THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Turning Waste into Resources

Rethinking the way we discard things

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Cover: Household waste covered in the sample of the waste characterisation Study.
Image taken by Abhilash Ram or Sara Berner on 13 February 2013.

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Abstract

Waste is one of the biggest challenges faced by our society. If not handled correctly, waste pollutes our natural environment with devastating results. However, it seems almost unavoidable that our society generates waste. Cyclical material use models have been proposed as a more sustainable alternative to our linear take-make-waste production culture. The aim of this licentiate thesis has been to investigate how to recover the material resources that today cannot go back into production, helping to redefine waste as a resource.

In order to do that this work first defines a framework to address material flow through society followed by a general background on waste and waste management. The main body of the licentiate describes three studies performed by the author in order explore the topic addressed. The studies investigated (A) how design and waste management collaborate, (B) how to facilitate designing with difficult waste and (C) how the waste system interface can be designed to facilitate resource recovery. Studies A, B and C are described in the central chapters of this work, with more information provided through the annexed Articles.

All three studies relied on the tacit knowledge of different relevant stakeholders in order to gain knowledge about the problem addressed. Studies B and C were carried out in collaboration with different actors, meaning that the knowledge gained in these studies have been generated collectively.

The work concludes two relevant gaps to address in order to improve resource recovery: (1) the connection between waste management and production systems and (2) the connection between the users and the waste system. The first gap was addressed partially in Study B, where the possibilities of designing with difficult waste were explored. The main barrier to design with waste was found to be the lack of reliable material knowledge. It was also made clear that designing with waste is a palliative solution. Difficult materials reaching the waste system should be avoided to the highest possible extent. In the case of pre-consumer waste this could be achieved by broader adaptation of industrial symbiosis and stricter production regulations. For post-consumer waste , difficult waste should be avoided by significantly improving waste sorting and collection systems.

Sorting and collection systems were addressed in Study C, which mainly investigated the relation between the users and the waste management system. Study C found that solutions that are in line with users' relations towards discarded materials are more easily adopted by the users, while solutions that generate value for the users could be a way to significantly improve user engagement. Biodegradable waste is currently insufficiently recovered, constituting a large portion of the discards that are landfilled or incinerated. Possibilities of recovering bio-waste shall be explored with future work.

Acknowledgements

This work would have not been possible without the help and collaboration of many people that in one way or another have been involved in this process. It is a long list, so bear with me, or skip forward to the next Sections.

I would like to thank David Gillblom and Taina Flink for seeing project possibilities in designing with waste. Ralf Rosenberg helped me see how different designing with waste really is compared to traditional design projects. I am very grateful that Oskar Rexfelt was happy to be involved in exploring these differences from the perspectives of design processes and methodologies. I would also like to thank Sandra Tostar and Erik Stenvall for finding the W2D project interesting enough to dedicate part of their time to it, providing the project with the much needed material knowledge. The W2D project would have not been possible without the students that found it interesting and dedicated their thesis to explore the possibilities of waste. So my thanks also go to Leo Li, Jonas Kääpä, Moa Parlsand, Klara Balkhammar, Kim Niskanen, Sofia Wallsten, Sebastian Rutgersson, Emil Brorson, Klara Friman, Ze Yu, Ajjar Posay and Angelica Elioneri for engaging in designing with waste without panicking (or just a little).

I am also very grateful that Lennart Wahlstedt was open minded enough to let me poke around in the waste generated at Poseidon, allowing for the beginning of a fruitful collaboration. At Poseidon Gisela Weber and Lilian Johansson were great guides into the daily issues around waste sorting in buildings, while Per Olsson and Tore Larsson helped me see the administrative and regulatory constraints. I am very thankful to have been able to count on the strong stomachs of Abhilash Ram, Sara Berner and Cansu Birgen to help me go through other peoples trash. I also wish to thank the group of students that engaged in the triangulation studies for the work with Poseidon, because you have all been very motivated and enthusiastic about the project. So my sincere thanks to Ida Aasa, Elisabeth Bergman, Sofia Friberg, Victor Petersson, Linn Wahlgren and Sara Westerlund .

I wish to thank Ulrike Rahe for providing me with the opportunity to pursue these studies and for her support in managing the projects we have undertaken, always seeing possibilities rather than limitations. Britt-Marie Steenari and Teodora Retegan have been great mentors and have managed to introduce me to the “hard” research that is needed to support material recycling and WM. My sincere thanks also goes to Alexandros Nikitas, who has provided thorough yet very spontaneous guidance for my work. I also wish to thank Robin Harder, Jagdeep Singh and Kamran Rousta for having the same interest in this topic as myself, but who are addressing the subject from slightly different angles. The conversations we have shared have been highly motivating and very enriching. I am glad to have the possibility to collaborate with people such as yourselves.

Last but not least I would like to thank my family and close friends for always supporting my crazy ideas. Especially Roger Langvik for helping me remember to enjoy life when I get too serious.

Preface

How did I end up wanting to focus on waste? I would say it is a rather long story. When starting my bachelor studies in industrial design I had a summer job in a furniture factory. There I had the opportunity to see in person how that industry paid to discard their waste. Their waste was composed of wood cut-offs of all sizes, large plastic films, metal clippings, torn cardboard among other things. In my design student eyes, these were all materials I would have paid for in order to do models and prototypes. This realization that someone's waste could be somebody else's gold, made me start to gain interest in waste topics. I even tried to collect industrial waste for a material bank to be used by architect and design students at my home university. That was my first approach to WM challenges. Unfortunately, a lot had to be done to deal with the waste at our faculty to start with, so the material bank project never materialized.

Later during my bachelor studies I heard about eco-design and felt strongly motivated to work further in that area. This meant that in parallel to my thesis work, we started an organization dedicated to promote eco-design education in Chile. We had good responses from students and positive contacts with the department for cleaner production within the Chilean Ministry of Finance.

After completing my degree, I worked in another furniture factory, now as an industrial designer. Here I saw the impacts that the decisions I made while designing had on the final product and the amount of waste generated at the factory. I made some product proposals with the common clip off waste generated at our facilities. However, I soon realized that such ideas were only palliative solutions to a larger problem, that would never be prioritized by the company.

My experience as an in-factory designer together with the experience of promoting eco-design in Chile, made me want to continue learning about sustainability. That is when I moved to Sweden to do the master program in Design for Sustainable Development, given by the department of Architecture at Chalmers. After completing my masters, I applied to the doctoral studies I am currently pursuing. This position has given me the opportunity to focus on the larger questions behind resource recovery from waste, with the liberties that only working from academy can give.

List of appended publications

Article I

Ordoñez, I., & Rahe, U. (2013). Collaboration between design and waste management : Can it help close the material loop ? *Resources, Conservation and Recycling*, *72*, 108–117.

Ordoñez planned the Study, analysed the data and wrote the Article with feedback from Rahe.

Article II

Ordoñez, I., & Rahe, U. (2012). How Design relates to Waste : A categorisation of Concrete Examples. In 17th International Conference Sustainable Innovation 2012, 29–30 October, Alanus University, Bonn.

Ordoñez planned the Study, analysed the data and wrote the Article with feedback from Rahe.

Article III

Ordoñez, I., Rexfelt, O., & Rahe, U. (2012). From Industrial Waste To Product Design. In T. Jachna, Y. Y. Lam, & S. Tzveetanova Yung (Eds.), *Incorporating Disciplinary Dynamics Into Design Education* (pp. 65–77). Hong Kong: DesignEd Asia Conference Secretariat. Doi: 9789881672124

Ordoñez and Rexfelt planned and performed the studies (i.e. Ordoñez did the product Study while Rexfelt did the design process review). The Article was written in collaboration between Ordoñez and Rexfelt, with feedback from Rahe.

Article IV

Ordoñez, I., Rexfelt, O., & Rahe, U. (2014). Waste as a starting point: educating industrial design engineering students to be active agents in closing material loops. To be presented at: *International Conference on Engineering and Product Design Education, 4 & 5 September 2014, University of Twente, the Netherlands.*

Ordoñez and Rexfelt performed the studies and wrote the Article together (i.e. Ordoñez focused on the interview and log material while Rexfelt focused on the report review), with feedback from Rahe.

Article V

Ordoñez, I., Harder, R., Nikitas, A., & Rahe, U. (2014). Waste sorting in apartments : integrating the perspective of the user. *Journal of Cleaner Production*, (Submitted in March 2014).

Ordoñez planned and implemented the Study with support from Harder. Nikitas provided help in implementing and later writing about the survey and its results. The Article was mainly written by Ordoñez, with the help of Harder and Nikitas and feedback from Rahe.

Terminology

Waste: substances or objects which are disposed of, are intended to be disposed of or are required to be disposed of by the provisions of national laws (European Parliament and Council 2008; UNEP 1989). The terms “waste” and “discards” (i.e. objects that have been discarded) will be used interchangeably in this report.

Resource extraction: the stage of production that takes natural or recycled (secondary) resources to make raw materials that can later be used for manufacturing.

Manufacturing: the stage of production where raw materials are turned into finished goods. It can refer to practices ranging from handicraft to fully automated production processes. In this licentiate it mostly refers to large scale common industrial production practices.

Production system: sub-system of the socio-economic system that turns resources (either taken from the biosphere or recycled) into finished products (goods).

Use phase: stage in the life of a product where it is used or is available for use by a person.

Waste system or **waste management:** sub-system of the socio-economic system that handles waste. It is a socio-technical system which function is to handle discards in a way determined by its social context. The waste system is also commonly referred to as the area of waste management (WM). In this Study both terms are used interchangeably.

Waste from extraction: unwanted by-products from the generation of raw materials.

Waste from manufacturing: unwanted by-products from the generation of finished goods.

Industrial waste: discards generated from a production system (i.e. generated either by extraction or manufacturing practices).

Municipal solid waste: discards collected and treated by, or for municipalities. It covers waste from households, including bulky waste, similar waste from commerce and trade, office buildings, institutions and small businesses, yards and gardens, street cleaning, contents of litter containers, and market cleaning. Waste from municipal sewerage networks and treatment plants, as well as municipal construction and demolition is excluded (OECD 2010).

Bio-waste: biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants (European Parliament and Council 2008).

Difficult waste: discards that the waste system can only discard (either in sanitary landfills or openly) or incinerate (with or without energy recovery).

Reuse: a way of redirecting material exiting the use phase or from the waste system, to be used again by the same or a different user. Some examples of reuse strategies are maintenance of goods (done privately or commercially), second hand shops and donations.

Re-manufacturing: redirecting material exiting the manufacturing stage or from the waste system, to be used again in order to manufacture goods.

Recycling: a way of reprocessing materials exiting the extraction phase or the waste system in order to turn them into new raw materials. Materials that are recycled typically undergo chemical changes by processes such as melt blending, for example.

Recovery: any strategy that keeps materials within the socio-economic system, namely reuse, re-manufacturing or recycling.

Industrial symbiosis: industrial practice where the waste and by-products of one manufacturing facility are used as resources in another production facility.

Pre-consumer waste: discards that have never reached a use stage. It is waste before any consumers have used it. It could be industrial waste, or finished goods that never came to be used.

Post-consumer waste: elements discarded after being used by a consumer. Typically post-consumer waste has signs of usage and how it has been worn down varies depending on how it was used.

Waste system user: a person that discards materials into the waste management system. It is not a person that works in the system (e.g. waste collectors).

Waste pickers: people who salvage reusable or recyclable waste from mixed waste discarded by others, in order to sell it or for personal use.

Waste collector: a person who is paid to collect waste from different locations and to take it to a designed waste treatment plant or landfill.

Resource Management: an ideal sub-system of the socio-economic system that would replace waste management. In contrast to waste management (that aims at discarding materials in the best possible way), resource management aims at keeping material resources in the socio-economic system, by increasing their value through new production.

Table of Contents

1 Introduction

Waste is one of the biggest challenges faced by our society today. If not handled correctly, waste pollutes our natural environment with devastating results. However, it seems almost unavoidable that our society generates waste. It can be said that waste is the unwanted by-product of human activity, more specifically of human manufacturing activities.

Very broadly described, our society produces a lot of things. To do that, the **production system** extracts material resources from the environment and transforms them into useful products. In the process, the production system also generates industrial waste, (i.e. waste generated by industries). The products, or goods, are then **used** by people in order to fulfil a need or perform an activity. Some products require additional resources to work (e.g. a coffee machine needs water, coffee grains, paper filters and electricity). These products are called **active products** and they generate waste whilst in use. In contrast, **passive products** do not need additional resources to work, and they do not produce any extra waste. However, when both passive and active products are not needed any more by the user, then the entire product is considered waste. All the waste generated in this chain of human activities, is handled by a **waste management (WM)** system.

This simple description, that follows a “take-make-waste” approach, is a linear production model, often called linear economy. To a large extent, this is how the production process has worked in society. The problem with this model is that it reduces the resources found in nature, turning them into undesired waste. This problem, initially aggravated by the industrial revolution, has become even worse with a growing population and consumer trends. Circular models have been proposed where waste generated by the system is instead used as material resources for new production (Foundation, 2012; McDonough & Braungart, 2002). These circular models (often called closed-loop models) would reduce the amount of resources taken from nature, as well as the amount of waste generated by society.

Unfortunately, bad habits are hard to break. Particularly when the habit is as complex as a global production system. Currently, a lot of work is being focused on turning waste into resources. This is reflected by the fact that some of the waste entering the WM system can be recovered by being reused, re-manufactured or recycled. Figure 1 shows the possible ways material resources flow through our society (i.e. the socio-economic system). The bottom Section of the figure shows a linear production model. That model is complemented by closed-loop paths (top Section of the figure) that bring waste back into the different stages of the system. However, some waste leaving the system is difficult to hanlde and can only be incinerated or discarded. The more waste leaving the system, the more natural resources the system will need to absorb in order to continue running.

