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Improving resource efficiency in the value chain of construction plastics

A pathway of service designs enabling increased circularity through mechanical recycling in a Swedish context

Master's thesis in Management and Economics of Innovation

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se
Report No. E2022:145

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Cover: Construction plastic pipes sorted at a recycling facility in Sweden. Photo taken during a site visit on 16 November 2022.

Printed by Chalmers Reproservice
Gothenburg, Sweden 2023

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Abstract

The Swedish construction industry generates more than 150 000 tonnes of plastic waste annually, and only 0.8-2.5 percent of this waste is recycled. A wide variety of plastic types complicates sorting and processing procedures, the low density of plastic materials leads to costly waste transportation, and the project-based nature of the industry implies temporary geographically dispersed plastic waste flows. While these barriers are commonly mentioned in previous research, there are many more reasons behind the low resource efficiency of construction plastic waste. This study was conducted together with the Swedish construction company NCC, to identify circular service opportunities enabling improved resource efficiency of construction plastic waste through mechanical recycling. First, by interviewing people with experience from the construction plastic value chain, six types of services enabling plastic recycling could be found and 113 barriers hindering the provision of these services could be presented in six categories. Further, ideas on how actors can collaborate better to increase the plastic recycling rate were identified through a concept mapping process and could be categorized into eight clusters, representing collaborative actions. Leveraging perspectives of collaboration complexity and service system maturity, eight service system designs were proposed that could enable collaborative actions in practice. A service ecosystem perspective was employed to highlight interdependencies between collaborative actions and suggest a pathway of service designs. Finally, through interviews with digital construction specialists, a knowledge gap was found with respect to how digital solutions could be used to improve plastic waste management. To increase the recycling rate of construction plastic waste, it is suggested that actors consider the proposed service systems to explore solutions with external actors.

Keywords: Construction, Plastic, Service Ecosystems, Circular Economy Business Models, Resource Efficiency Recycling, Service Triads, Reverse Supply Chain, Collaborative Actions, Barriers.

Acknowledgements

This master's thesis was conducted during the autumn of 2022 at the Department of Technology Management and Economics, at Chalmers University of Technology. The project was carried out in collaboration with the construction company NCC.

First, we would like to express our gratitude towards Árni Halldórsson, our supervisor and examiner at Chalmers University of Technology. We are grateful for the opportunity to write this particular thesis and for his valuable guidance during the research process. With his specific support in conducting a concept mapping process, we have learned a new methodology that we find valuable for our future professional careers.

Second, we would like to thank Magnus Österbring, our supervisor at NCC. He constantly helped us get in touch with the right experts in the field and his feedback has been critical to formulating the scope of the thesis. He has further provided invaluable support for improving the written thesis. We will miss the fun and insightful lunch conversations at the NCC office in Gothenburg.

Third, we would like to express our thanks to all the interviewees and concept mapping participants who made this thesis possible. Without your generous contribution, this thesis would not have been possible.

Finally, we would like to express our gratitude to the opponents of this thesis for their accurate and helpful feedback.

Teodor Linder and Joar Hellqvist, Gothenburg, January 2023

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

CEBM	Circular Economy Business Models
CLDP	Construction Logistics Service Provider
EPS	Expanded Polystyrene
GD	Goods Dominant
GHG	Greenhouse Gas
HDPE	High-density polyethene
IR	Infrared
LDPE	Low-density polyethene
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropene
PS	Polystyrene
PVC	Polyvinyl chloride
SD	Service Dominant
SE	Service ecosystem
WSP	Waste Service Provider

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1

Introduction

This chapter is divided into three sections. First, it addresses plastic usage in the Swedish construction industry and the current state of plastic recycling. Second, the purpose and research questions of this study are presented. Third, it outlines the boundaries of the study.

1.1 Background

Plastics started appearing as a building material in the construction industry in the 1950s, and the industry consumption has been steadily increasing since (Ahlm et al., 2021). Plastic as a building material usually lasts between 30–50 years with little maintenance required (Almasi et al., 2020) and shows lower greenhouse gas (GHG) impact compared to the majority of its often heavier building material alternatives (McKinsey & Company, 2022), despite 99 percent of plastics produced globally being based on fossil fuels. However, there is an urgent issue with respect to resource efficiency. It has been estimated the Swedish construction industry consumed 262 000 tonnes of plastic in 2017, representing 21 percent of national consumption, and further generated 150 000 tonnes of plastic waste (Ljungkvist Nordin et al., 2019). While statistics have low reliability due to limited data availability, studies (Fråne et al., 2022; Ljungkvist Nordin et al., 2019) indicate that the recycling rate of construction plastic waste is only around 0.8–2.5 percent. Although the climate impact from recycled plastics is 3.5 times lower than manufacturing virgin plastics (Almasi et al., 2020), the remaining waste is currently sent to energy recovery (Ljungkvist Nordin et al., 2019) resulting in over 4 percent of the total climate footprint from the construction sector (Almasi et al., 2020).

While the reasons behind the low recycling rate of construction plastics are many, commonly mentioned issues include costly transportation, geographically dispersed waste flows, difficulty in sorting plastic waste, and insufficient legislation. First, while the climate benefit from mechanical recycling compensates for long transports of plastic waste, the low density of plastic materials implies costly logistics challenging the economic benefit (Enebjörk et al., 2022). Second, the project-based nature of the construction industry implies temporary geographically dispersed plastic waste streams (Jansson et al., 2019b). Third, it is difficult to sort plastic waste into sufficiently pure fractions that allow mechanical recycling of high quality. The difficulty of sorting construction plastic waste might seem surprising as the plastic consumption from the construction industry can be primarily represented by a few polymer types used in a handful of different products. The plastic types PVC, PE, PS, and PP accounted for 77 percent of European construction plastic demand in 2017 (Ahlm et al., 2021), and are largely used in the production of floors, packaging, pipes, insulation, and profiles (Almasi et al., 2020). However, Almasi et al. (2020) notes that there are in total more than 50 different plastic types used within the construction industry and that the characteristics of each type further depend on additives such as pigments, oils, and softeners. The difficulty to separate these variants into pure fractions is clearly illustrated by Ljungkvist Nordin et al. (2019), estimating that 40 percent of construction plastic waste in 2017 was sorted out for recycling while only 0.8 percent was recycled due to insufficiently pure fractions. This further illustrates the fourth issue, that the current legal obligation (Avfallsförordningen 2020:614) to sort plastic waste into a separate fraction at construction sites (Ahlm et al., 2021) is not enough to achieve plastic waste fractions of sufficient detail to be recyclable. However, stricter legal policies are not necessarily the best approach to achieving recyclable plastic waste fractions. For example, Lindahl et al. (2022) found that standardizing and easing product requirement specifications can significantly reduce the number of used plastic types and enable better sorting and recycling.

In 2008, the European Commission required that 70 percent (weight percentages) of annual non-hazardous waste volumes from the construction industry should be recycled or reused by the year 2020 (European Commission, 2008). Material Economics (2022) notes that 60-70 percent plastic recycling rates are needed to meet European climate targets and that half of this target could be reached through mechanical recycling. Jansson et al. (2019a) identify services in the Swedish construction sector that seek to close loops for several product groups like plastic pipes, floors, and packaging through mechanical recycling. Jansson et al. (2019a) found that it was technically, environmentally, and economically motivated to gather and recycle most construction products, they also noted that further research must be done to learn how to handle the variations in plastic material flows and to get a complete picture of construction material recycling opportunities. The identified viability by Jansson et al. (2019a) in current business models raises the question of why current recycling services only result in a recycling rate of 0.8-2.5 percent. Material Economics (2019) notes that the potential for materials efficiency and circular business models is fragmented along long value chains, and therefore overlooked. Thus, there is a need to apply a value chain perspective to investigate circular service opportunities that can enable plastic recycling in the construction industry.

1.1.1 Purpose and research questions

With a network perspective on the construction value chain, this thesis aims to identify circular service opportunities enabling improved resource efficiency of construction plastic waste through mechanical recycling. This aim is to be reached by answering the three research questions below.

There are currently a variety of different services enabling plastic recycling. An enabling service is considered a service that directly or indirectly supports recycling processes. However, current enabling services are only provided on a small scale in the industry. Therefore, the first research question is:

1. Barriers to service provision: (a) What types of services currently enable plastic recycling within the construction sector and (b) what barriers are hindering the provision of these services?

Previously, studies have been done on what specific actors could do to increase plastic recycling rates (Almasi et al., 2020; Enebjörk et al., 2022; Jansson et al., 2019a). However, there is a need for a network perspective to better understand how such actions could be feasible in practice. Hence, the second research question is:

2. How could actors collaborate better to enable an increased recycling rate of construction plastic waste?

The European Environment Agency (2021) concludes that shaping sustainable waste management operations depend on the use of digital solutions, raising examples such as robotics and artificial intelligence (AI) for improved waste sorting. Focusing on plastics within the Swedish construction industry, Almasi et al. (2020) argues that digital information flows are a prerequisite for circular plastic waste flows. Enebjörk et al. (2022) illustrate that lack of documentation and information flows induces inefficient sorting of plastic waste and loss of recycling potential. Thus, there is a need to investigate how digital solutions could be used to improve waste management operations for construction plastic waste.

3. How can digital solutions be used to improve plastic waste management?

Following the aim of the thesis, the main emphasis is put on the second research question, whereas the first research question is of diagnostic nature to build an understanding of the current situation, and the aim of the third research question is to identify further enabling digital solutions related to previous empirical findings.

1.2 Boundaries of the study

A number of demarcations to the study are presented here to clarify within which boundaries the results from this report are relevant. The boundaries of the study are explained in two sections. First, the empirical context is outlined. Second, the demarcations of the study are presented.

1.2.1 Empirical context

This study is carried out with a large Swedish construction company. The value chain perspective in this study originates from the context of this particular construction company. A brief illustration of this value chain is presented in Figure 1. Related but not included actor types are also visible to show what part of the construction plastic ecosystem is considered as the value chain of construction plastics in this study. The arrows give a brief overview of plastic recycling flow as it becomes input and output in the construction process. All actors that are included operate in the Swedish market. However, some of the actors are multinational companies so the services can include plastic being transported outside of Sweden.

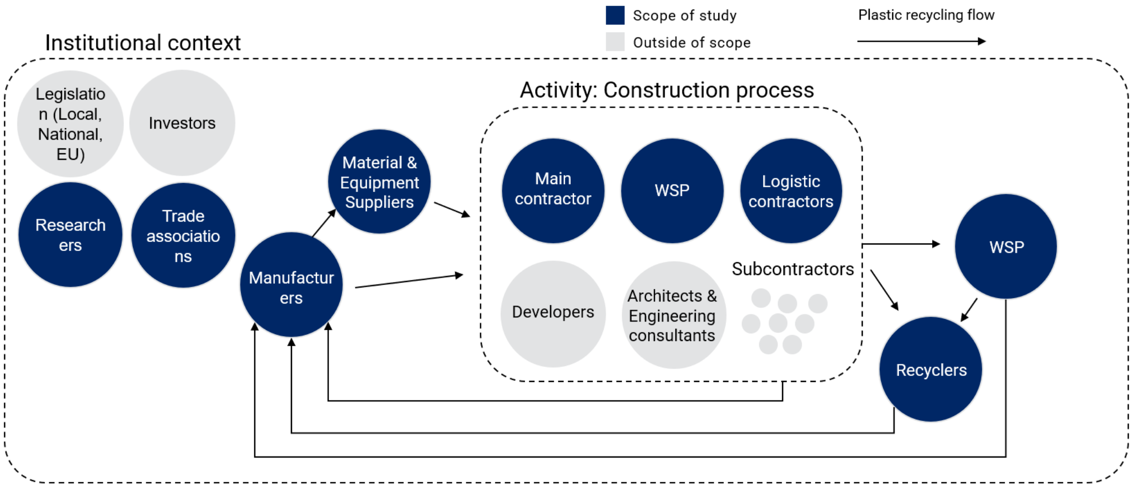

Figure 1: An illustration of the value chain connected to plastic waste recycling based on the client settings

A study on measures to increase the circular use of plastic in the Swedish construction sector by Almasi et al. (2020) highlights five main actor types for these measures; developers, material manufacturers, architects, and engineering consultants, construction contractors, and waste and recycling contractors. These actor types are used to describe the value chain context of this study. Almasi et al. (2020) states that the role of the waste and recycling contractors are fluid. In this value chain context, they were divided into waste service providers (WSPs) and recyclers with the difference that recyclers process the plastic waste into other plastic products or smaller sorted granulate while the WSPs have the authorization to transport, handle and sort waste but mainly do not process it. Additionally, logistic contractors, also referred to as construction logistic service providers (CLSPs), were added to the study scope to illustrate that waste logistics can be handled by several actors in a complex network. Finally, researchers and trade associations were included since they could contribute with expert knowledge about construction plastic recycling.

Since the ecosystem consists of many actors with indirect impacts on the flow of construction plastics some actor types were excluded from the study scope. Developers, architects, consultants, and investors are outside of the study focus since they are not directly connected to plastic waste recycling from construction. Moreover, this thesis investigates opportunities for what private actors can do in the current context when improving resource efficiency. Therefore, legislators are not included in the study.

1.2.2 Demarcations

The term recycling is used in this thesis based on the definition in the EU waste framework directive.

> *"Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations" (Council of European Union, 2008).*

Therefore, energy recovery of plastic does not fall under the definition of recycling in this thesis. However, recycling plastic into new products with a purpose other than the original is included in the definition.

Further, the feasibility of increasing the recycling rate through chemical recycling is not analyzed since it is not fully mature in the Swedish market and requires high investment costs and new policies to enable (Lassesson et al., 2021).

The main sustainability focus in this report is environmental sustainability as a reason for increasing recycling. This means that when looking to increase plastic resource efficiency, the starting point is environmental improvement. However, financial and social sustainability factors are important for the feasibility of opportunities in the industry context and are considered and analyzed throughout the report but environmental improvement is the baseline for recommendations and discussion.

Regarding the first research question, the goal is to create an overview of barriers affecting current services. The overview will not be an exhaustive list, but rather a tool for improving understanding of barriers to the provision of services that enable recycling. Further, regarding the second research question the collaborations for enabling plastic recycling will be examined with an exploratory approach, the findings should be viewed as indications of what can be done and not a comprehensive list. Finally, regarding the last research question, digital solutions will be investigated through an exploratory approach. The aim is not to identify an exhaustive list of digital solutions. Rather, the aim of the last research question is to identify illustrative examples of how digital solutions can be used to improve waste management operations.

2
Theory

In order to discuss findings related to circular service opportunities enabling improved resource efficiency of construction plastic waste, there is a need for three different perspectives. First, this chapter starts with an introduction to service concepts in a construction context. This is followed by perspectives on service systems and actor relationships. Second, a section on circular economy business models provides theoretical perspectives relevant to discuss circularity, value creation, reverse logistics, service types, and barriers. Third, perspectives on the potential of digital solutions in waste management are presented.

2.1 Services in a construction context

Servitization is the transition from solely selling products to selling bundles of products and services, and has been widely adopted within the manufacturing sector since the 1980s (Baines et al., 2009). Within manufacturing, common drivers for firms to pursue servitization include financial, strategic, and marketing-related reasons (Gebauer et al., 2005; Mathieu, 2001). However, manufacturing firms attempting servitization strategies often face challenges in designing services and adapting the existing organization (Baines et al., 2009). As noted by Oliva and Kallenberg (2003), providing services demands capabilities and organizational structures different from that of a traditional manufacturing organization, and further requires the ability to transition from transactional to relational customer interactions.

In contrast, the concept of servitization has not been widely explored in construction contexts. Exploring servitization in a construction context, Liu et al. (2021) find that it constitutes the provision of services in the construction phase of entities to increase productivity and reduce waste, and services for the subsequent use and maintenance of built entities. Due to the varying demands, collaboration in networks of actors is critical for the effective provision of integrated solutions that meet specific demands in a construction context (Liu et al., 2021). Studying tensions in construction waste management, Sezer and Bosch-Sijtsema (2020) argue the need to consider the life cycle of construction waste with a focus on networks of actors and flows of knowledge and applied skills rather than viewing waste as an output from a system of static activities. Based on the definition of service-dominant (SD) logic (Lusch & Vargo, 2014), Sezer and Bosch-Sijtsema (2020) state the definition of services as:

> *"/.../ the application of specialized competences (knowledge and skills) through deeds, processes, and performances for the benefit of another entity or the entity itself".*

The above definition is referred to when discussing services in this thesis.

2.1.1 Service system maturity

Traditionally, project management has been characterized by a linear mindset focusing on a set series of activities aimed to achieve a specified output within time, resource, and cost constraints (Vargo & Clavier, 2015). Vargo and Clavier (2015) also refers to this mindset as *"hard systems thinking"*, and notes that it is largely grounded in a paradigm of a Goods-Dominant (GD) logic which focuses on output where value is exchanged with the exchange of goods in a linear flow from production forward through the supply chain. A Service-Dominant (SD) logic is a contrasting perspective on the generation of value where services are considered the basis of exchange and that value is viewed to be co-created in actor exchanges. Extending the systems perspective within the SD logic, Vargo and Akaka (2012) presents a Service Ecosystem (SE) perspective which emphasizes the importance of actor networks to form service systems and holds resource integration between actors as a central theme to form such networks.

While the GD-, SD logic, and the SE perspective, all are theoretical frameworks for the study of value generation in the interactions between actors they also imply perspectives that actors can employ for value creation in their interactions with other actors. Comparing GD- and SD logic, Grönroos (2008) proposes two different models on how value can be created in the interaction between a supplier and a customer. The perspective on value Grönroos (2008) refers to in both models is value-in-use which perceives value to be generated when customers use resources. First, if following a GD logic, a supplier does not create value for its customer but rather takes a value-facilitating role. As a value facilitator, the supplier provides a foundation for value creation through the provision of goods, services, information, or other resources. Using the resources provided, the customer then creates value by adding their own resources and skills. Second, if following an SD logic, the supplier not only provides a foundation for value creation but further co-creates value with its customer by engaging directly in the customer's activities through which value is created. Comparing the two models proposed by Grönroos (2008), they could be viewed to reflect different levels of maturity when it comes to the logic actors adopt in their provision of services. In this view of maturity, the SD logic reflects a higher level of maturity due to the co-creation of value, which is missing in the value model based on a GD perspective. Further, the SE perspective proposed by Vargo and Akaka (2012) could be seen to illustrate an even higher level of maturity as actors here are not only co-creating value through direct engagement but further through resource integration. Based on these three perspectives, a continuum can be identified where each perspective represents a reference point along an axis of increasing service system maturity as illustrated in Figure 2 below.

