and noise. The degree to which these negative aspects harm the health of the building workers and what type of alternatives can be found to replace this equipment should be examined further. To optimize the disassembling process, a pilot project should be carried out. This way the difficulties and positive aspects become clear more easily and the process can be developed towards a more healthy, safe and efficient process. With this pilot project it could also be investigated if the finishing layer indeed comes off as easily as assumed.

After the hollow core slabs have come out of the office buildings, they have to be prepared for reuse. With the pilot project it should also be investigated how much work needs to be done in order to prepare the slabs for reuse. Answers to the following questions can be found by executing this pilot project. Do the slabs come out of the construction without much damages and how much work is it to remove all mountings attached to the bottom of the slabs? Is the visual quality that is reached by spraying a gypsum layer on this side of the slabs indeed sufficient?

The difference in magnitude of the camber of the slabs coming out of the pilot project should also be investigated. They should be compared to the cambers of new slabs with the same properties in order to determine the spreading in magnitude of the cambers as result of time and loading. It is important to know if measures are needed to even out this camber in order to get a nice visual view of the ceiling in the residential buildings. If it indeed turns out that the cambers of different slabs differ too much, solutions should be found to solve this problem.

Furthermore, it should be investigated if the block-outs present in the used residential projects are representative for the currently built dwellings and apartment buildings. An answer also has to be found on the question if it forms a problem for architects and engineers to design floors without large block-outs. Leaving large block-outs out of the

hollow core slabs is favourable for the reuse of hollow core slabs but also for the delivery time of the slabs. For the apartment buildings other common floor types such as wide plank floorings should be compared to using second hand slabs on basis of time, costs and environmental impact. The different types of floating floors should also be investigated especially to determine the sound insulation quality that can be reached. In the case study extra concrete is used to reach a sufficient level of sound insulation but other solutions might be more environmentally friendly and less time consuming.

To finally put the concept in the market, initiatives are required from several parties. A beginning is made of how this should be done by sketching different scenarios. A more detailed plan should be set up including the roles of each participant. The logistics are an important aspect of this plan.

If the pilot project has become a success and further initiatives are taken to actually bring the concept into the market, it should also be examined how disassembling can be made easier in the future. What construction systems and connections are possible in office buildings to stimulate the reuse of the floor slabs?

This research was aimed at reuse of hollow core slabs from office buildings to residential buildings. Reuse of other types of prefab elements can also be carried out such as TT-beams and load bearing façade walls. The type of building structure from which the elements are disassembled does not necessarily have to be office buildings. This was chosen because of the high structural vacancy, but in the future there can be an over capacity of other types of constructions. There are also more options for the type of constructions suitable for reusing the elements. This should also be investigated.

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