Construction and demolition waste management. Current legislation and the potential of material upcycling.

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Preface
The present final master thesis was conducted between February and June 2013 and was constructed in the framework of the Problem Based Learning (PBL) model of Aalborg University.
The main subject that this thesis is focusing on is Construction and Demolition waste management as well as an evaluation of relevant legislation is this area. The study is framing a European context and comprises data conducted with a demolition waste management company based in Denmark.
The present thesis is accomplishing the main subjects of the study program "Environmental Management and Sustainability Science", the business perspective and the policy level.
Special acknowledgements go first of all to Henrik Riisgaard, the supervisor of this thesis, who helped me with great support.
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Abstract

Construction and Demolition (C&D) waste considered as the third largest waste stream in the EU has significant environmental impacts. C&D waste is composed of various materials and hold vast potentials for material recovery. Regulations such as the European tax on landfill and incineration have been implemented in order to generate less waste and drive business initiatives towards more sustainability.

A sustainable handling of waste has also been set on political agendas. Strategies on the saving of resources align a decrease in resource extraction to an increase of waste recovery, since this gives substantial alternatives for natural resource substitution. The European Roadmap to a Resource Efficient Europe interlinks the importance of waste recovery to the depletion of finite resources and highlights especially the potential of C&D waste due to its great material flows. In order to align waste with resources, essential principles need to be established which promote the effectiveness of C&D waste management and a diversification in the perception of waste, since it is still mainly limited to disposed materials without further options of use.

This study presents different treatment possibilities of C&D waste and discusses business practises of C&D waste management as well as the current legal framework. The study builds on literature reviews, a case study research conducted with a demolition company in Denmark and an evaluation of the most relevant legislation, the EU Waste Framework Directive. Based on the analysis in this study it is shown that there are several reasons hindering an adequate C&D waste management and potential for material upcycling.

An unequal level among businesses of the C&D industry exacerbates supportive initiatives for C&D waste recovery operations and indicates that steps towards C&D waste effectiveness cannot be taken only by addressing business models. The legal framework regarding C&D waste is insufficient and needs adjustments especially in regards to hazardous materials' handling and communication towards local authorities and businesses. Education and training measures are lacking and therefore businesses remain unaware of environmental and health impacts as well as of the economic feasibility of recovery options of C&D waste.

A preferable approach to assess the current problem of material downcycling and inadequate waste management is recommended in a fusion between the construction and demolition industry by implementing coherent strategies in procurement with responsible authorities. The implementation of an agreement in form of a demolition recovery index would initiate a correct waste management and ease the process of reintroducing recovered C&D waste materials for new building projects. Further, it would involve authorities by strengthening their influence on essential but yet absent check-ups and guarantee a more balanced level of competition between C&D businesses.

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Abbreviations

4R	Reuse, Repair, Refurbish, Recycle
C&D	Construction & Demolition
C2C	Cradle to Cradle
CE	Circular Economy
CE_2	*Conformité Européene*
CPR	Construction Products Regulation
CSR	Corporate Social Responsibility
DDA	Danish Demolition Association
DKK	Danish Kroner
EC	European Commission
EMAS	Eco-Management and Audit Scheme
EPR	Extended Producer Responsibility
EU	European Union
EUR	Euro
GHG	Green House Gases
ISO	International Standard Organization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCT	Life Cycle Thinking
MRE	Maximum Resource Efficiency
MS	Member States
NBS	Network for Business Sustainability
NEPI	New Environmental Policy Instruments
PCB	Polychlorinated Biphenyl
PSS	Product Service Systems
PVC	Polyvinyl Chloride
SBM	Sustainable Business Model

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1 INTRODUCTION

Nowadays the focus is set on the environment. Not only scientific documents report about the on-going climate change and its direct impacts that can arise all over the globe, also the medial discourses present the treatment of our environment in a broad way. Environmental issues become a crucial part in business strategies and seem to enable advantages towards competitors in any industry. Certifications such as ISO14001 or EMAS are one potential way for companies to show that environment as an issue is been taking seriously in businesses.

Next to the major problem of global warming, resource use and efficiency plays a crucial role when it comes to environmental concerns. Finite resources will not last forever and might be depleted soon due to a society that consumes fast and generous. On the one hand this fast consumption of goods is demanding a rapid resource extraction, on the other hand it creates huge amounts of waste (Ellen MacArthur Foundation 2013). To treat waste materials as waste uses a lot of energy and causes pollution of the environment, which will exacerbate the global environmental problems such as global warming even further. At the same time waste seems to be the end of a product's or material's lifecycle with no further use and will end up in landfilling, incineration or destruction.

In this subject matter the questions arises: what if waste was no longer seen as a problematic issue that causes pollution of the environment, but as an actual substitution for resource extraction promoting further purposes and generate new value? Concepts such as Life Cycle Thinking, Cradle to Cradle and the Circular Economy have implemented this approach and focus on low waste generation and effective waste management (Lazarevic et al. 2012; Braungart & McDonough 2002; Ellen MacArthur Foundation 2013).

Construction and Demolition (C&D) waste is considered being the third largest waste stream in the EU after farming and mining, and is therefore responsible for approximately 450 million tons of waste produced each year in European member states (European Commission 2011b). Included in this stream is waste produced by total or partial demolition operations and construction activities, as well as waste produced by refurbishment and enlargement processes. Even if the C&D waste stream does hold a high amount of value recovery, only 55% of C&D waste is being recycled or reused within the EU member states (European Commission 2011b). Several initiatives regarding regulations on EU level and by national authorities aim to support an effective recovery process of C&D materials. However, the level of effectiveness in C&D waste management differs outstandingly beyond European countries.

Denmark has a long history of waste policies and is working efficiently to support recovery opportunities. Still, the level among businesses in the demolition industry is varying from best practice examples to ‘bad competitors’, which disregard the significance of selective demolition operations and further an accurate handling of hazardous substances inherent in C&D waste. Next to crucial pollution of the environment by landfilling and combustion processes of C&D waste, the waste materials do hold hazardous chemical substances that can leak and cause contamination of groundwater. To handle hazardous waste alike with non-hazardous materials, which hold the capacity to be recycled or even reused, causes extreme harm to human health, the environment and even abates economical benefits.

The question lies in the reason for the differing level among businesses in the demolition industry and which strategies could enhance the recovery possibilities of C&D waste. Is the legal framework on different scales, on national and EU level adequate to promote and communicate the value of recovery operations towards businesses? What are the driving forces for businesses to implement strategies, which follow a maximum potential of waste recovery and minimum environmental impacts? And to which extent are these driving forces supported and hindered by regulations in a multi-scale governance system?

The following paragraph illustrates current C&D waste trends within EU member states and elaborates on results in consequence of former regulations that have been implemented in waste policies.

1.1 C&D waste in the EU and Denmark

It is important to mention that the reliability of data for the C&D waste stream within the EU can be seen as a limitation of illustrations in the present report. There are several sources, which show great differences between the amounts of C&D waste in member states, and therefore it is difficult to present an exact overview of waste statistics. The reason for little quality and availability of reliable data can be seen in various aspects (European Commission 2011b; European Commission 2012).

The major reason for little quality in the data of C&D waste is the unequal level of reporting and defining, as well as the lack of control by national authorities in the EU. In some member states, such as Spain, Greece or the Baltic states the issue of waste treatment has not been considered for a long time yet and these countries just started to implement waste strategies in their political agenda, while for example Scandinavian countries have been working for a long period on waste strategies and recovery mechanisms. Therefore the reported data might be incomplete in some member states and cause confusion in the C&D waste statistics. Another reason could be the inequality in economic growth within the member states that lead to differences in investments in new constructions and less capital for demolition activities. Also the materials have influence on the C&D waste statistics, since brick and concrete lead to a greater quantity of waste materials than for example wood.

However the statistics below show a recent overview of the C&D waste stream within the EU and illustrate the differences in quantity of C&D waste (European Commission 2011b).

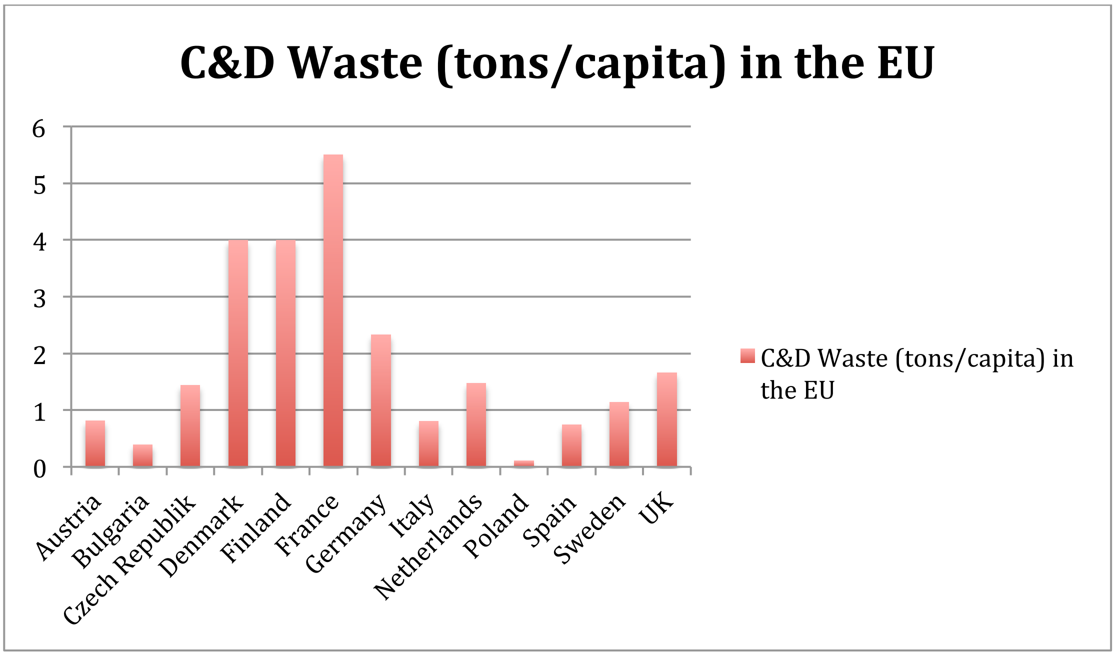

Figure 1 C&D Waste tons/capita in 2009 due to data reported by national governments. Source: (European Commission 2011, 10f)

Since the quality of the data is not fully reliable, the European Commission (EC) adjusted the data by assumptions based on the reasons for low quality data mentioned above. Also the data excludes the amount of waste produced by excavation activities, since these were seen as another indication for misleading results (European Commission 2011b).

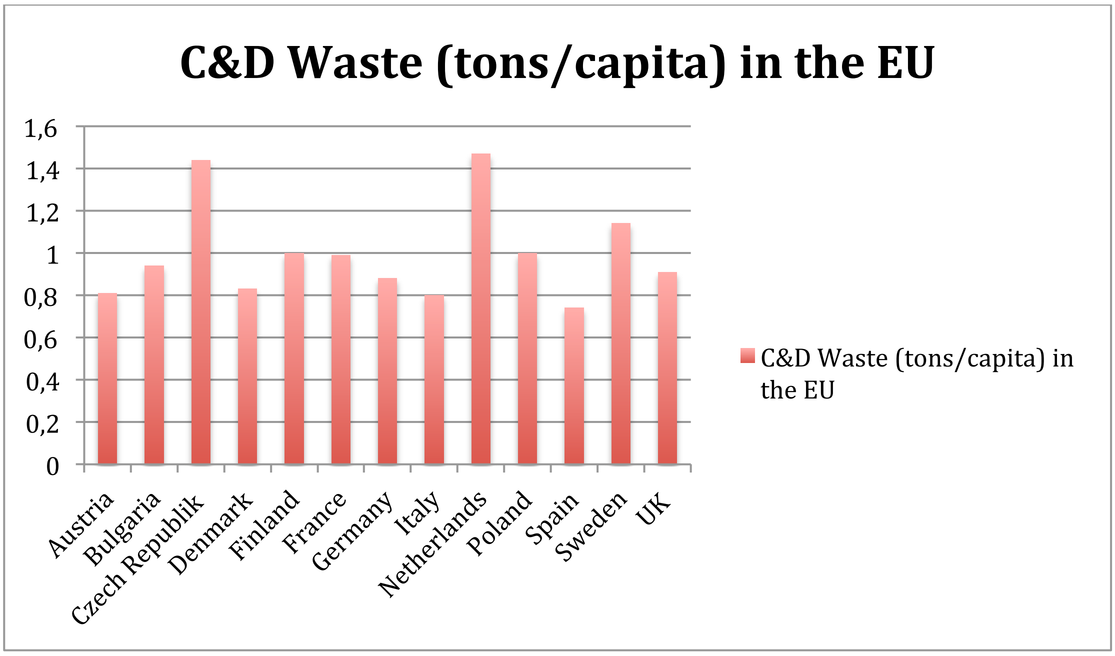

Figure 2 C&D waste (tons/capita) in 2009, with new assumptions by the EC and excluding excavator activities. Source: (European Commission 2011, 14f).

Figure 2 illustrates that the statistics are changing based on the assumption made by the EC.

1.2 Landfill tax in the EU and Denmark

As mentioned before, waste as an issue has not been put equally on political agendas in the European member states. The implementation of a waste taxing system though has decreased the amount of C&D waste in member states. The initiative of a tax on waste in Denmark in 1987 has been a successful instrument by the Danish government to reduce the amount of waste for landfill and incineration (Danish Environmental Protection Agency 1999; Fischer et al. 2012).

The waste tax was initiated as a EU wide tax but Denmark and the Netherlands were the first member states implementing the taxing system. The tax is considered as an economical incentive for companies to manage their waste efficiently and get impulses for working on waste treatment innovations regarding recycling and a direct reuse. After implementing the waste tax the European landfill level decreased from 39% to 6% in the period from 1985-2009 (Fischer et al. 2012).

In Denmark the taxing system began with 40DKK per ton and has risen to 475DKK per ton today. The level of landfill has decreased coherently with the rising price on landfill, and can therefore be seen as a successful top-down regulation by the government (see Figure 3). The landfill of hazardous waste was formerly excluded from the tax but has been integrated in the taxing system since 2010 with a price of 160DKK per ton. The tax is to be paid by the landfill site operator to the tax offices in Denmark and will be charged from the waste producer (Danish Environmental Protection Agency 1999; Fischer et al. 2012).