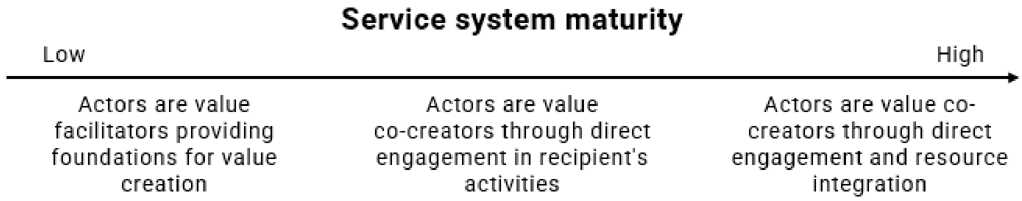

Figure 2: Levels of service system maturity divided by the logic adopted by actors. Based on perspectives from Grönroos (2008), and Vargo and Akaka (2012)

2.1.2 Relationships, actor networks, and capabilities

The concept of service triads (Wynstra et al., 2014) provides useful perspectives when analyzing the roles of different actors in service systems. Halldórsson et al. (2019) apply the concept of service triads to analyze the roles of households, waste service providers, and municipalities, and their interactions in household waste collection systems. Analyzing construction logistic setups, Eriksson et al. (2021) uses the concept of a construction logistics setup triad constituting developers, contractors, and logistics service providers to investigate how the interactions between them are affected by public actors. Similarly to these two examples, the application of the concept of service triads in this study can be expected to yield insights into the roles of actors in actor networks within construction plastic waste flows. Based on the illustration by Eriksson et al. (2021), Figure 3 visualizes a potential triadic service relationship between three central actors, where the white circles represent other actors in the network that the central actors are connected to and interact with.

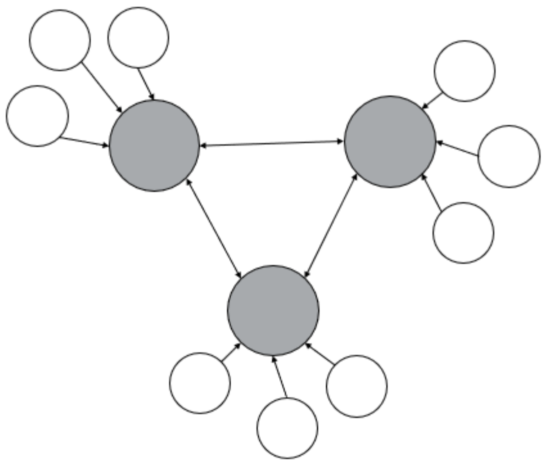

Figure 3: A theoretical service triad, embedded in a broader network of actors. Adapted from Eriksson et al. (2021)

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With a service ecosystem perspective, Wagner et al. (2017) notes that relational structures such as triads can be considered as building blocks of actor networks in broader ecosystems. Analyzing typical relational structures in aftermarkets, Wagner et al. (2017) does not confine to service triads but further identifies a number of tetradic relational archetypes. Wagner et al. (2017) further argues that understanding the typical relational structures between types of actors helps to understand the capabilities and resources needed for service provision in such networks.

2.2 Circular economy business models

The circular economy business model (CEBM) theory builds on business model innovation and circular economy as two essential concepts. CEBM theory explains the role of recycling within the circular economy and describes how value is created and distributed among the actors in a value chain (Geissdoerfer et al., 2020). Hence, the CEBM theory is helpful when exploring how new collaborations that enable recycling can create value for different actors.

In the review by Geissdoerfer et al. (2018) definitions of the term business model in existing research are analyzed. Based on this analysis they define business models as *"simplified representations of the value proposition, value creation and delivery, and value capture elements and the interactions between these elements within an organisational unit."*. Value has a central role in this definition and to show the strategic logic behind value it is categorized into three elements value proposition, value creation and delivery, and value capture based on the framework from Richardson (2008). Lüdeke-Freund et al. (2018) use a breakdown of four value elements by separating the element *value creation and delivery* into the two elements *value creation* and *value delivery*.

The term circular economy business model, CEBM, is explained by Geissdoerfer et al. (2020) as business models that are *"cycling, extending, intensifying, and/or dematerialising material and energy loops to reduce the resource inputs into and the waste and emission leakage out of an organisational system."*. In this definition, cycling refers to when materials and energy are recycled in a system through reuse, remanufacturing, refurbishing, and recycling. Figure 4 is an adapted illustration of the circular economy, originally by Geissdoerfer et al. (2020), where the arrows refer to cycling flows between functions in the economy. The green arrow refers to recycling flows and represents the scope of recycling CEBMs as when the material is taken from disposal back to production.

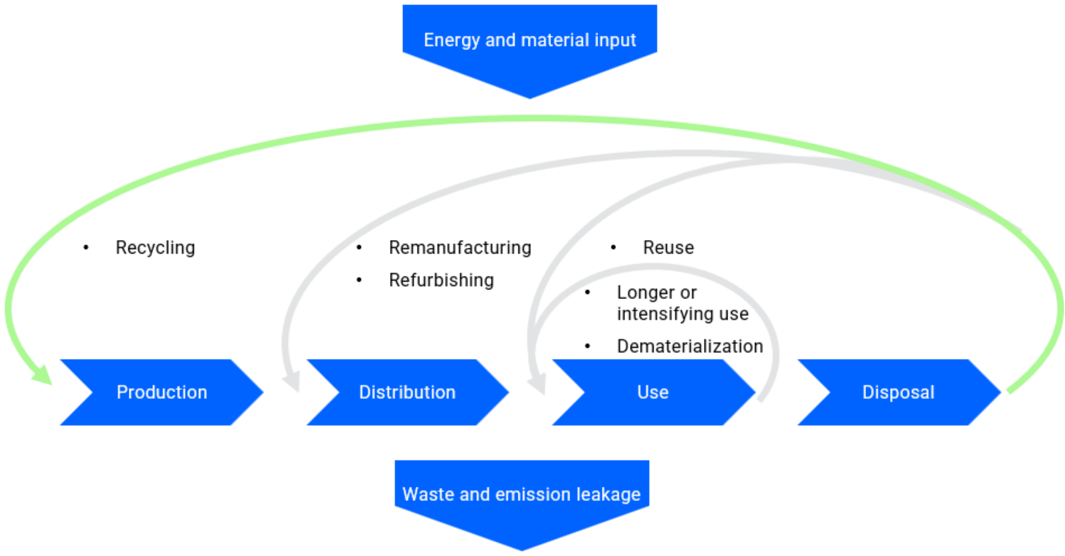

Figure 4: A description of recycling within the circular economy, adapted from Geissdoerfer et al. (2020)

To analyze differences and patterns among recycling CEBMs, value elements are used by Lüdeke-Freund et al. (2018) and Geissdoerfer et al. (2020). First, the value proposition is what a company will deliver to its customers and why the customers will pay for it (Richardson, 2008). A key feature of recycling CEBMs value proposition is material or product take-back which often relies on value chain collaborations and effective reverse logistics (Geissdoerfer et al., 2020). Lüdeke-Freund et al. (2018) state that the take-back value proposition is the provision of waste material or production residues that are otherwise disposed of. Additional value proposition examples are offering recycled input material to manufacturers and manufacturers offering products that use recycled material (Lüdeke-Freund et al., 2018).

Second, the value creation and delivery highlight how a company will create that value for customers and where this value comes from in terms of resources and capabilities (Richardson, 2008). The value delivery process is described by Lüdeke-Freund et al. (2018) to connect downstream and upstream supply chain actors. Therefore, a prerequisite is the capability and resources to organize reverse logistics (Lüdeke-Freund et al., 2018). Value creation is mainly done when used materials are made into new materials with higher value, upcycling, or lower value, downcycling Lüdeke-Freund et al. (2018). Other possible value creation potentials mentioned by Lüdeke-Freund et al. (2018) are to increase the reputation of a company, improve product experiences or give access to production inputs that substitute natural resources. In addition, Geissdoerfer et al. (2020) mention that the environmental value creation potential of recycling CEBMs is reduced waste output and reduced total new material and energy use.

The third and last value element, value capture, is explained by Richardson (2008) to focus on revenue sources for the company and what the economy of the business looks like. The value capture is largely based on material acquisition cost reduction and additional revenue from extended use of materials (Geissdoerfer et al., 2020). Lüdeke-Freund et al. (2018) mention reduced input and product costs as part of the value capture but also mention that normal or higher prices can be charged if upcycling has been done.

Lüdeke-Freund et al. (2018) highlight that CEBMs with recycling services as the value proposition are needed for increasing resource efficiency in general. Further, Material Economics (2019) specifically note that service-focused CEBMs have the potential to improve resource efficiency for plastic materials but that this potential often is overlooked since it is scattered among value chain actors.

2.2.1 Reverse logistics designs

The ability to organize reverse logistics that connect construction companies, manufacturers, and suppliers is a requirement for the value delivery of a recycling business model (Lüdeke-Freund et al., 2018). Therefore, reverse logistics theory is fundamental for the analysis of how to implement recycling collaborations. Blackburn et al. (2004) writes that the reverse supply chain design should be based on the marginal value of time (MVT) among the products i.e. how valuable it is to get them back fast. The MVT is often correlated with how high the demand uncertainty is for the products. Consequently, when the MVT is high, it is important to have a responsive, decentralized reverse supply chain but if the MVT is low the appropriate reverse supply chain is efficient and centralized. The goal of the decentralized supply chain structure is to increase supply chain responsiveness and maximize asset recovery by early process differentiation. The goal of a centralized supply chain structure is to achieve efficiency in terms of processing and transporting costs by collecting as much as possible at one return location (Blackburn et al., 2004).

2.2.2 Actions for circular business model transformation

Actions that incumbent firms can take to overcome barriers and achieve CEBM transformations are described in four steps by Frishammar and Parida (2018). These steps provide guidance in the discussion regarding what actors should consider when pursuing new collaborative actions connected to recycling CEBMs. First, firms have to gain adequate knowledge about the requirement for the transformation. A need is often to increase awareness of guidelines and opportunities about recycling and waste management but also to understand how changed business models create value and for what customers this value is created. Second, firms need to analyze internal business model potential, shortcomings, and scope to make the business model explicit. Third, there is a need for internal alignment with the updated model and external configuration with ecosystem partners so that the CEBM has a good fit in the company and with other actors. Fourth, and finally, the business model needs to be implemented and validated.

Frishammar and Parida (2018) raise key considerations regarding the implementation and validation. It is harder to realize benefits in practice than in theory because of potential trade-offs between economic and environmental dimensions. Further, actors in the ecosystem need to be aligned with each other for a successful CEBM scale-up. Lastly, firms need to balance iterative learning and adjustments with large-scale rollouts for successful implementation.

2.2.3 A theoretical framework for service types

To further describe different circular economy business models, a morphology was created by Lüdeke-Freund et al. (2018) based on the value elements and the eight subcategories products, services, target customers, value delivery processes, partners and stakeholders, value creation processes, revenues and costs. Each subcategory was given design options based on a data set of CEBMs. For the subcategory of CEBMs that had services as value propositions, this resulted in nine generic service design options, presented in Table 1. These nine theoretical design options for service CEBMs are useful for the analysis of current services and help as a frame of reference when coding descriptions of service types.

Service options	Description
Facilitating collaboration	Synergistic partnerships, collaboration among users or between users and producers
Take-back management	Deposit systems, product take-back, take back of used products or waste material
Customer Education	Education to reduce consumption or to reduce waste
Waste handling and processing	Waste collection, recycling, or sorting. As well as eliminating third-party waste
Product-/service-based functions	Leasing or renting out products or equipment, switching from product to a service or paying for functionality
Maintenance, repair, control	Product or equipment maintenance repair and control
Product-/service-based results	Results
Upgrading	Upgrading
Auxiliary services	Databases, shipping, installation and warranties

Table 1: A framework of service design options based on Lüdeke-Freund et al. (2018)

2.2.4 A breakdown for categorization of barriers hindering the provision of CEBMs for construction plastic waste

The following breakdown is based on the studies by Bianchini et al. (2019), Guldmann and Huulgaard (2020), Tura et al. (2019), and Vermunt et al. (2019) which through different methods of studying and compiling existing research about barriers for circular business models have identified barriers and barrier categories for circular business model implementation. The six barrier categories: (1) *Organizational*, (2) *Supply chain*, (3) *Technological, knowledge and informational*, (4) *Institutional*, (5) *Economic and financial* and (6) *Market* had overlap across the studies by Bianchini et al. (2019), Guldmann and Huulgaard (2020), Tura et al. (2019), and Vermunt et al. (2019) where they describe specific barrier examples further to show the emphasis of each category. These descriptive examples are presented in Table 16 in Appendix A. The categories *Technological, knowledge and informational* and *Economic and financial* have more than one descriptive word and encompass barriers that fit into at least one of these words. Finally, Table 2 below shows a breakdown of how barrier descriptions based on examples from interviews can be connected to barrier categories from CEBM theory.

Categories	**Barrier description**	**Barrier Examples**
Category name	Description	Example from interviews
		...
	...	...
		...
...	...	...

Table 2: Breakdown for barrier categorization

2.3 Digital solutions for traceability and sorting of plastic waste flows

This section constructs a theoretical foundation for the third research question based on two aspects. First, there is a need for theoretical perspectives regarding how digital solutions could be used to identify plastic waste streams suitable for recycling. Second, there is a need for theoretical perspectives on how digital solutions could be used to improve the sorting of plastic waste that has been identified and collected.

An organization that aims to facilitate the digitalization of business processes within the construction sector is BEAst (Byggsektorns Elektroniska Affärsstandard) (Samuelson, 2021). BEAst consists of over 100 member companies and organizations and develops digital standards for processes such as procurement, logistics, invoicing, and documentation. While the usage of digital standards could potentially improve the traceability of construction plastics, a lot of information is still being kept in analog formats. One such example is environmental product declarations (EPDs) or logbooks that typically are managed in analog formats which makes information about plastic building materials less accessible (Almasi et al., 2020). Sharing this picture, Ahlm et al. (2021) notes that the current absence of digital EPDs implies a lack of traceability which hinders the recycling of construction plastics. Jansson et al. (2019a) note that logbooks for new buildings enable traceability for the materials used which enables better recycling potential during the demolition of these buildings. However, these logbooks are not available for many of the old buildings that exist today. Almasi et al. (2020) emphasizes the benefit of digital logbooks and argues that higher materials efficiency for plastic could be achieved if this would be required by developers. The advantage of digital logbooks is further corroborated by Ahlm et al. (2021).

For improved waste sorting the European Environment Agency (2021) highlights robotics and AI as technologies that can improve the efficiency of plastic waste sorting. Important to note, however, is that this hypothesis concerns waste in general and not particularly plastic waste within the construction industry. Further, there are few studies on how these technologies apply to plastic waste within the construction industry. Regardless, studies on how AI and robotics could be leveraged to improve general plastic waste sorting are considered potentially capable of providing insights valuable to the context of sorting construction plastic waste. Analyzing household waste, Bobulski and Kubanek (2021) investigate how deep learning could automatize the sorting of plastic waste which is a difficult and expensive process when done manually. While Bobulski and Kubanek (2021) conclude that there is potential economic viability of using robotized sorting processes powered by AI, their tested model only differentiates between the four different plastic fractions of PET, HDPE, PS, and PP. Wilts et al. (2021) investigate robotic sorting based on AI through the implementation of such a system in a municipal waste recovery plant, focusing on HDPE, LDPE, PP, PET, other mixed plastics, and other types of waste. While the robot could grab targeted items effectively, additional items could follow along unintentionally, bigger waste items were more difficult to grab, and uneven waste distribution over the conveyor belt posed another challenge for the robot.

3

Research Methodology

The methodology of this master thesis has been divided into three distinct phases designed to answer each of the three research questions. In the first phase designed to answer the first research question, semi-structured interviews were held to identify current services enabling plastic recycling, as well as barriers hindering the provision of these services. The second phase was carried out using a concept mapping methodology to identify collaborative actions for increased recycling, meaning ways actors could collaborate to increase the recycling rate of construction plastic waste. An analytical framework based on relevant theory was applied to understand how identified collaborative actions could be feasible in practice. Third, to identify digital solutions that could be used to improve plastic waste management semi-structured interviews were held.

An overview of the methodology in this thesis is presented in Table 3 below. This chapter continues with an introduction to the concept mapping methodology, followed by sections on sampling, data collection, data analysis, and research quality approach.