The system diagram presented in Figure 1 serves as framework for this licentiate work. It does not intend to visualise the entire socio-economic system; it serves to show the production and usage of goods. In fact many elements of the socio-economic system are missing (e.g. the entire service industry, cultural activities), which are not represented since the focus of this work is around material resources. The first two stages, or sub-systems, in the diagram (i.e. resource extraction and manufacturing) constitute a simplified overview of the global production system. In reality these stages are more complex, having different facilities for producing parts and components that are later assembled into finished goods. However, the distinction that was deemed important to maintain is that part of the production system is dedicated to creating raw materials, giving material resources an initial increase in value. Production at this stage corresponds to the fields of chemical or material processing. In manufacturing, the raw materials experience a second increase in value. At this stage design and production principles are applied. In Figure 1 the use phase is not considered a system in it's own right, rather the purpose for having a production system to start with. The material output of using a product is shown in the diagram as waste, but the result of using something is considered a benefit or support for the user in whatever activity one might be engaged in. The waste generated in the first three stages increases in complexity with each stage. Municipal waste is the hardest type of waste to handle. The terms reuse, re-manufacturing and recycling are defined here corresponding to which stage of the process the materials are entered to, hence at what stage they will be reprocessed. However, in WM research definitions for these terms may vary. It is common to use the term recovery for any activity that return materials from the WM back into any previous stage. WM is the main focus of this licentiate thesis and will be discussed in further detail in the subsequent Sections.

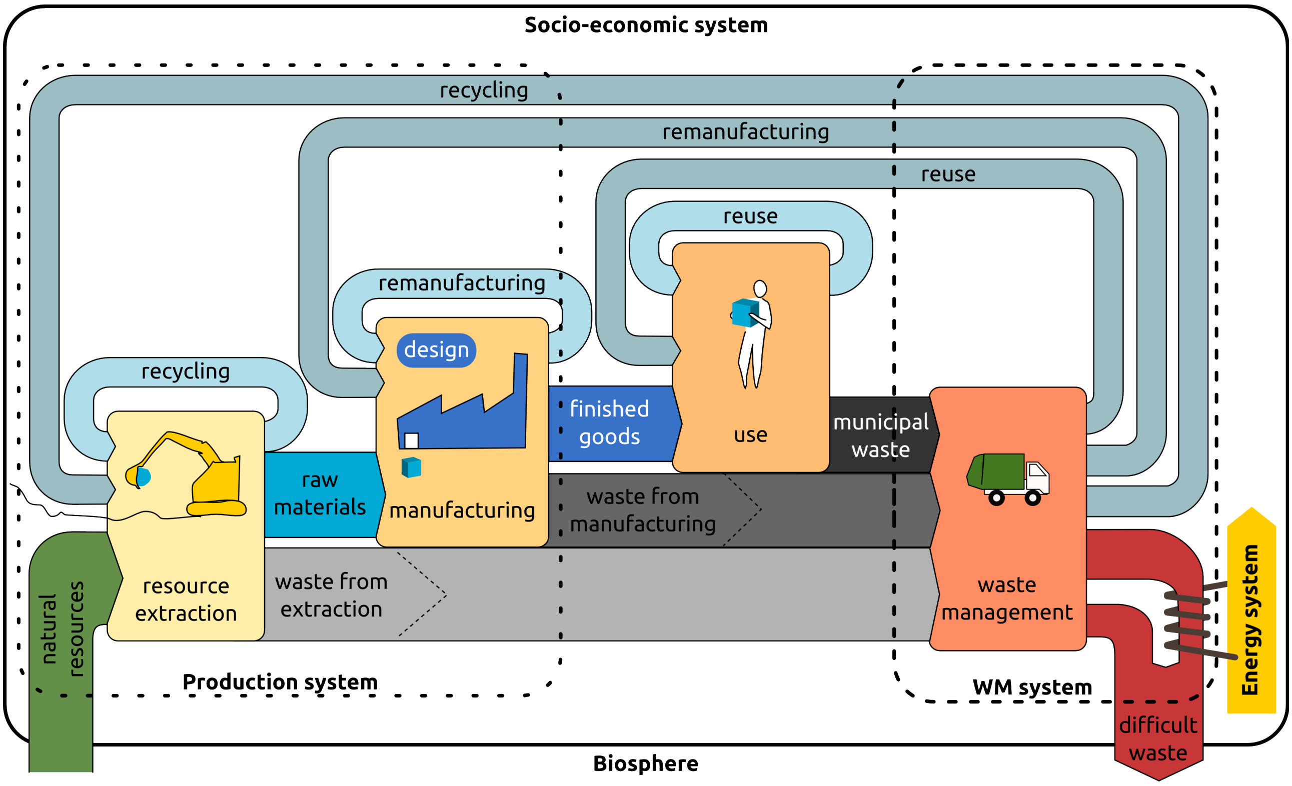

Figure 1: Material flows through society. Adapted by the author, based on (Singh 2013; Ludwig, Hellweg, and Stucki 2003; Foundation 2012).

1.1 Aim and objectives

In very general terms, this licentiate thesis aims to investigate what is required in order to reduce the amount of materials that currently are not recovered by the waste management system. For that a brief background on waste and waste management is provided, followed by the presentation of three studies that were done in order focus on specific relevant aspects of the framework presented in Figure 1.

1.2 Thesis structure

The licentiate is structured as follows: Section 2 presents the background for this work and is divided into three subSections: 2.1 a brief review of the author's background and theoretical background, 2.2 information about waste and waste management systems and 2.3 existing efforts of turning waste into resources. Section 3 details the overall methodological approach applied in this work and explains how it was divided into three studies. Sections 4 to 6 present studies A, B and C respectively. Each Study is briefly described with its aim, what methods were used and the results obtained. More details about the different studies can be found in the annexed Articles. Information regarding which Article and Study correspond to each other is found in Section 3, as well as in the chapters dedicated for each Study. The author then summarises the work presented in the licentiate thesis in a discussion chapter. The thesis ends with a chapter dedicated to the main conclusions of this work, meant to bring together the key results of the three different studies.

2 Background

This chapter, which is divided into three Sections, aims to introduce the reader to the context this research is based on. The first Section presents a brief description of the author's academic and epistemological standpoints followed by a short overview of the theoretical approaches relevant for the present research. The second Section is an introduction to WM topics. It starts by defining waste, later providing a historic overview of WM approaches, common WM elements and finally ends by describing how waste systems are currently designed. The third and last Section provides a general description of existing efforts aimed at resource recovery from waste.

2.1 Author's background and theoretical approaches

The rationale behind how the research presented in this licentiate was addressed has been generated by the author's academic background and epistemological standpoint. The author first engaged in civil engineering studies, which she left after two years in search for deeper meaning. Her interest in epistemology had her enrol in philosophy for a semester, after which her pragmatism led her to Study industrial design.

The author views fundamental science as a beautiful and sophisticated way of satisfying human curiosity. However it does not solve urgent problems. Applied science (a.k.a. technology) is very useful, but should always be accompanied by ethical reflection around how it enables or limits society. Irreflective use of technology has generated most of the problems society faces today. For the author, design should be the application of technology to solve different problems found in society, in a smart, yet aesthetically pleasing way.

Epistemologically, the author has a critical realist approach. Critical realism acknowledges the existence of an objective reality but accepts that it can never be understood fully. Reality is only accessed through subjective interpretation, making the interpretation of reality by different users an acceptable way to understand a fact. Reality is socially constructed, but not entirely so. People use casual language in order to build knowledge about reality. This knowledge is never absolute and can only describe reality partially. However it is useful for decision making and performing tasks. Theories build on this form of knowledge, will always be challenged by objective reality, which will not always be able to be explained by the theory. The author engages in this form of theory building (and finds it meaningful) because it facilitates design decisions that help shape a more desirable future.

2.1.1 Design discipline and the importance of the user

This work considers design as a discipline that combines three aspects; it makes products that fit into existing production processes, that serve a meaningful function for people and communicates a message, expressing an aesthetic statement. For the purposes of this Study, designers are considered as the creative agents in manufacturing industries, being key decision makers when developing future products.

For the purpose of this work it is considered that all product design endeavours are to some extent user centred. Different design traditions may have more or less emphasis on the importance of the final user's satisfaction with the product, but they do all consider the use situation and contrast the product or service with different possible users.

As in any user centred design (UCD), this research relies heavily on the tacit knowledge and experience that different actors have regarding a subject. The goal of UCD is to make products with a high degree of usability (Web Accessibility Initiative 2004), which is exactly what one would desire of a future resource management system. Usability has been defined by the ISO Guidance on usability as "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*" (ISO 9241-11 1998). Where:

- **Effectiveness** refers to if a task can be done or not
- **Efficiency** refers to the amount of effort and time put into performing this task
- **Satisfaction** is the feeling of pleasure that is experienced when a need or desire is fulfilled.

There are many benefits of applying UCD to complex problems. It may help organizations connect better with the people they serve. It can help when creating new solutions by reaching them faster and more effectively (IDEO 2011). However, the main reason to use this approach is because people are the experts on what they need (even though they may not be aware of it). It may be difficult for users to express their needs or even come up with ideas about what they want, but they are the main actors.

An underlying hypothesis in this Study is that a user centred (bottom-up, see also Section 2.2.3) approach to designing the waste system might significantly increase resource recovery from municipal solid waste. This is expected since UCD aims at designing to facilitate a task for the user, rather than expecting users to change their behaviour to better serve the system.

2.1.2 Design for sustainable behaviour

Since the author has addressed user behaviour towards WM activities, it is relevant to introduce Design for Sustainable Behaviour (DfSB). DfSB is a relatively recent research field within the area of sustainable design. It aims to reduce the environmental impacts that occur during the use phase of products. This research does not focus on the use phase of products as such, but rather on the use of the WM system.

Different strategies for DfSB were collected into a model that grouped them in five categories: enlighten, spur, steer, force and match (Lidman, Renström, and Karlsson 2011). Match strategies adapt products so that they fit current user behaviour, while generating less environmental impact. The other four categories all include strategies that are aimed at changing users' behaviour in one way or another.

Match strategies summarize the author's preferred attitude towards achieving sustainable behaviour (i.e. to change the product rather than the person). However, waste systems have many "none user generated" requirements that have to be considered. This makes it impossible to only rely on match strategies. Waste systems should match users behaviour to the extent possible in the given context. Beyond the point where matching the system interface to the user is possible, other DfSB strategies should be used.

DfSB is a theoretical basis that to some extent supports the present licentiate work. However, they have not been directly nor explicitly applied in the research done up to this point. It is expected that this will occur in the doctoral work following this licentiate.

2.2 What is waste?

“Waste is what is left behind when imagination fails” (Ekberg 2009). This phrase, often mentioned in WM environments, seems to be an open invitation for professionals from creative disciplines to come closer to WM challenges in order to help addressing them.

Going to more concrete descriptions, waste can be described as elements that have no value. However, when does something lose all of its value? Are there things that have no value whatsoever? These nearly philosophical questions, hint to the fact that value is a subjective appreciation, depending on the individual. The assessment of value (and its negation, thereof) are human appreciations. Therefore waste, with its negative connotation, is a purely human concept. It is not found as such in nature (McDonough and Braungart 2002).

However, many working definitions exist and are used for practical reasons in society. For the purposes of this Study one of the most wide spread and acknowledged definitions will be used: Waste are substances or objects which are disposed of, are intended to be disposed of or are required to be disposed of by the provisions of national laws (European Parliament and Council, 2008; UNEP, 1989). The terms “waste” and “discards” (i.e. objects that have been discarded) will be used interchangeably in this report.

Waste is normally categorised following some of the following criteria: Origin, composition, toxicity or management. Using origin as a criterion to categorize waste, one would describe waste depending on where it is generated (e.g. mining waste, agricultural waste, medical waste, household waste). Composition refers to what the waste is made of (e.g. lead, metal, paper, textile). Toxicity categorizes waste according to how dangerous it is for human health or the environment (e.g. radioactive, toxic, infectious, corrosive). Finally, management describes waste according to how it is treated (e.g. collected, sorted, recycled, landfilled, incinerated)(Baker et al. 2004). The need for categorizing is due to the importance of highlighting different properties of the waste. This licentiate will mainly use the origin and management categories, with less frequent references to composition types or toxicity.

The motivation behind the present work is to establish that waste is not waste; waste is a source of resources (European Commission 2011; McDonough and Braungart 2002; Foundation 2012). Unfortunately today not all waste can be turned into resources. Many hazardous and toxic materials cannot be safely recycled or reused (Scheinberg, van de Klundert, and Anschütz 2001). While other materials that are not toxic or hazardous do not have a cost-effective recycling industry to reprocess them (e.g. polyurethane foam often found in furniture, rubber, mixed plastics, tires, textiles). This may be because the recycling technology is lacking or because it is simply not profitable with current material prices.

Martin Bourque said at a Zero Waste conference: “*If a product can’t be reused, repaired, rebuilt, refurbished, refinished, resold, recycled or composted, then it should be restricted, redesigned, or removed from production*” (ZWIA 2013). Unfortunately, policy is far from regulating production in such a way that would avoid difficult discards. That is why there is a need to specifically address the challenge of re-incorporating difficult discards into new production processes.

2.2.1 Historic overview of waste management approaches

The need to handle municipal solid waste systematically appeared with urbanization (Ludwig, Hellweg, and Stucki 2003). Cities are characterized by having higher population densities that have a faster and more varied consumption of products than rural populations. These characteristics makes the waste discarded in cities (a.k.a. urban waste) more difficult to handle than the waste generated in rural areas (Baker et al. 2004). The majority (i.e. 53%) of the world's population now live in urban areas (World Bank 2012), which makes waste a growing problem, not only in proportions, but also in complexity (Bournay et al. 2006; Ludwig, Hellweg, and Stucki 2003).