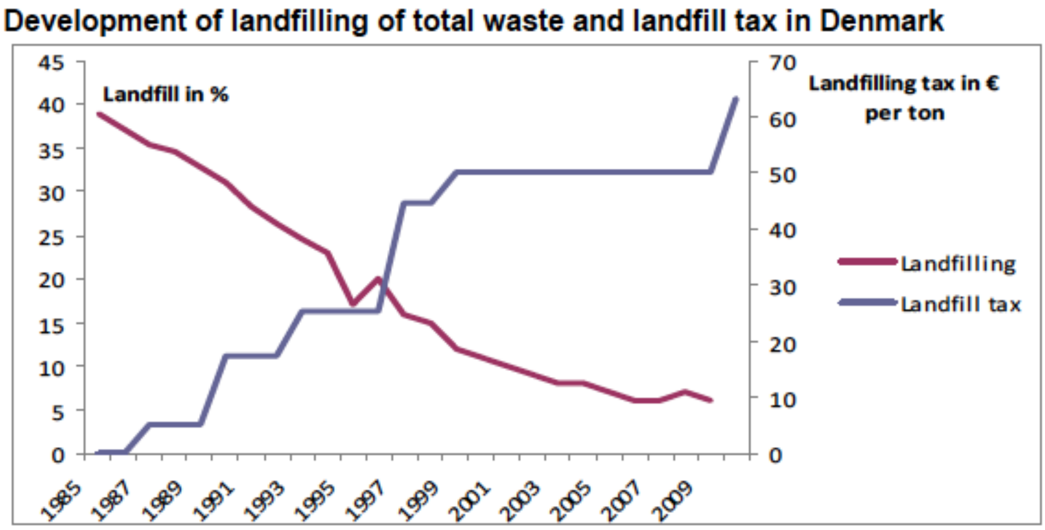

Figure 3 Development of landfilling of total waste and landfill tax (Denmark). Source: (Fischer et al. 2012).

Tex revenues are usually spent on public expenses such as health, education and police. In year 2010 the revenues of landfill tax in Denmark were estimated 12 million EUR (~90 million DKK). In earlier years the revenues were also partly spent on promoting technologies of recovery and cleaner production (Fischer et al. 2012).

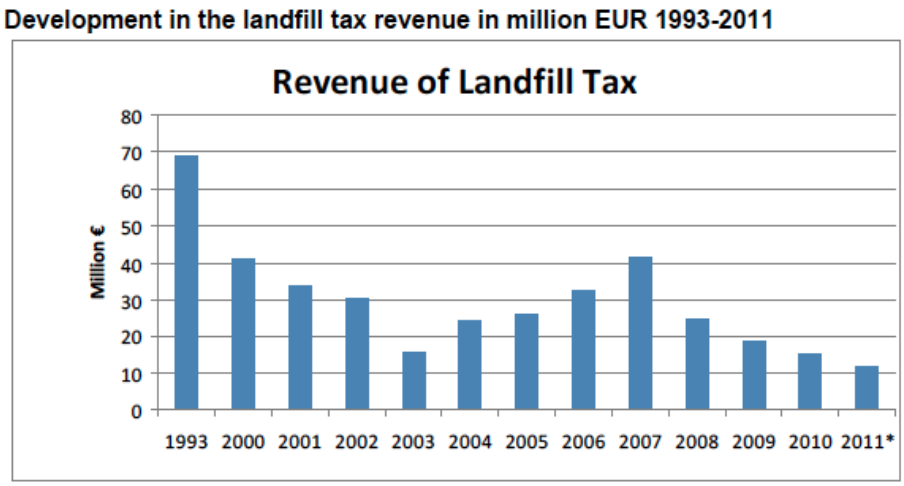

Figure 4 Revenue of landfill tax. Source (Fischer et al. 2012).

The taxation on landfill has influenced the development of recycling technologies in Denmark and has decreased the amount of waste that goes to landfill. Even though the price for one ton of landfilled waste is constantly rising, the revenues of landfill tax are decreasing (see figure 4).

1.3 Research question

The present report analyses current governance regulations on the management of C&D waste and investigates in possibilities of value upgrading of C&D materials. Based on information conducted by a case study research and the analysis of current regulations regarding C&D waste management, the study aims to identify reasons for a down-cycling of waste materials, weaknesses in legislations about hazardous waste management and driving forces in businesses to improve current waste management principles in order to lift up the demolition industry level.

Even though statistics have shown that certain regulations have decreased the quantities of generated C&D waste and initiatives have improved further recovering treatments of waste materials, C&D waste is still loosing its value due to recycling processes seen as first choice of recovery. The downcycling of waste materials hinders additional value creation and leads to the assumption that information about possible recovery operations based on value addition are not adequately communicated. However, a basic principle that needs to be achieved beforehand is to highlight the awareness of correct handling of hazardous C&D waste, which can be regulated by intervention by authorities as well as by initiatives among businesses in the industry. Even if in most European member states hazardous materials, such as asbestos and PCB[1], are indeed covered with a taxation system but still handled equally to non-hazardous materials during and after demolition activities, there is an urge to improve regulations, which give guidance on the importance of a selective demolition and an adequate communication towards commandments on how to handle hazardous materials.

The governance aspect of demolition waste, with its regulations, driving forces and weaknesses, plays an important role in the analysis of an implementation of C&D waste recovery options among businesses. On the one hand governance aspects of waste management are seen as factors of influence that affect business strategies in the C&D sector. On the other hand it needs to be investigated in the influence of businesses to transform current policies in their individual interest.

Therefore this study investigates in recovery and upgrading potentials with focusing on concepts that are based on the approach of a closed system and circular economy models. Further on, the study analyses the legislative framework on C&D waste in a governance perspective in order to identify

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[1] Polychlorinated biphenyl (PCB): stable organic composite, used as electrical insulation (Britannica Concise Encyclopedia 2006)

driving forces of C&D waste management and weaknesses in the handling of C&D waste. The study is guided by the following research question and respective sub-questions:

What are the key aspects for sustainable construction and demolition waste management and which core areas need to be improved in order to increase a recovery potential of construction and demolition waste?

1. How is C&D waste framed in supranational legislation and which key aspects are addressed to implement an adequate waste handling?
2. What are business drivers of a "frontrunner company" in regards to an effective demolition waste management?
3. Which initiatives should be supported in order to improve current waste management principles and how could these influence the level of waste recovery among businesses within the C&D industry?

The next chapter will present the methodology and the research design of this report.

2 METHODOLOGY

The following chapter elaborates on the methodology that was used in this report. It outlines the structure of this report, how elements of a case study research were used and how empirical data was conducted.

2.1 Research design

The structure of this report is divided into three main parts. The introductory part outlines the importance of the demolition sector regarding waste quantity and possible waste treatments. Further on it gives an overview about recent and current trends in demolition waste quantities in Europe, and specifically in Denmark. A description of the case study is also part of the introductory part, where the structure of the case company and respective waste management is presented. As C&D waste is considered being the third largest waste stream in the EU and is therefore responsible for various impacts, the introduction presents an overview of fractions of C&D waste and respective environmental impacts. These chapters of the report are considered as introductory parts presenting basic information about C&D waste and C&D waste management.

Regarding C&D waste trends it turns out to be difficult to reach and access reliable data regarding C&D waste quantities and waste handling, which would make the research more focused and valuable. For this reason the case study can give important insights in the sector and can work as a direct source of information that is considered reliable. Furthermore, the company aims to initiate further research on the demolition industry and crucial problems that need to be communicated, which can be initiated by this report.

The second part of the report presents a conceptual and theoretical framework. The conceptual framework presents the literature most relevant for assessing the research subject. These are the concept of the *Circular Economy* presented by two reports of the Ellen Macarthur Foundation, an association promoting the idea of a circular model of economic systems (Ellen MacArthur Foundation 2012; Ellen MacArthur Foundation 2013). Further on the research includes the *Cradle-to-Cradle* approach first introduced by Braungart and McDonough in 2002. The approach aligns with the concept of *Life Cycle Thinking* and is considered being highly relevant for this project as one part of the study is analysing the mechanisms of a closed system and the value aspect regarding demolition waste. A theoretical framework based on the governance theory further guides the study. The governance theory is used for identifying weaknesses in current C&D waste legislation and to point out power relations within authorities and the business sector. The governance theory is mainly presented by documents from

Jordan et al. 2005 and Schout &Jordan 2005. The second part of the report also includes an overview of the EU Waste Framework Directive published in 2008 and elaborates on the implementation of this EU regulation on a national scale by EU member states.

Besides the conceptual and theoretical framework of the study the literature comprises several scientific articles regarding C&D waste and official documents published by institutions such as the EU. Of major importance is the report by Fischer et al. (2012): *Overview of the use of landfill tax in Europe* and the report published by the EC (2011b): *Service Contract on Management of Construction and Demolition Waste*, since these documents are providing relevant statistics regarding C&D waste.

The third part of the report presents the results of the research and finalises with conclusions and recommendations. The results are represented by several points of importance regarding C&D waste management. The results summarize different aspects of the research area of this study: governance structures of C&D waste, C&D waste legislation and C&D waste industry's business models.

2.2 Research methodology

The research objectives of the present report are to analyse the possibilities of upcycling of demolition waste materials and to evaluate on current C&D legislation on EU level. Therefore empirical data collected by interviews with a case company and relevant legislation documents are analysed with indicators based on the conceptual and theoretical framework of this report. The relevant documents about current legislation mostly published by the EU are evaluated critically regarding potential of C&D waste recovery under the principles of the CE and are analysed regarding weaknesses based on principles in the governance concept.

In order to collect valuable data from the business perspective the present study contains extractions of a case study research.

2.3 Case study research

A case study generally investigates an in-depth research about a specific subject based on a real life case. The research usually involves quantitative and qualitative data and aims to produce knowledge in a specific research area that can be applied to similar cases (Bryman 2008). This study investigates mostly in qualitative data conducted by interviews and literature reviews but also contains quantitative data regarding quantities of C&D waste. In a case study research the case should not be chosen randomly but wisely under certain criteria.

Flyvbjerg identifies four categories how a case can be dedicated: an extreme case, a critical case, a paradigmatic case and maximum variation cases (Flyvbjerg 2006). The present case study can be classified as an extreme as well as a paradigmatic case. The company is considered being a frontrunner company in the demolition business and has achieved remarkable improvements on waste recovery. Further more it considers general problems in the sector and aims to represent a good example on how to open up new perspectives regarding demolition waste management. Due to the fact that the company is working closely on new regulations with the Danish government, the company has an exemplary role. The company investigates in possibilities to lift up the demolition sector and tries to find solutions on how to implement a common framework and perspective on responsible demolition procedures and waste handling. For this reason the company fulfils the role of an extreme case and a paradigmatic case due to its will to establish a new paradigm in the perception of waste.

2.4 Data collection

Interviews provide the possibility to collect new data material personally which might not be available otherwise and is therefore highly relevant for the expressiveness of a research study (Williman 2005). The interviews conducted in this report were focusing mainly on qualitative and open questions while quantitative data was collected by information material prepared by the company. The interviews were recorded in order to keep all valuable information and were transcribed afterwards. The company confirmed that all information can be communicated to the public and does not have to be treated in a confidential manner.

The empirical data in this report was conducted by interviews in two personal meetings with one demolition company based in Denmark. The company is considered being a frontrunner in the treatment of demolition waste in the recycling manner and is therefore able to provide valuable information regarding trends and problems as well as progresses and possibilities in the demolition industry. Further on, the manager of the company is the chairman of the Danish Demolition Association (DDA) and can give valuable information in a broader term. A question guide structured the interviews, which was prepared beforehand.

The first interview was set as an initial interview to discuss the research topic in a broader term. Several important aspects were already discussed in the first interview, which influenced the preparation of the guiding questionnaire for the second interview. General problems in the demolition industry and the influence of regulations by the government were key aspects to be discussed in the second interview.

2.5 Delimitations

In order to capture the full complexity of environmental impacts of various lifecycles of C&D waste every lifecycle stage needs to be taken into consideration, however delimitation in the scope of this report are set. This project focuses mostly on demolition and sets priority mostly in residential buildings. Lifecycle stages before demolition such as material extraction, manufacturing and processing and construction activities are not covered fully in this report. However, the construction industry is mentioned in some parts in this report since it is closely related to the demolition subject and is considered relevant in the results of this report.

Figure 5 shows material flows in lifecycles of C&D waste and illustrates the scope of the study.

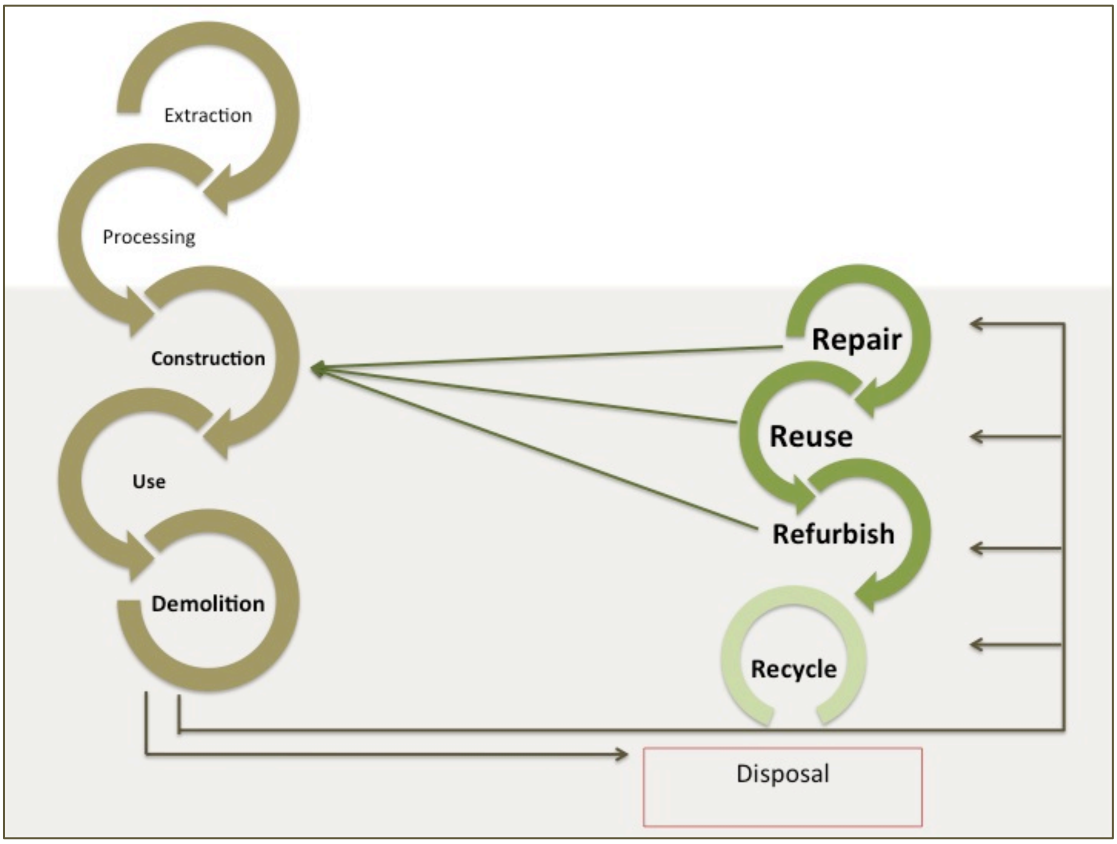

Figure 5 Scope of the study. The arrows show the material flow in the demolition waste lifecycle. The arrows do not aim to illustrate quantities of material flows. The scope of the study is highlighted in the grey square.