Content of RQs	**Data needed**	**Data collection**	**Results presentation**	**Analytical approach**
1. Identifying (a) current services and (b) hindering factors?	• Existing services • Barriers inhibiting plastic recycling	Semi-structured interviews with experts across the value chain	• Identified service types • Barrier descriptions	• CEBM patterns • CEBM barriers
2. Identifying collaborative actions	• Ideas on collaborative actions • Labeled clusters of ideas • How clusters relate to each other	Concept Mapping with experts across the value chain	• Tables with clusters of ideas • Summarized expert's perspectives on clusters	Analytical framework based on concepts of service triads and tetrads, and service system perspectives
3. Identifying digital solutions	Ideas on digital solutions	Semi-structured interviews with experts on digital solutions	Table with areas of application and hindering factors	Comparison of digital trends and empirical observations

Table 3: Research methodology overview

3.1 Introduction to concept mapping

Combining qualitative and quantitative data collection methods, concept mapping in its typical form is a mixed research methodology (Vaughn & McLinden, 2015) that through a form of structured conceptualization can help generate conceptual frameworks for planning (Trochim, 1989). Typically, concept mapping is conducted through the six steps of (1) *preparation*, (2) *idea generation*, (3) *structuring*, (4) *representation*, (5) *interpretation*, and (6) *utilization*, where the third and fourth steps constitute the quantitative elements of the process. Essentially, these steps are carried out by having (1) a selected group of participants (2) brainstorm ideas in relation to a given focus prompt, to then (3) having participants individually structure the collective group of ideas so that (4) an average clustered map of ideas can be computed based on the clustering of the participants, which then is used as a basis for (5) a final group discussion where participants help interpret how the concept map helps answering the initial focus prompt, and (6) how it can be used. The method is particularly unique in terms of how it enables researchers to work collaboratively with participants throughout the process and how enables capturing a wide range of unique ideas within a participant community. Considering the exploratory nature of the second research question, and the complexity of the construction value chain, the methodology was deemed appropriate as it not only allows identifying a wide range of ideas from a participant community but further as participants are part of interpreting the results. However, concept mapping also stands out when it comes to the amount of time and effort that participants need to invest in the process, particularly for the third step (Vaughn & McLinden, 2015). Thus, the methodology was adapted from its typical form in order to make sure that enough participants would be willing to participate and to ensure that the process could be well executed within the time frame of this thesis. The adaptations made with regard to *structuring* and *representation* will be outlined in section 3.4.2. Additionally, how the steps of *idea generation* and *interpretation* were carried out is described in section 3.3.2. In essence, the process was adapted to a more qualitative approach excluding the quantitative elements typically included.

3.2 Sampling

The main sampling method chosen for this research was non-random purposive sampling. Bell et al. (2019) describes that it is used so that the interviewees can be chosen in terms of specific criteria that allow the research questions to be answered. It is therefore useful in qualitative research since the aim of the study can steer the sampling considerations. Most sampling in this study was done through *generic purposive sampling* since there was a need (particularly for the first and second research questions) to gain insight from a wide range of actors from the construction value chain. However, *snowball sapling* was also used since it makes it possible to utilize knowledge and contacts from interviewees to establish new contacts that suit the sampling criteria (Bell et al., 2019).

3.2.1 Sampling for identification of existing services and barriers

To capture current types of services enabling the recycling of construction plastics as well as current barriers to them, it was deemed necessary to interview representatives from actors across the whole empirical context, see Figure 1. Thus, the actor types that were sought to be represented in the sample were manufacturers, material and equipment suppliers, construction companies, WSPs, and recyclers. While representatives from these actors were thought able to provide deeper insights into existing services and barriers, it was further considered appropriate to reach interviewees with a broader perspective on what services the studied actor types provide and what barriers they face. Hence, researchers and trade associations were included in the sample as well. However, the actor type only illustrates one side of the sample criteria. Further, when searching for interviewees it was desired to include individuals that had been or were working with topics related to construction plastic waste, service development, sustainability, or circularity with respect to construction plastic waste. However, it was still desired to generate a sample where the interviewees had varying experiences and could contribute with complementary knowledge. The final sample is presented in Table 4 below.

ID	Company	Role	Date
C1	Construction company A	Sustainability specialist	2022-10-19
C2	Construction company A	Sustainability manager	2022-10-28
C3	Construction company A	Environmental coordinator	2022-10-21
M1	Manufacturer A	Environmental Specialist	2022-10-19
M2	Manufacturer B	Manager	2022-10-31
M3	Manufacturer A	Salesperson	2022-10-19
RI1	Research institution A	Assistant Professor	2022-11-03
RI2	Research institution A	Project manager	2022-10-13
RI3	Research institution B	Senior Researcher	2022-10-18
S1	Supplier of construction products A	Sustainability manager	2022-11-02
T1	Trade association A	Environmental Manager	2022-11-04
T2	Trade association B	General Manager	2022-10-20
T3	Trade association C	Manager	2022-11-02
R1	Recycling company A	Salesperson	2022-10-20
R2	Recycling company B	Chief Executive Officer	2022-10-21
R3	Recycling company C	Commercial Manager	2022-10-21
WSP1	Waste service provider A	Project manager	2022-10-18

Table 4: Overview of the interviews conducted in the first interview round

To determine the sample size of the semi-structured interviews the concept of saturation was used. Bell et al. (2019) states that theoretical saturation can be reached when new data no longer give new insight or new dimensions of theoretical categories. In this research, saturation was desired when exploring current services and barriers meaning that saturation was to be reached before the continuation of the study. Saturation was reached after 17 interviews when the insights from the final interviews proved to confirm the service types and barrier categories from previous interviews.

3.2.2 Preparation of concept mapping

The *preparation* step includes determining the participants. When it comes to determining the sample of participants, Trochim (1989) notes that it is beneficial for the conceptualization to bring in a variety of people relevant to the subject. Thus, the second research question in this study concerns actors across the value chain of construction plastics, participants from a wide array of actor types were included in the sample. Here, the researchers benefited from already having conducted the first round of interviews when determining participants for the concept mapping process as the established network of interviewees could be leveraged. Since the concept mapping methodology had been adapted to a more qualitative one, snowball sampling was deemed appropriate based on the considerations by Bell et al. (2019). The final sample, presented in Table 5 below, included 15 participants in the *idea generation* step, and six participants in the *interpretation* step. Regarding sample size for the concept mapping process, Trochim (1989) notes that 10-20 participants are a manageable number but that there are studies with more respectively fewer participants in the process, or having different sample sizes for different steps of the process. However, the aim is still to create samples that can generate a wide variety of unique ideas, and that enable good group discussion in the interpretation step. Thus, regarding sample size for *idea generation*, the researchers found 15 participants enough as these participants represented two different manufacturers of plastic products, one construction company, three different waste service providers, a recycling company, and four different research institutions. For the *interpretation* step, the researchers found it critical to limit the number of participants to ensure that every participant would have their say on each topic. However, it was still made sure that key actors across the value chain were included, having representation from a manufacturing company, a construction company, two different waste service providers, and one recycling company.

ID	Company Type	Role	Idea generation	Interpretation session
C1	Construction company A	Sustainability Specialist	Workshop	
C3	Construction company A	Environmental Coordinator	Workshop	✓
C6	Construction company A	Research Coordinator	Workshop	✓
M1	Manufacturer A	Environmental Specialist	Workshop	✓
M2	Manufacturer B	Manager	Workshop	
R3	Recycler C	Commercial Manager	Workshop	✓
RI1	Research institution A	Assistant Professor	Survey	
RI3	Research institution B	Senior researcher	Workshop	
RI4	Research institution B	Senior researcher	Workshop	
RI5	Research institution C	Senior researcher	Survey	
RI6	Research institution D	Project manager	Survey	
WSP1	Waste service provider A	Project Manager	Survey	
WSP3	Waste service provider B	Analyst	Workshop	✓
WSP4	Waste service provider C	Commercial manager	Survey	✓
WSP5	Waste service provider A	Project Manager	Survey	

Table 5: Overview of the concept mapping participants in this study. Participation in the interpretation session is indicated with "✓"

3.2.3 Sampling for identification of digital solutions

The network of experts that the researchers had gotten in touch with from the first interview round was helpful to identify an appropriate sample for the second interview round. The researchers were able to ask previous interviewee subjects if they knew someone who was working exploratory with digital solutions for improved waste management, or digital solutions in service development. Through past interview subjects, the researchers were able to identify dour different experts, representing three different actor types in the construction value chain. These four interviewees are presented in Table 6 below.

ID	Company Type	Role	Date
C4	Construction company A	Digital Transformation Manager	2022-11-11
C5	Construction company A	Digital Transformation Manager	2022-11-14
CLSP1	Construction Logistics Service Provider A	Business Development Manager	2022-11-11
WSP2	Waste Service Provider A	Business Solution Manager	2022-11-11

Table 6: Overview of the interviews conducted in the second interview round

3.3 Data collection

Different data collection methods were used to get the desired primary data. Two rounds of semi-structured interviews were conducted to collect the data needed to answer the first, respectively the third, research questions. The data needed to answer the second research question was collected using a concept mapping methodology and was further complemented with findings from the first round of interviews. The following sections will explain the data collection methodologies in more detail.

3.3.1 Interviews

Bell et al. (2019) notes that semi-structured interviews are preferable when the researcher has a somewhat clear focus for the interview, but still wants the flexibility to dive deeper into potential topics raised by the concerned interviewee, this type of interview was used for both interview rounds in this study. An interview guide was sent out prior to each interview to help make sure that desired topics were covered in each interview and also to prepare interviewees for the subject at hand before the interview. Information about recording was included in the guide as it is important to inform about and get approval for recording before the interview (Bell et al., 2019). To ensure the quality of the collected data, general information about each interviewee as name, job title, and company, was collected in line with what is suggested by Bell et al. (2019).

Two rounds of interviews were conducted in this study. The first round served the purpose to provide insights valuable in relation to the first research question of this study. The second round of interviews, building on the identified service types, focused on deepening the insight into key areas identified through the interview process to provide valuable knowledge in relation to the third research question. Since the interviews were semi-structured and both rounds dealt with services for plastic recycling, there appeared unintended relevant data from the first round that was considered to be evidence for the research question meant to be answered by the second round and vice versa.

In the first interview round, 16 interviews were held and recorded, each having a duration of 45 minutes except T1 who could not allocate more than 30 minutes for the interview. Interviewees M1 and M3 were interviewed simultaneously, as they believed their combined knowledge would enable a more insightful findings based on the interview guide, giving the first round a total of 17 interviewees. See Table 4 for an overview of the first round of interviews. The second round of interviews consisted of four 30-minute interviews and is summarized in Table 6. The interview with C2 was held in person while the rest was held with video conferencing software.

3.3.2 Idea generation and interpretation in the concept mapping process

Apart from determining the sample, the *preparation* step in the concept mapping process also includes developing the focus prompt to be used in the *idea generation* step (Vaughn & McLinden, 2015). The researchers developed different suggestions and discussed these prompts with the two supervisors of this thesis to ensure a focus prompt that was suitable for the second research question. The final focus prompt used in the idea generation step in this thesis was:

> "In the Idea Generation workshop, we want you to generate short phrases or statements which describe ... how actors could collaborate better to enable an increased recycling rate of construction plastic waste”

The aim of the *idea generation* step is to obtain the individual perspectives from each of the participants in light of the focus prompt (Vaughn & McLinden, 2015). In this concept mapping process, nine of the 15 participants were gathered for a 30-minute virtual workshop held with video conferencing software. This workshop was divided into three phases. First, the researchers held a brief introduction and described the background and the aim of the thesis. Participants were encouraged to ask questions at any point during the workshop if anything was unclear. Further, since the focus prompt was broad, participants were encouraged to try to be as specific when writing their ideas. Second, participants were given a bit over 10 minutes to write as many ideas as they could come up with in relation to the focus prompt. The digital tool Mentimeter was leveraged for the collection of ideas. Third, after participants had submitted their ideas, the researchers could directly present the submitted ideas to the whole group. Participants were then able to briefly read through the ideas and were encouraged to point out if there were any ideas suggested that seemed unclear.

The six participants that were not able to attend the workshop were instead sent a digital form. Microsoft forms was used for this process, and it was made sure to provide the same instructions in the form as the participants would get in the workshop. The participants were encouraged to contact the researchers if they had any questions before starting the form and if there was anything they would like to add after completing the form. One of the respondents sent such an email to add another idea she came up with.

The second part of the concept mapping process that regarded data collection was the fifth step of *interpretation*. Vaughn and McLinden (2015) note that the aim of the interpretation step is to gather the participants to have them discuss how the concept map of ideas helps answer the focus prompt and how it could direct future actions. When the concept mapping process is conducted in its typical form, the interpretation step should also include discussions around further analytical constructs created in the fourth step of *representation* (Trochim, 1989; Vaughn & McLinden, 2015). However, since interrelated analytical steps of (3) *structuring* and (4) *representation* were adapted in this concept mapping process, explained in section 3.4.2, the only analytical construct that was covered in the *interpretation* step was the concept map of the ideas obtained clustered into groups of similarity. In order to understand how the constructed concept map answered the focus prompt, and how it could be used to direct actions forward, the six participants noted in Table 5 were gathered for a 40-minute interpretation session workshop. During the workshop, the concept map with its eight identified clusters of ideas – eight collaborative actions – was discussed with respect to two aspects. First, participants were asked if the label given to each cluster captured the contained ideas and if there were any of the ideas that did not seem to belong to the collaborative action they had been associated with. Second, participants were asked to share if there were any of the ideas within a collaborative action that they perceived as particularly important and to raise any additional remarks that should be considered to make the collaborative action possible. Having participants discuss perspectives in the group enabled a deeper understanding of the collaborative actions identified.

The workshop was held with video conferencing software and all participants consented to have it recorded. This enabled the researchers to focus on facilitating the workshop and still be able to correctly capture all the perspectives from each participant by transcribing the recorded material afterward.

3.4 Data analysis

In this section, the conducted data analysis is described in three parts. First, the thematic analysis of interview data is explained. Second, the analysis of the data generated in concept mapping is described. Third, it ends with an analytical framework that illustrates how integrated theoretical perspectives will be applied to analyze the findings of the study.

3.4.1 Analysis of interview data

Thematic analysis in form of coding was used in this study to process the data from the recorded interviews. According to (Bell et al., 2019) the coding method breaks down information into smaller components so they can be processed in a better way. Recorded interviews were reviewed and relevant information was transcribed into categories that were relevant for answering the research questions. In accordance with the considerations from Bell et al. (2019) the categorized data was labeled with codes so that connections between the data and theoretical ideas could be drawn. Coding was done in one or two layers. To answer research question 1a examples from interviews were coded into different service types. The Table 1 with service design options by Lüdeke-Freund et al. (2018) in section 2.2.3 was used as a frame of reference to do the initial coding. When coding barriers for research question 1b, they were first coded to general barriers or barriers for specific services. Later, they were coded at a more detailed level regarding what they were inhibiting using the structure presented in Table 2 in section 2.2.4. To answer the third research question, digital solutions mentioned by interviewees were identified. The viability of these digital solutions was analyzed by comparing potential application areas and hindering factors.

3.4.2 Structuring and representation of generated ideas in the concept mapping process

The steps of *structuring* and *representation* were adapted to lower the burden on the participants in the concept mapping process to ensure that enough participants from a variety of different actor types would be represented. Thus, while the *structuring* step typically means having participants sort the generated collection of ideas into groups of similarity (Vaughn & McLinden, 2015), this process was instead conducted by the researchers of the study. Since the hierarchical cluster analysis typically conducted in the representation step (Vaughn & McLinden, 2015) depends on the input of sortings from the participants, this part of the methodology was no longer applicable. The rationale behind the typical quantitative process is that it enables the construction of a conceptual map entirely based on the collective perspective, that further is free from any subjective beliefs of the researchers (Vaughn & McLinden, 2015). To handle this issue and to make sure that the generated concept map of collaborative actions reflected the beliefs of the participants, the researchers made sure to ask participants whether they agreed with the conceptualization during the *interpretation* step, as mentioned in section 3.3.2 earlier.

The steps of *structuring* and *representation* were adapted into a five-step process. First, in line with Vaughn and McLinden (2015) the list of ideas obtained from the *generation* step was refined to make sure that it only contained unique ideas. Duplicate ideas were removed and submitted ideas that contained two or more unique ideas were split into separate unique ideas. Second, the two researchers numbered the ideas in the refined list and individually sorted them into groups of similarity. Third, the researchers compared the overlaps of the two different groupings and constructed a final grouping through an iterative process of discussion and regrouping. Fourth, The researchers individually wrote a suggested name for each cluster. Fifth, the researcher compared the names suggested to then create a final name for each cluster. The eight named clusters obtained represented the concept map of eight different collaborative actions that were brought to the interpretation workshop explained earlier in section 3.3.2.

3.4.3 Analytical framework

In order to answer the second research question, there was a need to identify possible ways actors can collaborate. While the empirical findings from the concept mapping methodology were deemed to generate a map of potential collaborative actions, there was a need for an analytical tool to understand how each collaborative action could be feasible in practice. This understanding could be built through the analysis of three perspectives. First, the actors central to, and the role of each actor in, the service systems enabling each respective collaborative action. Second, the collaboration complexity with respect to the number of central actors involved and the intensity of collaboration. Third, how value is generated in respective service systems. Building these three perspectives by leveraging the concept of service triads and tetrads (Wagner et al., 2017; Wynstra et al., 2014), insights from the GD–, SD–logic, and service ecosystem perspectives (Lusch & Vargo, 2014; Vargo & Akaka, 2012; Vargo & Clavier, 2015), lays a foundation to categorize collaborative actions with respect to collaboration complexity and service system maturity as described in Figure 5. Such a categorization was deemed appropriate to understand the resources and capabilities needed for actors to pursue the respective collaborative actions, and how different collaborative actions relate to each other.