Before large cities appeared, waste management (WM) had a "**dilute and disperse**" approach, where the residual material was expected to be absorbed by the environment (Baker et al., 2004). Since resources were scarce, household goods were repaired and reused. Since goods were seen as valuable resources, little waste was generated. Epidemic outbreaks in urban centres during mid 19th century shifted the WM approach to "**collect and remove**" in order to protect the population from unhygienic living conditions. This approach means that waste is collected from urban centres to be discarded openly somewhere else. Most low and medium income countries still rely to some extent on open dumping of waste (e.g. Cambodia, Latvia, Mexico, Morocco, Surinam, Turkey) (Hoornweg and Bhada-Tata 2012). The environmental movement from the 1960s and 70s promoted the importance of disposing waste in a way that would minimize pollution, bringing forward the "**concentrate and contain**" approach. This meant an increased focus on minimizing gas and water leakages from landfills as well as gas emissions from the incineration of waste (UN Habitat 2010).

Concerns about global warming have increased the focus WM has on **avoiding methane generation** from biodegradable waste. Methane is a powerful green house gas, which is naturally generated when biodegradable waste (such as food waste or garden clippings) is decomposed in the absence of air. These conditions are normally present when biodegradable waste is disposed in landfills. That is why, since the early 1990s, most developed countries have avoided discarding untreated biodegradable waste in landfills, without collecting the methane gas generated.

The latest WM approach is linked to a growing perception that society may run out of material resources. Global demands on resources are increasing, while the capacity of the planet to deliver the needed resources is decreasing (Baker et al. 2004; Holmberg 1998). The risk of resource depletion has changed the WM approach once again to seeing "**waste as valuable resources**", as it once did when goods were scarce. This means that strategies such as Reducing, Reusing and Recycling waste (a.k.a. the three Rs) are now more extensively used in WM efforts.

Several authors have proposed zero waste systems (El-Haggar 2007; Ludwig, Hellweg, and Stucki 2003; Curran and Williams 2012) and much has been written on how to achieve a completely closed-loop material system (McDonough and Braungart 2002; Foundation 2012). Despite all these proposals, global waste trends remain largely unaffected by resource conservation efforts. Globally waste is mostly dumped or landfilled. While incineration and landfill treatment are still the predominant ways of disposing municipal solid waste, even in Europe (Blumenthal 2011).

2.2.2 Common stages and elements in waste systems

Waste systems are described in literature in many different ways, depending on the focus of the Article or book. WM normally consists of several stages that represent the different steps in the process of handling waste, starting from receiving it into the waste system to its disposal. There are many inconsistencies of how waste systems work from one location to another, so a unified view of what are the stages that constitute WM is lacking.

In an attempt to illustrate what can be expected of common waste systems, this Section explains the different stages normally found in WM. WM stages can be divided into the stages that the users interact with (i.e. the interface of the waste system) and the stages where the users are not involved (i.e. internal waste system). In Figure 2 the author has structured common WM stages, together with examples of elements that are commonly found at every stage.

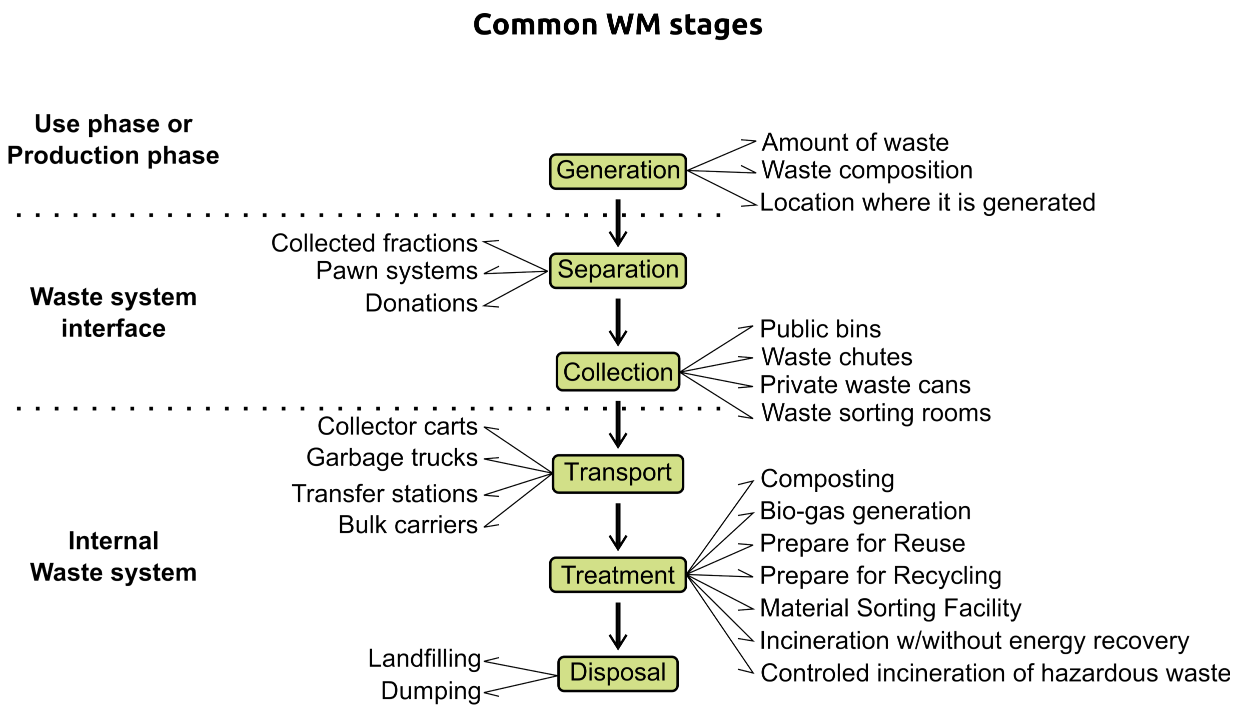

Figure 2: Common WM stages and examples of their constituting elements.

The initial stage is waste **generation**. This corresponds to when something is considered waste and discarded by its owner. It can be argued, that it is not a part of the waste system per se, rather the stage where the use or production phase of a product gives material to the waste system. Characteristics about waste generation relevant to know are the volumes produced and what it is made of. This can be partially explained by where it is produced (e.g. restaurant waste has a different composition to office waste) but may also be specified as more detailed information.

Some research denotes separation as a stage on its own, while others associate it to the following stage of waste collection. Nonetheless, **separation** corresponds to the action of segregating different types of discards from each other. This can be done by the waste generator (i.e. before discarding it into the system), or later in the WM system. The purpose of separating wastes is to be able to treat the sorted fractions in different ways. What is separated by the user depends on what fractions are collected by the waste system or other systems that take in discards (e.g. pawn systems for PET bottles or aluminium cans). This is why separation and collection are often treated as a common stage. **Collection** is when the material is passed from the generator to the WM system (i.e. the person that generated the waste no longer owns the material. This is commonly done by leaving the materials in bins that are emptied on a regular basis.

Transport corresponds to the action of moving the discards from where they are generated to where they will be treated. **Treatment** is the core of what WM does. Here the discards are processed in some way in order to increase their value to recover them back into the socio-economic system, or so they can be discarded in a non harmful way. To increase the value of waste, common procedures are applied to separate valuable materials, clean the materials and later compress the sorted fractions for transport.

The last stage of WM is **disposal**. It corresponds to when the waste system leaves the waste somewhere in the biosphere. It can be done in an uncontrolled manner (i.e. open dumping) or through sanitary landfills. Controlled landfills could be considered still to be inside the WM system, since effort is made in order to minimize gas emissions or leakage of fluids (a.k.a. Leachate) from landfills. Still, when landfills are decommissioned (i.e. they are closed down and no more waste can be placed there) their contents become a part of the environment.

2.2.3 Designing waste systems

The first thing decision makers need to know in order to plan their WM strategy is the amount and composition of waste that their location is generating. Unfortunately reliable waste generation data is a challenge in which most cities do not perform well (Wilson et al. 2012). When **waste generation** data is not available Waste Generation Models are crucial for planning. These models aim at explaining or estimating current or future waste generation volumes and composition based on economic, socio-demographic or managerial data (Beigl, Lebersorger, and Salhofer 2008).

Besides these predictive models, **system analysis tools and models** to support decision making around waste management have been developed since the 1970s. An extensive review of reported models categorises these as ranging between systems that help design the future waste system (System Engineering models) and models that help assess the performance of existing systems (System assessment models) (Juul et al. 2013). The same Study reports that the most common approach applied by the system engineering models correspond to optimisation models, where a defined function is either minimised or maximised given certain constraints. Among the optimisation models reviewed in that Study the majority were focused on the WM system (considering the recycling and disposing issues), while few focused on Waste to Energy technologies. Only one linked the WM system to the energy system (Olofsson 2001), while many models included aspects of the energy system by reflecting that in the price for waste as fuel, for example. Another approach is to use two independent already existing models (one for the waste system and another for the energy system) and link them in order to achieve combined systems optimisation (Eriksson and Bisaillon 2011). However, none of the models associated the waste system to the production system, having only markets for recycled material (often considered external variables) as a connection to new production possibilities.

All the system models discussed here, focus on the technological components of the waste system. They represent the most common technology-centred approach to WM, which has so often failed (Scheinberg, van de Klundert, and Anschütz 2001). That is why the **Integrated Sustainable Waste Management** (ISWM) framework was developed, to counterbalance this technology centred view. ISWM describes waste management rather as a socio-technical system interconnected with the context of where it is located. It consists of three dimensions: stakeholders, waste system elements and relevant aspects (Figure 3). The waste system elements correspond to the technological components studied by system analysis tools. The two other dimensions included in the framework describe the larger environment in which the waste system elements are found, taking in social aspects and governance strategies needed to have a well-functioning system.

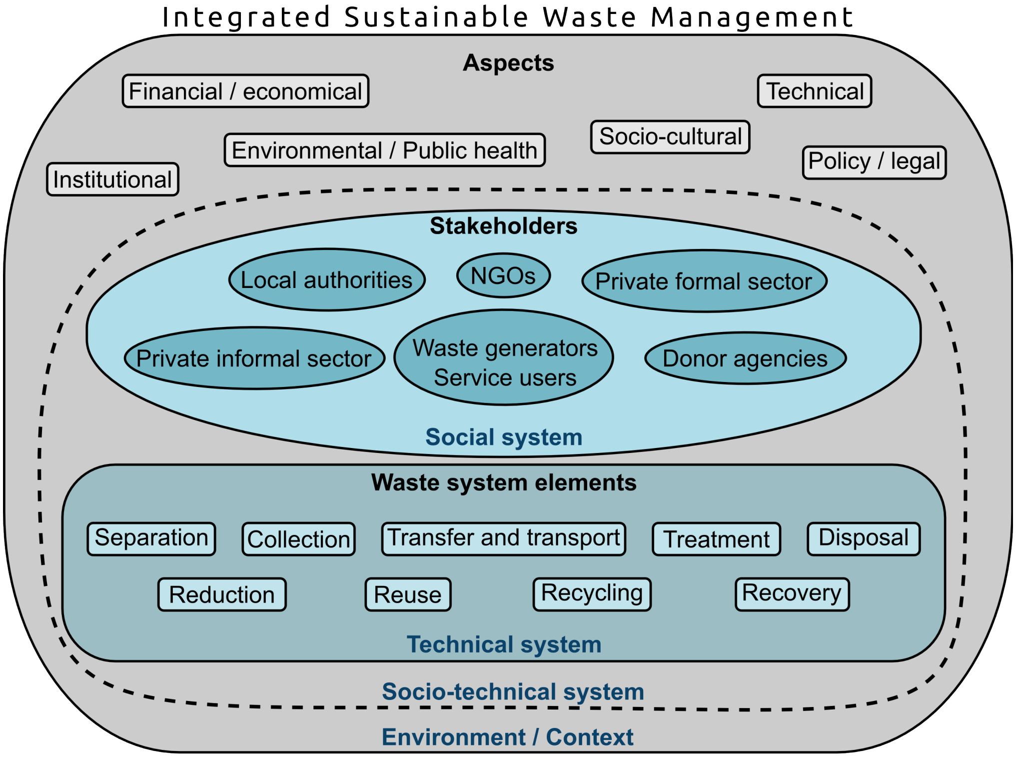

Figure 3: Components of the ISWM framework. Adapted by the author from (UN Habitat 2010)

Stakeholders are all the actors that have an interest or interact with the WM system. They may include waste generators, local authorities responsible for managing waste, private service providers (e.g. waste collection companies), the informal sector (i.e. waste pickers), material dealers, recycling industries and even manufacturers that use recovered materials in their production. They may vary from one city to another, so they must be identified for each local context (Scheinberg, van de Klundert, and Anschütz 2001).

Waste system elements in the ISWM framework include and "*recognise the high-profile elements 'collection', 'transfer' and 'disposal' or 'treatment'* ", also present in broadly used definitions of WM (European Parliament and Council 2008; UNEP 1989) and WM research in general, while giving "*equal weight to the less well understood elements of 'waste minimisation', 'reuse' and 'recycling and composting'*." (Scheinberg, van de Klundert, and Anschütz 2001).

Stakeholders and waste system elements constitute the socio-technical system in the ISWM framework. The context in which these are located is called aspects by Scheinberg (similar to the concept of environment in Socio-technical systems theory described in Hendrick & Kleiner, 2001).

The **aspects** in ISWM are considered as different lenses for assessing the WM system. There are six defined aspects (as seen in Figure 3) that range from environmental impact and financing schemes (most traditionally included in WM work) to socio-cultural and institutional elements that affect WM (most commonly neglected).