2.6 Scientific paradigms

The present research is influenced by two different scientific paradigms that have rather opposed approaches. On the one hand it aims at identifying solutions for problematic issues of waste handling which are expressed quantitatively. This proceeding would lead to a positivism approach where results are obtained by objective research that is not influenced by own interpretation or social norms and values. On the other hand the research involves various information and a theoretical framework that is based on social constructivism principles that admits individual interpretation and affection by values and subjectivity (Tukker 2000; Lazarevic et al. 2012).

However in some analytical parts and results of this research this texture of scientific approaches will give different point of views about the dissociation of the research subject.

The next chapter will provide a description of the case company and illustrates respective recycling operations.

3 KINGO KARLSEN A/S

Kingo Karlsen A/S is a demolition company based in Silkeborg and Gadstrup, Denmark. The company was founded in 1955 by Jens Kingo Karlsen and has since then focused on the recycling of demolition waste. In the post war years an urgent need of building materials evolved and Kingo saw its potential in buying houses in order to tear them down and sell the demolition waste as recycled building materials (Kingo Karlsen 2013).

3.1 Company structure of Kingo

Kingo has two departments based in Silkeborg and in Gadstrup with approximately 60 employees. The turnover of both departments is equally to approximately 50%. The board of the company is run by three persons, which are responsible for both departments. Thomas Kingo, the grandson of the founder of the company, is member of the board, administrative director and chairman of the Danish Demolition Association. Kingo also hires employees from sub-contractors to work on demolition sites in Denmark (Kristensen 2013).

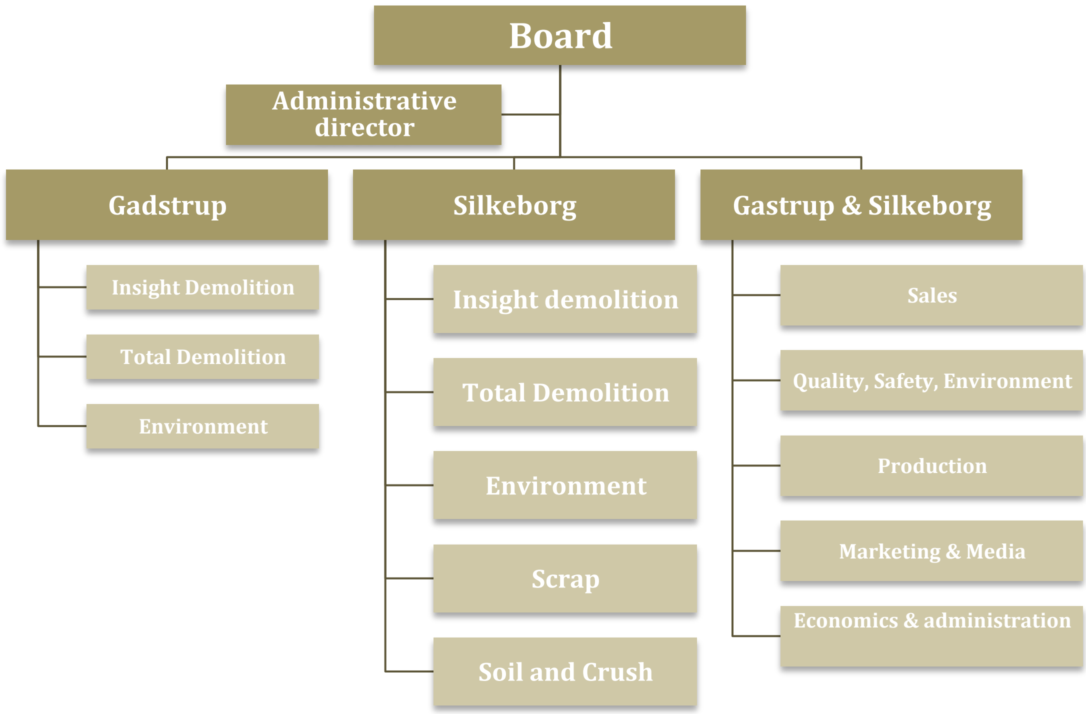

Figure 6 Company structure of Kingo

3.2 Recycling at Kingo

Kingo can be considered as a frontrunner company in terms of demolition waste handling and recycling due to its high level in recycling of demolition waste. In 2012 the company had an average recycling rate of 97,7% where the remaining 2.3% are considered hazardous waste such as PCB or asbestos, which are then landfilled or destructed (Kristensen 2013)

The company has a recycling area on site in Silkeborg where materials are being transported from demolition sites if recycling processes are not feasible at the demolition site. The preferable handling of the recycling of the materials is considered on the demolition site as this saves transportation to the recycling site and back. Since it is common that recycled materials are being reused in new projects on the demolition site, it seems likely to keep the material on site without further transportation. Thus, it is not everywhere possible or allowed to recycle materials on site. The Danish government is giving special permissions to businesses in case on site recycling is reasonable, otherwise the Danish legislation allows the recycling only at special facilities, such as Kingo's in Silkeborg (Kristensen 2013).

Photo 1 Automatic scale for truck weight.
Photo 2 Truck unloading bricks at the specific recycling site.

Further on, Kingo's recycling site is also used by external companies or private persons to give off materials. These materials are also being recycled by Kingo and afterwards sold for example as gravel for the construction of roads. The site has an automatic scale, which registers the amount of and type waste transported in. Afterwards the material is being brought to the specific recycling site. The recycling site allots specific areas for different materials. The materials get recycled by crushing and are being sold afterwards usually as gravel or asphalt for road construction to different places in Demark (Kristensen 2013).


Photo 3 Crushed Bricks of different size.
Photo 4 The most preferred crushed concrete 0-32 cm. This crushed concrete contains cement and is therefore more stable.


Photo 5 Recycled asphalt.
Photo 6 Concrete without reinforcement.

The recycling site apparelled with a closed water system that covers the entire recycling surface. Due to the fact that also contaminated soil, PCB and asbestos substances are treated on site it is of high importance to avoid any leakage of polluted water into the ground.

Water from the site is transported via pipes to a large basin where it is cleaned and can be transported to an artificial pond later on. Water from this pond is used for cleaning processes and dust regulation of the recycling hills. The water system is running fully automatically and can be regulated by electronic devices. Further on, oil filters are being implemented which clean the water for further use. Due to this closed water system the company has rather low water consumption (Kristensen 2013).

Kingo is by regulation of the Silkeborg Kommune not allowed to let any water from the recycling site into the natural groundwater system. Therefore the company is using the water on site for dust regulation in a sprinkler system. If the weather conditions are changing to heavy wind the dust of the noise hill (where clean soil is kept) and other recycling hills could be blown to the neighbouring areas. The sprinkler system will moisten the hills and thereby assure their stability towards heavy weather. Spare water is being released by the sprinkler system to evapotranspiration (Kristensen 2013).

Photo 7 Water system. the water is transported via pipes to the basin and will be cleaned with filter from oil and polluting substances. Afterwards the water runs into the artificial lake.
Photo 8 Sprinkler to spread water for dust reduction and evapotranspiration.

Photo 9 Concrete plates from Aalborg Politigården polluted with PCB. 5cm of concrete need to be taken of and send to destruction in order to use the rest of the concrete plate (left).
Photo 10 Soil without knowledge about the contamination and composition of it. The soil is kept on asphalt ground to ensure no leakage into the ground (right).

The recycling site has a special area with a different surface where polluted and contaminated material can be recycled without leaking into the ground. The most common polluting substances in demolition waste are asbestos, PCB and mercury (Kingo Karlsen 2013; Danish Environmental Protection Agency 1999). These substances cannot be recycled and end up in landfill or destruction. Still, the Danish government gives out permissions to use for example concrete contaminated with asbestos, e.g. at an on-going project at the old Carlsberg brewery in Copenhagen. The use of this must be registered for future construction and demolition activities. In this case the soil is being recycled to the stage of a very low level of asbestos contamination, which is considered less harmful. In the case of concrete boards contaminated with PCB, the concrete needs to be cut of in a large size to assure that no more PCB is infiltrated in the remaining concrete board (Kingo Karlsen 2013).

The next chapter will introduce general C&D waste with respective fractions and environmental impacts.

4 Construction and demolition waste

As outlined in chapter 1 of this report, the C&D waste stream is the third largest waste stream in the EU and therefore responsible for several environmental impacts. The built environment is a major consumer of energy and resources. To provide building materials for future construction projects, recovery activities of C&D waste are valuable options and can help to reduce an appreciable amount of energy consumption, emissions and resources. Further on, the recovery of C&D waste can save areas for landfilling and land use for resource extraction. Regarding resource use the taxation on natural resources, e.g. the taxation of natural gravel in Denmark, Sweden and the UK in 1995, has been used to promote recycling initiatives of C&D waste in order to e.g. secure the provision of groundwater (Thormark 2001; European Commission 2011c). Crucial environmental impacts occur during construction phases as well as during and after demolition operations. The levels of environmental impacts depend on the recovery options of C&D waste, the type of materials used and the treatment of hazardous substances.

The following paragraph presents the main composition of C&D waste and illustrates recovery possibilities.

4.1 Aggregates in C&D waste and recovery possibilities

C&D waste occurs in construction and demolition phases as well as in refurbishment processes. C&D activities can be further classified into the following (Del Río Merino et al. 2010, p.118):

- Total or partial demolition of residential and office buildings as well as of civil infrastructure.
- Construction phase of residential and office buildings as well as of civil infrastructure.
- Soil, rocks and vegetation arising during the construction and demolition phase.
- Waste occurring by road planning and road maintenance activities.

Waste fractions that arise during C&D operations comprise various materials. According to the European Waste Catalogue C&D waste is classified differently in the following groups (European Commission 2002, sec.A23) :

- Mixture of concrete, bricks, tiles and ceramics
- Wood, glass and plastics
- Bituminous mixtures, tarmacadam and other tar products

- Metals
- Soil (including excavated soil from contaminated areas), stones and dredged soil
- Insulation materials and construction materials containing asbestos
- Gypsum based materials
- Other C&D waste containing mercury; PCB (floorings, sealed glazing units, capacitors); mixed waste containing dangerous substances

Considering the case of Denmark and other Scandinavian countries, C&D waste fractions and possible recovery options are illustrated in table 1.

	Recovery Possibility
Concrete, clay bricks,	Can be crushed, afterwards used as artificial gravel for road construction and road filling; Reuse possibilities of 50%.
Wood	Raw, untreated wood (usually rafters, tie beams of timber roofs, full length wood studs) has a level of reuse between 10-20 %; the energy recovery in combustion is high.
Metal	Usually studs and structural elements; in office and residential buildings 10% of metal elements are capable for reuse.
Mineral wool	Reuse possibilities with small remanufacture activities; re-melting into new mineral wool material or torn into loose mineral wool material; 90% reduction of energy consumption compared to production of new mineral wool.
Glass	Glass can be recycled in various ways; the reuse of glass is limited to the reuse of windows and door elements.
Plastics	Plastics are mainly recycled; direct reuse of plastics is not common due to erosion and damage while demolition; PVC is the most common plastic used in construction; PVC has a high level of environmental impacts due to toxic emission while combusting.
Gypsum	Potentials for reuse up to 25% as dismantled gypsum boards used in inner walls

Table 1 C&D waste fractions and recovery options. Source: (Thormark 2001, pp.117–118).

The major part of C&D waste is considered to be inert and therefore not dangerous for the environment. Yet, special attention needs to be paid to the last group of C&D waste categorized by the European Waste Catalogue. Hazardous and harmful substances, such as PCB and asbestos can be carried with other materials into the biological system. The EEC Directive on dangerous materials classifies hazardous waste and highlights the importance of separate packaging, transporting and storage from non-hazardous waste. The measures and instruction how do to so lies in the competence of the national authorities (European Commission 1991).

4.2 Environmental impacts in construction and demolition activities

Several environmental impacts occur in relation with C&D activities. Besides impacts that can be related indirectly to C&D waste, such as resource extraction and use, energy consumption and emissions e.g. in combustion, construction and demolition activities themselves are responsible for several impacts that cause environmental harm.

The following paragraph elaborates on environmental impacts that occur due to construction and demolition activities (Environment and Conservation 2009; del Río Merino et al. 2010):

Dust, noise and vibration

Construction and demolition activities require heavy vehicles and specialized equipment such as sorting conveyors, crushing machineries and loading and un-loading trucks. These can cause high levels of noise and ground vibration on the waste recovery facilities as well as on demolition sites. Direct neighbours of a waste management facility or a local C&D site might be affected by these impacts. The transportation of C&D material by heavy transportation vehicles can also cause noise and dust problem. The same goes for recovery activities, which involve sorting, crushing and grinding operations. The impacts of dust, heavy noise and vibration can lead to a loss of biodiversity, air pollution and surface instability.

Water and land

Water run-offs can transport dust, sediment and contaminants from the waste facility or the C&D site into drainage systems and natural water habitats and can thereby affect the water quality and cause groundwater contamination. Water used for recovery operations or cleaning processes can be polluted with oil spills or hazardous substances and can cause pollution in the natural water system. This can also happen due to weather conditions with rain and storm.

Small quantities of organic and biodegradable waste substances that are illegally co-disposed with assumed inert C&D waste can cause landfill gas, which can stay in the ground and affect water and soil quality.

Toxic substances

Nowadays, the most commonly known toxic substances of C&D waste are asbestos and PCB. These substances can be found in roofing plates, floor tiles, exterior concrete walls and insulation elements. Other harmful substances could be toxic heavy metals such as mercury, lead or cadmium as well as substances that occur due to pesticide treatments and putrescible waste.