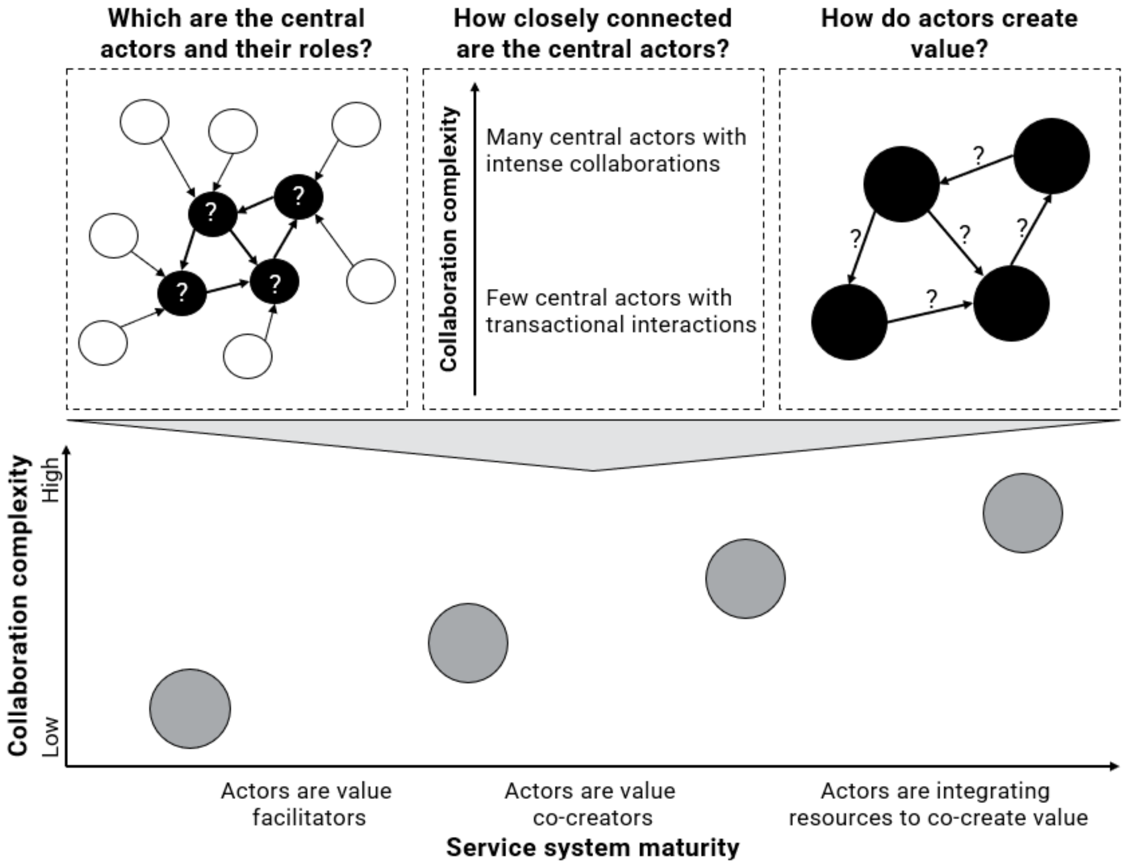

Figure 5: An analytical framework to analyze collaborative actions enabling increased recycling

3.5 Research quality

To ensure the quality of this research, trustworthiness was used as a measure. According to Halldórsson and Aastrup (2003) trustworthiness can be divided into credibility, transferability, dependability, and confirmability.

Credibility indicates how well the respondents' constructions of reality match the representations made by the researches(Halldórsson & Aastrup, 2003). This was worked with by leveraging insights from interviewees to support understanding in the following interviews. Regarding concept mapping, the probability of good credibility was higher since respondents were responsible for a part of the data analysis as well as the data generation. To further help the researchers understand the interviewees a site visit to a large recycler facility was done on November 16, 2022.

The second trustworthiness component, transferability, represents how well the study can make general claims about the world (Halldórsson & Aastrup, 2003). Transferability is challenging for this study since construction and waste systems work differently around the world and all the respondents are based in Sweden. Increased transferability was pursued by having a diverse sample of interviewees so that the data would reflect different views making the findings more transferable. Several respondents were part of multinational companies, giving a more general view of barriers and opportunities. However, it is important to note that findings come from a context with EU and Swedish regulations. For the reader to get an understanding of the study limitations and be able to conduct similar studies in other construction contexts the methodology is explained in a transparent manner and the interview guides are attached in appendix B.

Dependability is the third component of trustworthiness and concerns how stable data is over time (Halldórsson & Aastrup, 2003). To achieve dependability, thorough documentation was done during the research process by taking notes, describing theoretical models, and describing the logical methods and processes.

The final component, confirmability, reflects that the findings are free of bias from the researchers (Halldórsson & Aastrup, 2003). To make sure that the findings reflected the results, the interpretations and recommendations were clearly described so they can be traced back to their sources. Since the researchers were responsible for the structuring and representation of concept mapping ideas validation was important for confirmability. The concept mapping clusters were therefore validated by the interpretation session group and the general findings were validated through a presentation to the construction company client. Finally, the findings were shown to an opponent group and reviewed to strengthen objectivity.

4

Empirical Findings

This chapter is divided into five sections and presents the main findings of the study. First, existing barriers to increased plastic recycling that were identified in the first round of interviews are presented. Second, to answer research question 1, identified service types enabling the recycling of construction plastic waste are presented and connected with specific hindering factors. Third, the eight identified collaborative actions are presented along with the ideas they comprise. Fourth, summarized insights from the interpretation session are presented for each of the four actor types that were represented in that session. Last, findings from interviews on how digital solutions could be used to improve plastic waste management are summarized together with the hindering factors they face.

4.1 Barriers behind the low recycling rate of construction plastic waste

Analyzing the first round of interviews resulted in 113 statements about barriers to construction plastic recycling. These describe the hindering environment for services that currently enable plastic recycling giving a foundation for answering research question 1. These statements were grouped into six categories based on the format in Table 2 that builds on theoretical examples that can be viewed in Table 16 in Appendix A. Descriptions of types of barriers found within each category are summarized in Figure 6. The full categorization with illustrative examples from interviews can be found in tables 17,18 and 19 in Appendix A.

Economic and financial	Technological, knowledge and informational	Supply chain	Institutional	Organizational	Market
Low financial impact of improved plastic handling process	Technological challenges	Lack of network support, partners, and needed resources	Ineffective legal instruments	Difficult to organize for effective on-site sorting into many fractions	Unstable market of recycled plastics
Complex recycling logistics is a critical cost issue	Lack of collection, aggregation, and sharing of information on plastic waste flows	Supply chain actors lacking incentives for handling plastic waste	Lack of procurement regulations that generate demand-pull	Narrow focus of existing sustainability strategies	Competitive plastic market and low price of virgin plastics
Incineration flows are currently more cost effective than CEBMs	Lack of knowledge and experience in waste handling	Collaboration and communication issues			

Figure 6: Overview of identified barriers inhibiting material recycling of construction plastic waste. Full categorization can be found in the tables 17, 18 and 19 in Appendix A

First, in the category *Economic and financial* barriers, the interviewees highlighted three problem areas. First, C2 and RI2 argued that questions regarding the plastic recycling process are not getting prioritization because of the lack of financial impact of changing the plastic handling process in construction projects. Second, C2, R3, M2, and T3 said that the plastic recycling process is complex and carries high logistic costs. Examples of logistic cost drivers were the need for separate handling of different plastic types in different fractions according to C2 and the low density of plastic according to T3. Third, as a consequence of the cost drivers, using new CEBMs in many cases results in higher expenses than using linear supply chains for energy recovery according to WSP1 and T2.

The second category *Technological, knowledge, and informational* consists of three problem areas. The first area relates to technological aspects. Transparent plastics have a higher recycling value but C3 stated that colored plastics are needed in construction plastics since it protects some products from UV radiation. This is a barrier when striving for a transparent standard among construction packaging. R3 states that there is no technology that can enable the automatic sorting of rigid plastics into high-quality fractions that enable recycling that is not downcycling. Second, in the problem area of collection, aggregation, and sharing of information C2 mentioned that there are too few metrics that show plastic recycling results, that compilations are missing about climate savings from recycling flows, and that statistics are lagging behind. These barriers limit feedback and information flows that would incentivize working towards circular systems. C3 added to this by mentioning the lack of efficient communication systems for sharing relevant information with other actors. The third problem area concerns a lack of knowledge and experience in waste handling and was mostly mentioned by interviewees from research institutions. RI2 talked about a knowledge gap regarding how to handle waste among onsite people and a big discrepancy regarding experience and information made available for different construction site workers. RI1 mentioned a lack of knowledge among purchasers on what material has recycling systems when buying plastic products for construction projects.

Supply chain is the third category that consists of three problem areas. The first is the lack of network support, partners, and resources. An example from C1 is the lack of off-site sorting possibilities while RI3 highlighted the lack of recycling plants wanting to receive not fully sorted plastic. The second barrier regards path dependency on the functioning linear supply chain where there are few incentives to change the current structures and processes. Both RI1 and M1 said that incentives are low to sort plastics for the actors that are present on a construction site where the waste first occurs. RI1 pointed out that the supply chain focus is mainly on flows going into the construction site and less focus is on outflows. The third supply chain problem area concerns collaboration and communication issues. In the interview with RI3, this was raised for actors in general. M2 expressed the need for manufacturers and waste contractors to collaborate to close the loops and have both product designs that fit the supply chain and supply chains that work for the products. T2 said that it can be hard to communicate with smaller involved subcontractors in the current value chains.

The fourth category describes *Institutional* barriers broken down into two problem areas. First, a majority of interviewees mentioned ineffective legal instruments. T2, RI2, and R1 pointed out that the European Union law for sorting plastics in one separated fraction is not enough to enable high-quality recycling. C3 talked about the lack of legal obligations concerning the production of recyclable products. T3 stated that good regulations exist but that insufficient law supervision is a barrier because less serious actors can break laws to be able to undercut complying actors without consequences. Second, the lack of regulations that generate demand pull for plastic products with recycled material is a problem area highlighted by T1 and R3. R3 mentioned that they have suffered from large demand uncertainty when they sell processed plastic waste and that one reason is that there is no quota obligation for recycled plastic in place. According to R3, a quota obligation could be a fixed threshold that stabilizes the demand and enables longer-term investment and planning.

Furthermore, the fifth category *Organizational* is divided into two problem areas. The first is the difficulty to organize for effective on-site sorting into many fractions. According to C3, this challenge is a crucial reason for the low recycling rate. RI2 mentioned a reason for the challenge being a lack of standard procedures for the on-site sorting of different fractions. RI3 added that the many different actors on construction sites make the sorting procedures harder. Furthermore, T2 emphasized that the lack of physical space and time to do on-site sorting can be a consequence of recycling not being considered in the early stages of planning. The second problem area is the narrow focus of existing sustainability strategies is a prob. An example that was raised by T1 is that the strategic focus historically mainly has been on removing dangerous waste and not on removing non-recyclable waste.

The sixth category is about *Market* barriers and is also divided into two problem areas. The first area concerns market instability. R3 mentioned that the market prices for recycled plastic granulates are very volatile. Even in larger markets like recycled PP and PS, the prices can swing on a month-to-month basis, making planning difficult. The second area regards the competition in the construction product market. R1 explained that it is hard for new recyclable products to compete since products are often procured based on price competition only, and not sustainability aspects.

4.2 Current services enabling plastic recycling within the construction sector

The first interview round resulted in several different examples of services that currently enable plastic recycling within the construction sector. To answer research question 1(a) with Table 1 as a theoretical framework, these were compiled into six distinct service types, listed in Table 7. In this section, the general functions of the service types and how they enable recycling are described. Additionally, to answer research question 1(b), they are connected to examples from problem areas described as hindering factors. Finally, an overview of the service types is presented in Figure 7.

Identified service types
Collaborative services for sorting
Waste handling and processing
Take-back management
Joint waste transportation and intermediate storage
Leasing or renting out equipment
Knowledge sharing and information provision

Table 7: Identified service types that currently enable plastic recycling within the construction sector

The first identified service type is called *Collaborative services for sorting* and was described by WSP1, RI2, C1, C3, and C2 as having the main focus on enabling recycling by improving on-site sorting. The interviewees explained that on a construction site, a WSP has personnel that manages the waste containers, information signs, and coordinates call-offs and pickups. The potential ways value is created for the construction contractor are that the gate fee for disposing of plastic is reduced when plastics fractions are of higher quality, the logistic efficiency related to waste collection can be increased when coordinated with WSPs, and the construction workers can have an efficiency increase since less time is spent on waste handling. Regarding financial hindering factors, C3 mentioned that the outcome of a service in this service type is uncertain since it depends on the competence and motivation of the responsible person. A risk is that the value created by gate fee reduction and construction worker efficiency increase becomes too low to motivate the additional cost of on-site WSP personnel. Regarding organizational barriers, C2 added that construction site workers risk losing the sense of responsibility for waste sorting when external waste coordination personnel is present.

Waste handling and processing was mentioned by all interviewees in the first round and covers the type of services that occur after the plastic has reached a WSP. These include but are not limited to off-site sorting, shredding, grinding, granulating, cleaning, and storing. This service type is enabling recycling since it is directly value-adding to plastic waste. After the provision of these services, plastic can be sent to manufacturers who after using it in production processes can sell products with recycled plastic to construction companies. R3 stated that this step does not turn the waste into a product or production material according to current law. However, the waste definition can be a gray area and manufacturers use shredded flakes or granulate as products directly in injection molding without having permission to handle waste. According to WSP1, one specific hindering factor is the large variety of plastic types in waste streams which has the implication of making processing more expensive and risks lowering the output quality. Another specific hindering factor is the need for manual labor, which is a result of the input variety combined with the technological limitations for automated sorting according to R3. Regarding the supply chain, RI3 and WSP1 said that waste handling facilities are few making the logistics costly when having to source material from distant sources. Finally, problems for other upstream services are also indirect problems that can increase material and operational costs for *Waste handling and processing*.

The service type *Take-back management* was mentioned by RI2, RI3, C1, T2, C3, S1, RI1, T3, C2, M1, and M3 and covers services that manage takes-back of plastic waste to manufacturers. Thus, services enable recycling by managing logistics and separating products into fractions that specific manufacturers have the competencies to recycle. The examples mentioned in interviews cover take-back of installation residue for different types of products and take-back of packaging. The logistic arrangement for the take-back differs between examples and can be done by subcontractors or waste service providers. A specific hindering factor according to C2 is that waste quality requirements can limit manufacturers from using a recycled mix since a mix can create variations in product quality. C2 said that installation residue often has high quality but still can be hard to use due to variation requirements. Further, T3 highlighted that take-back plastic flows are even smaller and more dispersed than regular plastic waste flows, cutting the service profitability.

The next identified service type is *Joint waste transportation and intermediate storage*. RI1, R3, and RI2 mentioned that existing services of this type enable recycling by reducing related logistic costs in two ways. First, the plastic volume per transport can be increased through the development of hubs where plastic from projects that are close can be stored until a truck volume is reached. Some tested hubs handle waste from different actors. Second, the logistic cost can also be reduced by having one truck pick up waste from multiple construction sites in the same collection round, these pickups have been synchronized by two-way communication or via a digital platform. One specific hindering factor mentioned by RI2 is the lack of actor networks that collaborate and trade with each other. A consequence of this mentioned by RI2 was that attempts at hubs and joint transportation had not been reliable enough to be viable. Therefore, a foundation for this service type is to have an established connected actor network. Further, no interviewed value chain actor expressed historical efforts of owning and operating a waste hub like this on more than a project level. CLSP1 saw the possibility of them taking the ownership role but with the help of third-party waste handling.

The fifth service type is *Leasing or renting out equipment* that can enable plastic recycling by lowering handling and logistic costs. Interviewees, M2, R3, RI1, RI2, WSP1, and C2 mentioned this type of service and highlighted equipment types: compressors, balers, and containers. RI2 mentioned compressors being used to compress plastic on-site to make it less bulky and increase density to enable more plastic per transport. WSP1 said that transports often become expensive because construction sites lack compressors but that the use of compressors relies on a good sorting of the plastic since it makes later separation more complicated. Balers and containers help structure the storage of plastic waste according to R3. RI2 stated that timing and space on the construction site are hindering factors since the equipment is bulky and mostly needed during short times of construction projects when large volumes of plastic packaging waste occur. Containers are mentioned to be bundled in the service office from a WSP but can also be rented from CLSPs according to CLSP1 and R1. A specific hindering factor mentioned by S1 is that most containers only have one big compartment making it hard to keep small plastic fractions apart if they are not separated in sealed bags before being thrown into the containers. Additionally, RI1 mentioned the lack of space for equipment on the construction site.

Several services of the type *Knowledge sharing and information provision* were described as being overarching enablers of plastic recycling by T1, T2, WSP1, M1, M3, C2, RI2, and R1; thus, it comprises the sixth service type. Three example services were sorting education, feedback, and information sharing about recycling capabilities. First, R3 mentioned education about different types of plastics and how to distinguish them from each other being offered from recyclers to sorting personnel. WSP1 further talked about sorting education being offered by WSPs to contractors and about the relevance of providing updated information about sorting methods. Second, feedback was mentioned by M1, M3, and T1 regarding recycling statistics provided both to construction companies on a project level and to manufacturers to show their material recycling rates. Third, T2 mentioned that trade organizations gather and share information about what actors have the capabilities to recycle different building materials. A challenge with these three services is that communication needs to be done between many different actors. There is a need for knowledge sharing about recyclability both internally between different parts of a construction company such as procurement and environmental coordinators and externally to subcontractors, manufacturers, and WSPs according to RI2. Additionally, a specific hindering factor is the lack of follow-up consensus for recycling such as common KPIs, feedback, and instructions according to C2 and WSP1.

To summarize, these six identified service types are currently enabling plastic recycling but are limited by several hindering factors. Many of these hindering factors are indirect or direct consequences of barriers within the barrier categories presented in Figure 6. A descriptive overview of the six identified service types is presented in Figure 7 where they are connected with key actors, service actions, and specific hindering factors.

	Identified service types					
	Collaborative services for sorting	Waste handling and processing	Take-back management	Joint waste transportation and intermediate storage	Leasing or renting out equipment	Knowledge sharing and information provision
Key actors	-Contractor -Subcontractors -Waste Service Provider -Recycler	-Subcontractors -Waste Service Provider	-Contractor -Material Manufacturer -Subcontractors -Waste Service Provider -Trade associations	-Construction Logistics Service Provider -Waste Service Provider -Recycler	-Construction Logistics Service Provider -Waste Service Provider	-Contractor -Material Manufacturer -Subcontractors -Waste Service Provider -Recycler
Service examples	-Coordination of waste fractions, containers, and pickups -Alignment of recycling capabilities -Alignment of sorting procedures	-Transport -Off-site sorting -Shredding, grinding, and granulating -Cleaning -Storing	-Transport (reverse logistics) -Residue collection and sorting -Input in the manufacturing process -Authorization provision	-Multiple site pick-up and co-transport -Storage of plastic fractions at a hub -Co-transport to a recycler	-Rental of equipment e.g., Compressors or balers -Rental of different waste containers	-Feedback on recycling -Information sharing of recycling capabilities
Specific hindering factors	-Outcome uncertainty -Shared waste responsibility issue	-Varying waste input -Need for manual sorting -Expensive transport	-Material quality requirements -Small and dispersed plastic flows give high logistic costs	-Need for a network of competitors to trade and collaborate -No obvious owner of hubs in the current value chain	-Lack of space for equipment on construction site -Lack of containers designed for plastic waste	-Lack of recycling follow-up standards -Many different actors on construction sites

Figure 7: Descriptions of the identified current service types based on key actors, service examples, and specific hindering factors

4.3 Collaborative actions for increased recycling of construction plastic waste

The concept mapping process was designed to provide answers to the second research question and resulted in eight clusters of ideas. Each cluster represents a collaborative action that has the potential to increase the recycling rate of construction plastic waste. The eight collaborative actions are presented in Figure 8 below, and subsequent sections will describe each one in more detail.