The traditional and most commonly used approach to designing waste systems is from a top-down perspective (i.e. systems perspective) aimed at optimising technical solutions. The ISWM has expanded this to include “softer” aspects, such as socio-cultural norms and stakeholder participation. However, to some extent the ISWM framework still operates from a top-down perspective. It includes several stakeholders, but does not necessarily focus on the service users as crucial actors for the development of the system. In contrast, a user centred view towards waste management would be a bottom-up perspective. This point of view is often neglected when designing waste systems, resulting in WM solutions that strive to optimise the system rather than satisfy the needs of its users.

2.3 Current efforts to turn waste to resources

Today, efforts to turn waste into resources can be divided in two groups: those that focus on changing the production system (e.g. Cradle to cradle, Circular Economy, Industrial Ecology, Zero Waste in Industry) and those that focus on improving waste management (e.g. Integrated Sustainable Waste Management, Zero Waste in Society).

The group that focuses on changing industry is proposing that manufacturers should develop products in a way that would allow them to retrieve their used products back. Used products would then be reprocessed in order to make new ones. The proposal would allow manufacturing companies an opportunity to plan when products would become obsolete and to estimate the amount of material available for the next production cycle. This also requires a functioning take back system (inverse logistics) which has actually led to the idea that companies would not sell products any longer, instead they would lease them out for a period and then collect them (Foundation 2012; McDonough and Braungart 2002).

A problem faced by this approach is that many recycled materials have inferior properties if compared with virgin material. That is why the idea of material cascading was put forward. Cascading a material means that it is recycled to a reduced quality, but it can still be used in a different product, with a lower value, e.g. transforming clothing into fibrefill for furniture and, later, into insulation material (Foundation 2012).

However, this incorporates the additional difficulty of moving materials from one industry to another. Regardless if cascading is done, to implement reverse logistics is still quite a difficult challenge. Especially considering that commerce currently span a global market, with manufacturing companies located mainly in Asia. Industry decides where to make and sell their products, resulting in products being manufactured and transported all over the world. It is rare for manufacturing companies to effectively implement reverse logistics for their products, which means that these products are discarded through the normal WM system. In contrast to production, waste systems are local. Local authorities are responsible for the collection and treatment of waste, while citizens determine what type of products are consumed, in what format and if they finally end up in the waste bin or not.

The work focused on improving WM, has had clear intentions of converting into resource management and minimising residual waste (i.e. waste that can only be discarded rather than reused or recycled). As long as a large amount of material resources find their way into the waste system, there will be a need to mine these resources from the landfill and use them for manufacturing new products. Material recycling is a direct way of doing this, raising the discards to the value they would have as a secondary raw material. However, this value is volatile and dependent on the fluctuation of international markets, some materials do not tolerate recycling well and some materials (e.g. composites) do not even have recycling markets.

Another way to generate value from discards is to design using these materials. This often results in a higher value for the discard than it would receive in a material market or even higher than the value of the originating product (Crabbe 2012). Even though there has been an "up-cycling" trend among designers, it has not affected waste trends in a noticeable way.

It has been argued that current isolated efforts in creating a resource management system are not enough for achieving long term sustainability (Singh 2013). Singh argues that there is a need for a shared vision among actors involved in production and consumption activities. More specifically, the efforts of converting WM to resource management will rarely happen if the WM system does not work significantly closer to production industries. WM has the potential to provide the inverse logistics service needed by industry, if there were clear requirements from the productive sector. Defined in terms that WM could understand and comply with. There is a need for much better collaboration between these two sectors. Ideally we would not have two separate systems (waste management and manufacturing systems) that collaborate, but one combined waste to resource system (as seen on Figure 4). The global nature of production and the local nature of WM make this virtually impossible. However, this work is focused on the possibilities for close collaboration for these two sectors in the hopes of being able to combine them to some extent.

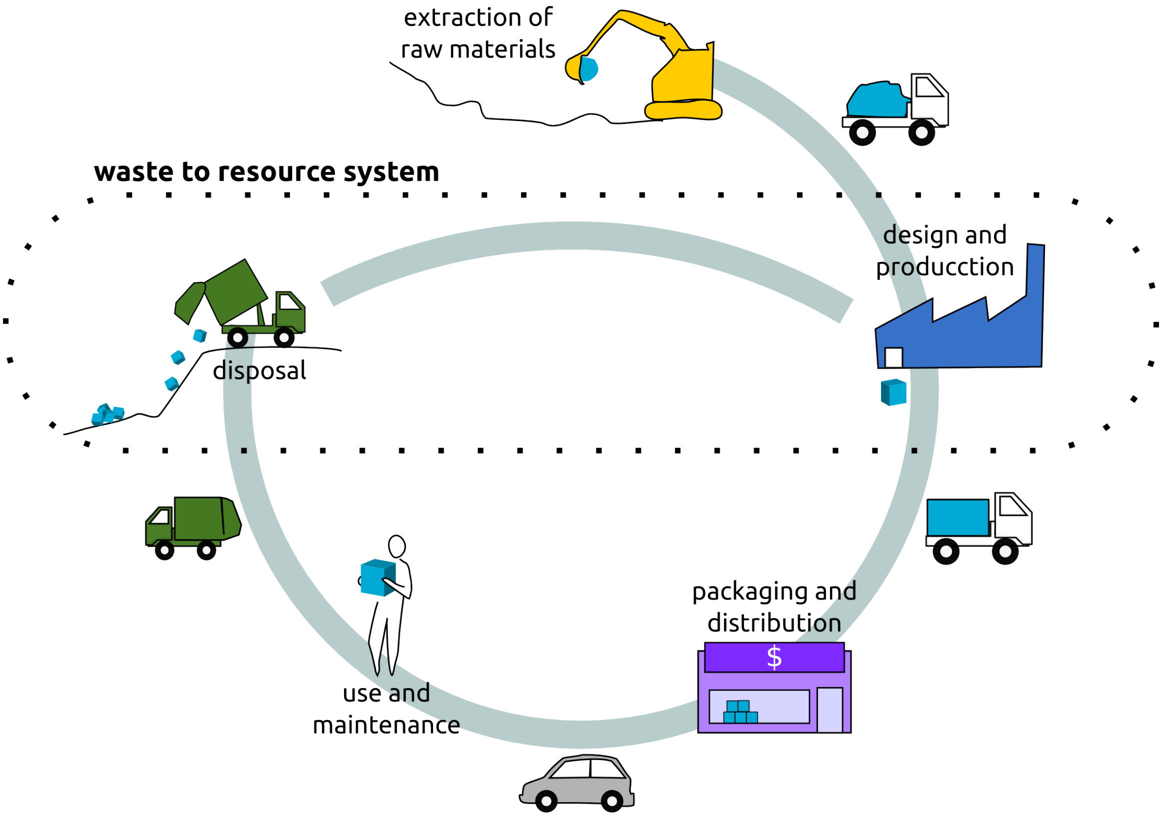

Figure 4: Life cycle of a product based on (UNEP and SETAC 2013), showing the area for a waste to resource system.

3 Overall methodological approach

The aim of this research is pragmatic: resource recovery from waste has been studied in order to propose actions to achieve a better recovery rate or recovery of a higher value. This work has loosely followed the Action-research stages, which the author sees as closely related to a common user centred design (UCD) steps. This process includes initially investigating what is done in practice, to highlight any problems that may arise there, followed by suggesting a course of action in order to improve any issues detected. Lastly, the results of the proposed actions are evaluated, to determine if further changes are required (Lewin 1946).

The experimental work presented in this thesis began with an exploratory Study meaning to further investigate resource recovery from waste. Since information about collaborations between WM and the productive sector were difficult to find in literature, an interview Study was done (Study A).

Study A aimed at answering the following questions: Are there any collaborations between WM and designers? If so, of in what form do they collaborate? How is it done? What are the results of such collaborations? The interview Study targeted professionals working in managerial positions in WM institutions and designers that had in some way worked actively with waste. The results of this Study are presented in detail in Articles I and II and summarised briefly in Section 4.

The main result of the interview Study has been the creation of a mapping to describe the different areas that contribute to the effective use of resources. Eight areas were identified, two of which were considered to require close collaboration between WM and designers. This decision is explained in detail in Section 4. The areas of “waste as input material for new products” and “waste system interface” were selected for further work, resulting in Studies B and C respectively. Study B investigated how to design using waste as a starting point, aiming at learning how to facilitate this task. Study C, on the other hand, aimed at re-designing the waste system interface to allow for increased resource recovery, focusing on the final users of the system.

Study B investigated whether it is possible to design with waste and if so, the ways to do so. But more importantly, it tackled the question of how it could be made easier for designers to use waste material. Particular focus was given to waste material not serviced by a profitable recycling system as of today. Study B began by investigating existing products made from waste to evaluate the current state of the art. Subsequently, a series of case studies were carried out, where design students were asked to develop products using difficult discards as starting points. Collaboration was established with Stena Recycling (the largest recycling company in Sweden), in order to identify difficult discards that are readily available in large quantities. Study B is described further in Section 5, as well as Articles III and IV.

Study C started by investigating waste systems in general, focusing on how they could contribute to resource recovery. A WM model was established, based on models found in literature. Waste sorting and collection systems (SCS) were identified as the WM interface towards society. In order to investigate how SCS are designed and maintained in practice several practitioners were contacted, resulting in a collaboration with Poseidon AB (one of the largest housing companies in Gothenburg). This collaboration entailed the possibility of conducting a case Study, as well as testing possible improvements. Study C is further described in Section 6, as well as in Article V.

Both project B and project C are still ongoing. However, this licentiate thesis presents the results obtained from these studies to date. Figure 5 shows how the three studies are related and the outcomes of this work in the form of their respective publications.

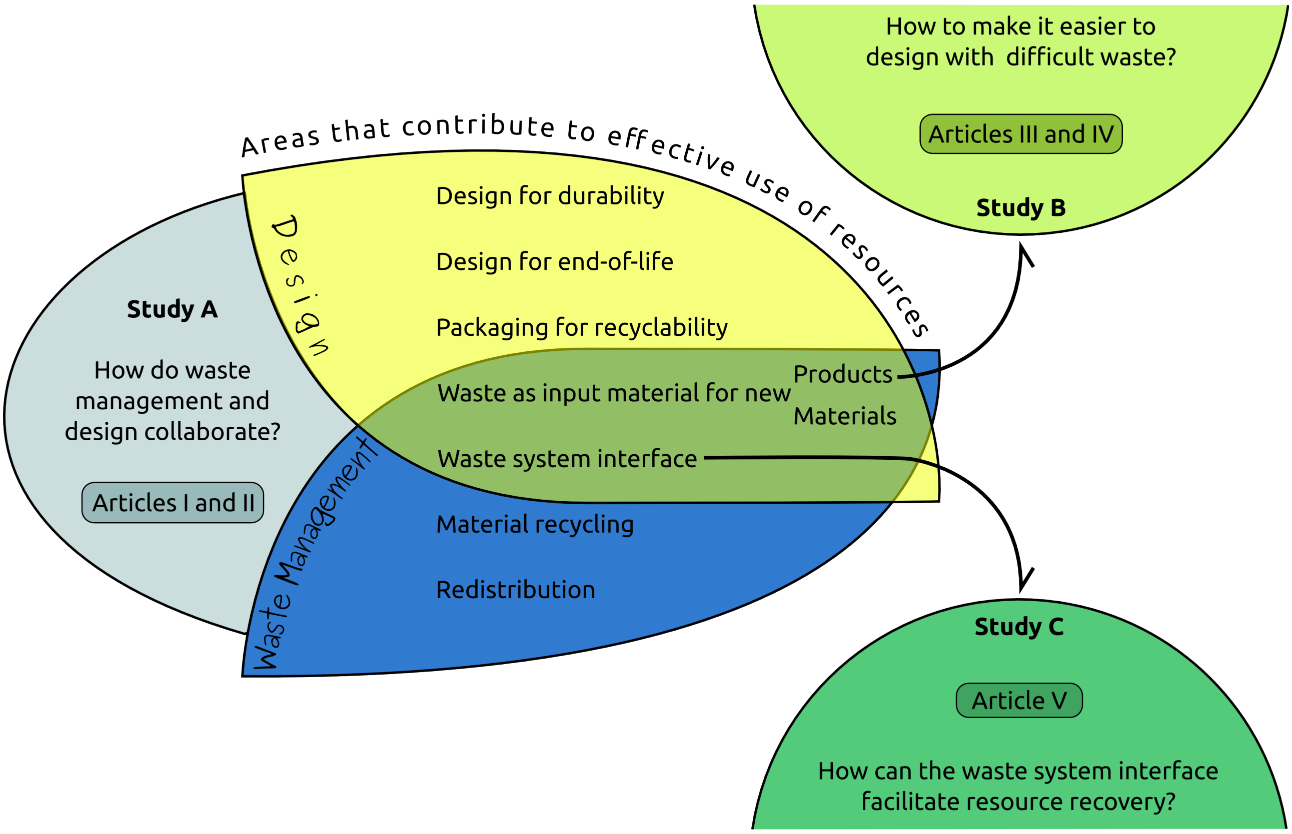

Figure 5: Overview of the studies that constitute the licentiate.

4 Study A: Exploratory interview Study

As an introduction to the research topic and as a way of investigating current practices an exploratory interview Study was designed and carried out early in the research work.

4.1 Aim & Method

The aim of the Study was to find out if any current collaborations between designers and WM professionals existed. The Study also explored if the interviewees considered these two sectors to be connected and if so, in what way. The author's main research activities therefore began with a Study of this kind in order to explore and get familiarized with the tacit knowledge of actors involved in WM or designers that have actively worked with waste. Figure 6 shows what parts of the licentiate framework were addressed in the Study as well as the methods used.