Asbestos fibres can become airborne and can thereby be carried into the surrounding environment. PCB is migrating into materials such as concrete or stone and is thereby contaminating other materials. Both substances are highly toxic and cause ground contamination and crucial human health diseases by inhalation or skin contact.

4.3 Construction and sustainable development

The built environment and its arising waste in different respective phases is an important aspect that needs to be taken into consideration when thinking about the concept of sustainable development. Since it is linked to intense resource use and the fact that construction is usually a long lasting component of the environment, it will affect future generations that must handle waste and hazardous substances of buildings from earlier times. This is not only to be considered for future generations, nowadays it is already a problematic matter to manage contaminated materials and huge amounts of C&D waste, since in former times knowledge about specific substances was not as advanced as it is today. As presented in the International Conference on Sustainable Construction in 1994, to ensure a responsible handling of the built environment for future generations is an important issue to be considered by architects and construction businesses (Kibert 1994). Architects and construction businesses therefore have to reconsider their building concepts and material use in the sake of future waste management. Also authorities at different scales should support businesses in this interest.

The construction sector constitutes a complex case in terms of long-term planning since buildings and infrastructural constructions usually last for centuries and therefore they need to be planned anticipatory. Yet, the construction sector also gains advantages from an early consideration of material use and architectural design since several building materials that end up as demolition waste have the potential to be reused in new building complexes.

In order to improve the reliable information about construction products, the European Commission adopted in 2011 a new regulation regarding a common technical language about construction product performance. The aim of the

Construction Products Regulation (CPR) is to promote a clarification of basic concepts and the use of Conformité Européenne (*CE*[2]) marking, a simplification of procedures and to promote credibility for the entire system. The new regulation repeals the Construction Products Directive No 89/106/EEC, yet the regulation will be in force first in July 2013. The regulation is to be applied by manufacture businesses, their users such as architects, construction businesses, as well as by legal authorities of EU member states, which shall inform businesses and users about construction products in a so called system of national CPR product contact points.
The aim of this initiative is to create common standards in EU member states in order to simplify the evaluation of construction material and product performance. This aim also brings along the importance of transparency regarding environmental impacts of construction materials (European Commission 2013a).

The next chapter will present an overview of concepts that are relevant for the research subject of this report.

5 CONCEPTUAL FRAMEWORK

Several concepts and approaches came up during the last decades to respond to the increasing awareness towards environmental impacts and the linkage to resource use and the generation of waste. The following chapter elaborates on the most relevant concepts regarding C&D waste recovery in a chronological structure. The most relevant concept for the scope of the present report is the Circular Economy. Although it is listed at the end of the chapter since it is based on the concept of Cradle-to-Cradle and Life Cycle Thinking.

5.1 Cradle2Cradle (C2C)

The cradle to cradle (C2C) concept first came up in 2002, developed by Michael Braungart and William McDonough, initiating a new approach towards a zero waste strategy and circular system effectiveness. The concept's idea is to establish a beneficial industrial system enabling synergies that promote goals in economic, social and environmental terms. The concept includes, similar to the concept of the circular economy, a differentiation between biological and technical components in a closed system (Braungart & McDonough 2008).

The biological metabolism (resource extraction, manufacturing, consumption and reintroduction to natural system) and technical metabolism (recovery and reuse) enable a potential flow of nutrients within the system and due to that no waste is produced. Biological nutrients are understood as biodegradable materials that can be reused for different purposes and are reintroduced into the biological circle to work again for biological processes. Biological components are found in products of consumption such as textiles. Technical nutrients are products of services with frequently synthetic and mineral materials. In the idea of the C2C concept the manufacturer retains ownership of the product and delivers service to the customer, which enables mutual benefits and also promotes a stable relationship between actors in the service relationship (Braungart et al. 2007).

C2C sets the focus on eco-effectiveness of interdependent natural systems where process outputs become inputs of further use. Compared to the concept of eco-efficiency, which is rather based on the approach of linear systems, eco-effectiveness focuses on the effectiveness of 'waste', which is reintroduced as secondary resources. Due to that the concept requires a radical change in the way systems are designed and components are working. The idea is to avoid any harm or pollution at the beginning of a process so that no ex post corrections are needed. As Braungart (2008, p.45) claims *"being less bad is no good"*, manufacturer need to start doing good at the earliest stage. Furthermore doing better by doing well for society is a major principle in the C2C concept. In an effective interdependent system any biological or technical nutrient need to be reintroduced into system circles.

According to the concept, recycling initiatives indeed prolong the lifetime of materials but with certain disadvantages. The recycling of a material transforms it into a material with less value, since it cannot be used for the same purpose after all. Further on, also the recycling of material has a certain end of life where it will be disposed and most likely landfilled. Hence recycling is just a deferment of putting material to waste and therefore the recovery process needs to focus at a different level. Direct reuse enables a value maintenance or even a value enhancement as biological and technical nutrients are directly re-entered into the system without additional transformation (Braungart et al. 2007).

5.2 Life Cycle Thinking (LCT)

Following the shift from cradle to grave to a closed system with zero waste and secondary resources, namely C2C, all stages in the lifecycle of products and materials gain importance. Inputs and outputs at any stage of the lifecycle are important in the life cycle thinking concept and in practice in the life cycle assessment (LCA). The European Commission defines LCT as the following: a concept which tries *"to identify possible improvements to goods and services in the form of lower environmental impacts and reduced use of resources across all life cycle stages"* (European Commission 2010, p.1).

LCT is established as a valuable concept in various sectors across industries. Extended producer responsibility (EPR) and the polluter pays principle (PPP) are concepts that support pollution control mechanisms across product chains and resource use. EPR drives manufacturers and representative businesses to follow the path of their products across national borders to identify potential areas of environmental harm and pollution. Even though goods are travelling on global markets, the main responsibility of pollution control shall stay with the producer. Especially in complex product chains, where several suppliers and distributors are involved, the management of environmental impacts at all lifecycle stages is crucial in order to improve effectiveness and value across the value chain (Lazarevic et al. 2012).

In regards to waste, life cycle thinking enables to identify sources of waste at every lifecycle stage and is therefore considered being a useful tool for the assessment of environmental impacts in regards to waste management. Based on results of potential source of waste production, suggestions for beneficial substitutions can be made in areas like the following: waste incineration with recovery of energy, raw materials from mechanical recycling of waste and fuel out of biological treatment of waste (Lazarevic et al. 2012, p.200).

Since a few years the concept of LCT has gained attention in the EU policy. The EU Waste Framework Directive (see chapter 6.1) is based on a LCT approach to improve the management of different kinds of waste at any stage of the lifecycle trying to include all different actors involved (European Union 2008; Lazarevic et al. 2012).

5.2.1 Life Cycle Thinking and Construction and Demolition waste

In case of LCT in C&D waste this would mean to include several stages of the production of waste, but also to involve in- and outputs of the treatment of C&D waste (Mercante et al. 2011).

The following points outline different lifecycle stages that need to be taken into consideration only in regards to demolition waste:

Resource Use: What is the impact balance of the substitution regarding virgin materials and recycled waste materials.

Transportation: All CO2 emissions and fuel consumption produced due to transportation of demolition waste from demolition sites to recovery facilities, facility on site transportation with regards to capacity and density of transportation containers.

Energy consumption: Type of energy (nuclear, hydro, wind power) consumed by equipment and facilities on demolition sites as well as at facilities, units of energy consumed at incineration plants and landfill activities.

On-site storage: Storage containers for different fractions, temporarily storing bags.

Facilities (based on a cradle-to grave approach, including disposal): Water and energy consumption, produced emissions. Pre-treatment activities (weighing, mechanical separating); recovery activities (preparing for reuse, refurbish, recycling); disposal activities (landfill, incineration); treatment of hazardous waste material.

5.3 The Circular Economy

The Circular Economy is a concept based on a circular approach of natural systems. The concept's core is aiming an economy that is regenerating materials and avoids the production of any kind of waste. Every material used goes back into the system and is aimed for a further reuse. The principal lies in thinking in cascades where value can be gained due to extracting additional value from materials by connecting them to other functions. Compared to a linear economy, where materials are produced with the purpose of being used by a single consumer and generally end up in disposal after a certain period of lifetime, the circular model is considering every component of the economy as a valuable resource (Ellen MacArthur Foundation 2013).

The Chinese government first applied the concept in 1998 by creating a development strategy based on environmental protection, pollution management and sustainable development (Bilitewski 2005). The Chinese government implemented the Circular Economy model into political strategies and focused on ecological principles based on a natural *material metabolism.* The aim of the new strategy of the Chinese government was to implement key principles of the Circular Economy such as the maximization of resource efficiency, a shift in the input/output- flow of materials and to follow three simple keywords: *reduce, reuse, recycle* (Hu et al. 2011).

The circular economy is an industrial economy, which is restorative by its intentional principals and appeals to a design of products, which enables a continuous availability of the product without relative loss of value. A core principle is to create products that are designed to enable a further treatment and a possible reuse without any or with less modification. Thereby the concept relies on a major distinction between the definition of *consuming* a product and *using* a product. The consumption of a product refers to its *"inevitable fate like food and drink that are irreversibly altered during their useful life"* and *"cannot be put in the same use afterwards"* (Ellen Macarthur Foundation 2013, 26). The use is related to a service system where *"retailers and manufacturers retain ownership of their products (or have an effective take-back arrangement)"* and *"act as service providers, selling the use of performance of products, not their consumption"* (Ellen Macarthur Foundation 2013, 26).

The concept actively works on the improvement of resource systems by raising their potential of resilience. The aim is to improve the system as a whole instead of investigating in the improvement of single components. By integrating products with circular design, a linear one-way model of products is barred from the economy and creates thereby a shift from linear to circular systems. Crucial requirements for this approach are functioning systems of effective flows regarding materials, labour and information in order to ensure the possibility for rebuilding social and natural capacities. Further on the concept distinguishes between two types of components of material flows. The *biological nutrients* are considered as materials, which are designed to recover into the biosphere harmlessly and have their further task to rebuilt natural capital (Ellen Macarthur Foundation 2013, 26) while *technical nutrients* are accomplished to *"circulate at high quality without entering the biosphere"* (Ellen Macarthur Foundation 2013, 26). By this the concept is differentiating natural and non-natural (man-made) components circulating in one economy, which have different functions and need to be seen in separate ways. While natural components can be safely re-entered into the biosphere by composting or anaerobic ingestion, technical nutrients are man-made materials that are designed for recovering and refreshing and prepared for a minimum energy input by holding a maximum value level (Ellen Macarthur Foundation 2013).

The purpose of design is a major difference in the system of the Circular Economy compared to concepts that focus on circular loop systems. Products in a linear economy are not designed for regeneration and have therefore a short period of lifetime with the general purpose of being consumed. The possibility of recovery treatments mostly ends at the possibility of recycling and causes therefore a quick loss of value. The circular economy model in contrast relies on the principle of designing products that are regenerative and therefore able to return into economical cycles with their initial purpose and function. Thinking in cascades is treating every component (no matter size or function) as a valuable unit for other circles of the economy (Ellen Macarthur Foundation 2013).

Value plays a crucial role in the Circular Economy. Value is comprised in every component in the circular economy and there are two basic principles on keeping the value continuously in circles. 1. Retaining resource value by transforming waste into useful by-products within other cascades. Thereby new effective value flows are emerging within or across different value chains. 2. Maintaining the essential effectiveness of the entire system instead of improving and changing individual parts of the system, as this will modify the overall system (Ellen Macarthur Foundation 2013).

Further on a source of value creation lies in the duration of use. To keep products, materials and single components in use longer will increase the value level in the overall economy. Therefore, in order to retain value in the circular economy the concept relies on four principle treatments for technical nutrients that would be considered as waste in a linear economy: *Reuse, Refurbish, Remanufacture* and *Recycle*.

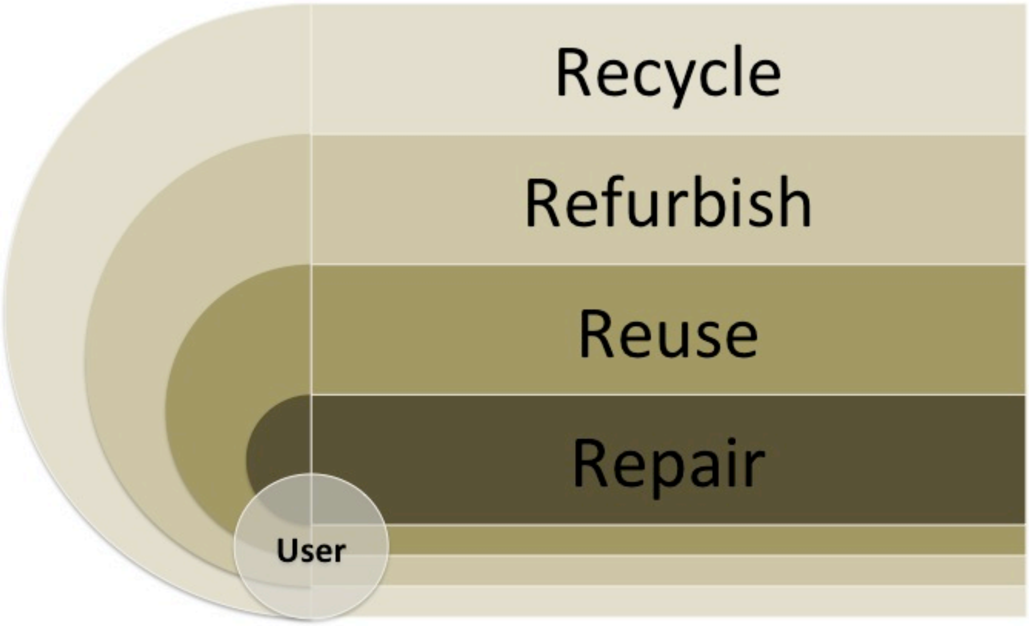

Figure 7 Circular Economy Model of technical nutrients. Inspired by (Ellen MacArthur Foundation 2013).

The key principle lies in the direct reuse of components since no additional energy input for adjustments is needed and components simply fulfil their purpose again. Direct reuse keeps present value, creates additional value by a longer lifetime and by implementing value in other circles or cascades and saves costs (for energy, material, labour) and externalities (GHG, water, toxic substances). Refurbishing and remanufacturing retain value and prolong lifetime due to modernization or restoring processes. Comparatively, recycling is the process that causes the highest loss of value and creates additional costs due to the extra costs in changing the product in its original purpose. In recycling, the material/product is downcycling because the level of value before and after the recycling process is not equal. For example bricks are crushed and recycled and are used afterwards as gravel for road construction. The value of bricks and the value of gravel is not the same and therefore the material lost value, which is considered as downcycling. But, in order to make it possible to reuse components more than a single time, the products need to be designed for iterate circling or for staying longer in a single cycle (Ellen MacArthur Foundation 2013). .