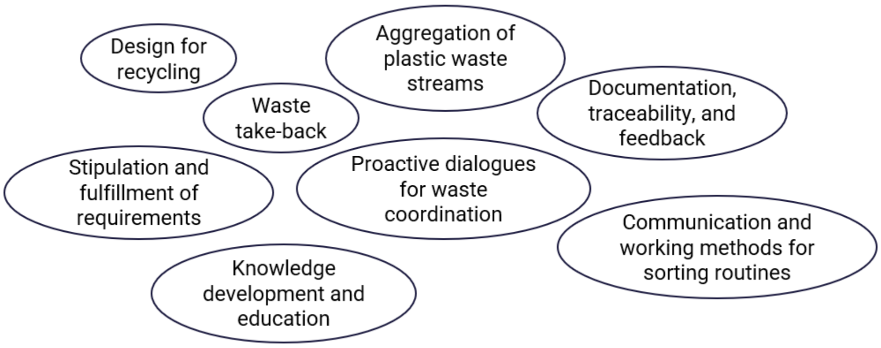

Figure 8: Concept map of identified collaborative actions (plotted without any relative order)

4.3.1 Design for recycling

The six statements the researchers grouped together and labeled *Design for recycling* are presented below in Table 8. The majority of the ideas regard examples of how different actors could collaborate with manufacturers and suppliers to design products, respectively packaging, that are possible to recycle. Thus, ideas number 14 and 34 are a bit different in nature as they regard how the application of modular construction could enable higher recycling rates of waste flow from demolition and refurbishment. While these design strategies do not regard products or packaging, they were still considered to be part of the category *Design for recycling* as they capture how other actors than manufacturers can increase recycling rates through new designs.

Design for recycling
10 - Material suppliers and waste contractors can have better dialogues on how to design plastic packaging to facilitate recycling/increase recycling rates.
14 - The use of modular construction techniques can create better conditions for recycling by allowing cleaner plastic waste fractions during demolition.
21 - Material manufacturers can redesign plastic products that are currently not recyclable to create better conditions for recycling.
23 - Recyclers and material manufacturers can communicate better so that more material can be used for new products.
30 - Construction contractors and suppliers of building materials can develop standards for packaging designed for recycling.
34 - Construction contractors can develop building systems that enable separation of plastics during demolition/refurbishment.

Table 8: Ideas within the collaborative action *Design for recycling*

4.3.2 Waste take-back

While the four unique ideas within the cluster *Waste take-back*, presented in Table 9 have similarities, they were kept because of two different nuances. First, different types of plastic waste or product flows have different requirements for the structure of waste take-back systems. Second, the systems may vary further in structure depending on which actors are to be central in these systems.

Waste take-back
11 - Material suppliers and contractors can set up installation waste recovery systems.
12 - Material supplier and contractor can set up packaging take-back systems.
18 - More recycling schemes for plastics - where producers cooperate with waste contractors regarding logistics and take-back of their own materials/products can be created.
29 - Material suppliers/manufacturers can develop systems for taking back waste

Table 9: Ideas within the collaborative action *Waste take-back*

4.3.3 Aggregation of plastic waste streams

The five ideas within the cluster *Aggregation of plastic waste streams* all concern how different types of actors could collaborate for more efficient waste handling and transportation. These ideas are presented in Table 10 below.

Aggregation of plastic waste streams
3 - Recycling contractors can set up facilities for post-sorting of plastic waste from construction plastics.
8 - WSPs can pool more materials and have intermediate storage sites for cost-effective logistics.
13 - Recyclers and waste contractors can work together on collection and logistics to create better conditions for recycling.
16 - WSPs can develop intermediate storage services to facilitate the collection of different types of plastics that require large volumes to be recycled.
28 - Local and regional collection hubs can be established to enable more efficient transport.

Table 10: Ideas within the collaborative action *Aggregation of plastic waste streams*

4.3.4 Documentation, traceability, and feedback

The ideas within the cluster *Documentation, traceability, and feedback*, presented in Table 11, regard actions for increased documentation of plastic flows and actions for sharing that documentation in such ways that plastic recycling can be increased.

Documentation, traceability, and feedback
15 - Improved transfer of information on material characteristics when plastic materials are passed on to the next actor in the value chain.
17 - Contractors need to document volumes going to recycling and get feedback from recyclers on recycling rates.
22 - Clearer information structures from material suppliers to contractors to WSPs are needed to ensure knowledge of the composition of plastics.
44 - Actors can establish a data information flow that runs through the entire value chain.
49 - Actors can collaborate to align systems - measurements and KPIs.

Table 11: Ideas within the collaborative action *Documentation, traceability and feedback*

4.3.5 Stipulation and fulfillment of requirements

The ideas presented in Table 12, do all concern requirements or demands that in some way can increase plastic recycling. However, idea number 20 regards supervision to ensure that requirements are followed rather than how requirements and demands could be stipulated. Though, since supervision that requirements are followed is closely related to requirements for increased recycling, it was considered part of the cluster. This resulted in the label *Stipulation and fulfillment of requirements*.

Stipulation and fulfillment of requirements
1 - Procuring actors can require recycled plastics when purchasing materials.
4 - Contractors can work together to demand homogeneous plastics - such as packaging plastics.
20 - Increased supervision of waste management can improve compliance with sorting requirements.
31 - Cooperation between recyclers and manufacturers of plastic components/products can be intensified to increase demand for recycled plastics e.g. review the possibility to match the quality of recycled material with the performance requirements of the customer.
45 - Actors can work together to reward procurement that rewards recycled plastics.
46 - Actors can work together to limit the number of plastic types on the market.

Table 12: Ideas within the collaborative action *Stipulation and fulfillment of requirements*

4.3.6 Proactive dialogues for waste coordination

The seven ideas within the cluster *Proactive dialogues for waste coordination*, presented in Table 13 all reflect actions of proactive information sharing to establish better conditions for a more efficient waste handling of higher quality. While the majority of ideas regarding how different actors can cooperate, ideas nr 40 and 47 reflect the further need for contractors to have internal proactive dialogues between purchasing and construction functions to optimize waste handling.

Proactive dialogues for waste coordination
2 - Contractors and WSPs can work more closely together to highlight recycling opportunities in specific projects.
7 - Actors can make an inventory of materials during demolition/renovation so that recycling stakeholders can get an insight into what can potentially be recycled.
24 - WSPs can inform recyclers about waste streams that can potentially be recycled.
25 - Demolition companies/property owners can inform recycling operators about potential materials that can be recycled during demolition/renovation.
32 - Waste contractors can be clearer about which plastic fractions should be sorted out separately in a construction project based on the local conditions for handling and recycling.
40 - A better dialogue between the purchasing function and the production of the construction company - further to the waste contractor - can create better conditions for recycling.
47 - Internal cooperation between purchasing function and waste generation in construction companies can increase the possibility of recycling plastic waste.

Table 13: Ideas within the collaborative action *Proactive dialogues for waste coordination*

4.3.7 Communication and working methods for sorting routines

As the majority of the ideas within the cluster *Communication and working methods for sorting routines*, presented in Table 14, regard actions for improved on-site waste handling, idea nr 41 stands out a bit as it considers a more holistic perspective. However, as it still concerns a working method for improved sorting of plastic waste, it was considered to be part of the cluster.

Communication and working methods for sorting routines
6 - Actors can work together to enable sorting into distinct plastic fractions on-site to facilitate downstream recycling.
19 - All actors on a construction site can work together and design ways of working to achieve cleaner fractions.
36 - Working with plastic recycling targets on-site can increase incentives for operators working there.
37 - A dialogue between the developer and all subcontractors can enable increased waste separation.
38 - A dialogue between the developer and the waste manager can enable increased waste separation.
39 - Inventory takers can identify recyclable plastic materials during demolition and communicate this to the developer and contractor.
41 - Actors can examine waste streams together to create a holistic view of waste streams from different construction projects and optimize what sorting should take place on each project.

Table 14: Ideas within the collaborative action *Communication and working methods for sorting routines*

4.3.8 Knowledge development and education

The ideas within the cluster *Knowledge development and education* is presented in Table 15. The majority of ideas reflect different actions for knowledge development and how actors could provide education and training to others to improve plastic waste handling processes.

Knowledge development and education
5 - A closer dialogue with recyclers is needed to make the whole value chain aware of which plastics are and are not suitable for mechanical recycling today.
9 - Recyclers can clarify the types of plastics and conditions required to enable recycling.
26 - Recyclers can provide training to collectors and sorters to maximize the proportion of recyclable material in deliveries to recyclers.
27 - The industry can communicate the environmental benefits of recycling plastics in relation to energy recovery.
33 - Recyclers can educate in sorting procedures on the construction site.
35 - Recyclers and waste contractors can provide demolition companies with criteria for which plastic materials are recyclable (e.g. age of material).
48 - Actors can work together to shift focus from waste reduction to multi-cycle resource use.

Table 15: Ideas within the collaborative action *Knowledge development and education*

4.4 Actors' perspectives on collaborative actions

The discussion between the six participants of the interpretation session revealed further insights into the eight collaborative actions and the respective ideas they comprise. This section aims to illustrate the perspective that was raised by each of the four actor types that were represented in the session.

4.4.1 A manufacturer's perspectives on the collaborative actions

During the discussion around several of the collaborative actions, M1 raised the need for increased supervision and the need for more legal requirements. Regarding *Design for recycling*, the representative noted the criticality of following standards to define recyclability for products. His company had started using the ISO-14021 standard which requires that a product needs to be prone to mechanical recycling and that there is a collection system for the product. He further argued during the discussion around *Stipulation and fulfillment of requirements*, that there is a need for supervision so that products that are claimed to be recyclable actually are recyclable and fit into an existing collection system. Relating to his perspectives on lack of supervision, the representative argued in the discussion around *Proactive dialogues for waste coordination* that current legal policies are insufficient as they only recommend, and do not require, inventory taking of materials in demolition projects. He believed that the current legal framework needs to be adapted as material inventories in demolition projects are critical to increasing plastic recycling rates. On the topic of recycling plastic waste flows from demolition, the representative argued in the discussion around *Knowledge development and education* that knowledge development is especially important to capture the recycling potential of the materials in old buildings. Regarding *Aggregation of plastic waste streams* the representative viewed all the ideas as important because of two reasons. First, he argued that they allow for more cost-efficient transport as enough volumes can be collected before delivery to recycling actors. Second, it allows a more environmentally friendly logistical system as the number of transports needed can be reduced.

4.4.2 A construction company's perspectives on the collaborative actions

During the discussion around *Design for recycling*, C3 argued the importance of involving recycling actors when designing products to be recyclable as she had experienced discrepancies regarding the perception of recyclability between manufacturers and recyclers. On *Waste take-back*, C6 shared that while the collaborative action could increase plastic recycling rates, having waste take-back systems for many different types of waste might require on-site sorting into a lot more fractions than possible. Further insights into possible tensions between different collaborative actions were revealed in the discussion about *Aggregation of plastic waste streams* when C3 noted that using shared waste hubs might challenge the traceability of plastic waste. The representative made clear that it is important for a construction company to know the recycling rates of the waste flows from each particular project. It is possible that such information is lost if different WSPs aggregate waste flows from different projects. During the discussion around *Stipulation and fulfillment of requirements*, C6 shared the importance of supervision of legal sorting requirements to create more fair competition as smaller and less serious construction companies can be more cost-effective in waste handling by avoiding following existing regulations. In the discussion around this collaborative action, C3 noted the importance of idea nr 1, as higher demand for products containing recycled plastic would be generated if procuring actors require recycled plastics when purchasing materials. Regarding how requirements could be stipulated, C6 then asked M1 if construction companies could leverage the mentioned standard ISO–14021 when ordering recyclable products containing recycled materials from manufacturers – something that M1 viewed as feasible.

In the discussion about *Proactive dialogues for waste coordination*, C6 argued the need for proactive dialogues already from the design phase in construction projects and not just intensified collaboration from the procurement to the construction phase. Regarding conditions for on-site waste management, C3 noted during the discussion around *Communication and working methods for sorting routines* that at some construction sites, it might be beneficial that each subcontractor takes care of their own waste, instead of having all subcontractors sort waste collectively with the WSP. In the last discussion around *Knowledge development and education*, C6 argued the need for a shared standard between actors on how to calculate their climate footprint from their operations with respect to plastic waste.

4.4.3 Waste service providers' perspectives on the collaborative actions

In the discussion around *Design for recycling*, WSP3 raised two perspectives. First, the representative argued the need for the collaborative action as she believed the decisions made in the design phase of construction projects to have a strong impact on the recycling potential. She further argued the need for including recycling actors in the design phase of construction projects as she believed their perspectives to be valuable to actually be able to design for recycling. Second, she underscored the benefits of modular construction as it could potentially increase the quality of the waste fractions from demolition projects. Both WSP3 and WSP4 further noted the current issue of products being claimed to be recyclable while they are not recyclable in practice. On *Waste take-back* WSP4 raised the need for collaboration between different actors to solve the logistical issue. The representative extended this perspective subsequently arguing the need for *Aggregation of plastic waste streams* to make logistics more cost-efficient, mentioning that a standardized waste trading system could be a solution to make shared hubs between WSPs feasible. WSP4 shared that standards such as BEAst could perhaps be used to enable *Documentation, traceability, and feedback*. On *Stipulation and fulfillment of requirements* WSP4 shared that he believed it to be a common issue that smaller construction companies are not following the legal sorting requirements and that there is a need for supervision to make that happen.

When discussing *Proactive dialogues for waste coordination*, WSP4 raised two perspectives. First, he believed that the current training required to become a material inventory taker at demolition projects is insufficient as the training only focuses on how to identify hazardous materials and not evaluating recycling potential. Second, he stressed the importance of intensified collaboration between different functions within construction companies and further argued that personnel from WSPs should connect with the purchasing functions of construction companies to create the best conditions for optimized waste handling. On *Communication and working methods for sorting routines* WSP4 argued the need for WSPs to provide feedback on the sorting efforts of on-site construction practitioners. He argued that it is critical that WSPs reward good sorting and conversely charge higher fees for mixed fractions and communicate the benefits of high-quality sorting. In the last discussion on *Knowledge development and education*, WSP3 argued the importance of the collaborative action as good waste handling practices start with good knowledge, and stressed that knowledge sharing between different actors needs to increase.

4.4.4 A recycler's perspectives on the collaborative actions

In the discussion around *Design for recycling*, R3 argued for the inclusion of recycling actors in such activities, as other types of actors might not have the knowledge of what materials and products are recyclable in practice. The representative agreed with the others that it is critical to collaborate between actors to create cost–efficient logistics needed for *Waste take-back*. Nuancing this perspective on *Aggregation of plastic waste streams*, R3 said that different WSPs have different presence and capabilities in different parts of the country and that this is one of the key reasons why collaborative aggregation of plastic waste streams is critical. On *Documentation, traceability, and feedback* the representative noted that his recycling company is always able to report back their recycling rates of certain plastic waste flows, but that it becomes difficult to report recycling rates on waste streams from distinct projects if these streams have been aggregated in transportation. In the discussion around *Stipulation and fulfillment of requirements*, the representative argued that the current absence of supervision of legal sorting requirements is a critical issue that needs to be resolved.

4.5 Digital solutions for improving plastic waste management

As explained in the methodology section 3.3.1, input from the first round of interviews provided findings valuable for the third research question as well. Figure 9 presents the results from combining these findings with the findings from the second round of interviews with experts on digital solutions.

	AI enabled robotized sorting	IR Camera enabled robotized sorting	IoT sensors	Automated feedback reports	Digital transport optimization	Digital product information sharing
Area of application	**Enabling robotized sorting.** Could be done through AI powered image recognition systems	**Enables robotized sorting** through IR camera recognizing polymer types	**Automizing waste call off** through automated measurement of degree of filling within waste containers.	**Improved waste management** through faster feedback on waste management practices	**Improved transportation efficiency** through digital platforms	**Improved traceability** of product characteristics
Hindering factors	• Difficulty to separate items into sufficiently pure fractions	• Incapable to separate items on characteristics beyond polymer type	• Plastic waste flows vary in size over project time. Automatic measurement in containers does not provide proactive insights for sudden large plastic waste flows	• Lack of data collection points in plastic waste flows • Lack of information sharing to collect the data needed	• Depends on close collaboration between different actors • Requires data availability on waste flows and available transportation capacities	• Not in line with current ways of working • Lack of established shared standards for communicating product information such as EPDs

Figure 9: Application areas and hindering factors for identified digital solutions

AI and IR cameras could be viewed as two different enablers of robotized sorting where the former could rely on image recognition and the latter on IR camera technology to recognize polymer types. From the first round of interviews, WSP1 and RI2 mentioned projects aiming at implementing robotized plastic waste sorting systems powered by AI to increase efficiency in plastic waste sorting operations. However, R3 argued that such systems will not be able to generate satisfactory results to automatize sorting in the foreseeable future. Regardless of whether a robotized sorting system would be powered by AI or IR camera technology, R3 argued that they similarly would not be able to separate plastics into fractions that are pure enough. The IR camera technology is limited as it only recognizes polymer type and not other characteristics. Similarly, if a system would be powered by AI using image recognition, it would similarly struggle to generate sorting into sufficiently pure fractions. However, R3 noted that while neither of these two solutions could automatize sorting, IR-enabled robotized sorting is an efficient complement to manual sorting as it does recognize polymer type effectively. Such a system was present in the sorting process within the recycling facility where R3 was working.