The interviews were semi-structured serving as a guide to cover specific questions (to facilitate in analysing the material), while allowing the interviewees to elaborate on topics relevant to them. The selection criterion for engaging interviewees was the work they were involved with at the time. In total 25 interviewees were contacted through the institution they worked at, or directly by mail after previous investigation of their work. Some interviewees were contacted based on the recommendations of other interviewees, that could see a link between them and the author's Study.

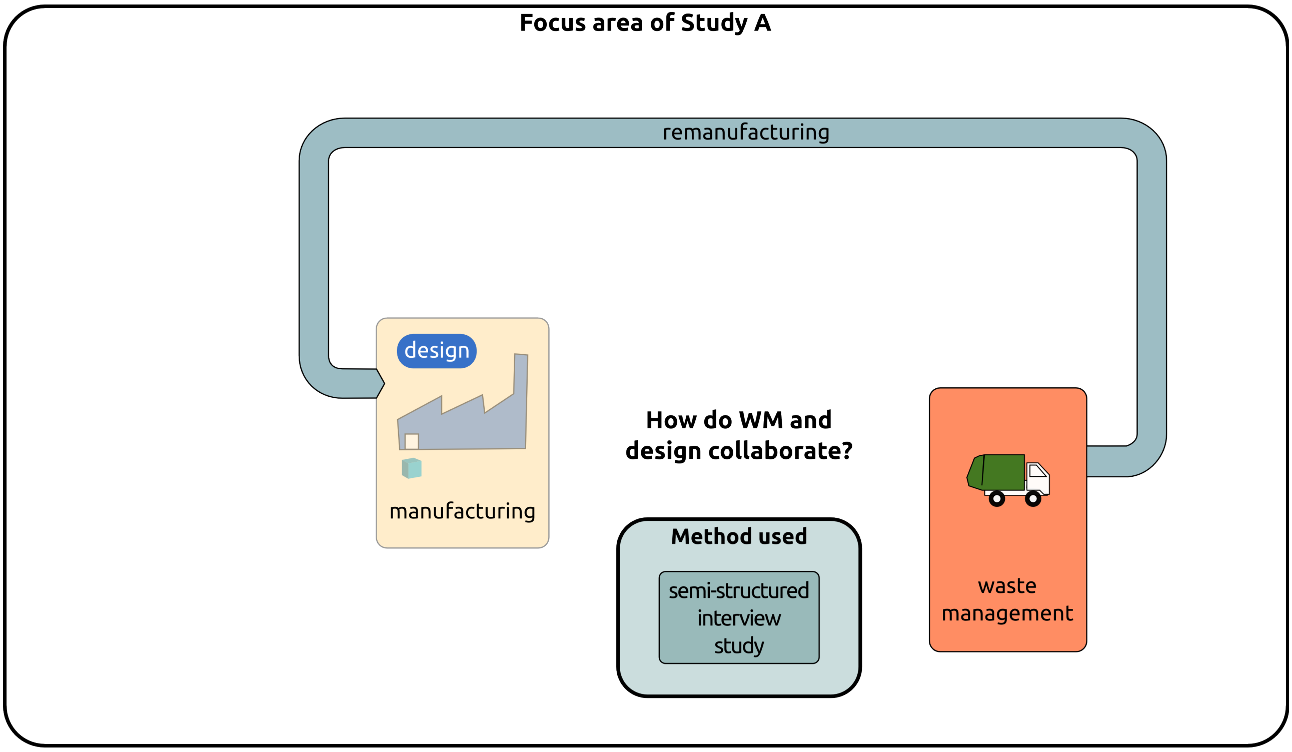

Figure 6: Components from figure 1 relevant to Study A and overview of the methods used

4.2 Results

The Study resulted in a journal Article (Article I) and one conference paper (Article II). The journal Article (titled: “Collaboration between Design and Waste Management: Can it help close the material loop?”) focused on establishing if there were any collaborations between designers and WM institutions. In the cases that there was a collaboration, the Study investigated how could these synergies could work. This Article resulted in the identification of a scale of collaboration areas between design and WM. As seen in Figure 7, this scale can be seen as ranging from collaborations that are more centred in the design discipline (i.e. work that would take place during the design phase of a product) to work that is focused on WM requirements (i.e. commissioned by a WM institution to be fulfilled by designers).

Figure 7: Scale of collaboration areas between design and waste management.

The conference Article II (titled “How Design relates to Waste: A categorisation of Concrete Examples”) collected all 74 examples considered by the interviewees as good cases of how WM and design relate. The examples were further investigated and organised into five categories that are explained and exemplified (with a selection of the most clear examples for each category) in the Article. The categories found were:

- Material Recycling
- New Materials from Waste
- Redistribution
- New Products from Waste
- Design for End-of-Life

In general terms it can be said that the interviews gave examples of existing or possible collaborations, but that these cases were not strong or central to the work of WM. This speaks of still weak connections between WM and production systems. Also, the way the interviewees described the waste system and how it works, spoke loudly of a perceived gap between the waste system and the users needs or understanding. Both these gaps (between WM and production, as well as between WM and the users) were deemed important to address with future work.

4.2.1 Where did these conclusions led?

The conclusions of both articles drawn from the interview Study were considered a mapping of possible areas to investigate further. Of the ten areas mentioned “design for end-of-life” was repeated in both categorisations. The area “waste as input material” could be considered as including “new products from waste” as well as “new materials from waste”. These considerations highlighted seven potential research areas for further investigation.

As seen in Figure 5 (on page 14), the seven resulting areas were categorised as belonging to the design or WM domains. To some extent, certain research areas belonged within both domains. These areas were thought to benefit the most from close collaboration between design and WM. Given that closer collaboration between these sectors is thought to yield better results in closing material loops in society (previously explained in Section 2.3), these research areas were considered most interesting and relevant for further research.

Improvement in each sector (i.e. design and WM) separately is still needed to achieve more effective resource usage. However, the research areas corresponding to either domain are to some extent addressed in each sector independently. For example, redesigning packaging to improve recyclability has already be done by designers in packaging industries, without the need for close collaboration with WM. In parallel, WM has incorporated the redistribution of goods as a strategy to retrieve materials back into the socio-economic system, through second hand shops, for instance, without needing to redesigning these goods. These isolated efforts are still required, however the focus of this licentiate has been on areas with potential to serve as a bridging factor between design and WM. Any areas currently developed by either sector independently were discarded for further research.

“Design for durability”, “design for end-of-life” and “packaging for improved recyclability” are all design strategies that have been adopted by industry to some extent. “Material recycling” and the “redistribution” of discards are practices currently incorporated in WM. This left two possible research areas: **waste as input material** and to design the **waste system interface**. Both of these areas were further explored in the parallel projects covered by Studies B and C, and are described further in the following chapters (Section 5 and 6 respectively).

Waste as input material for new materials was considered interesting to address from a chemical or material engineering background. Given the authors background in industrial design, **waste as input material for new products** was deemed more appropriate to pursue within this licentiate.

4.2.2 Insights about designing with waste

The interview Study addressed designers who had worked with incorporating waste in product development. They described their experience of designing with waste and discussed products developed with waste known to them, as did the other interviewees. Their comments gave relevant insights and are summarised below.

Quality is a crucial factor when working with waste material. A designer commented: “*There are so many examples in the recycling world that are not nice, that lack the final steps of design to make them desirable objects again*.” Another interviewee stated: “*It is not enough (to be recycled or reused) to sell products*.” Designers should not expect the product they develop to be preferred over a similar product, just because it is made of discarded materials. On the contrary, most likely they would have to design an extraordinary product to compensate for the impression that it is of inferior quality.

Regarding **value**, one interviewee commented that when people realise that a product is made of discarded materials, they expect it to be extremely cheap. They do not consider the extra work of selecting, gathering or preparing the material that has gone into the product. They assume the designer got it for free and are therefore not willing to pay much for it. To this a designer even states: “*We have to fool the public as long as possible that this is smart new design. They don't need to know it is reused or recycled.*”

Inconsistency in the waste flow generates the challenge of being able to "*standardise a product from something that is not standard*". This issue can partly be addressed by using pre-consumer waste (i.e. waste that has not been used by a consumer), since it is easier to predict availability and it has not been subjected to different use conditions. Increased product **complexity** results in more complex waste flows, that are harder to incorporate in design. Furthermore, it increases the difficulty of separating materials for recycling.

4.2.3 Insights about waste systems

Interviewees were asked to describe the waste systems they were familiar with, highlighting the advantages and disadvantages they observed. This Section presents a summary of the comments collected under the interview Study.

All in all the overview of how waste is treated was considered **unclear**. Although people working with waste were aware of the handling process, they recognised that information campaigns to inform the general public seem to have problems getting through. One designer mentioned that some items can be disposed of in more than one way in a system, provoking confusion for the users.

Some interviewees commented that there are many **myths** around how waste is actually treated. The main myth being that recyclables separated at source are sent to the incinerator or landfills. This myth is mostly unfunded in the European Union (EU), although, unfortunately there is some truth to this myth in other locations. A WM professional from Chile, clarified that separately collected electric appliances end up in the landfill after being stripped only of their major metallic components.

Waste collection infrastructure is inconsistent between cities and even districts within the same city. Therefore, when people change homes the infrastructure for disposing waste is different. The distance to the recycling centre (if any) changes, as well as the space available at home to have separated fractions. What type of fractions one is expected to separate may also vary. All these factors are thought to affect user participation in waste sorting schemes.

"**Money is waste management's only motor**." said one man working in the WM field. "*Once you understand this it can serve as an incentive or a punishment*." Not only is WM moved by money, but it takes a lot of money to run WM activities. An interviewee from WM said: "*Waste is a constant problem for the municipalities. They spend around a third of their annual funding on waste. It is the largest item after public lighting*."

The economic viability of different **disposal options depend on the location and circumstances**. A waste manager in Chile stated: "*Here, we don't have space problems. We have thousands of unoccupied kilometres to put our waste, so I can't see that we will be investing in incinerators any time soon.*" In contrast, a manager from India said: "*There is a big demand on land for dumping. Growing cities are getting closer to the dumps, generating rising land prices. In fact, land prices in Mumbai are higher than in New York. This (among other reasons) is why the government is now more inclined to use Waste-to-Energy plants*." In Chile incinerators were considered much more expensive than regulated landfills, which have a cost of disposing of USD $20 per tonne of waste. Whereas in Sweden the situation is opposite, since the USD $175/tonne of landfilled waste is significantly higher than the gate cost for incinerating waste. More details can be found in Article I.

5 Study B: How to design with waste?

Study A identified “using waste as an input material for new product development” as a topic that would require closer collaboration between WM and design. Study B was carried out to further investigate this topic in particular.

5.1 Aim

Study B assumes that designing with waste can be an effective way of increasing recovery of discards back to the production system. That is why Study B aims at investigating how designing with waste can be accomplished and facilitated. The main research questions addressed were: What are the main barriers designers are faced with when using waste as input material? What is required to help designers tackle these barriers in a better way? What methods do they use?

Identifying and classifying the various methods that have the potential to support product development from waste material, could later come to constitute a methodological approach for designing with waste. Such a methodology would be useful for promoting the designing with waste practice to a larger group of designers, and thus helping increase the amount of discards that would be recovered.

5.2 Methods

Study B started by analysing the state of the art of designing with waste by performing a **product Study**. The product Study gathered 57 examples of existing products made mainly out of discards. The examples were investigated with the intention to identify some description of how designing with waste was done. Given the interest of Study B in increasing the possibilities for resource recovery, it was relevant to evaluate if the example products were suitable for mass-production and if they were made of materials that are currently not serviced by a well-established recycling system. Therefore, three criteria were used to categorise the examples in the Study: (1) if the waste material was recycled or remanufactured[1] (2) if they were handmade or mass-produced and (3) if the discards used were serviced by an existing recycling system or not. The examples were partly obtained from the interviews in Study A, complemented with products found in three eco-design books (Barbero et al. 2012; Fuad-Luke 2009; Fusion Publishing 2008).

In parallel to the product Study, a **literature review referring to traditional design processes** was conducted in order to explore what types of process stages could be common to designing with waste. This review was performed by Dr. Oskar Rexfelt, who is an academic with broad experience in design methodology and co-author of the Articles III and IV.

To further investigate the questions posed, a series of **case studies** was arranged to provide the opportunity of following the design-with-waste process closely. This was achieved by engaging a number of master and bachelor students in conducting product development with waste materials as their theses projects. This was done as part of the Waste to Design (W2D) project, presented to the Mistra Closing the Loop Initiative (Mistra 2012). This project, a collaboration between Stena Recycling, Semcon and Chalmers, received funding from the Mistra initiative to run between August 2013 and August 2015,

1 In Article III the term “reused” was used to mean what is defined as “remanufactured” in this licentiate. These terms were more accurately defined by the author after Article III was written, generating this term inconsistency.

and is currently ongoing. The materials used in the case studies were single factions of industrial waste. Meaning that the materials are available in large volumes and their composition is generally known. These discards consist of materials received currently by Stena Recycling but are not of interest to any profitable recycling markets. Therefore, these materials will either be incinerated for energy recovery or landfilled. In both cases Stena Recycling pays a fee per tonne of material in order to discard it. A number of discards were offered to the students to choose which fraction they wished to work with.

The Study plan refers to having two or more groups of students working with waste each year, generating a minimum of six comparable case studies generated in three consecutive years (the second year is currently ongoing). Data was collected for each case by four methods: supervision sessions, weekly logs, report results and semi-structured interviews. As in normal thesis work, the projects were supervised and resulted in a final report. **Supervision sessions** provided students with advice on how to complete their work, while giving the supervisor an insight into the difficulties encountered by the students in the different Study stages. Since supervision sessions were booked by the students as and when needed, the sessions took place at irregular intervals. To compensate for the lack of consistency, students were asked to submit **weekly logs** of their work. These logs provided a short overview of the work produced each week of the project. Results of the work carried out were gathered and shown in thesis **reports,** in a clear manner, providing the main conclusions and outcomes with a retrospective perspective. Additionally, **semi-structured interviews** were held with each group following the presentations of their thesis work, in order to collect their personal reflections about the process of designing with waste.