5.3.1 Examples of the Circular Economy applied in businesses

There are several examples of businesses that can be found which have implemented a circular approach in their business strategy. The circular approach is focusing thereby on a service approach, where products retain ownership by the company, which produces the product, as well as the approach to keep materials longer in the circle and prolong their lifetime.

Company	Location	Product	Business Strategy	4R model
Desso	Netherlands	Carpet/carpet titles	C2C, take-back program for used carpets originally from Desso or competitors	Reuse, Recycle
Gamle Mursten (Rebrick, EU funded project)	Denmark (+Italy)	Bricks	Closed loop, cleaning process of clay bricks, value creation	Reuse, Repair
Thors Design	Denmark	Furniture (Azobé wood from decommissioned wharfs)	Prolong lifecycle of wood by reusing it with different purpose	Reuse, Refurbish

Table 2 Businesses applying the CE in business models.

5.4 Delimitation of the conceptual framework

Comparing the three concepts basic similarities can be found since all three concepts are in some areas interrelated to each other. In order to give argumentation for the relevance of the concepts regarding the research subject of this report, the following paragraphs will elaborate on similarities and differences.

Approach

The C2C concept and the CE are similar in their approach because they are both based on the principle of circular systems. The CE concept highlights thinking in cascades in order to enable circularity. The LCT concept is based on life cycle stages that are usually divided into extraction of materials, processing, manufacturing, use and disposal. The aim of the C2C concept is following a zero waste strategy by closing the system and the CE's aim lies in an intentional design, which enables value maintenance and additional value creation. LCT focuses on identifying and reducing environmental impacts throughout the lifecycle of products and processes.

Addressed audience

A main difference lies in the concepts' addressed audience: the C2C concept addresses businesses and product manufacturers to promote business synergies for doing good for the environment and by this, sharing financial benefits, also the concept promotes the idea of doing well beyond own business interests by doing well in societal terms. In the CE the society itself and the businesses are addressed to rethink the entire economy to promote a circular system with maximum value creation. LCT shifts the main responsibility to the manufacturing business and embraces principles such as EPR or the PPP.

Focus

All three concepts share the idea of resource efficiency and the reduction of environmental impacts but focus on different principles. The C2C concept focuses on business synergies for promoting a system with a minimization of waste. LCT is focusing on the management of complex environmental impact assessments to identify the source of pollution. The CE focuses on design principles that enable a maximum value creation. The value aspect is crucial for the subject of demolition waste since recycled material are downcycling due to their modified purpose. Design matters in the constructional phase of buildings, which will lead later on to the level of value maintenance in the demolition part. If buildings and materials are designed to meet the purpose of recovery, meaning that they are processes without any harmful or hazardous substances and are assembled in a way that actual reuse is possible without great modification, a downcycling process could be prevented.

Indicators

The analytical category in the implementation of LCT, the LCA, lies in an input-output acquisition, where impacts regarding resource input and outputs (e.g. energy consumption or emissions) are analysed. As analytical categories the CE provides a framework of different possibilities to recover waste (4R) and a differentiation of biological and technical nutrients that offers a framework for the analysis of C&D waste.

The analytical indicators of the C2C concept and the CE are similar since both concepts are categorizing into biological and technical components in the system. The difference lies in the definition of technical components (CE) and in the technical metabolism (C2C). The CE implies non-biological and man-made components into the technical nutrients, while the technical metabolism of the C2C concept is focussing only on service systems with less focus on material flows. Compared to the C2C concept where biological and technical components are divided into natural materials and services, the CE distinguishes between biological (natural) nutrients that can return into the natural system and man-made (technical) nutrients, which are being used (and not consumed) and cannot return into a natural cycle after all.

Conceptual framework and C&D waste management

In regards to the analysis of C&D waste management, the CE model is considered the most valuable due to several reasons. The current problem of recycling processes is the loss of value that occurs in the recycled materials. The CE focuses on value maintenance and value creation by applying the order of the 4Rs on waste materials for prolonging lifetime and maximizing value.

The aim of this study is to address businesses in the demolition waste sector, as well as involved construction businesses and to identify current legislative weaknesses in regards to C&D waste management to conclude with helpful recommendations for further regulations and business strategies. In order to improve the current C&D waste management framework, a rethinking in the term of waste in regards to resource effectiveness and sustainability might be a new way to address the issue. The CE concept addresses businesses by changing their perspective in business models to strategies where waste is linked to economic value. In order to initiate the shift from a linear economy to a circular economy, a rethinking of production and consumption patterns is crucial as products and material components need to be intentional designed to fulfil the aim of a secondary resource instead of ending up as disposed waste; furthermore a service system that implies functioning take-back arrangements and economically promoted reusing options. C2C and especially LCT are addressing business models only indirect and disregard the meaning of a societal change for enabling a circular system where waste is seen as a potential solution for minimizing resource extraction and waste disposal, while the CE sees the rethinking of linear systems as a first milestone to be achieved.

The present case of C&D waste is not clearly definable in terms of biological and technical nutrients according to the C2C concept. C&D waste consists of biological degradable materials such as wood or soil and can therefore be considered as biological nutrient. At the same, concrete for example is only biodegradable as raw powder, the mixture with water for construction activities transform the structure into a non-degradable material (Murray-White 2012). Bricks are only biodegradable through erosion processes during a long period of time. The main consistence of C&D waste is not considered as biodegradable and therefore not as entire biological nutrients. C&D waste usually refers to residential housing or infrastructural activities and these objects are usually not remaining ownership by a construction company. A residential building for example passes several stages of ownership beginning by the construction company, the owner of the building, tenants and the further. For this reason it is complicated to approach C&D waste with the concept of offering a service while the ownership remains at one person or company. C&D waste can therefore not be classified as technical nutrients according to the definition based on the C2C concept. Therefore the project focuses on the definition of technical nutrients in the circular economy by the Ellen MacArthur Foundation (Ellen MacArthur Foundation 2013).

	C2C	LCT	CE
Focus	Circular systems, eco-effectiveness	Lifecycle stages	Circular systems and cascades
Aim	0-waste, closing the loop	Identifying & reducing environmental impacts	Intentional design, value upkeep & creation
Addresses	Businesses, producer	EPR, polluter pays principle, manufacturer	Society and businesses
Assesses	Business synergies to promote a closed system	Management of complex environmental impacts	Design and value
Indicators	Biological & technical metabolism, service	Inputs & outputs	Biological & technical (man-made) nutrients
Approach	Pro-active	Pro-active and Re-active	Pro-active
Flows	Material flows	Material flows	Material and information flows

Table 3 Cradle-to-Cradle, Life Cycle Thinking and the Circular Economy in comparison.

5.5 Sustainable Business models

Sustainable Business Models (SBM) are currently most commonly associated with a rethinking of product systems. Instead of selling a product, greater benefits and less environmental impacts can be achieved by implementing Product Service Systems (PSS). As stated by the Ellen MacArthur Foundation, a PSS facilitates an easier way of implementing take-back systems by businesses in order to increase recovery and direct reuse potential. Also the C2C concept highlights the aspect of closed product and value chains where take-back arrangements increase businesses' economical benefits and do at the same time promote an environmental friendly business strategy (European Commission 2008; Ellen MacArthur Foundation 2013; Braungart & McDonough 2008).

In the case of the demolition industry this perspective is not fully suitable since demolition businesses are placed at the end of a product chain and little connected to the construction of a building. A take-back arrangement in terms of materials from the built environment would therefore be more linked to the construction industry instead of demolition businesses. As mentioned before the time-gap between the construction and demolition of buildings is crucial and PPS might therefore not be the right approach regarding waste handling in this sector. Instead, business models in the construction and demolition industry need to be approached differently.

The Network for Business Sustainability (NBS) published a framework for driving business models towards more sustainability (Figure 8).

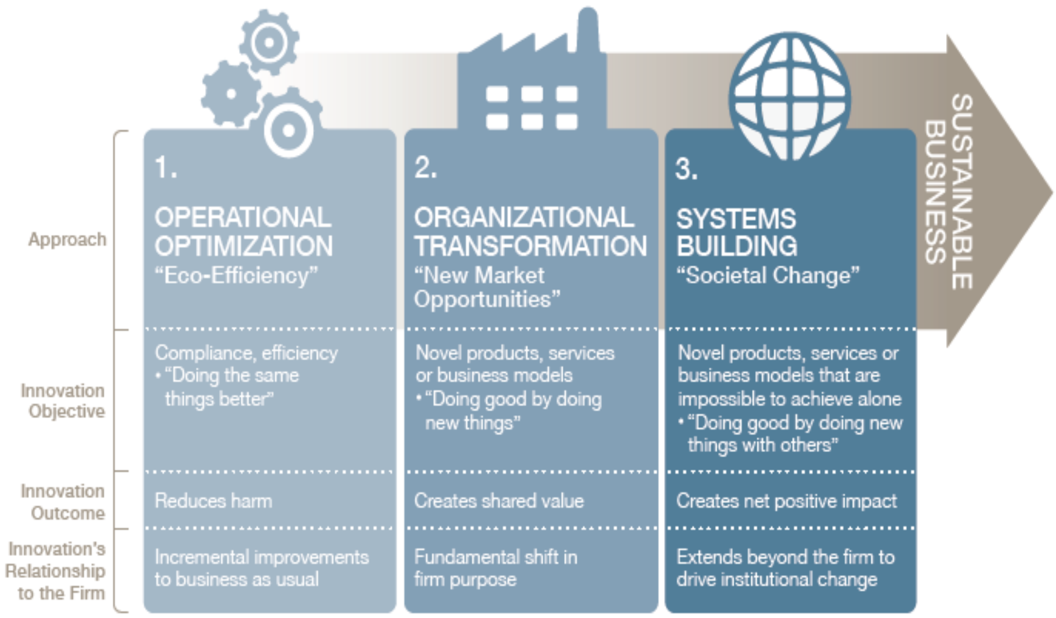

Figure 8 Innovating for Sustainability. Source: (Network for Business Sustainability 2012)

The framework is divided into three stages and differentiates between aim and outcome of the framework regarding the implementation in business models. A shift from stage one to three will increase the business sustainability and businesses need to focus on aspects beyond the company instead of addressing only internal changes (Network for Business Sustainability 2012).

The next chapter will introduce the EU Waste Framework Directive, considered as the most relevant legislation in regards to C&D waste.

6 EU WASTE FRAMEWORK DIRECTIVE 2008/98/EC

In 2008 the EC published the Waste Framework Directive as a guidance regarding the management of various kinds of waste for EU member states. The Framework presents a waste hierarchy, which member states shall implement in their national waste strategy while promoting the option regarding the waste hierarchy (reuse, recycle, recover) that creates the most beneficial environmental outcome. The Framework distinguishes further on between waste and by-products. By-products are in definition by the EC "[a] *substance or item resulting from a production process"* (European Union 2008, p.11) and are considered only as by-products according to the following criteria: further use of the substance/object is given; is used directly without further processing other than normal industrial activities; is produced as an integral part of a production process; and the further use is lawful by fulfilling all relevant quality standards regarding environmental and human health impacts (European Union 2008, p.11) .

The Waste Framework Directive sets a hierarchy focusing on the treatment of waste: prevention, prepare for reuse, recycling, recovery and disposal. At first of the hierarchy stands the prevention of waste, where non-waste is seen as products (-resources) for further purpose and use. Based on this hierarchy the EC sets up the target to achieve 70% of C&D waste prepared for reuse and recycling, to be achieved in 2020 as part of the European Resource Strategy driven by the EU Roadmap 2020 (European Union 2008).

According to the Waste Framework Directive waste is considered being a secondary raw material when it has run through a recovery process and if it complies with specific criteria such as a demand of the product/substance on the market, fulfils technical requirements for certain purposes and is coherent with existing legislation standards; and if the use of the product/substance does not cause environmental or health impacts. Waste materials and substances that are possibly explosive, oxidizing, highly flammable, irritant, harmful, toxic and eco-toxic are considered as hazardous waste and need to be separated from other waste materials. Also it is not allowed to mix hazardous materials with non-hazardous materials in order to lower the concentration of hazardous substances.

The Waste framework Directive is set as a preliminary achievement towards the EU strategy "Europe 2020" on the use of natural resources published in 2011 (EU Resource Strategy). The strategy aims to reduce the material use by following a decoupling of economic growth from resource use and a decoupling of environmental impacts from resource use (European Commission 2011a).

Member States of the EU are asked for several requirements to promote the resource strategy: developing tools for progress monitoring and reporting; developing related plans and programs with their own measures and indicators to promote a sustainable use of resources in the business sector; ensure full implementation of the EU waste framework including minimum targets defined in the individual national waste prevention strategy (European Union 2013).

The waste hierarchy plays an important role in the consideration of reducing material use by preventing waste while instead using it as a secondary resource. According to the EC, C&D material reuse and recycling is the most important activity relevant for a decrease of material use since it has vast amounts of material flow (European Commission & Bio Intelligence Service 2011).

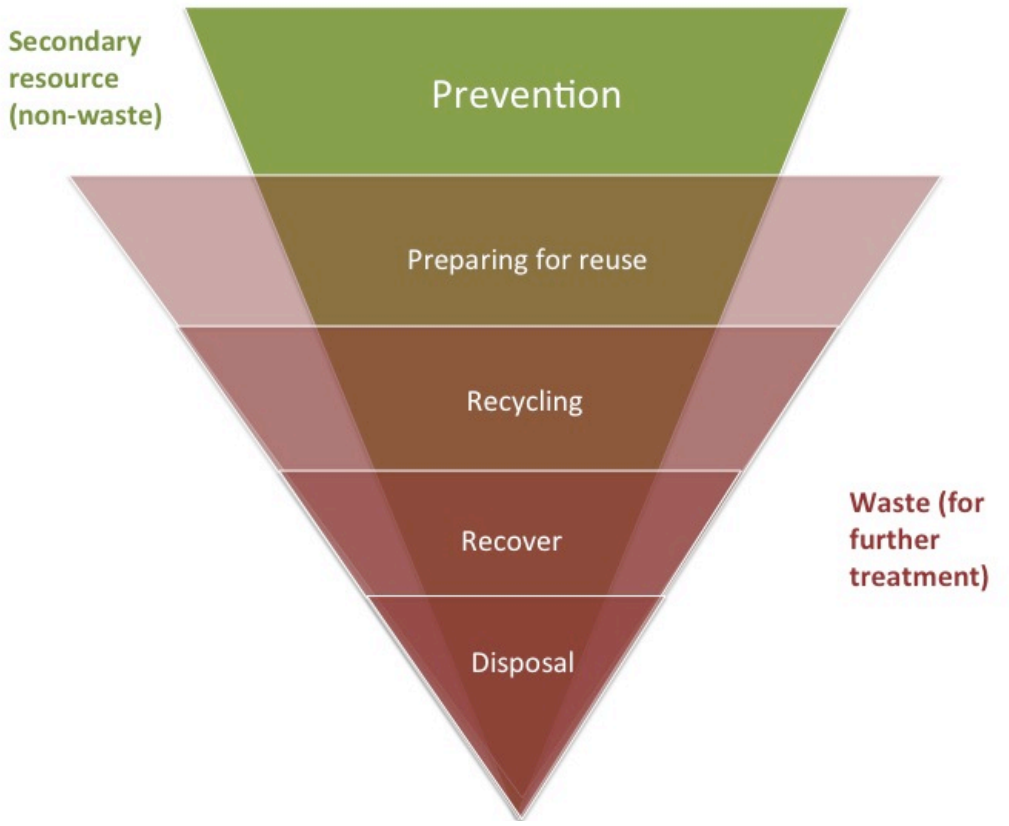

Figure 9 Interpretation of the waste hierarchy according to the EU Waste Framework Directive. Inspired by (European Union 2008).