For improved on-site waste management, C4 argued that connected sensors could be used to measure the degree of filling in waste containers. Specifically, C4 believed that higher efficiency could be achieved as the sensors could automatize the call-off of plastic waste containers. On the contrary, RI2 argued that plastic waste flows vary greatly in types and sizes during different phases of construction projects. While RI2 believed that sensors could provide valuable data for planning waste management operations if plastic waste flows are stable, she argued that the fluctuating flows in the construction context removed the viability of such sensor technology.

Automated digital feedback reports were mentioned as a solution that could be applied in various contexts. C4 mentioned that dashboards on construction sites illustrating sorting performance could nudge practitioners to improve their on-site sorting efforts. WSP2 considered automated feedback reports as tools for providing feedback to WSP clients on the ultimate results of their sorting efforts. However, both interviewees noted the lack of stable information flows as hinders to such solutions.

Representing a construction logistics service provider, CLSP1 raised the perspective that they have tremendous room for improvement with internal transport optimization for their rental business. They planned to include transport optimization features in their digital construction logistics platform. CLSP1 further mentioned that they in some projects had planned the waste management operations executed by waste service providers. Thus, he believed that it could be possible to use digital transport optimization tools for better planning of waste management operations. However, he noted that this would depend on close collaboration between different actors, and requires transparency on relevant data.

C5 argued sharing product information digitally in standardized ways improves traceability as data kept digital does not disappear. While mentioning standards that exist within the construction industry, such as EPDs, BEAst, and the environmental database administered by Boverket, C5 argued that industry actors face challenges in establishing shared ways of working. She further noted that before considering how information should be bundled and how it should be communicated, there is a need to contemplate what information that could generate value and for whom. Both C4 and C5 argued that it is much more critical to look into developing better ways of working with the data and digital solutions that currently are at hand, rather than relying on novel digital technologies to increase recycling rates of construction plastic waste.

5

Analysis & Discussion

This chapter is divided into two sections. First, to answer the second research question, each of the eight identified collaborative actions is analyzed through the analytical framework presented in Figure 5. A pathway of collaborative actions is presented to illustrate and discuss their practical feasibility. Second, to answer the third research question, identified digital solutions are discussed considering the theoretical perspectives in section 2.3.

5.1 Service systems enabling collaborative actions

It was clear from the interpretation session that all participants believed the eight collaborative actions have the potential to increase the recycling rate of construction plastic waste. However, to answer the second research question there is a need to analyze how service systems could be designed for collaborative actions to work in practice. In this section, the analytical framework in Figure 5 is applied to each of the eight identified collaborative actions to propose enabling service systems. The proposed service systems are based on the ideas within each collaborative insight, combined with related findings regarding the identified service types presented in section 4.2. Further, the feasibility of the proposed service systems is analyzed with respect to collaboration complexity and service system maturity. Drawing on this analysis, a pathway of collaborative actions is illustrated to discuss interdependencies between collaborative actions and derive implications for actors.

These proposed service systems are presented as schematics illustrating which actor types are central and which fundamental services are underlying each collaborative action. The services are presented as arrows. Additionally, some related services are illustrated with dotted arrows to put the service systems into context. The four actor types material manufacturer, contractor, WSP, and recycler reoccurred during the concept mapping process and constitute a base of actor types that span the complete flow of plastic waste.

5.1.1 Design for recycling requires strong connections between actors

The ideas within the collaborative action *Design for recycling* both regard different ways to adapt the composition of plastic products so that a larger share of construction plastic products are recyclable and the use of modular building methods so that plastic building materials are easier to separate during demolition which would facilitate recycling. The actors mentioned among these ideas include material manufacturers, construction companies, WSPs, and recyclers. Drawing on the ideas given within this collaborative action, as well as insights from the interpretation session discussion, Figure 10 below illustrates a schematic representation of a proposed service system that enables design for recycling.

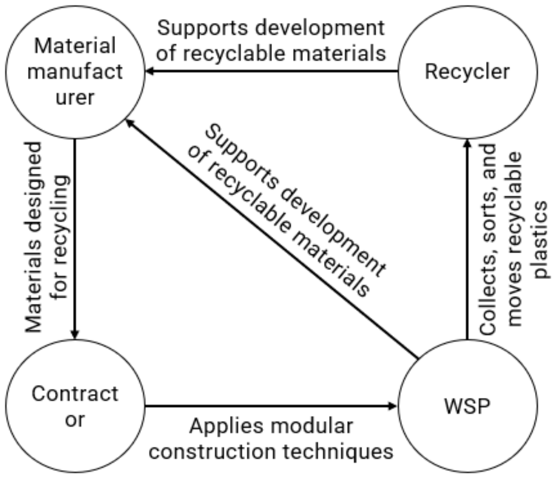

Figure 10: Service system enabling *Design for recycling*

The arrows in Figure 10 illustrate services provided by one actor to another. Similarly to how the arrow between the contractor and WSP captures ideas nr 14 and 34, the other arrows capture the other ideas within *Design for recycling.* Drawing on the service system maturity framework, based on Grönroos (2008) and Vargo and Akaka (2012), both the recycler and the WSP are respectively co-creating value together with the material manufacturer as they not only provide knowledge but further support the development of recyclable products. The results from the interpretation session further indicate that support from the recycler would be particularly critical to ensure that products claimed to be recyclable actually are recyclable. This could imply that recyclers not only need to support but further be integrated into some phases in product development. The WSP further co-creates value with the recycler as it not only collects and transports but further sorts plastic waste which directly supports the recycler. The manufacturer and the contractor have value-facilitating roles as their services do not directly support another actor in the creation of value but rather enable another actor to create value. Overall the service system reflects an above-medium degree of service system maturity.

The proposed service system reflects a high degree of collaboration complexity.

First, it could be assumed that the key actors in the service system would further be dependent on partners in the broader network. In order to apply modular construction techniques, for example, the contractor could need to collaborate with other actors such as external architects and engineers. Second, the actors in the proposed system could need to collaborate intensely in order for the actions to be effective and lead to higher recycling rates.

5.1.2 Waste take-back needs adaptation depending on the type of plastic waste

The involved actors in *Waste take-back* according to the ideas from the concept mapping process are construction contractors, manufacturers, WSPs, and material manufacturers. The collaborative action is closely related to the current service type *Take-back management* presented in Figure 7. *Waste take-back* enables recycling by separating products into fractions that specific manufacturers have the competencies to recycle. Because plastic is considered waste when used at the site, the transport is mainly done by WSPs that have authorization for waste handling. The role of the WSPs in this collaborative action is only to provide the necessary logistics to get waste from the subcontractor to the manufacturer. When looking at the floor residue, a trade organization is involved to connect manufacturers and subcontractors in a structured way. Based on insights from the identified current service *Take-back management* in Figure 7 and the concept mapping process, Figure 11 was created to show a possible service system schematic that enables *Waste take-back.*

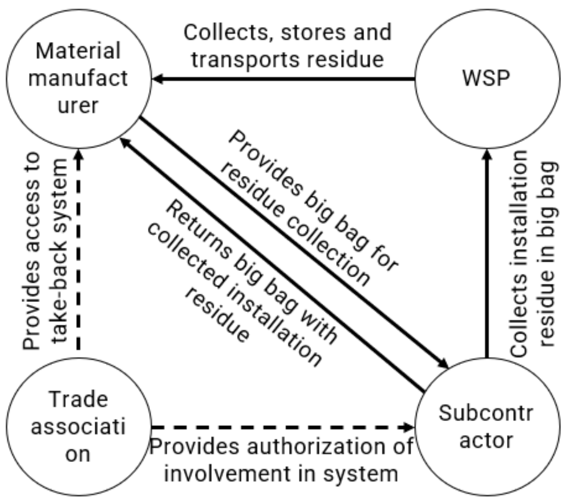

Figure 11: Service system enabling *Waste take-back*

In Figure 11 the arrows show services between actors, the full arrows show the fundamental services for the service system while the dotted arrows show additional possible services, in this case how a trade organization can help the system by connecting manufacturers and contractors in through an authorization based system. Big bags are mentioned in the schematic but other container types might be preferable for more bulky products like plastic pipes. The schematic focus is on floor installation residue but the collaborative action is not limited to this. In accordance with ideas 12 and 18, it is also possible to set up waste take-back for packaging and other products. The preferred arrangement of the service system is dependent on the product type, increasing the collaboration complexity. Consequently, multiple recycling schemes where manufacturers take back their own products were proposed. Additionally, idea nr 29 within the collaborative action *Waste take-back* says that the manufacturers can develop the take-back system. It is important that manufacturers are can tailor the system to their needs since their ability to utilize the retaken product is central to the effectiveness of the collaborative action. These product-specific take-back systems are enabled by subcontractors that gather small and dispersed plastic flows. This initial collection of dispersed residue could further enable *Aggregation of plastic waste streams*.

Multiple take-back schemes make a reverse supply chain decentralized and responsive which would be suitable if the product has a high MVT according to Blackburn et al. (2004). However, the identified barriers to plastic recycling speak for plastic generally having a low MVT. Several barriers focused on processing and transporting costs and there was no mention of price loss due to slow reverse supply chains. The only time-related barrier was the limited time to remove waste from the construction site to free up space for further construction. To overcome the cost barriers, the reverse supply chains can be centralized but have a more responsive design of the on-site sorting and collection of take-back to not impede the construction project. But centralizing supply chains demands collaboration with high complexity since it requires handling plastic products from different manufacturers and subcontractors. The success of the centralization of the supply chain, therefore, depends on the availability of aggregators. Therefore *Waste take-back* has a co-dependency with the collaborative action *Aggregation of plastic waste streams*.

Central themes in *waste take-back* are resource integration and the co-creation of value by collection, transport, and handling of plastic, thus it reflects a mature service system according to the service ecosystem perspective from (Vargo & Akaka, 2012). It is also dependent on collaborative actions for *Communication and working methods for sorting routines* since most collection and sorting is done by subcontractors and some sorting needs to be done based on both the manufacturer and the plastic types.

To conclude, this service system is a service triad where manufacturers, subcontractors, and WSPs cycle residue or packaging in fractions that specific manufacturers have the competencies to recycle. In the case of the current observed service system of floor residue collection, the addition of an authorizing trade organization makes it a service tetrad with the two advantages that subcontractors can use authorization to differentiate themselves as sustainable companies and that information sharing can be easier.

5.1.3 Aggregation of plastic waste streams requires significant coordination and challenges traceability

The actors that were mentioned in the ideas that constitute the collaborative action *Aggregation of plastic waste streams* include WSPs and recyclers. While recyclers were suggested to be key players, it needs to be considered that recyclers do not have the same legal authority to transport and handle waste as WSPs. Thus, when designing a feasible service system for *Aggregation of plastic waste streams*, WSPs were considered to be the key actor type as they have distinctive waste handling authority. The proposed service system, presented in Figure 12, is derived from the ideas from the concept mapping process, as well as dimensions of the identified service type *Joint waste transportation and intermediate storage*, and comprise a main service triad between different WSPs. Figure 12 only aims to illustrate that the proposed service system centers around collaborating WSPs, but the particular number is deemed to depend on the local context. By optimizing waste transportation, the service system has the potential to bring down logistical waste handling costs, and transport-related GHG emissions. Essentially, the service system reflects a cost-efficient centralized reverse supply chain as described by Blackburn et al. (2004) which is suitable when goods have low MVT, which is the case for plastic waste.

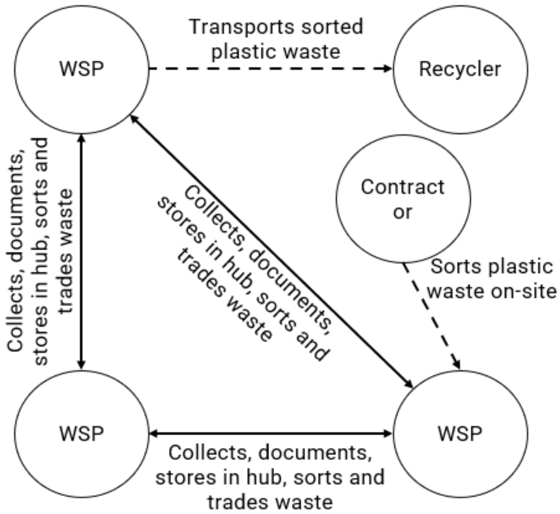

Figure 12: Service system enabling *Aggregation of plastic waste streams*

In the proposed service system WSPs exchange services such as multiple site waste collection, documentation, and waste storage and sorting of waste in a shared hub. Thus, the service system reflects a high degree of service system maturity as WSPs are integrating resources to co-create value. While the recycler and contractor are not considered part of the core service system as they do influence waste aggregation, the dashed lines illustrate how the triad of WSPs is interconnected to other actors in the network. The on-site collection and waste sorting, done by contractors affect how the WSP can collect waste, and the requirements from recyclers, affect how the WSPs should sort plastic waste in their hub. This indicates that the system would be coupled with a high collaboration complexity as it not only implies close collaboration between WSPs but further that they need to collaborate closely with other network actors.

As the proposed service system has the potential to mitigate key identified economic and financial barriers by decreasing plastic waste transportation costs, it could strengthen the development of the services enabling plastic recycling that are affected by these barriers. However, there are three challenges that need to be addressed for the system to work in practice. First, competing WSPs need to establish a trading system to enable their collaboration. Such a system would need to address both the service of multiple site waste collection and the collectively handled plastic waste at shared hubs. Multiple site waste collection refers to the identified service type where one WSP offers to collect plastic waste from multiple construction sites in a single round, potentially including sites managed by other WSPs, if that WSP has the opportunity to conduct a more efficient transportation round. But having WSPs collecting plastic waste from each other's clients requires significant coordination between WSPs involved and further relies on each actor documenting volumes picked up at each site. Second, aggregation challenges the traceability of plastic waste streams. Contractors need to know the end-of-life treatment of the plastic waste streams from their construction site, but this would become difficult when plastic flows from different sites are aggregated. Third, as the geographical locations of construction projects are temporary, WSPs need to choose hub locations carefully as proximity to construction projects clearly affects the cost of waste transportation.

5.1.4 Documentation, traceability, and feedback requires information sharing across the whole value chain

Based on the ideas regarding *Documentation, traceability, and feedback*, this type of collaborative action should ideally involve actors from the whole value chain. The proposed service system schematic in Figure 13 illustrates four base actor types which plastic is transferred between in a construction recycling flow. This schematic can be expanded with subcontractors and material suppliers in the same format. This collaborative action is an overarching enabler of recycling and has similar characteristics to the identified current service type *Knowledge sharing and information provision* in Figure 7.

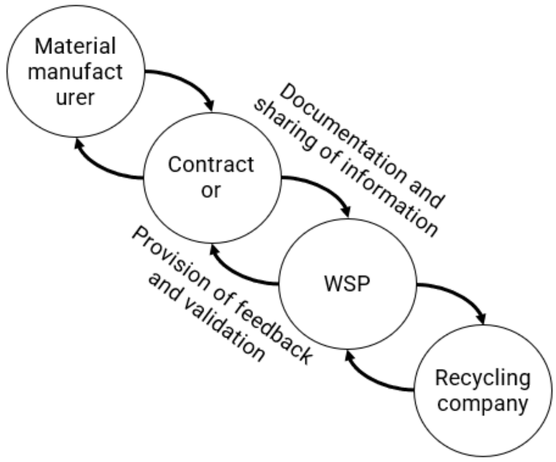

Figure 13: Service system enabling *Documentation, traceability, and feedback*

Based on the ideas in Table 11, there are two main aspects that make up this collaborative action. The first regards information sharing when plastic materials are passed on to the next actor in the value chain, and the second regards the provision of feedback. Documentation and information sharing create a foundation for traceability and can make sorting and recycling easier by overcoming general barriers to information sharing. Further, in line with idea nr 22, it is important to have clear information structures to ensure that knowledge of the plastic composition is passed on correctly all the way. A discussed information structure is BEAst, where more recycling information potentially could be made standard on delivery labels.

The second aspect is the provision of feedback and validation which is usually given the reverse way from the plastic flows. As Frishammar and Parida (2018) argues, feedback and validation are essential when scaling up CEBMs to be able to make adjustments based on iterative learning. Additionally, in line with idea nr 49, it is important to know how feedback is supposed to be given in terms of measurements and KPIs. The alignment of the feedback format must be done collaboratively to get actors to agree. Furthermore, one of the specific hindering factors to overcome in current services was the lack of recycling follow-up for which this collaborative action is especially important.

The collaboration complexity for *Documentation, traceability, and feedback* is increased since there are many actors to be aligned and active to enable good traceability and feedback but remains at an average level since the required relation intensity is low. Since there is no resource integration needed and value is facilitated rather than co-created, as information is shared, this service can function in a service system with low maturity.

Additionally, in the interpretation session, a recycler pointed out that they can provide feedback on recycling rates of certain plastic waste flows, but that *Aggregation of plastic waste streams* impedes the reporting of recycling rates at a project level. Therefore, these collaborative actions do not facilitate each other as many other collaborations do.

5.1.5 Stipulation and fulfillment of requirements imply reciprocal demands on recyclability, sorting quality, and recycling rates

The majority of the ideas within the collaborative action *Stipulation and fulfillment of requirements* did not refer clearly to specific actor types. Rather, they were suggestions of what actors could do in general. Thus, the service system underlying this collaborative action could be assumed to look different depending on the chosen network of construction actor types of the study. However, as manufacturers, contractors, WSPs, and recyclers were included throughout the concept mapping process, due to their critical roles in the construction plastic value chain, the proposed service system presented in Figure 14 is based on these four actor types. Together, the ideas within the collaborative action imply suggested ways to use formal requirements to stimulate demand for recycled plastics and to limit the number of different plastic types. This is in line with the findings by Lindahl et al. (2022) saying that increased recycling can be reached with the stipulation of new standards that greatly limit the number of plastic types. Higher demand for recycled plastic is critical for the economic viability of recycling business models and fewer plastic fractions could facilitate the task of sorting and processing plastic waste.