Figure 8 provides an overview of the parts of the licentiate framework that were addressed in Study B as well as the methods used.

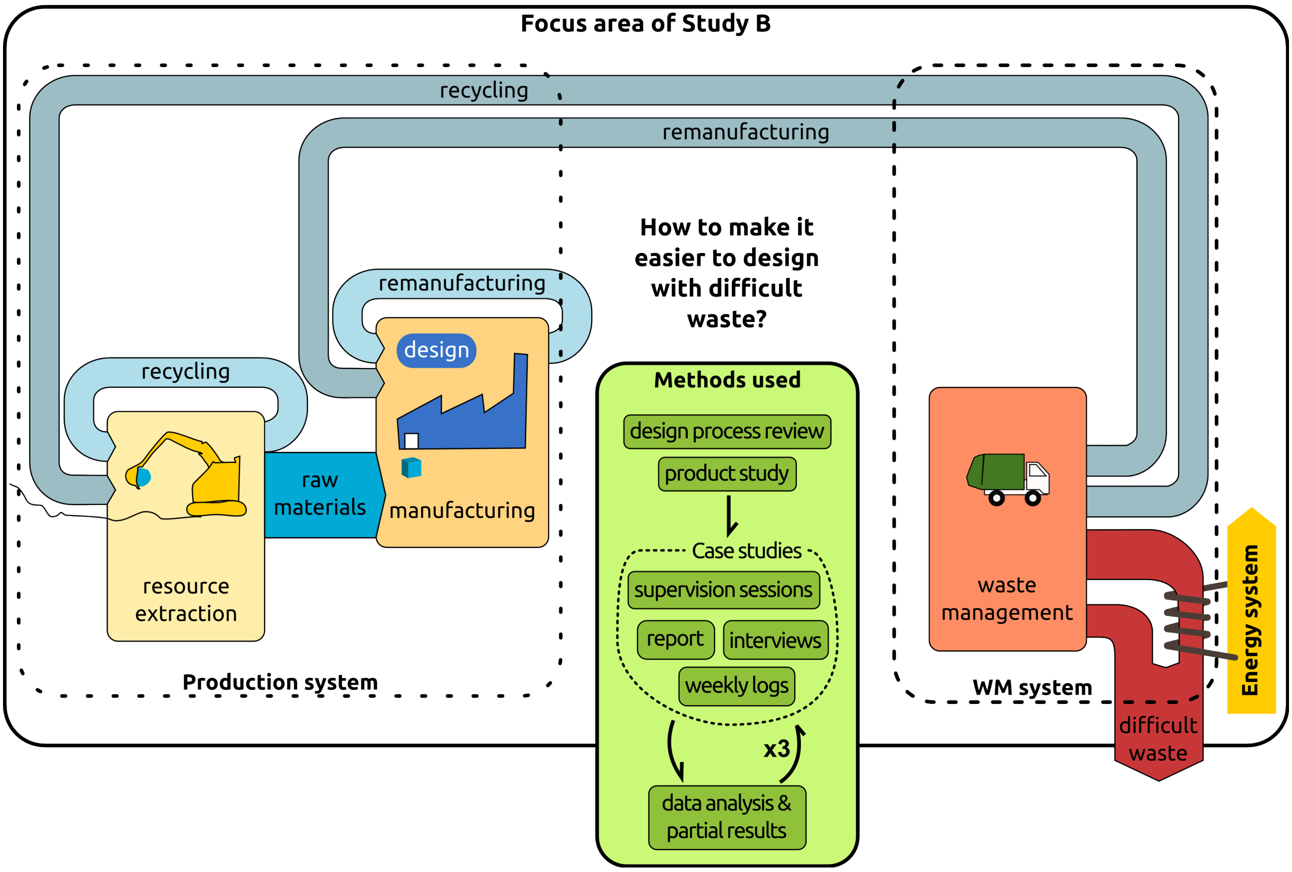

Figure 8: Components from figure 1 relevant to Study B and overview of the methods used

5.3 Results

5.3.1 Initial studies

The product Study was presented together with the review of traditional design processes in Article III. Despite the product Study being aimed at finding indications to the methods used when designing with waste, no such descriptions were found. This could be explained by the fact that designers rarely document or make public their working processes (Cross 2011). Or, it may be because design with waste is a relatively new area of design that is still in the early phases of proving that it can be done, rather than how (Article III).

Of the 57 examples of products investigated in the product Study, the categorisation revealed that recycled products tended to be serialised (~80%) and to use materials that were not suitable for disposal through a previously defined recycling system (~74%). Remanufactured[2] products tended to be handmade (~70%) and were more evenly distributed between materials that could be disposed of in an existing recycling system (Table 1).

Strategy used	N° of cases	Handmade or Serialised		Existing recycling system		Comments on Method
Recycle	27	**HM**	5	**Yes**	7	No
		S	21	**No**	20	No
Remanufacture	27	**HM**	18	**Yes**	12	No
		S	9	**No**	15	No
Both	3	**S**	3	Depends on each item		No

Table 1: Summary of the Product Study, sorted by strategy used.

Given that no method description was found in the product Study, the review of traditional design processes served as a tool to propose possible stages needed when designing with waste. It resulted in an expanded design process that included a pre-process stage to be executed before a traditional design process (shown in Figure 9). The pre-process was later shown to the students involved in the W2D project as a suggestion of the actions they needed to take.

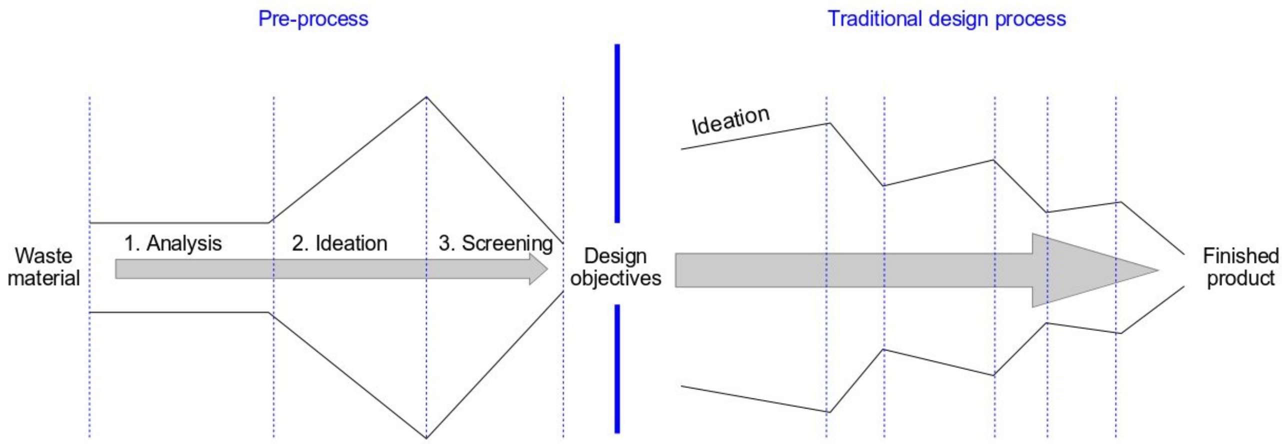

Figure 9: Design pre-process proposed followed by a traditional design process.

2 As noted previously, Article III uses the term “reused” instead of “remanufactured”. This can be seen on table 1.

5.3.2 W2D first year

In the first year of monitoring the Study four pairs of students engage in the project, two pairs of master students and two pairs of bachelor students. Article IV describes their work in more detail, together with the analysis of the information gathered by their reports, weekly logs and interviews.

Article IV concludes that significant material related knowledge is required, since the lack of reliable information for the discarded materials was identified as the most challenging aspect of the project. Information is lacking because a good contact with the producers may be missing, but also because post-consumer waste is submitted to contrasting use situations that may degrade the material in different ways. Research into post-consumer waste flows that do not have active recycling markets seems to be scarce.

Students generated several ideas of possible uses for the discarded material (ideation stage in the proposed pre-process), this phase being easier for them than the "product selection phase" (screening stage) that followed. In order to select a good product to develop further, students experienced that reliable knowledge regarding the material was required to be able to propose a suitable and competitive product.

The interviews showed that the stages of the proposed pre-process were followed, but not in such a linear and clear way. The time dedicated to the pre-process was much more than the time dedicated to traditional product development. The analysis stage was mainly focused on the material properties of the waste to be used. Information was needed to select a product to develop, often requiring more research than the one done initially. Material properties were also considered crucial for the traditional design process, which resulted in more or less constant efforts to research material properties during the entire process. Figure 10 shows the proposed process of designing with waste adapted to fit the descriptions of the students' experience.

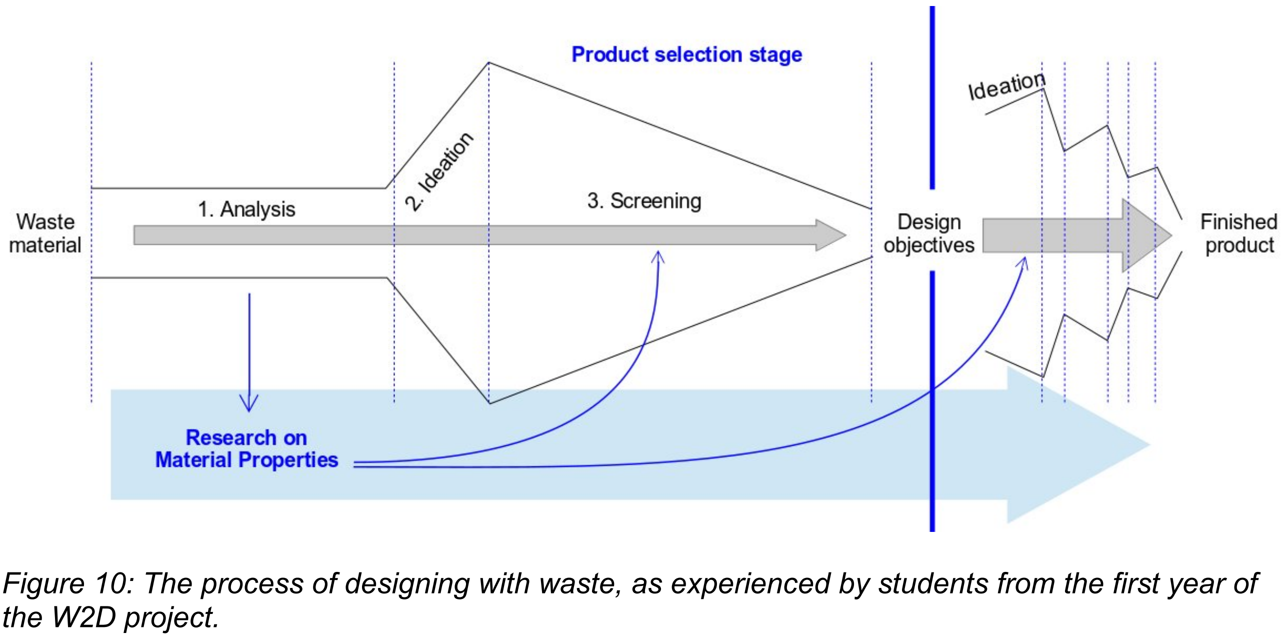

Figure 10: The process of designing with waste, as experienced by students from the first year of the W2D project.

5.3.3 Recommendations and first review of the proposed model

Based on the results from the first year, four groups of recommendations could be drawn. These recommendations are grouped according to what stage of the development process they correspond to, as shown in Figure 11.

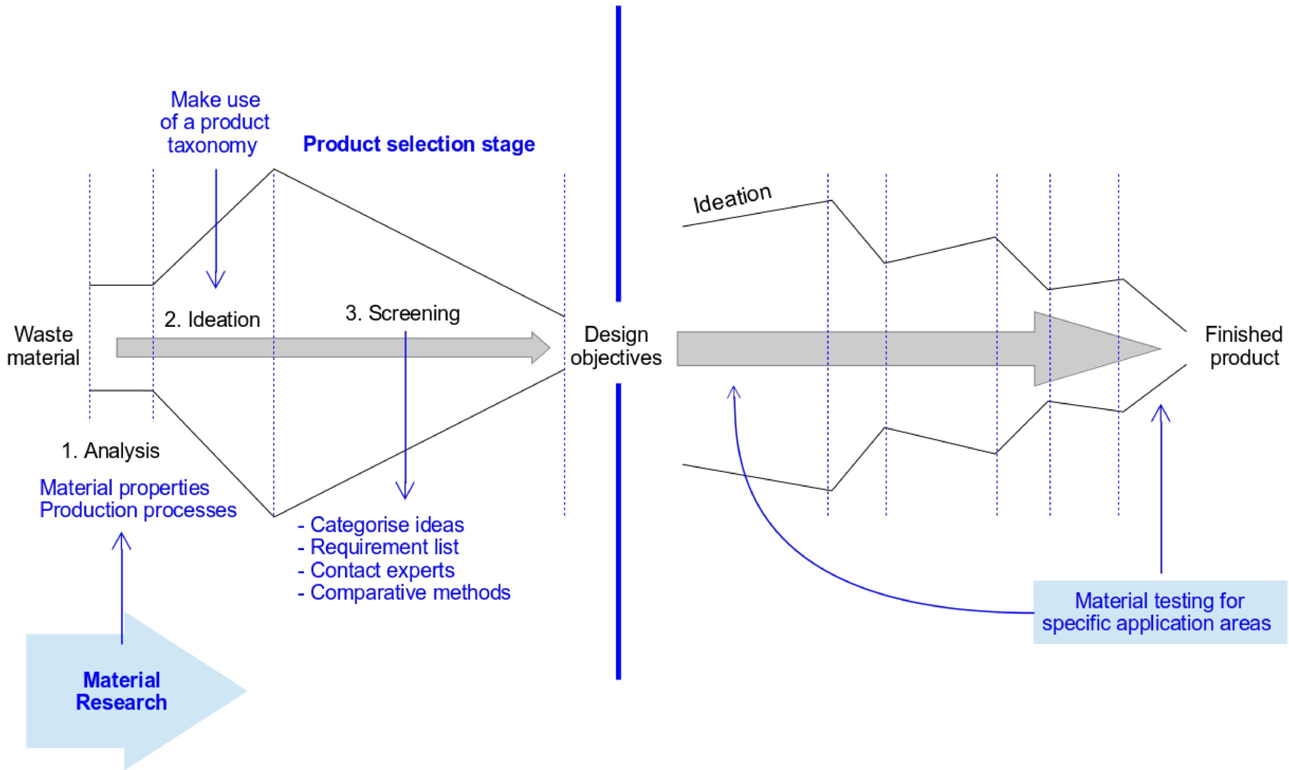

Figure 11: Suggestions that could facilitate designing with waste.