Figure 9 illustrates an interpretation of the waste hierarchy according to the EU Waste Framework Directive. The overall prevention of waste is set as the main target of the framework, where non-waste is taken as secondary resources. The hierarchy follows the path of a reverse pyramid where disposal is seen as the final stage of waste. According to the Waste Framework Directive, member states have to manage waste in accordance with the waste hierarchy. Further on, member states need to facilitate and improve recovery activities and initiate separate waste collecting systems to avoid the mixture of different fractions, if environmentally and economically practicable. To promote reuse and high quality recycling activities, member states shall encourage the initiative of reuse networks, the use of economic instruments, procurement criteria and initiate quantitative objectives (European Union 2008, p.13).

Figure 9 also aims to illustrate that the prevention of waste is included in any stage of the hierarchy. The prevention pyramid filters the different treatment possibilities, meaning that every possible treatment is contributing to the prevention of waste in general. The prevention pyramid is tapering towards the end of the hierarchy in disposal. Also the level of waste prevention is getting smaller the more it heads towards disposal. The figure shows that the pyramid of waste (illustrated in red) is still bigger than the waste prevention pyramid (illustrated in green) and hence illustrates that waste treatment possibilities are not covering the whole range of waste prevention.

Figure 10 LCT in EU Waste Framework Directive. Inspired by(European Union 2008).

The framework focuses on the question when waste ends and when it is considered becoming a secondary raw material and interlinks this question to the Life Cycle Thinking concept. Every waste produced at various lifecycle stages need to be analysed in order to reduce environmental impacts and prepare a framework for new resource strategies. Important at this point is that according to lifecycle thinking in the EU framework, design gets attention in a separate stage of the cycle.

6.1 EU Waste Framework Directive and LCA

If justified by the LCT concept, specific waste streams or materials can be excluded from the waste hierarchy in regards to the management and respective potential impacts (European Union 2008). As an example: as outlined in the Waste Framework Directive, reusing is the preferable option of waste recovery as less environmental impacts occur compared to recycling processes, where materials are transformed and this transformation usually causes emissions or energy consumption. But if the recycled material could substitute natural resource extraction and this substitution would lead to a more beneficial environmental balance compared to the impact balance in terms of reusing, a shift in the waste hierarchy would be justified by the results conducted in an LCA study. This could be the case in terms of recycled concrete processed to gravel. The natural extraction of stone and sand that is afterwards processed as gravel could have a higher balance of environmental impacts in regions where these resources are rare, and therefore a substitution by recycled concrete could justify a shift in the waste hierarchy.

Chapter 7 present the theoretical framework used in this report based on the governance theory.

7 THEORETICAL FRAMEWORK

In order to analyse C&D waste management regulations on a policy level this report is, besides a conceptual framework, also guided by a theoretical framework. Especially in environmental manners, the policy level consists of different mechanisms to control and manage environmental impacts. Applying the governance theory on these different mechanisms enables to analyse different structures in the current C&D waste legislation. In identifying and capturing power relations, possibilities for improvements and legislative weaknesses in current waste regulation the principles of the shift from government to governance is playing a crucial role. Therefore the following chapter will present basic arguments for the shift from government to governance and will elaborate further on environmental regulations in the governance paradigm.

7.1 From Government to Governance

The government plays a crucial role regarding the implementation of regulations in the C&D waste industry. Regulations such as landfill and incineration tax are instruments by national authorities to control environmental policy aspects in the waste management sector. In the last two decades there has been a shift from governmental intervention to the so-called term *governance*. Rhodes (1996, pp.653–653) explains governance as *"a change in the meaning of government* [and] *a new process of governing"* while Pierre and Peters (2000, pp.1–2) go more into detail and claim that governance covers *"the whole range of institutions and relationships involved in the process of governing"*. Richards and Smith (2002) do not see a great difference in what states do, but how it is been done and Bakker (2007) adds that in governance different information and principles are used for determining who has the power to decide. Harrington (2008) describes government as a centralized and vertical arrangement of power and justification while in governance power is arranged horizontally and carried out by a broader society. As such, there is no single definition of the term governance and its level in policy is hard to measure. Certain is that governance is defined as public policy making which involves actors outside the direct policy body and the common opinion is that governments lost influence and power by the shift to governance (Jordan et al. 2005a).

Contrariwise scholars have found that in the paradigm of governance the government has gained even more power and acts as a key player in governance effectiveness. It takes more responsibility as a support function and manages different tasks on national level (Petersen et al. 2009; Carlsson & Sandström 2008; Lockwood et al. 2009).

7.1.1 Regulations in governance

Regulations by government are addressing the *steering* (Jordan et al. 2005a, p.478f) of society by governmental intervention, while in terms of governance the society is far more self-regulated. Governance gives (non-political) actors the possibility to influence this self-regulation by doing more societal coordination in their own interest. Governance as such is a *"self-organizing and coordination network of societal actors"* (Schout & Jordan 2005) that are taking over the business of government. Governments have shifted from a command and control framework to a softer range of policy instruments; policy goals have stayed the same, the difference lies in the operation of states and in different forms of control (Jordan et al. 2005a).

There are several aspects, which brought the shift from government to governance. On a macro level, multi-level institutions such as the EU, which try to regulate states by a common regulatory framework. On a meso level national states governments, which interact between European legislations and communicate regulations to regions. And on a micro level, regions and local authorities that need to interpret European and national regulations and make them fit in their localities. Among all scales, international cooperation, conventions and the influence on policies by non-governmental organizations. (Bulkeley 2005; Reed & Bruyneel 2010). Further more governance stands for a privatization of formerly governmental scope of duties such as infrastructure, transportation or security. As Stoker (1998) describes it, the public and the private sector have melted and boundaries and competences have shifted.

In environmental policies, governments are using regulative policy instruments to address the control of harmful materials, management procedures or suchlike. Next to regulations stand the non-regulatory policy instruments which Jordan et al. describe as *'new' environmental policy instruments* (NEPIs) (Jordan et al. 2005a). These NEPIs are designed and suggested by non-state actors and, in governance, also implemented by these.

7.1.2 New environmental policy instruments (NEPIs)

NEPIs are contrary to governmental regulations since they are created in a governance framework, closer linked to industries and usually connected to companies' ambitions. NEPIs contain market-based instruments such as eco-taxation and tradable permit systems, eco-labels, environmental management systems and voluntary agreements.

	Steer Society	Governmental influence	Example
Market-based instruments	High	High	Eco-taxation, tradable permits
Eco-labels	Medium/High	Medium	EU-Ecolabel, Nordic Swan, Forest Steward Council
EMS	Medium/High	Medium	ISO 14001, EMAS
Voluntary agreements	Medium	Medium/Low	CSR

Table 4 Effects of NEPIs

Table 4 shows the effects on society and the level of influence by the government among different NEPIs. While NEPIs are having relatively high impacts on society, the governmental influence is decreasing in comparison of market-based instruments to voluntary agreements. Market-based instruments are usually strongly steered from the government by determining price levels and legislative frameworks for trades. The governance influence in Eco-labels or EMSs is moderate; national governments can set their own framework for eco-labels (applied by e.g. the Netherlands for flower industry, Austria for tourism) or can adapt the eco-label framework by the EU (applied by the UK). In regards to the implementation of an EMS such as EMAS, the EU demands regular audits by external organizations. In voluntary agreements the governmental influence is rather low as the agreement is usually based on ambitions by the industry to improve their image. Only negotiated agreements are based on direct treaties between the public and private sector (Jordan et al. 2005a; Schout & Jordan 2005).

Interesting for the C&D waste sector is the term of voluntary agreements. According to the European Commission (2013c) voluntary agreements in environmental manners are recommendable to focus on, since they are largely recognized for offering various benefits. Voluntary agreements also initiate a pro-active approach in industries and promote faster achievements of environmental goals. Another form of voluntary agreements, unilateral commitments (general statements by individual companies, e.g. CSR) are highly self-regulatory since they are not based on legally bindings on community level (Jordan et al. 2005a; European Commission 2013c).

The variety of NEPIs is large and can be applied variable. To enforce a common environmental policy in the EU is complicated since countries are interpreting governance instruments such as NEPIs differently. Further more, in the governance framework it is not only the national state that regulates but also international organizations and the regional communes, which need to implement national and European frameworks according to their interpretation.

The next chapter will present the results conducted in this report.

8 RESULTS

Based on collected information by interviews, literature review and policy documents several aspects have been identified as major areas of interest relevant for improving current principles of C&D waste management. The focus points are relevant for improvements in C&D waste policies, C&D business models and C&D waste management, and potential for material upcycling. Waste legislation, business sector models and handling and design of materials are all being considered equally relevant for general improvements in the C&D industry. Policy-regulations regarded under the principles of the governance paradigm related to C&D waste indicate that there are significant weaknesses in current legislation. Business models and potential for material upcycling analysed with the concept of the Circular Economy highlight several aspects for improvements such as hazardous waste management, knowledge and information transfer and a rethinking of current economical patterns.

8.1 Rethinking the linear economy

As pointed out by the Ellen MacArthur Foundation (2013) a crucial milestone to achieve increased value throughout the lifecycle of waste is demanding a basic re-thinking of current business and economy models. As shown before, C&D waste has great potentials of recovery and therefore can save crucial amounts of landfill and resources. However, value of C&D waste gets lost due to various reasons.

Roughly demolishing causes an intermixture of hazardous and non-hazardous materials that will end-up as landfill, even though non-hazardous waste implied recovery value. According to Kingo the preliminary reason of downcycling of materials is seen in the irresponsible handling of hazardous waste. Some demolition companies still operate without considering recycling options. Even though it has been shown that C&D waste contains high potential for recovery, some companies prefer to demolish in large-scale instead of tearing buildings down in selective phases. Materials with large recovery potential are getting mixed with materials that cannot be recovered, such as hazardous waste materials. The mixture of hazardous and non-hazardous materials is afterwards simply sent to landfill. Fining and taxing systems were implemented in order to avoid operations like this. However, companies who are not considering recovery treatment are sometimes offering demolition jobs for even less than the overall tax on hazardous waste would be (Kingo 2013).

According to Kingo, companies which are selectively demolishing buildings with the aim of further recovery are pricing their jobs twice to three times higher than companies operating without preparation for recovery. This is due to additional time, which is spent on selective waste handling and hazardous waste treatment. The formula is simple: non-recovery demolition operations are usually far more cheap and therefore often more attractive to clients (Kingo 2013).

8.1.1 Rethinking design

A crucial aspect in the recovery of C&D waste is the process of material downcycling. If materials are not directly reused without major transformation in their purpose, the material loses value. Recycling processes such as the crushing of concrete are having preferable environmental impact balances and are usually cost efficient, but they detract materials' value. According to the Circular Economy model value can only be maintained and additionally created if materials are circulating in cascades where they fulfil purposes in their original entity. Materials therefore need to be reintroduced into value cascades that promote the purpose of the material (Ellen MacArthur Foundation 2013).

Recycled concrete gravel is usually processed for road construction and maintenance (Kristensen 2013). In order to follow a circular model based on value cascades materials need to be directly reused in new construction projects. As outlined before, the Danish company Gamle Mursten has implemented this approach and is complying with the waste hierarchy in their business model by preparing bricks for direct reuse. In this case additional value is obtained to bricks since they hold value regarding history and uniqueness. Bricks hold the advantage of a constructional design that makes actual reuse rather simple. Compared to other common construction materials, bricks are less affected by mould and disaggregation and since they are designed as textured modules, a reuse in new builds is simple and efficient (Kristensen 2013).

Other materials are designed differently and therefore do not hold potential for recovery. Concrete is one of the most common construction material but at the same time has a rather little recovery balance regarding direct reuse. Wood has high demands for reuse on the market but only if in large scale and untreated. Insulation materials are, if at all reused, usually only demanded by private customers that need the materials for repair activities. Further on, a direct reuse of insulation materials is considered problematic due to large holds of potential hazardous impacts (Kristensen 2013).

Hence, a major aspect in promoting recovery possibilities of C&D waste is to focus on design aspects. In order to recover materials and construction elements without downcycling, material and product design matter for simplifying the potential of recovery options. Further more, C&D waste can be recovered on a high level only if necessary actions were taken beforehand. According to Kingo, priority lies in selective demolition operations in order to ensure that waste is being treated for the sake of recovery (Kristensen 2013).

8.1.2 Market demands

In order to promote recovery options of C&D waste for businesses, incentives need to be created. This can be conducted by regulations with cost advantages and respectively fines as implemented by landfill and incineration tax (Fischer et al. 2012). Additional to this market-based instruments initiated by authorities, incentives for recovery can rise due to market forces. There are two possibilities how market demands can arise; on the one hand customers and buyers are demanding specific products and business sectors are responding to this need, on the other hand industries can create the demand on products with effective marketing. As outlined before, in the case of reused bricks or wood effective marketing initiatives have created a specific market for products in this segment (Gamle Mursten 2013; Thors Design 2013).