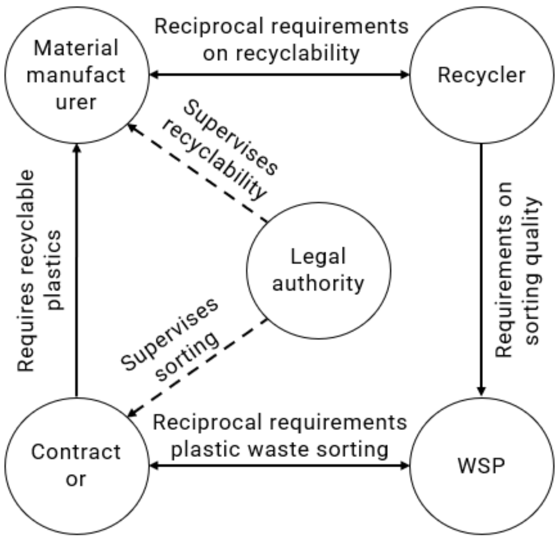

Figure 14: Service system enabling *Stipulation and fulfillment of requirements*

The suggested roles of each actor type are derived from the ideas within this collaborative action as presented in Table 12. The legal authority was added as an additional possible actor in the service system based on insights from the interpretation session discussion where representatives from all four actor types noted the importance of supervision. Overall, the proposed system reflects a rather low degree of service system maturity as each actor carries value-facilitating roles.

In the proposed service system, contractors are stipulating clear demands on recyclable plastics. To ensure recyclability, manufacturers need to align product characteristics with the recycling capabilities of recyclers. Further, reciprocal requirements are needed between contractors and WSPs, but in terms of plastic waste sorting. This alignment is further influenced by sorting quality requirements on WSPs, stipulated by recyclers. However, the ideas within *Stipulation and fulfillment of requirements* captured by these actions were not perceived to be sufficient by the interpretation session participants. Rather, it was emphasized by representatives from all four actor types that there is a need for supervision by some authority in two respects. First, there is a need for supervision to make sure that legal sorting requirements are followed. Second, there is a need for supervision on recyclability to ensure that products claimed to be recyclable fit into existing waste collection and processing systems. A potential legal authority was added to the proposed service system that conducts supervision in line with the insights from the interpretation session.

Each action is affected by the existence of other actions in the system. However, the potential impact of each action is not fully dependent on the existence of other actions. For instance, improved stipulation and fulfillment of requirements on plastic waste sorting between contractors and WSPs could be assumed to have a positive impact on plastic recycling rates even if recyclers would not improve requirements on sorting quality stipulated by WSPs. Thus, the collaboration complexity in this system is considered low as each relationship in the tetrad is rather independent of the other relationships between other actors.

While both the service system maturity and the collaboration complexity are considered low for the service system underlying this collaborative action, it is hypothesized that the development of this system depends on the existence of the collaborative action *Knowledge development and education.* During the interpretation session, the construction company representative C6 asked the manufacturer representative M1 if requirements on product recyclability and requirements on recycled products could be stipulated based on a particular ISO standard that M1 had mentioned during the session. The conversation between the two representatives indicates that it is beneficial for actors to learn from each other in order to be able to stipulate more effective requirements. This implies that knowledge development is enabling the development of this service system.

5.1.6 Proactive dialogues for waste coordination require waste stream focus during project planning phases

Proactive dialogues for waste coordination revolves around the service of informing early on potential waste streams to downstream actors so they can prepare better conditions for recycling this waste. In addition, recyclers must confirm local conditions for recycling plastic fractions to upstream actors so contractors can coordinate fractions. The statements from the idea generation session involved contractors, WSPs, and recyclers regarding *Proactive dialogues for waste coordination.* However, ideas nr 40 and 47 in Table 13 reflected the need for contractors to have internal proactive dialogues between procurement functions and construction functions to be able to coordinate for recycling. Based on the concept mapping information, the service system scheme in Figure 15 was created.

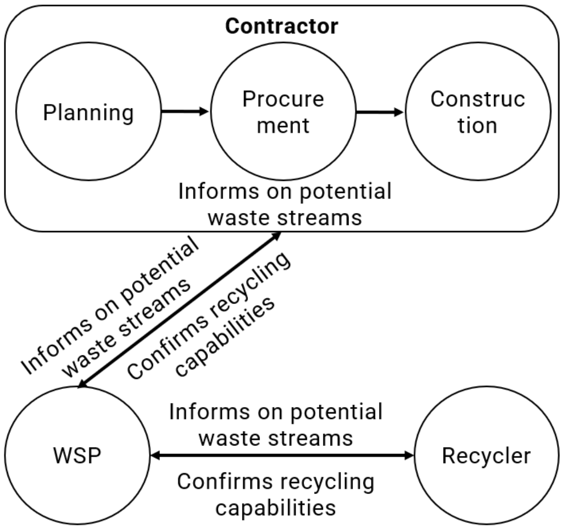

Figure 15: Service system enabling *Proactive dialogues for waste coordination*

The service system is illustrated as a triad where the arrows indicate mentioned services between actors, procurement and construction illustrate two internal functions within the contractor actor. To clarify, the arrow from contractor to WSP in Figure 15 does not limit the dialog to any specific contractor function. In the interpretation session, it was argued that for good coordination, these dialogues should start already in the design phase of the construction project. It was further argued that WSPs should connect with contractor procurement personnel to create the best conditions for optimized waste handling. The pursued effect is that information on potential waste streams reaches WSPs and recyclers earlier so there is time for planning efficient waste handling. Thus, the value is co-created through dialogues that need to be customized based on the project. Therefore it can be argued that collaborative action requires a moderate degree of service system maturity with well-functioning information flows to be successful.

Ideas 7 and 25 in Table 13 illustrate different examples of how proactive communication could improve plastic waste handling in demolition and renovation projects. Before demolition or renovation, recyclers can be informed about potential recyclable material to be separated by the company doing an inventory of the site. Today most inventory taking concerns dangerous waste. Adding inventory taking on recyclable waste has the potential to help WSPs and recyclers prepare and recycle more plastic. However, according to M1, the current legal policies do not require taking an inventory of materials in demolition projects even though it recommends it.

The collaboration complexity of *proactive dialogues for waste coordination* is argued to be higher than average because the collaborative action has to start proactively by the construction company even though most of the direct value goes to the recyclers that can coordinate their operations accordingly. Further, the waste stream focus often has low priority in early project stages. If waste stream conditions change in later stages, these changes must also be communicated.

5.1.7 Communication and working methods for sorting routines require alignment

All ideas within the collaborative action *Communication and working methods for sorting routines* reflect ways actors can increase plastic recycling rates through improved procedures for plastic sorting and communication of these procedures. These topics were not exclusively covered in the concept mapping process but were also discussed during the first round of interviews. Thus, the proposed service system, presented in Figure 16 is generated by combining the ideas from the concept mapping process with insights from interviews around services of the type *Collaborative services for sorting.*

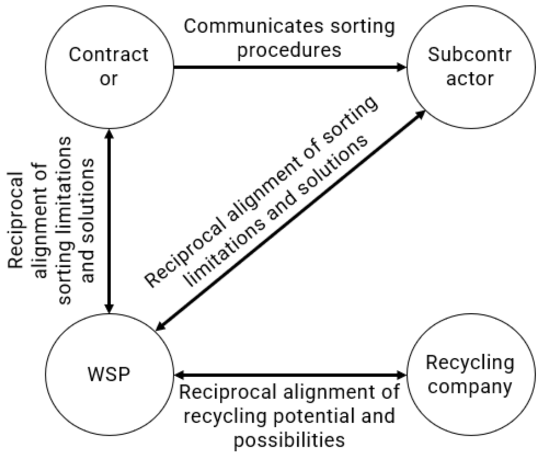

Figure 16: Service system enabling *Communication and working methods for sorting routines*

While subcontractors were not explicitly mentioned among the ideas within this collaborative action, their critical role was emphasized by respondents in the interpretation session. A critical element in this service system is the reciprocal alignment between WSPs and contractors, respectively subcontractors, to iterative improve sorting procedures based on shifting on-site conditions in construction projects. To ensure that established procedures are known to everyone on-site it is critical that representatives from the contractor clearly communicate procedures to subcontractors. Further, communication and alignment between WSPs and recyclers of recycling potential and recycling possibilities could help optimize plastic sorting at construction sites to improve recycling rates. Thus, the proposed system reflects a medium degree of service system maturity as the WSP is co-creating value in the respective interaction with each other actor in the system. A value facilitating role is only to be identified where the contractor communicates sorting procedures to subcontractors.

The development of the system could be seen as particularly dependent on three other collaborative actions. First, a shared vision and understanding of plastic waste handling through *Knowledge development and education* could be seen as a necessary factor to be able to reciprocally align procedures and communicate these effectively. Second, an established system of *Stipulation and fulfillment of requirements* could facilitate the alignment of sorting procedures. Third, *Documentation, traceability, and feedback* could be an enabler to align on optimal sorting procedures since such procedures are deemed difficult to achieve without documentation and iterative evaluation of sorting performance.

The proposed service system further reflects a medium degree of collaboration complexity as reciprocal alignments are hypothesized to require intense collaboration. However, the service system requires collaboration between the many actors related to a construction project it does not require the engagement of further actors. Thus, collaborative action could be executed for a construction project independent of other projects.

5.1.8 Knowledge development and education imply a critical foundation for further actions

The majority of the statements from the concept mapping process regarding *knowledge development and education* concern how recyclers can educate and transfer knowledge to other actors. There is a knowledge gap between actors regarding recycling that needs to be bridged to enable more recycling. Without a strong foundation of knowledge and education, it is difficult for individuals to effectively collaborate and work towards resource efficiency. To effectively do *communication and working methods for sorting routines* in a day-to-day setting contractors first need to have a strong knowledge foundation around plastic waste sorting. Therefore, focusing on *knowledge development and education* can create a critical foundation for further actions.

Ideas 5, 9, and 25 in Table 15 focus on educating about what types of plastics and conditions are required to enable recycling today. Both to manufacturers to enable the action *design for recycling* and to contractors and WSPs to enable better sorting. To further enable better sorting, on-site trainings can be carried out with the help of recyclers. An enabling service system for these educational services is presented in Figure 17. The ideas about general education e.g. the environmental benefits of plastic recycling compared to energy recovery and multi-cycle resource use are important to create a shared vision in the value chain. However, they are not illustrated in the service system since there is no connection to any actor as provider or recipient.

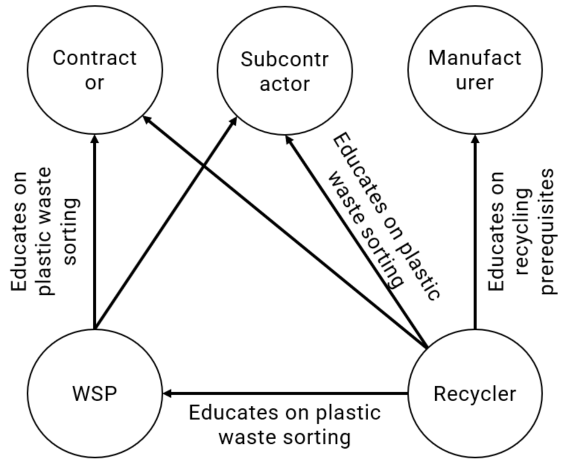

Figure 17: Service system enabling *Knowledge development and education*

Knowledge development and education can be seen as a collaboration with low complexity since it can be done by a few actors with good effect. The arrows in the service system in Figure 17 work independently for the pair of actors that they connect. The exception is that WSPs can forward the knowledge from the recycler to contractors and subcontractors.

Knowledge development and education can work in a service system with low maturity since the educators can be seen as value facilitators that provide simple foundations for value creation. Finally, successful recycling education has the effect of making the businesses of WSPs and recyclers more effective in the future when they receive plastic fractions of higher value. Therefore, education does not need to be a profitable service by itself to be incentivized for WSPs and recyclers.

5.1.9 A pathway of collaborative actions for increased resource efficiency of construction plastic waste

Previous analytical sections have illustrated that proposed service systems for collaborative actions reflect different levels of collaboration complexity and service system maturity. Thus, each service system requires different capabilities and resources for involved actors. A collaborative action that requires high collaboration complexity and high service system maturity is arguably more difficult (less feasible) to accomplish than the contrary. While the specific capabilities and resources needed for a service system are deemed to depend on the practical context, the illustration in Figure 18 provides general guidance for actors on the feasibility to pursue each collaborative action.

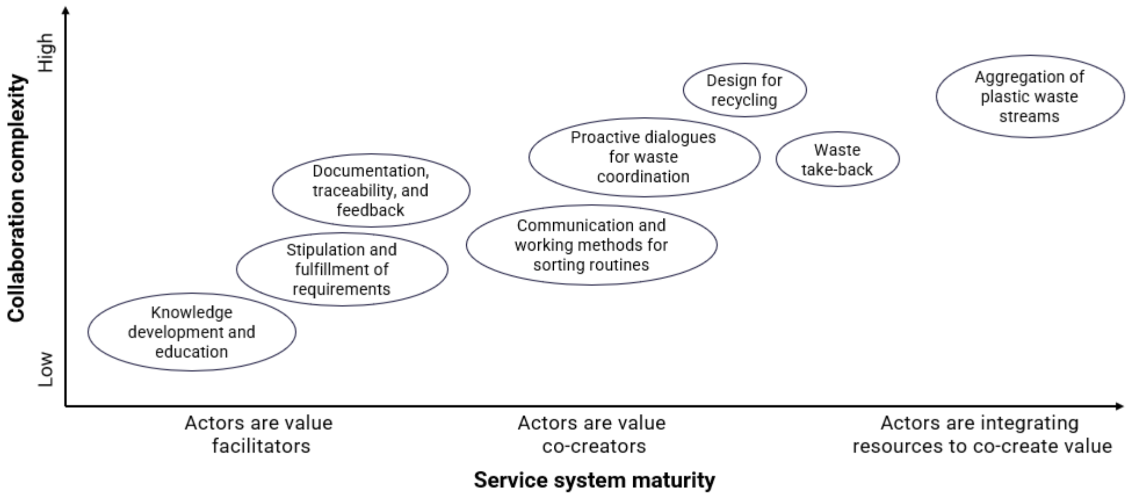

Figure 18: Collaborative actions mapped to collaboration complexity and service system maturity levels

Figure 18 illustrates a pathway on how actors could approach developing the service system for each collaborative action, where the development of these service systems could be seen as mechanisms to build capabilities needed for actors to manage complex collaborations and integrate resources to form mature service systems. Based on previous analytical sections, it is clear that the development of collaborative actions where collaboration complexity and service system maturity are low could enable the development of less feasible collaborative actions.

Drawing on Vargo and Akaka (2012), the potential formation of the proposed service systems implies the creation of a service ecosystem comprised of these interconnected service systems. While Figure 18 provides a direction for actors on how to form a service ecosystem enabling increased plastic recycling, it is important to consider the implications for actors involved in transitioning towards such a system with respect to their relations to other actors and to actors' operations and offerings. As service systems often are loosely bound and changing as actors are engaging with each other (Vargo & Akaka, 2012), actors involved need capabilities to adapt to changing relational dynamics. In the analysis of aftermarket relational structures, Wagner et al. (2017) notes that as actors try to increase their competitiveness, they might try to influence networks to their own favor and try controlling other actors. As such potential phenomena can not be ruled out in the case of the eight identified collaborative actions, actors need to be aware of changing dynamics and manage their relationships with other actors carefully. This is further supported by Eriksson et al. (2021) arguing that the relationships in a network affect each other and further change over time. Since the project-based nature of the construction industry often imply temporary relationships (Eriksson et al., 2021), managing external relationships effectively is deemed a particularly critical capability in this construction context.

Actors involved in a transition towards a mature service system will face further implications for their businesses. As noted by Grönroos (2008), adapting a service logic opens up new business opportunities for actors as they engage directly with counterparts to co-create value. However, it is hypothesized that construction actors will experience challenges of organizational change similarly to how Oliva and Kallenberg (2003) and Gebauer et al. (2005) argue that manufacturing firms struggle to adapt service logic as it implies a shift from transactional to relational business logic and requires organizational change. Further, the transition implied by the proposed service systems not only shifts the logic in their interactions but also alters the purpose of these interactions. As all collaborative actions regard different ways for actors to enable plastic recycling on a larger scale, the interactions in the underlying proposed service systems imply that actors need to incorporate circularity principles into their business models and change their perspective on how they capture value in their respective interactions. As construction actors jointly can enable a more effective system for plastic waste handling, each actor needs to identify how they can initiate and capture value from such an improvement. Drawing on Frishammar and Parida (2018), this implies adjusting business models for the actors involved, and external configuration with ecosystem partners so that the adjusted CEBM has a good fit with the other actors.

5.2 There is a knowledge gap regarding digital solutions in construction waste management

The empirical findings presented in section 4.5 illustrated six different identified digital solutions that some interviewees perceived as capable of improving plastic waste handling. However, limitations to all these digital solutions were identified, which limit their practical feasibility to different extents.

Completely contradicting opinions were identified among the interviewees regarding both AI-enabled robotized sorting and IoT sensors for automatizing waste call-off. Two interviewees mentioned experimental projects around AI-enabled robotized sorting of construction plastic waste, aiming to improve sorting efficiency. Another interviewee argued that AI-enabled robotized sorting is not capable of sorting into sufficiently pure fractions, which invites discussion on whether this digital solution is applicable in a construction context. Perhaps the bulkier nature of plastic waste from the construction industry makes it difficult to fit into automatized sorting processes as the ones described by Bobulski and Kubanek (2021) and Wilts et al. (2021). In the case of IoT sensors automatizing waste call-off, one interviewee saw potential while another argued that such a solution is not applicable to the varying plastic waste flows on construction sites.