Material research should, as much as possible, be separated from the product development process. It would be ideal if material research could be externalized and conducted by material experts that could communicate the results to the designers. Identifying material properties (with focus on the distinct features of the material) and production processes that can be used are the main results needed from this research.

Ideation was considered simple by the first group of students, however the use of a product taxonomy could help designers cover possible application areas systematically. It is important that the ideation is done based upon the results obtained from the material research phase.

Screening was deemed the most difficult stage of the pre-process proposed. It is recommended to first categorise the ideas generated in the previous stage. If possible, categorisation should be done based on the material properties the ideas rely mostly upon. A list of requirements based on the material properties obtained could help provide an initial screening of ideas. This might highlight the need for additional material research, which should be done to investigate the most interesting product type options. When these steps have narrowed down the product options to few types of products, comparatives methods (e.g. Pugh matrix, SWOT analysis) can be used to select the best ones. Evaluation criteria to be used in these comparative methods can be based on the material properties, but may also include more general criteria, that aim at making the product selected better than its competitors.

The material quality of discards can rarely be guaranteed by Stena Recycling (or other recycling companies) or the waste generator. In order to ensure the material quality required, **testing of the material** will be needed. What material properties are crucial for the production process and use phase depend on the application area the product will have. That is why the most effective approach would be to determine the material properties to be tested once the application area is established. This could be done in early product development stages, as well as in later stages. Material testing in later stages could be done on product prototypes and could be considered as quality assurance measures.

5.3.4 W2D second year

The recommendations described in the previous Section were presented to the students currently participating in the W2D project during spring of 2014.

To test if more material related knowledge would help designers use waste in new production, students participating in the second year were encouraged to choose a material that had already been studied during the first year (to build upon the previous material research done in the W2D project) or to use a material investigated previously outside of the project.

A collaboration with a PhD project from material engineering was initiated for the second year, with the intention to facilitate even further the use of material knowledge. PhD work conducted by Erik Stenvall has been about Studying and defining the properties of the blended plastic fraction obtained from Waste of Electrical and Electronic Equipment (WEEE). This means that students that wished to focus their thesis on using this material would have a solid material knowledge support. The W2D project also offered thesis work for students from material engineering, that could help to do material testing for the applications defined in collaboration with students from product design. This resulted in a close collaboration between a product design student and a material engineering student during the spring term of 2014.

Conclusions from the analysis that is still ongoing will be included in revised recommendations to be given to the last group of students.

6 Study C: How to improve the waste system interface?

Waste system interface appeared in Study A as an area that contributes to effective use of resources. Currently the WM interface is determined mostly by WM professionals that define the waste system's requirements and hire designers or relevant industries to develop the elements that are needed (e.g. public bins, outdoor collection points, garbage trucks, etc.). Designers are rarely engaged in rethinking the larger WM system.

The waste system interface is where the service users interact with the waste system, i.e. the separation and collection stages of WM (as previously explained in Section 2.2.2). It is not uncommon that these stages are combined and just referred to simply as collection, separate collection or sorted collection. In any case it refers to the stages of WM where the users interact with the system.

It has been argued that even though sorted collection is part of a larger waste system, it can be studied as a separate sub-system on its own right (Gallardo et al. 2012). Gallardo also defines that separate collection can be divided into two sub-stages: pre-collection (done by the user) and collection (done by the WM system). This reflects the fact the actions of separating and collecting discards have to be passed from the user to the waste system. Depending on the context, this delivery may be direct (e.g. when a user discards material into a public garbage can on the street) or have several layers (e.g. a user tosses waste into their waste bin at home, once that is full he/she takes it to the building's waste bin, that later gets collected by a WM company). The important characteristic for sorted collection systems to be effective is the consistency between the collection layers. Figure 12 shows collection layers that may be present in a WM system. It can be that any of the intermediate steps are missing depending on the context. However, the layers always go from the user to the system.

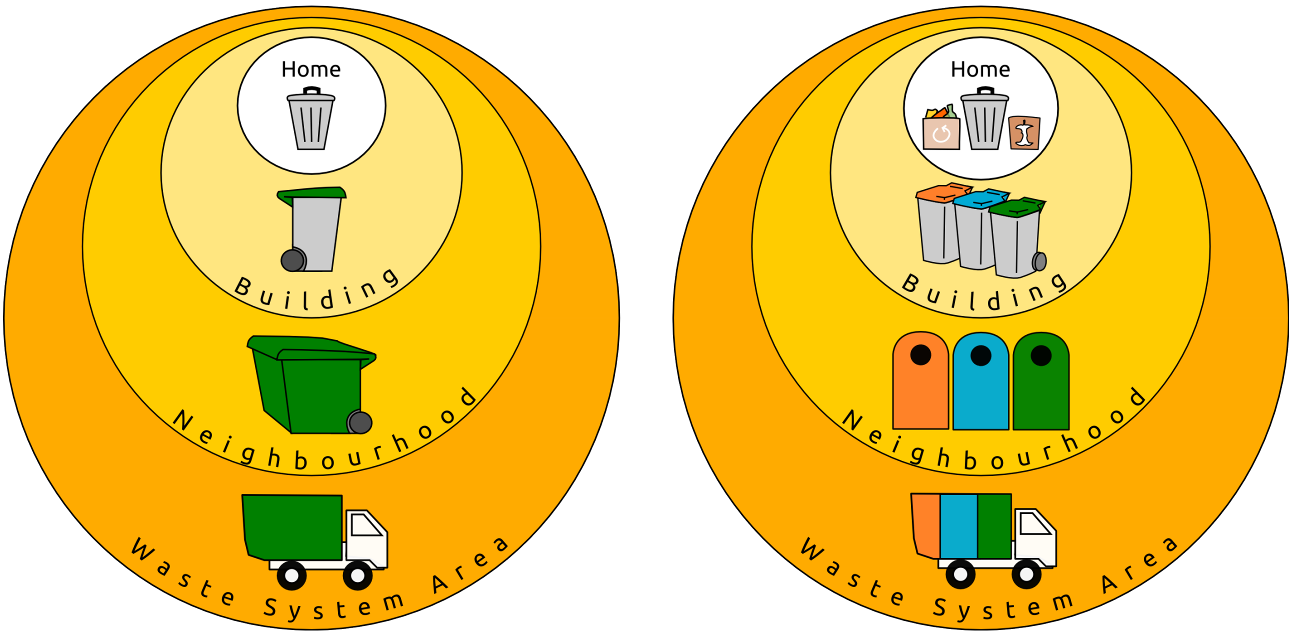

Figure 12: Possible layers for waste collection.

6.1 Aim

The main goal of Study C was to investigate how WM interfaces can be designed in order to facilitate resource recovery. In order to increase resource recovery, collection systems should increase the amount of materials directed to recycling, re-manufacturing or reuse, while reducing the amount of material that is destined to incineration or landfilling. In practical terms this commonly means reducing the amount of mixed waste generated by users. The mixed waste fraction is normally destined to incineration or landfilled, with the exception of locations where material recovery facilities (MRF) sort mixed waste into recyclable fractions.

In order to learn how existing waste system interfaces are designed and managed, several stakeholders in Gothenburg were contacted. The idea was to work closely with a stakeholder to learn from their experience and help them improve their current solutions if possible. This led to establishing a collaboration with Poseidon AB (one of the largest housing companies in Gothenburg). Poseidon has developed the waste sorting facilities available in their buildings and works constantly with the challenge of improving waste sorting among their tenants. The company's goal of reducing the amount of mixed waste collected in their buildings would mean reducing the fraction of waste that today is only incinerated.

6.2 Methods

The work conducted with Poseidon consisted of an in depth **case study** to analyse current waste sorting practices. Two buildings in a district that has problems with waste sorting were targeted for the Study. The targeted buildings incorporated 46 apartments each, housing 94 tenants in one building and 90 in the other. The case Study consisted of interviews with key actors, a waste characterisation Study, field observations, a user survey and the analysis of the waste weight data that was available for the area (details and results in Article V).

The caretakers from the buildings were **interviewed** to obtain general information about how the waste collection system functions. This included (but was not limited to): financing, who are the service providers, what legal requirements they have, what problems occur and how they work to solve them.

The **waste characterisation study** (i.e. measuring what material fractions make up the waste) was conducted in order to get more information about the type of waste generated in the targeted buildings. This was done by taking samples of the waste collected in the targeted buildings in order to analyse it to see what it was composed of. Waste from the mixed waste and biodegradable fractions were targeted for this characterisation. It complemented the **waste weight data analysis**, giving a more detailed picture of the waste generated. Waste weight data has been collected for this district since 2011, when they changed to a weight based billing system, whereby waste generators have to pay per kilo of mixed waste generated. The data was obtained from the municipal recycling office (Kretsloppskontoret) for the purposes of the Study.

Twelve **field observations** took place in order to observe sorting behaviour outside of the fractions targeted by the characterisation study. These observations entailed a general overview of the waste sorting rooms and more specifically notating if none-corresponding elements could be found in the containers for packaging material. This gave a wider picture of common user mistakes, while showing some shortcomings of the system.

A **user survey** was done in order to collect users attitudes towards the existing system and current behavioural norms. It was sent to all the apartments of the targeted buildings. The survey investigated among other things, what fractions were reported as most commonly sorted by the respondents, which of these were considered most complicated to sort and what would the respondents need to make waste sorting easier.

This work generated some suggestions for improvement, some of which were relatively simple for the housing company to implement. It was also decided to **triangulate** the Study by having another group investigate how to improve waste sorting in a larger group of buildings. Triangulation was done by having a group of students from technical design do their bachelor thesis on this topic (work still ongoing at the current stage). This allowed for multiple triangulation, since more than two data sources were used by different investigators using slightly different methods (i.e. students did not perform a characterization Study but relied more on focus groups and interviews) (Thurmond 2001). Triangulation helped corroborate that the conclusions were to some extent generalisable, while also providing more possible solutions.

For Study C, the connection between the user and the WM system is critical. This is illustrated in Figure 13, together with a summary of the methods used for the Study.

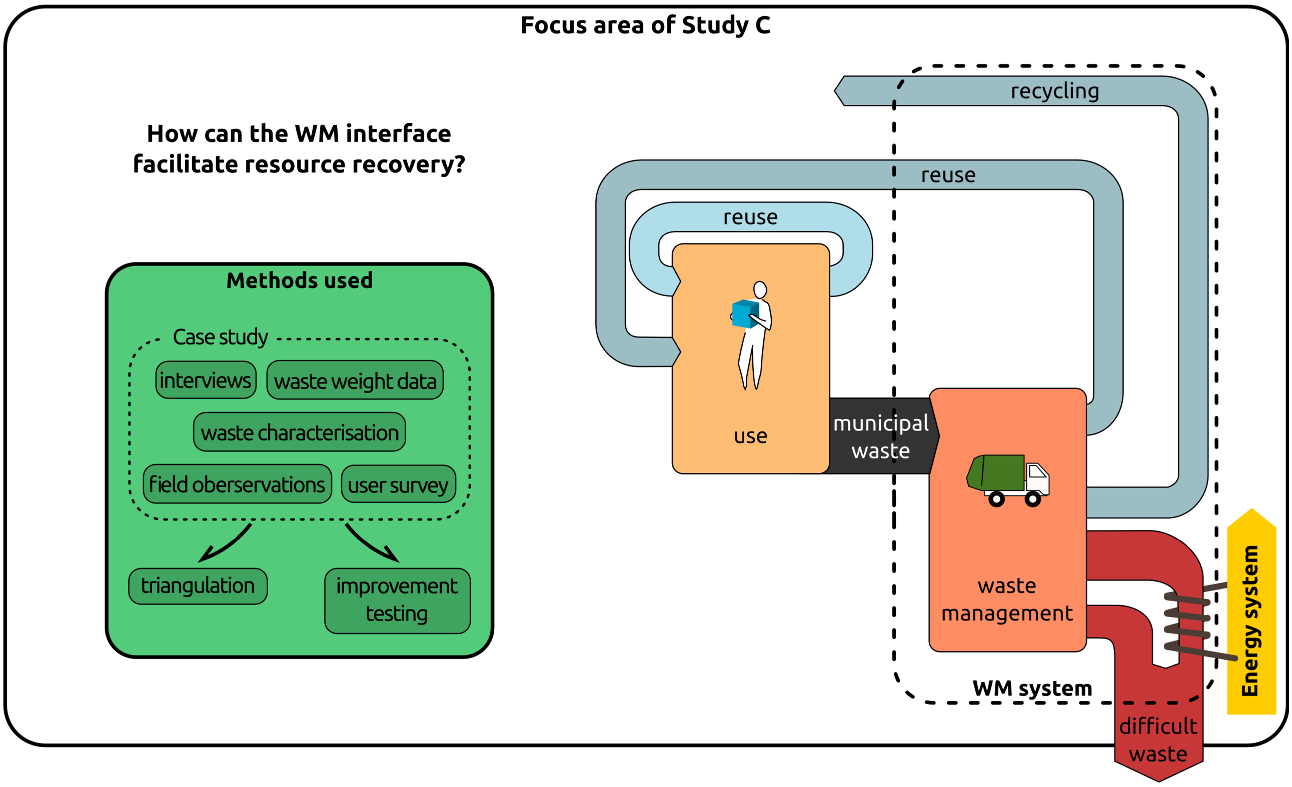

Figure 13: Components from figure 1 relevant to Study C and overview of the methods used

6.3 Results

The main result from the Study so far has been to highlight that housing companies (as well as other WM stakeholders) can and should take a more active role in improving the waste system. This should go beyond what is required of them by their local authorities and legislation if they want to have well-functioning collection systems. Housing companies have the advantage that since they provide waste sorting for several tenants, the volumes of materials collected could justify taking other non-traditional actions.