Kingo has found strategies to sell reusable doors and windows as niche products to private customers. As explained by Kristensen (2013), customers visit Bango A/S (independent company, formerly part of Kingo Karlsen A/S) to find unique doors and windows which cannot be bought in regular shops selling new products. Bango A/S offers three different segments of doors and windows; reused products that have been used in other buildings before, defective products that are newly produced but unfeasible for new builds due to e.g. wrong sizes, and entirely new products. Therefore it is guaranteed that customers find every segment they are looking for. However, Bango A/S is selling only to private customers and does not collaborate with construction companies since these are demanding new doors and windows for building projects (Kristensen 2013).

According to Kingo, market demands on reused or recovered products are closely linked to a so-called "green wave" that has been evolved in market trends, in production as well as in consumption patterns. This green supplies and demands might have eased the market access for reused products of C&D waste (Kingo 2013). However, the marketization of reused or recovered products of C&D waste is yet limited to visible items. Products such as insulation for walls and roofs are not attractive for recovery since there are no market demands on these parts of C&D waste. Further on, according to Kingo it is difficult to introduce different reused products (such as insulation materials) to the market because of the principle of pricing. Reused bricks or wood are successful even though they are high priced on the market and therefore more expensive than new products. The difference is that these are visible items legitimating high price by uniqueness and look. Insulation materials would have to be priced high on the market as well, but there would be no demands on these materials since they are not attractive in look and uniqueness (Kingo 2013).

8.2 Weaknesses in current legislations

Current legislation regarding C&D waste has weaknesses especially in the framework for the treatment of hazardous materials. To address the problem of potential migration of hazardous materials into recovered materials is a crucial starting point that needs to be framed specifically by legislation. Further on the application of results conducted by LCAs incorporated with the EU Waste Framework Directive might need to be reconsidered.

8.2.1 Hazardous materials

Hazardous materials such as PCB or asbestos have been banned for construction work already for many years; in the demolition business these substances are still a crucial issue. Hazardous materials can appear in nearly all parts of buildings, beginning with asbestos in roof plates to PCB substances in flooring. These toxic substances can cause acute and long-term health diseases by staying in the environment (Del Río Merino et al. 2010).

According to Kingo (2013) the current problem is a missing guidance in regulations enforced by authorities. Even though several regulations and directives cover hazardous waste, a detailed regulation on how to treat hazardous C&D waste is not introduced yet. This is an important issue since the demolition industry is recording a high level of recovery and contaminated materials might be recovered as well. Therefore Kingo sees the most problematic issue in an inappropriate handling of hazardous C&D waste by companies in the industry. A not ignorable percentage of companies operate with radical demolition principles where hazardous and non-hazardous materials are not handled separately from each other. The mixture of materials is then being recovered and used as e.g. bottom layers for buildings or roads. According to Kingo (2013) the problematic issue regarding hazardous substances in C&D waste is that authorities are not making check-ups on companies' waste management. Also clients who are not questioning the operational principles by demolition companies are exacerbating the problem. According to Kristensen (2013) an inadequate handling of hazardous materials counts especially for small and unprofessional businesses who do not have knowledge, capacity and interest for an adequate waste management. Even if especially public clients or large project groups are asking for demolition businesses with certification or a good reputation in this field, there are still enough customers who prefer a cheap but incorrect demolition instead (Kristensen 2013; Kingo 2013).

As outlined before, hazardous substances have the capacity to stay in the environment for more than 100 years and do therefore inhere a risk for stored eco-toxicity and human toxicity (Scharff 2012; Hauschild et al. 2008). In order not to prolong the problem of toxic substances there is an urge for more detailed regulation on the treatment of hazardous substances in C&D waste. Other European countries have implemented own regulations and guidelines on the treatment of hazardous substances based on EU legislation.

Such as Germany implemented the 'PCB Abfallverodnung/PCB-Richtlinie' in the year 2000 regarding relevant safety precautions; a manual on a selective separation of PCB and other materials; packaging and transportation instructions and contact points for adequate PCB disposal as well as contact details for information centres (Bundesministerium 2000). Further on, Germany has translated the PCB regulation into individual guidelines for restoration and refurbishment operations on county (Länder) base (Innenministerium 2012).

In order to secure an adequate handling of toxic substances of C&D waste and to avoid shifting the problem to future generations, precise regulations by authorities on all scales, meaning EU, national state and municipal level need to be introduced. Further-on, education and information transfer need to be guaranteed in order to ensure a proper implementation of regulations by businesses in daily working routines.

8.2.2 LCA in waste hierarchy

The waste hierarchy according to the EU Waste Framework Directive can be shifted if plausible argumentation is delivered by LCA studies. The LCA studies' argumentation is based on balances of environmental impacts and can justify a shift in the waste hierarchy due to less harm or pollution for the environment. However, the potential of shifting the waste hierarchy by arguing with findings about the level of environmental impacts by LCA studies has its weaknesses.

Especially regarding toxic substances LCA does not include important factors and shows difficulties of how to estimate potential effects in future times. Currently the Life Cycle Inventory (LCI) does not precisely consider impacts by eco-toxicity and human-toxicity in the long term. The level of harm by waste and in particular hazardous waste on humans and eco-systems is hard to measure since there is no persistence in the indicators. Units of emissions of CO2 or energy consumption can be measured steadily regarding different life cycle stages. But, until now no reliable category for human-toxicity or eco-toxicity has been implemented in the LCI. Another aspect why LCA based argumentation in terms of waste has its limits are the problematical time horizons. There are short-term impacts that can be measured by LCA studies but long-term impacts such as emission from landfills are hard to predict (Hauschild et al. 2008).

LCA studies are focussing on present ‘direct' impacts at life cycle stages, impacts that can be currently measured because there is no impact considered in future times. Landfilling for example can have extended impacts for long periods of time. Until now, these long-term impacts have been assessed with one of three different approaches: (1) estimation of impacts in conceivable future without considering impacts afterwards, (2) modelling of impacts by defining kinetics, and (3) modelling of impacts until an equal balance between leachate concentrations of landfill substances and the substance backgrounds of the environment is reached (Hauschild et al. 2008).

Any of these approaches regarding impacts' measurements and predictions are not fully reliable in terms of future predictions. There is no scientific proof that emissions from landfill disappear after a conceivable period of time and therefore it is not plausible to evaluate a precautionary assessment. The second approach is usually based on an assumed time period of 10^4-10^5 years, but this period of time does not consider estimations on technologies in waste treatment and geological changes such as erosion or seismic activities, which could affect the impacts of landfilled waste. Currently emissions of landfill for the specific period of time are taken into measurement by linking them to other life cycle stages, by this they will usually dominate the calculation. To overcome this bias LCA studies assume that emissions of landfill are getting less problematic over time and might therefore not be as relevant to equation. The third approach assumes that emissions occur only until the leakage concentration is equivalent to the surrounded environment, as substances then become part of the eco-system. Background levels of the surrounding environment can differ large-scale and the alignment of landfill to the ecosphere can vary between different substances (Hauschild et al. 2008).

A differentiation between short-term and long-term impacts is not yet fully implemented in LCA studies and lacks reliable data in the LCI. Even though the majority of C&D waste is considered being inert, persistent substances can survive also in high temperature combustion processes and a full biodegradation of C&D waste is therefore not guaranteed (Del Río Merino et al. 2010). Fractions of C&D waste such as PVC, PCB and heavy metals might decompose during the assumed time period but inherent hazardous substances can then migrate into natural systems. Even though the usual percentage of heavy metal leakage into the biosphere accounts for only 1% between a time period of 100 years, various studies have concluded that 99% of these toxic substances can remain in the ground for even more than 100 years (Hauschild et al. 2008; Hansen 2004).

The issue of stored human toxicity and eco-toxicity in the case of landfilling is only one example that highlights the difficulties regarding the potential of LCA studies to capture human harm as well as short-term (<100 years) and long-term (>100 years) impacts.

The recovery of waste and in particular hazardous material waste is another area where LCA might not be fully reliable as an assessment tool. If in certain cases the waste hierarchy is shifted, for example recycling seems to be preferable instead of reuse due to a preference of energy recovery, hazardous substances can be transported from the original material to the recycled material and can thereby affect the surrounding eco-sphere. This could be the case when recycling is preferred in order for materials to work as a substitution for natural resource extraction. The recycled materials could include hazardous substances such as PCB, which is often carried with concrete, and the use of the recycled concrete would prolong the problem of hazardous substances (Lent 2003; Scharff 2012).

As outlined before, LCA does not fully consider long-term impacts and even if recycling was the preferable option regarding other more direct environmental impacts resulted by LCA, the harm of hazardous substances was to be only temporarily displaced. The temporary solution might currently seem to have positive effects on the environment but can turn out as externalities for future generations.

8.2.3 Objectivity in LCA as a clear-decision tool

The aim of the possibility to shift the waste hierarchy by LCA studies is to identify best solutions for waste stream treatments in environmental terms. LCA as a tool might have strengths compared to others because it is reliable for its transparency, which gives overview of mostly quantitative facts. The assessment of environmental impacts across the waste hierarchy is an issue driven problem as it expresses certain system uncertainties and usually involves different actors as well as several level of life cycle stages. Regulations such as the Waste Framework Directive are drawn at supranational level with multinational influence, but the justification of LCA is asked for and being carried out at the local level, where there are various stakeholders who hold interest in certain decision making processes. Also the direct implementation of the waste hierarchy is being carried out at a business level where companies have to place the Waste Framework Directive in their waste management practices (Lazarevic et al. 2012).

As stated by several studies that have evaluated opinions by LCA experts on the objectivity of the tool, LCA cannot be seen as a fully objective assessment because there are several assumptions that need to be decided on by the LCA conductor. Therefore LCA studies cannot deliver universal and definite answers that would be reliable to an extent where they would be sufficient for policy-decisions. LCAs are also affected by value judgements of the LCA conductor or consultancy firm and subjective interpretation might already influence the LCI. The subjective conduction of the LCA and the interpretation of results do not always reflect best options and are not universal applicable and might therefore be reconsidered as a reliable tool for shifting decisions for waste management in order not to institutionalise LCA studies for policy-making (Ekvall et al. 2005; Heiskanen 2000; Tukker 2000).

8.2.4 LCA bias in scientific paradigms

LCA studies' difficulty to work as a reliable tool for policy decision making lies in unpredictable conditions, uncertainties in time horizons, insufficient LCI databases and subjectivity of conducting and interpreting results. The problem is that policy-makers see LCA as a tool based on principles of the positivism paradigm and therefore assume the outcome of it as reliable facts. LCA is assumed to be an environmental assessment tool based on scientific results, which reflect the world and its truth. In the positivism view, subjectivity, values and opinions are being left out from scientific results. In this perception LCA would give valuable and credible arguments, which could then be applied in decision-making process at policy levels. However, LCA might have the aim to present objective facts but is rather embedded in the paradigm of social constructivism where it is influenced by values, subjectivity and opinions. Besides, studies of LCA are conducted in an arrangement of controversial and conflictive assumptions. Information and knowledge on which the conducting of the LCA is based are affected by opinions and values (Tukker 2000).

The interpretation of the results is driven by the perception of different actors involved, which have various levels of information and interest. Subjective interpretation and the power of influence in decision-making processes by actors involved would therefore affect the outcome of the LCA and hence it might have to be rethought if LCA is considered a suitable tool for the aim of positivistic results under socially constructed conditions.

8.3 Education and knowledge

An adequate handling of C&D waste presupposes knowledge about the respective regulative framework and complying procedures in practice. Regulative commandments by authorities on the one hand do not imply an immediate understanding by businesses and an easy implementation of these in daily working routines. Working procedures and business strategies on the other hand might not be taken correspondingly into consideration by the framework of regulations set by authorities. Especially in terms of hazardous waste handling insufficient knowledge can cause incorrect waste management with serious impacts on health and environment. Since in most European countries there has not been introduced a regulation on how to handle hazardous waste in detail yet, businesses remain unaware of toxic substances' impacts and principles on how to avoid these.

According to Kingo there are two reasons why C&D waste, and especially hazardous waste, is still treated wrong. On one hand companies are aware of doing it not correct but do not care since they might not consider crucial impacts and also actual benefits by how to do it correctly. On the other hand companies simply do not know where to find the right information and who to consulate. This also might be due to confusion provoked by various regulations on different scales (EU, national, regional) and diverse interpretation (Kingo 2013).

In order to ensure a correct waste handling companies would need to have internal experts that know about current regulations, waste materials and hazardous substances. Not every company has capacities to focus on these issues. According to Kingo a preferable approach is to educate and train every employee who is involved in waste management regarding correct handling. To hire only one expert in this field is according to the company not effectual since a huge percentage of personnel is involved in the waste handling process, beginning at the demolition site until the handling at the companies' facilities. Kingo also states that the knowledge transfer and education shall be connected to the companies' ambitions. For a successful education of employees to consider environmental aspects, it is necessary to have the ambition to do so even if there are no direct financial benefits as outcome at first. Knowledge and information transfer is to be considered implemented in business models and educational time apart from the daily business should be of interest by the companies' management (Kingo 2013).

In order to create a helpful guidance on hazardous waste handling monitoring and documentation processes of materials and their associated risk could be an important tool for businesses and authorities. These information pools could provide valuable information based on experiences and could spread knowledge across actors involved, as it is recommended also in the Waste Framework Directive to be implemented on national state responsibility (Rushton 2003; European Union 2008).

8.4 Policy-making and competition

As argued by Jordan et al. (2005), in the governance paradigm the society is rather self-regulated as with traditional top-down commandments by the government. Even though the EU has set a framework, which gradates the waste hierarchy, the framework allows actors outside the direct policy body to re-frame the hierarchy. As outlined before, consultancy firms are conducting various LCA studies in order to point out arguments to shift the waste hierarchy. Thereby other stakeholders are being involved in the policy-making and the arrangement of actors involved in decision-making processes turns out more complex. The policy making is involving several actors with different background: beginning with the C&D waste management company who has interest in shifting the EU waste hierarchy, the consultancy company who is working on LCAs in order to deliver arguments for the shift in the waste hierarchy and communes and regional authorities who are the first instance to decide on individual regulations. Further, the entire process is working under the umbrella of national and EU legislation, which give room for individual policy-making.

The governance paradigm eases a potential participation of businesses in policy-making processes. In the case of Kingo the government was asking the company to support decisions with their practical knowledge. The intention of collaboration between authorities and private businesses is per se a felicitous idea. Businesses have the knowledge from practice that can help to adjust regulations in a way to support businesses in economic terms and ensure complying working procedures at once. The challenge is seen in the influence that companies can have to transform legislations in their interest without considering following problems (Schout & Jordan 2005; Kristensen 2013; Kingo 2013).