Summarising, the problems detected from the case Study can be grouped as seen below. Each category is described here briefly, followed by a suggestion presented to Poseidon of how to address the problems. These suggestions are more widely discussed in Article V.

- **Mismatch between the technical system** (i.e. waste sorting infrastructure available for the tenants) **and the desired waste sorting behaviour**. If the desired behaviour is that tenants sort out most of their organic waste, the capacity of the system to store biodegradable waste should be increased, while reducing mixed waste containers.
- **Mismatch between the technical system and users' perspective.** The categories presented in the system do not necessarily fit with how users categorise their waste. Most tenants do not understand why it is only packaging material that should be sorted. This could be addressed by providing categories better suited for the users or by providing a stronger information and communication campaign.
  - **Ambiguous sorting possibilities**. Some discards generate uncertainty among users, since they may fit in more than one category (e.g. certain paper elements like napkins, receipts, etc.). These ambiguities should be minimised by clarifying where the confusing elements should be discarded.
  - **Lack of sorting possibilities**. Of the elements that cannot be sorted into the system today, the most interesting group is textiles. Textiles are normally discarded in a bag of their own, naturally separated by the users from the other waste generated in the household. Since textiles are a natural category for the users, providing the option to collect them separately is likely to have good results.
  - **Inconvenient sorting possibilities**. Bulky and electronic waste is currently sorted in a different room than the rest of the waste. However, tenants tend to leave these fractions in the mixed waste containers that are more accessible to them. To avoid this, containers for both bulky and electronic waste should be available in the main sorting room.
- **Bulky waste** is often discarded in conditions that could potentially be reused or requiring some minor repairs. Activities for reusing bulky waste such as garage sales and free-cycle events could be promoted by the housing company.

From these suggestions, Poseidon decided to focus on increasing textile collection. They started a project with Renova (Gothenburg's waste service company) and Human Bridge (a local aid association), where they would test textile collection during a one year period. It is considered to be one of the most comprehensive efforts of its kind in Sweden so far (Renova, 2014). The project started in March 2014 by setting up containers for textiles in 30 test buildings in Gothenburg. They have collected more than two tonnes of textiles in the first month only (Poseidon AB 2014).

The waste characterization Study showed that almost 40% of the waste discarded in the mixed waste container was in fact **biodegradable waste**, while 25% corresponded to packaging waste and 5% corresponded to textiles. Biodegradable waste was also perceived in the survey as a problematic fraction to sort, together with bulky waste.

This result of biodegradable waste being problematic to sort was corroborated by the group of students that performed the triangulation studies. The students focused on investigating the issues related to this fraction more extensively, categorizing their findings into four main problem areas: **distance**, **space**, **information** and **disgust**. Distance refers to the problems that may arise when taking waste to the sorting room. Space refers to requiring more space in the apartments in order to collect the waste in different fractions.

Better information was desired by the tenants, about what happens to the sorted waste as well as how to better sort the fractions. Finally disgust referred to the aversion some people have towards rotting discards, which makes these people avoid separating biodegradable waste (students Aasa, Bergman, Friberg, Petersson, Wahlgren and Westerlund , personal communication, April 1st, 2014).

7 Discussion

The present work aimed at investigating a very broad topic to start with: what needs to be done in order to reduce the amount of waste that today cannot be recovered. After the initial exploratory interview Study (Study A), two specific research areas were identified: (1) How to design with difficult waste and (2) how to design the waste system interface in order to facilitate resource recovery. These research areas were addressed in studies B and C respectively, that ran in parallel but completely independent of each other.

Engaging in two studies simultaneously is a considerable challenge, which could be reconsidered. On the one hand, being part of two different studies meant that the author could not dedicate her full attention to one particular project. This resulted in less focused and thorough work than if one would have only engaged in a single study at a time. However, after the initial study it became apparent that there was so much to do, that the more people we were able to involve in improving the WM system the better. Involving other actors has been a big part of both studies, which has meant that once the studies were running the author had people with whom to share the work load. Closely collaborating with practitioners has also meant that the results of this research are heard first by the practitioners and later by the academic community, resulting in possible quicker implementation and direct impact (as in the case of Poseidon, see Section 6).

7.1 Designing with Waste

One of the main contributions of the W2D project was to highlight knowledge gaps about the waste materials used. These knowledge gaps correspond to their material properties, but also to some limitations that current regulation has in place for using waste material in new production. The fact that this knowledge was insufficient or lacking was considered the main barrier to do design with waste.

This lack of knowledge is a consequence of not having product manufacturers actively engaged in the waste handling stage but exclusively focussed on the production. When the students decided to work with pre-consumer waste and were able to contact the waste generators, it was much easier to retrieve information and quality assurance is easier to achieve.

However, industrial pre-consumer waste is the result of inefficient production processes, and as such should be minimized to the highest possible extent. It is the manufacturers, responsibility to ensure that their artefacts are produced with maximal resource efficiency and when waste cannot be avoided, producers should find the best way to dispose of this material. Best disposal practices should not be limited to what local WM has to offer, but rather in engaging with a proactive way in maintaining the highest possible value for the materials to be discarded. Industrial ecology has emerged as a field that is specifically focused on how to facilitate industrial symbiosis, where the waste and by-products of one factory could be used in another (Chertow 2000) by the development of eco-industrial parks, for example. If this is done successfully, there will be no need for external designers to try to develop products with industrial discards. Rather, in-house designers will have the task of establishing a symbiotic system with the discards generated in their company.

If industrial symbiosis should be widely adapted, the W2D project is left to focus on post-consumer waste, which is much more irregular and unpredictable. Collection and sorting of post-consumer waste, accompanied by quality assurance and supportive legislation, then becomes crucial for achieving the standards of material quality required for new production. This means that designing the WM system so that it can ensure high (or acceptable) material quality is a prerequisite for establishing design with waste as a mainstream practice.

Designing with waste is a palliative approach to deal with design that does not respect the need for closing material loops. If all products were designed to fit back into existing secondary material markets or leased out by their manufacturers to be taken back when their use phase is over, there would be no need to design with waste. However, currently many difficult materials find their way into the waste streams with no possible way out. Unless this is avoided by stricter production regulations, designing with waste will still be necessary.

7.2 Waste system interfaces

Much is being done today to increase resource recovery from municipal solid waste. Growing environmental awareness, together with current social and political circumstances are in favour of supporting the task of turning waste management into an effective resource management system. International and local policies have in many cases promoted regulations that help finance or motivate material recovery activities. Examples of supportive policies are different types of extended producer responsibility (EPR) schemes or weight based billing systems (also called pay as you throw, PAYT).

EPR is a two sided blade. On the one hand it is a clear format with which to finance the take back system. This financing liberates the collection systems from depending economically on volatile material prices or municipal subsidy. On the other hand, the problem with this is that it generates requirements on the collection system that may conflict with the requirements that users have on the collection system. For example, in Sweden it is only EPR for packaging that currently finances curb side collection of their products. This means that only packaging products should be disposed in curb side collection facilities, which is not logic for the user. In this case, the EPR financing system generates the mismatch between the technical system and the user (as reported in Section 6.3).

Despite the inconsistent results obtained by implementing different PAYT systems in Sweden, it has led to an average of 20% reduction in mixed waste generation (Dahlén and Lagerkvist 2010). It is still uncertain where the avoided material ended up (since the same Study reports no clear increase of recyclables under the same time period) or if it was simply not generated. However, PAYT systems are well received by local authorities and give an economic incentive for users to reduce their waste generation. In Sweden the PAYT fees vary between 1.3 to 3.9 SEK per kilo of waste generated, which is added to a base fee for the collection service (Avfall Sverige 2013). Considering the average waste generated per person in Sweden (including bulky waste) the PAYT fees would range between 500 to 1500 SEK per person per year. These prices on waste may not generate an economic incentive large enough to motivate all users, but they certainly do give large waste generators motives to improve their sorting. Large waste generators may be anything from large family households, to institutions, offices, commerce, restaurants and housing companies. Poseidon is an example of how some housing companies have already started acting upon this opportunity (as presented in Section 6).

PAYT schemes are a way of allocating WM costs to the users. In contrast pawn systems (pant in Swedish) are a way of giving a value for the discarded material to the user. The most common examples of pawn systems are the collection of PET or glass bottles and aluminium cans. These systems work remarkably well and to some extent should be expanded. The core difference between these systems and the rest of the WM collection options, is that they generate value for the user as well as the system, rather than just generating value for the system. More solutions that generate value for the user should be developed in order to better motivate waste sorting in society.

As reported in Section 6.3, the sorting of biodegradable waste is problematic despite users having access to separated collection for this fraction. It seems that in order to sort more biodegradable waste users need more motivation as well as better products, services and infrastructure to support this behaviour. In line with findings from Study C, other authors state that between 30% to 40% of the mixed waste generated in the EU is biodegradable waste (Martínez-Blanco et al. 2010). This makes biodegradable waste a clear target for minimizing mix waste volumes.

Despite some considerable progress in increasing resource recovery, the challenges of changing WM still seem daunting. The author's impression is that blind faith in technological solutions has taken away the awareness that each and every one of us is responsible for contributing to sustainable resource usage. The illusion that the waste problem can be solved by technology only has increased the divide between users and the WM system as whole. Much has been reported about the need of the waste system to improve, when the reason for even having a waste system comes from the way we as a society relate to material resources and discard them. In the long run, the system will be whatever society wants it to be. That is the level of user involvement one should aspire for.

7.3 Future work

It is evident that WM needs to provide better solutions for sorting out biodegradable waste in a way that better engages users. That is why the author's future work will address possible solutions for separated collection and treatment of biodegradable waste, with the intention of providing a more satisfactory user experience. To increase user motivation by delivering the products, services and infrastructure for treating bio-waste at the users' side (rather than from the WM perspective) will also be investigated.

There are several options for turning biodegradable waste into some sort of resource for the user. Composting turns biodegradable waste into a good growing medium rich in nutrients. This can be achieved by the natural rotting process, or even with the aid of worms or other organisms that facilitate this process. Small scale digesters can be used to generate bio-gas that can be used for cooking or heating. The author's future work will develop and evaluate these options by investigating user acceptance to different solutions, as well as their barriers for implementation.

8 Conclusions

The main purpose of this thesis was to research what could be done to reduce the amount of difficult waste that cannot be recovered by current WM solutions. Study A resulted in a list of seven strategies that could support more effective use of resource, thus reducing difficult waste. The strategies identified were: **design for durability**, **design for end-of-life**, **design of packaging for improved recyclability** (all of which can be executed from the design discipline), **waste used as input material for new production**, the **design of**

the waste system interface (which would require some type of collaboration between WM and design), **increase material recycling** and **redistribution of used goods** (which can be addressed by WM alone).

In broad terms Study A provided the background and rationale for choosing to conduct further work with two connections: (1) **between WM and production systems** and (2) **between WM and its users**. These connections can be said to be relevant for the two strategies that require some sort of collaboration between WM and design. Specifically, to be able to design with waste, the connection between WM (where the waste is obtained) and future production should be strengthened. While, the waste system interface is how users relate to WM. These two connections with their respective strategies were addressed in Studies B and C respectively.

Study B aimed at investigating the main barriers designers face when using waste as input material for new production. The strongest barrier encountered was the **lack of reliable knowledge regarding material properties** on which to base the design work. Also, the design process did not start (in the W2D case) from a specific need to be fulfilled, but rather from a material that needed to be used. This fact added uncertainty to the design process. The product selection stage was deemed very important for the work to succeed, but has been still perceived as fuzzy and difficult in the case studies so far. The pre-process proposed for the case studies extends the time needed to do product development, resulting in longer and unclear product development efforts.

There will still be a need to be able to design with waste as long as difficult waste continues to enter into the waste system. However this process is problematic still and should be avoided. In the case of pre-consumer waste, it could be avoided by broader adaptation of industrial symbiosis and stricter EPR regulations. For post-consumer waste, the improvement of the waste system interface should aim to minimise the waste not recovered. This requirement highlights the relevance and significance of Study C.

Study C investigated how WM interfaces (a.k.a. collection systems) can be designed in order to facilitate resource recovery. In order to increase resource recovery, collection systems should increase the amount of materials directed to recycling, re-manufacturing or reuse, while reducing the material that is destined for incineration or landfilling. In practical terms this means reducing the amount of mixed waste generated by users. Insights from Study C point out that those **solutions that are in line with users' attitudes towards discarded materials** are more easily adopted by the users. While **solutions that generate value for the users** could be a way to significantly improve user engagement. If users themselves can convert their discards into resources they can benefit from, then these materials do not turn into waste and never reach the WM system.

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