Regulations also have the impact to motivate businesses and to stimulate initiatives to work even better than regulations are directing (Schout & Jordan 2005). As outlined by Kingo, the will of businesses within the C&D industry to lift up other companies and to eliminate bad competitors is given. However, at this time Kingo sees the improvements of waste management throughout businesses connected to regulations set up by authorities. According to Kingo a possible way to ensure the credibility of demolition companies can be managed by certification. A special certification on the treatment of hazardous waste could lift up the level of companies within the industry, as the so-called bad competitors could not operate business anymore. An initiative by companies in the industry is seen as not enforceable at this time, since there are still too many companies that handle waste incorrect and do not perceive the will to change. As stated by Kingo, this is due to a weak legislation framework and limited ways for authorities to check operations, which enables businesses to act against standards. Therefore Kingo awaits stricter regulations especially in terms of hazardous waste management (Kristensen 2013; Kingo 2013).

Further on, a certification on specific waste handling methods such as the regulation about contaminated soil requested by Kingo tightens the competition level among businesses within the industry. In first instance it is reasonable to spread credibility throughout the industry in order to ensure a correct waste handling. However, too much regulative intervention by authorities can have a contraire impact in terms of upcoming initiatives and motivation within the industry. A tightened framework with low tolerance for improvements by practice of businesses can turn out disadvantageous in spite of progressing ideas raised by practical knowledge (Jordan et al. 2005a).

Non-regulatory instruments in environmental terms, as they are described by Jordan et al. (2005a) are reasonable alternatives as they are linked closer to industry and rely on business' ambitions. Voluntary agreements affect the reputation of businesses by relying on motivation and ambition among companies within the industry. A self-regulatory approach promotes initiatives by industry and help to equalize the level within the industry since voluntary agreements are usually aligned to include all companies within across sector (European Commission 2013b).

8.5 Fusion of construction and demolition businesses

Construction and demolition businesses can be defined as supply and demand sides. The construction industry constantly needs construction products and materials for new builds while demolition businesses are dependent on buyers that demand recycled materials. To fuse these actors would have various benefits (WRAP 2013).

The common argumentation by demolition companies why materials cannot be recovered and upcycled at the same time is seen in the structure of construction materials. These materials are not yet being designed for fulfilling their purpose over again and in order to prolong the lifetime of materials they need to be designed differently. According to Kingo (2013), a direct knowledge and information transfer between construction and demolition industry is not given even though they could be linked more closely. Construction companies are working with architects and together they decide on the design of new builds. Demolition companies have knowledge on how to adjust design aspects in order to simplify recovery operations in future demolition activities. A knowledge and information commutation between these two actors could create benefits for the C&D industry. In environmental terms several impacts could be avoided by detailed pre-planning consultations in cooperation with responsible authorities.

Maximum resource efficiency, zero-waste strategies, low emissions and energy consumption are milestones set on various agendas and policies, to fulfil and implement these in business models might be easier by C&D business fusions instead of following individual strategies.

The C&D sector is a difficult case since between construction and demolition activities there is usually a large time gap in which regulations, demands and trends can change. However, the built environment is not a fast consumer good that can be replaced easily by new generations. A fusion of knowledge between these actors could therefore lighten difficulties in future.

8.5.1 ICE Demolition Protocol

In 2008 the Institution of Civil Engineers (ICE) published a Demolition Protocol in collaboration with the British Waste and Resource Programme (WRAP). The ICE Sustainability Initiative who first introduced the basic idea of a demolition protocol, was funded by revenues of the landfill tax in Europe. The Demolition Protocol has been developed to support a framework to implement the waste hierarchy and emphasis on the access of reusing options in buildings. The protocol focuses on Materials Resource Efficiency (MRE) associated with demolition and construction activities by introducing a framework on how to increase the potential implementation of the waste hierarchy in practice. Target audiences of the demolition protocol are policy-makers and businesses. The protocol aims to deliver guidance for an early decision-making process on how to reach the highest level of resource efficiency throughout C&D waste (Institution of Civil Engineers (ICE) 2008).

An important aspect is seen in the pro-active cooperation and interaction between construction businesses, legal authorities and demolition contractors because a management plan for efficient reuse may only be successful if demolition materials are reused directly on site for new builds. Managing C&D waste results in environmental and cost benefits for all actors involved. The common handling of C&D waste is that the materials usually belong to demolition businesses after the demolition operation. Even though demolition businesses usually recover the materials by recycling and afterwards selling them on specific markets, the overall best solution is found in the direct reuse of materials on the specific or a nearby site for new construction. This saves costs for transportation and direct environmental harm due to lower emissions (Institution of Civil Engineers (ICE) 2008).

In the past this potential of direct material reuse as well as the use of recycled materials has been prohibited by local and national authorities since demolition businesses did not have permission to select or recycle on site. Besides the fact that this prohibition was complicating a reuse of materials at new construction sites, it also causes large amounts of emission due to material transportation (Kristensen 2013). In this case regulations by authorities were destructive in regards to materials resource efficiency.

The Demolition Protocol allots a precocious planning of material reuse in agreement with responsible authorities. Therefore a Demolition Recovery Index (DRI) shall be defined beforehand in order to measure potentials of C&D waste recovery and to set targets to which extend recovered materials are being used for new builds.

8.5.2 Demolition Recovery Index (DRI) as negotiated agreement based on NEPI

Even if the C&D industry has already achieved a high level of recovery of C&D waste, however the initiatives to do so were mostly enforced by regulations from authorities. As mentioned by Kingo (2013), at this point initiatives by businesses among the industry are still considered to be very difficult to stimulate if it is not an initiative from top-down. Also the uneven level regarding waste recovery and compliance with legislation is proved to be a barrier for establishing a common initiative by the industry (Kristensen 2013).

A combination of commandments by authorities and motivation by businesses might be a reasonable framework in order to improve general waste handling methods in the industry, as well as to increase the potential of material upcycling in C&D waste. As outline before, a certification for demolition businesses for C&D waste handling might hinder competition and therefore potential for innovations by businesses might step into the background. A less radical approach might be established by a consultation between authorities and demolition businesses, which would then together develop a management-plan with targets formulated in the interest of all involved actors. This could be managed in form of negotiated agreements, as according to Jordan (2005b) these instruments are a balance regarding influence by authorities and the private sector. Based on negotiated agreements in the form of Green Public Procurements authorities could demand a certain DRI for C&D projects, but the operational part regarding demolition and waste handling would still remain task for the demolition contractors. However authorities on different scales would work in a supplementary function by providing guidance on legislation. This approach would work in terms of *fusion* according to Jordan et al. (2005b) and would still guarantee possibilities for intervention by authorities without losing responsibility as commonly criticized in public-private agreements (Petersen et al. 2009; Carlsson & Sandström 2008; Lockwood et al. 2009). The EU has investigated in a public procurement act this year, however only in new produced construction materials and electricity products including eco-labels (European Commission 2013a).

8.5.3 Business strategies (green business models)

The framework for business sustainability is an adequate approach to evaluate the current status of the C&D industry and to assess future prospects in regards to sustainable C&D waste management. Based on several results of this study the C&D industry can be classified in stage one (Operational Optimization) and two (Organizational Transformation). The major part of C&D businesses is currently located at stage one since the perception of waste being a resource is mostly implemented in business strategies and also the technological progress has driven recovery measures. However, most frontrunner businesses still operate in a re-active manner by adapting pollution control principles and an adequate treatment of hazardous waste is according to Kingo only implemented in a limited percentage of demolition companies (Kingo 2013; Kristensen 2013).

Some businesses have reached stage two in the sustainable business framework by specialising on new business models and the creation of products for new market segments. However these companies represent a minor percentage of companies and the perception of these specific products are still associated with venture and uncertainties. Also C&D waste includes only limited components for recovery that are proper for current marketing activities, such as bricks or wood (European Commission 2013b).

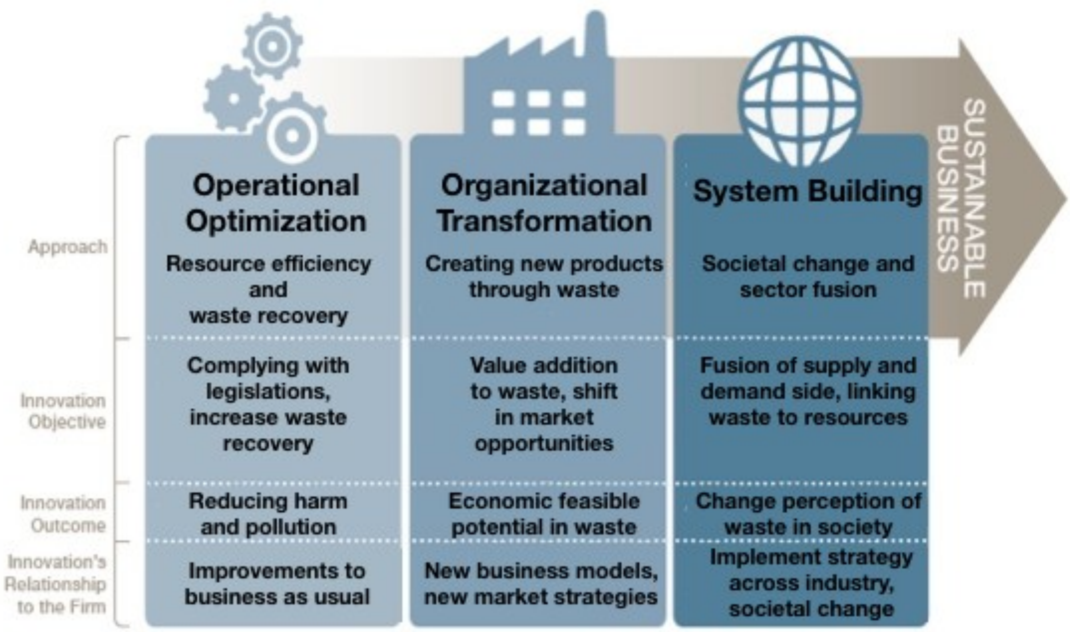

Figure 11 Business sustainability framework applied on C&D industry.

As discussed before a system building (fusion) between the construction and demolition industry would generate mutual benefits on both sides. However as outlined before, a societal change in the perception of waste is needed to achieve greater recovery potential of C&D waste and to fuse waste and resources as interlinked entities. Therefore business strategies of demolition businesses need to be created in accordance to construction business' models and vice versa. A cross-industrial strategy based on information transfer and shared perceptions might therefore initiate synergies concluding in mutual benefits for demolition as well as construction businesses.

Chapter 9 presents the conclusion of this report based on the conducted results.

9 Conclusion

C&D waste, as the third largest waste stream in the EU is important to consider in order for achieving progress regarding resource efficiency and adequate waste handling. This report has shown that C&D waste holds great potential for recovery and statistics have illustrated that the demolition sector records vast levels of C&D waste recycling especially in comparison to other waste streams. However this report has also shown that there are still several aspects that disclose potential for improvements.

Drivers that promote a high recovery rate of C&D waste influence demolition companies. Recycled C&D waste materials can be sold on the market and therefore businesses obtain economical benefits. However, progress in recovery operations of C&D waste by frontrunner companies in the demolition sector cannot be seen as general achievements regarding businesses across the industry. Especially the perception of a selective demolition due to hazardous C&D waste is not spread throughout the sector. Hazardous materials are still mixed with non-hazardous materials and thus lower the recovery potential of C&D waste. An inadequate handling of hazardous C&D waste is linked to insufficient information and absent education measures. Therefore it needs to take initiatives that promote educational training for employees and in particular knowledge transfer by practice examples. These initiatives can be taken by businesses across the sector or by top-down commandments by authorities.

Concepts like the polluter pays principle (PPP) or extended producer responsibility (EPR) are included in regulations in order to expand the waste issue on businesses. However, these concepts do not fully attain the C&D sector. A distinctiveness regarding demolition businesses is that they cannot be linked easily to the beginning of pollution. Construction businesses are responsible for the building process and material use, while demolition businesses come in later and do usually not have influence on former operations. Further on, a constructional phase and the demolition activity might have a long time span in between and therefore difficulties occur by addressing the responsibility of pollution. Demolition businesses can neither be associated with the polluter nor with the producer of waste. To address C&D waste management and in particular the C&D industry only by business models is not fully covering the problem. But rather should this issue be expanded on adjustments in legislation and a rethinking of waste in societal terms.

In order to diversify the perception of waste, a societal change is needed. If waste is no longer seen as negative outcome of production but as potential substitution of resource extraction, it might ease initiatives by businesses to implement this perception into business strategies. Therefore a system building between construction and demolition businesses is crucial in order to improve processes along time, increase the potential for recovery in future and follow coherent business strategies that complement each other.

Several regulations on EU level address C&D waste generation and handling in general, and also the problematic issue of hazardous waste. The EU Waste Framework Directive approaches waste by implementing a waste hierarchy on national state level. The report has shown that this regulation has its weaknesses in the possibility of individual shifting of the waste hierarchy legitimized by LCA studies. Lack of objectivity and the bias of assumptions make LCA studies as a tool in this regards not fully reliable.

Additionally, the waste hierarchy is addressing all kinds of waste and does not distinguish between different waste streams, which would be necessary since C&D waste is holding entirely different components, which bring along various environmental impacts. Therefore it is recommended that C&D waste regulations need to be adjusted to the specific case and further need to focus more precisely on principles for ensuring systems including knowledge and information flow. Transparent information about the composition and environmental impacts are soon introduced for construction materials, however only for newly processes ones. This approach needs to be transferred also to recovered demolition waste materials in order to secure transparent marketing and correct handling of C&D waste. Referring to the implementation of NEPIs, the Construction (and demolition) Product Regulation could then be comprised with standards in the negotiated agreement interlinked with the DRI.

Following coherent business strategies of construction as well as demolition businesses and an adequate legal framework which guides businesses for complying with regulations and standards would support an establishment of functioning systems of effective material flows and knowledge exchange, which are crucial in order to transfer to a circular economy. Value maintenance and additional value creation rely on the effectiveness of the entire system and therefore one-sided advancements by parts of the industry do neither hinder a material downcycling nor support a material upcycling.

This report has summarized current problematic areas regarding C&D waste but also highlighted how potentials for improvement can be assessed. It is worth to mention that the C&D industry cannot achieve changes as fast as other sectors could. The built environment is not a fast consumer good and demolition businesses still need to manage hazardous materials from former constructions. But even if this time issue hinders the industry to achieve fast success it is also indicating that decisions today are even more important since they will influence future generations notably. Therefore this report concludes that C&D waste and C&D waste management needs to gain momentum in addressing business models, respective legislation as well as a societal rethinking in the perception of waste.

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