Interviewees did not provide contradicting opinions when it came to automated feedback reports for improved waste handling, or digital transport optimization systems. However, the same interviewees that raised the respective solution acknowledged the common hindering factor of limited data availability on plastic waste flows.

In contrast to previously raised solutions, findings indicate a clear viable application for IR-enabled robotized sorting despite its limitations. An interviewee raised that IR-enabled robotized sorting provides a clear complement to the manual sorting of plastic waste. While the technology is not capable of sorting plastic waste into fractions that are pure enough to fully automatize plastic waste sorting, it does recognize polymer type effectively and is used in existing sorting facilities for construction plastic waste.

The potential impact of the identified solution of digital product information sharing for improved traceability in plastic waste flows is supported by several studies (Ahlm et al., 2021; Almasi et al., 2020; Jansson et al., 2019a). However, an interviewee noted that there is a lack of shared standard on how such information should be shared digitally and worked with. This issue indicates that different construction practitioners have contrary opinions as in the case of the applications of AI and IoT sensors discussed earlier. Thus, based on the limited sample of interviews it seems like there is a lack of consensus among practitioners regarding the potential of digital solutions and thus how different digital technologies could be applied. While no clear contradicting opinions could be identified for the solutions of automated feedback reports, or digital transport optimization systems, there were neither any success cases to be identified.

Altogether, this indicates that there is a knowledge gap within the construction industry regarding how digital solutions could be leveraged for plastic waste management. While this could be a consequence of the low level of digitalization of the construction sector (McKinsey & Company, 2016), it illustrates the need for further research to bridge the gap to implement digital solutions.

6

Conclusions

The aim of this study has been to identify circular service opportunities enabling improved resource efficiency of construction plastic waste through mechanical recycling. First, existing services enabling plastic recycling and the barriers they face were investigated through 17 semi-structured interviews with experts. Second, a concept mapping methodology was conducted together with 15 experts to explore opportunities on how actors could collaborate better to increase the recycling rate of construction plastic waste. Potential service system designs that could enable recycling through identified collaborations were derived from these empirical findings. Third, examples of digital solutions that could enable increased plastic recycling were investigated through four semi-structured interviews with experts that worked exploratory with digital solutions in the construction context. This three-step methodology allowed the below conclusions to be drawn.

First, to describe the current service environment, it was concluded that current services could be divided into six service types that were described with their service examples, involved actors, hindering factors, and the way they enable recycling. Further, when investigating barriers to current services there were clear similarities with barriers from existing CEBM research. Therefore, barriers to current services could be grouped into categories with similar delimitations that had been used in previous categorizing studies. These categories were named *Economic and financial*, *Technological, knowledge, and informational*, *Supply chain*, *Institutional*, *Organizational* and *Market*.

Second, eight collaborative actions that illustrate how actors can collaborate better to increase the plastic recycling rate were identified through the concept mapping process: *Design for recycling*, *Waste take-back*, *Aggregation of plastic waste streams*, *Documentation, traceability, and feedback*, *Stipulation and fulfillment of requirements*, *Proactive dialogues for waste coordination*, *Communication and working methods for sorting routines*, and *Knowledge development and education*. Through the application of an analytical framework based on collaboration complexity and theory on service ecosystems, value creation, and service triads the researchers could propose potential service system designs for the implementation of these collaborative actions in practice. These service systems are representations of service opportunities enabling recycling and encapsulate the aim of the study. The discussion concluded that the development of service systems could be seen as mechanisms to build the capabilities needed to manage more complex collaborations and integrate resources to form mature service systems. Thus, the collaborative actions could be illustrated in a pathway of service designs. Additionally, it was concluded that to follow the pathway, actors need to manage external relationships effectively in each service system within the broader service ecosystem.

Third, a knowledge gap was found with respect to how digital solutions could be used to improve plastic waste management. While six different identified digital solutions were considered to have the potential to improve waste management practices, only the solution of IR-enabled plastic waste sorting had viable implementation in current plastic waste flows. Regarding the other digital solutions, contrary views were identified among the interviewees.

6.1 Implications for practice

The main practical implications from the empirical findings in this study regard the actor types manufacturer, contractor, recycler, and WSP. As the findings in this study are context-specific, firms need to analyze and consider their particular business environment and value chains when considering the implications of this study. However, the presented frameworks about service system designs, collaborative actions, and barriers can support firms in this process.

Actors providing services enabling plastic recycling need to identify which barriers hinder the service provision. Here, actors could benefit by first examining their current business models and service designs with respect to the different value dimensions. Further, the methodology for barrier categorization used in this study could be valuable for actors to understand which type of barrier directly affects their service provision, and to help them prioritize actions forward. In addition, actors need to investigate how they can reduce the impact of specific hindering factors by leveraging their resources and the network of actors they are embedded in.

To increase the recycling rate of construction plastic waste, this thesis finds that there is a need for new types of collaborations between actors in the construction industry. The eight identified collaborative actions could be used as a guide in designing these new collaborations. Not only could these collaborative actions lead to increased plastic recycling, but also imply cost savings for actors from more efficient waste management practices. The pathway of service designs can help actors design their interactions when pursuing different collaborative actions. However, actors need to consider which capabilities and resources are needed for the development of a respective service system. While the pathway suggested provides guidance in what order to pursue different collaborative actions as they enable each other, actors need to manage the internal transformation required when pursuing complex mature service systems. Key elements in such internal transformations are the adoption of service-dominant logic and the development of capabilities to manage many intense external relationships. As all collaborative actions ultimately regard increasing plastic recycling which is dependent on effective reverse logistic flows, actors need to consider how to design these reverse supply chains. In such a design, there is a balance between effective plastic recycling and an efficient reverse supply chain. As the value of plastic waste does not decrease over time but rather decreases when fractions are mixed, a potentially viable design is a decentralized on-site collection of sorted plastics that are transported to recycling facilities through intermediate storage and further sorting at waste hubs aggregating plastic waste streams.

In terms of digital solutions, actors should continue to explore how these could be used to improve waste management practices. There is a need for a broader discussion and knowledge sharing regarding the implementation of digital solutions to build consensus among practitioners. However, actors should not rely solely on digital solutions to improve recycling rates in the near future. Rather, to increase the low recycling rate of construction plastic waste, actors need to act immediately using the tools available. In terms of digital product information sharing, actors should determine what information holds value, and for whom, and share that information using current available digital systems and solutions.

6.2 Further research

This work has been done based on a single value chain connected to one specific construction company. While the generalization of findings was extrapolated based on the specific case, further research including perspectives from a more diverse set of actors could result in insights that are representative of the whole construction industry.

Further, as actors within the Swedish construction industry are deemed to face changing circumstances regarding plastic recycling, driven by changing external environment, the identified services and barriers will likely change and are recommended to be revisited as the plastic recycling industry changes.

As the concept mapping process focused on ways to collaborate to improve plastic recycling it generated findings at a high level of abstraction. Further research could do more narrow concept maps, focusing on specific collaborative actions to give deeper insights into how they can be implemented.

The digital solutions that were found rely on a small set of dedicated interviews. Further studies are needed to investigate the potential and feasibility of identified digital solutions, but also to explore additional digital solutions that could improve plastic waste management based on a broader sample.

Furthermore, since the service opportunities were examined with an exploratory approach, the findings should be viewed as indications of what can be done and not a comprehensive list. Therefore, there is a need for further research to identify more service opportunities in the interface between the construction industry and plastic recycling. Additionally, since the identified service systems span over a broad range of actions and are not tested in practice, there is a need for feasibility studies specifically targeting the different service systems to determine the cost of implementation. Finally, the analytical approach based on service theory and CEBM theory resulted in proposed designs for collaborative actions. Further research in the form of similar studies can be done to test the analysis method's validity.

Bibliography

Ahlm, M., Boberg, N., Hytteborn, J., Miliute-Plepiene, J., & Nielsen, T. (2021). *Kartläggning av plastflöden i byggsektorn: Råvara, produkter, avfall och nedskräpning.* http://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-8908

Almasi, A., Ahlm, M., Berglund, R., & Johann Bolinius, D. (2020). *Möjligheter till minskad klimatpåverkan genom cirkulär användning av plast i byggsektorn: Sammanställning av befintlig kunskap.* http://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-8509

Baines, T., Lightfoot, H., Benedettini, O., & Kay, J. (2009). The servitization of manufacturing: A review of literature and reflection on future challenges (R. Roy, Ed.). *Journal of Manufacturing Technology Management*, *20*(5), 547–567. https://doi.org/10.1108/17410380910960984

Bell, E., Bryman, A., & Harley, B. (2019). *Business research methods* (Fifth edition) [OCLC: 1132388532]. Oxford University Press.

Bianchini, Rossi, & Pellegrini. (2019). Overcoming the main barriers of circular economy implementation through a new visualization tool for circular business models. *Sustainability*, *11*(23), 6614. https://doi.org/10.3390/su11236614

Blackburn, J. D., Guide, V. D. R., Souza, G. C., & Wassenhove, L. N. V. (2004). Reverse supply chains for commercial returns. *California Management Review*, *46*(2), 6–22. https://doi.org/10.2307/41166207

Bobulski, J., & Kubanek, M. (2021). Deep learning for plastic waste classification system (M.-S. Yang, Ed.). *Applied Computational Intelligence and Soft Computing*, *2021*, 1–7. https://doi.org/10.1155/2021/6626948

Council of European Union. (2008). The waste framework directive. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32008L0098

Enebjörk, A., Löwenberg, K., & Sporre, A. (2022). *Materialåtervinning av plast – utvärdering och praktisk implementering.* https://www.sbuf.se/Projektsida?project=ef7355ca-1b5e-4fa9-bec8-0c6211559f43#:~:text=Avfallet%20som%20g%C3%A5r%20till%20f%C3%B6rbr%C3%A4nning%20kan%20reduceras%20genom%20ut%C3%B6kad%20sortering,analyser%20av%20inneh%C3%A5ll%20i%20plastemballaget

Eriksson, V., Hulthén, K., Sundquist, V., Fredriksson, A., & Janné, M. (2021). The role of public actors in construction logistics: Effects on and of relational interfaces. *Construction Management and Economics*, *39*(10), 791–806. https://doi.org/10.1080/01446193.2021.1970785

European Commission. (2008). *Directive 2008/98/ec of the european parliament and of the council of 19 november 2008 on waste and repealing certain directives* (Vol. L 312/3). Official Journal of the European Union. https://data.europa.eu/doi/10.2800/297122

European Environment Agency. (2021). *Digital technologies will deliver more efficient waste management in europe.* Publications Office. https://doi.org/10.2800/297122

Fråne, A., Anderson, S., Andersson, C., Boberg, N., Dahlbom, M., Miliute-Plepiene, J., Unsbo, H., Villner, M., & George, M. (2022). *Kartläggning av plastflöden i sverige 2020: Med avseende på råvara, produkter och avfall.* http://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-10269

Frishammar, J., & Parida, V. (2018). Circular business model transformation: A roadmap for incumbent firms. *California Management Review*, *61*(2), 5–29. https://doi.org/10.1177/0008125618811926

Gebauer, H., Fleisch, E., & Friedli, T. (2005). Overcoming the service paradox in manufacturing companies. *European Management Journal*, *23*(1), 14–26. https://doi.org/10.1016/j.emj.2004.12.006

Geissdoerfer, M., Pieroni, M. P., Pigosso, D. C., & Soufani, K. (2020). Circular business models: A review. *Journal of Cleaner Production*, *277*, 123741. https://doi.org/10.1016/j.jclepro.2020.123741

Geissdoerfer, M., Vladimirova, D., & Evans, S. (2018). Sustainable business model innovation: A review. *Journal of Cleaner Production*, *198*, 401–416. https://doi.org/10.1016/j.jclepro.2018.06.240

Grönroos, C. (2008). Service logic revisited: Who creates value? and who co-creates? (G. Svensson, Ed.). *European Business Review*, *20*(4), 298–314. https://doi.org/10.1108/09555340810886585

Guldmann, E., & Huulgaard, R. D. (2020). Barriers to circular business model innovation: A multiple-case study. *Journal of Cleaner Production*, *243*, 118160. https://doi.org/10.1016/j.jclepro.2019.118160

Halldórsson, Á., & Aastrup, J. (2003). Quality criteria for qualitative inquiries in logistics. *European Journal of Operational Research*, *144*(2), 321–332. https://doi.org/10.1016/s0377-2217(02)00397-1

Halldórsson, Á., Vural, C. A., & Wehner, J. (2019). Logistics service triad for household waste: Consumers as co-producers of sustainability. *International Journal of Physical Distribution &amp Logistics Management*, *49*(4), 398–415. https://doi.org/10.1108/ijpdlm-02-2019-0065

Jansson, A., Boss, A., & Lundberg, L. (2019a). *Återvinning av plast från bygg- och rivningsprocesser.* http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-44554

Jansson, A., Ekici, S., & Lindkvist, L. (2019b). *Repipe demo – large scale collection, sorting and recycling of pipes.* https://resource-sip.se/projekt/repipe-demo-insamling-sortering-och-atervinning-av-ror-i-stor-skala/

Lassesson, H., Gottfridsson, M., Nellström, M., Rydberg, T., Josefsson, L., & Mattsson, C. (2021). *Kemisk återvinning av plast: Teknik, flöden och* *miljöaspekter.* http://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-8960

Lindahl, M., Lundin, E., Sundin, E., & Hatti-Kaul, R. (2022). *Går det att ersätta dagens allaplastvarianter med ett färre antal?* https://mistrarees.se/custom/uploads/2022/11/Unity_2022-23_webb.pdf

Liu, D., Wang, H.-W., Zhong, B.-T., & Ding, L.-Y. (2021). Servitization in construction and its transformation pathway: A value-adding perspective. *Engineering*. https://doi.org/10.1016/j.eng.2021.09.013

Ljungkvist Nordin, H., Westöö, A.-K., Boberg, N., Fråne, A., Guban, P., Sörme, L., & Ahlm, M. (2019). *Kartläggning av plastflöden i sverige: Råvara, produkter, avfall och nedskräpning.* http://urn.kb.se/resolve?urn=urn:nbn:se:naturvardsverket:diva-8118

Lüdeke-Freund, F., Gold, S., & Bocken, N. M. P. (2018). A review and typology of circular economy business model patterns. *Journal of Industrial Ecology*, *23*(1), 36–61. https://doi.org/10.1111/jiec.12763

Lusch, R. F., & Vargo, S. L. (2014). *The service-dominant logic of marketing.* Routledge. https://doi.org/10.4324/9781315699035

Material Economics. (2019). Industrial transformation 2050 - pathways to net-zero emissions from eu heavy industry. https://materialeconomics.com/publications/industrial-transformation-2050

Material Economics. (2022). Europe's missing plastics - taking stock of eu plastics circularity. https://materialeconomics.com/publications/europes-missing-plastics

Mathieu, V. (2001). Product services: From a service supporting the product to a service supporting the client. *Journal of Business &amp Industrial Marketing*, *16*(1), 39–61. https://doi.org/10.1108/08858620110364873

McKinsey & Company. (2016). Imagining construction's digital future. https://www.mckinsey.com/capabilities/operations/our-insights/imagining-constructions-digital-future

McKinsey & Company. (2022). Climate impact of plastics. https://www.mckinsey.com/industries/chemicals/our-insights/climate-impact-of-plastics

Oliva, R., & Kallenberg, R. (2003). Managing the transition from products to services. *International Journal of Service Industry Management*, *14*(2), 160–172. https://doi.org/10.1108/09564230310474138

Richardson, J. (2008). The business model: An integrative framework for strategy execution. *Strategic Change*, *17*(5-6), 133–144. https://doi.org/10.1002/jsc.821

Samuelson, O. (2021). *Digitaliseringssatsningar i den svenska bygg- och installationsbranschen.* https://www.sbuf.se/media/zgindbby/digitaliseringsinitiativ-sbuf-slutrapport-2021-01-07.pdf

Sezer, A. A., & Bosch-Sijtsema, P. (2020). Actor-to-actor tensions influencing waste management in building refurbishment projects: A service ecosystem perspective. *International Journal of Construction Management*, *22*(9), 1690–1699. https://doi.org/10.1080/15623599.2020.1741493

Trochim, W. M. (1989). An introduction to concept mapping for planning and evaluation [Special Issue: Concept Mapping for Evaluation and Planning]. *Evaluation and Program Planning*, *12*(1), 1–16. https://doi.org/https://doi.org/10.1016/0149-7189(89)90016-5

Tura, N., Hanski, J., Ahola, T., Ståhle, M., Piiparinen, S., & Valkokari, P. (2019). Unlocking circular business: A framework of barriers and drivers. *Journal of Cleaner Production*, *212*, 90–98. https://doi.org/10.1016/j.jclepro.2018.11.202

Vargo, S. L., & Akaka, M. A. (2012). Value cocreation and service systems (re)formation: A service ecosystems view. *Service Science*, *4*(3), 207–217. https://doi.org/10.1287/serv.1120.0019

Vargo, S. L., & Clavier, P. (2015). Conceptual framework for a service-ecosystems approach to project management. *2015 48th Hawaii International Conference on System Sciences*. https://doi.org/10.1109/hicss.2015.166

Vaughn, L. M., & McLinden, D. (2015). Concept mapping. In *Handbook of methodological approaches to community-based research* (pp. 305–314). Oxford University Press. https://doi.org/10.1093/med:psych/9780190243654.003.0030

Vermunt, D., Negro, S., Verweij, P., Kuppens, D., & Hekkert, M. (2019). Exploring barriers to implementing different circular business models. *Journal of Cleaner Production*, *222*, 891–902. https://doi.org/10.1016/j.jclepro.2019.03.052

Wagner, S. M., Jönke, R., & Hadjiconstantinou, E. (2017). Relationship archetypes in aftermarkets. *International Journal of Production Research*, *56*(6), 2250–2268. https://doi.org/10.1080/00207543.2017.1378826

Wilts, H., Garcia, B. R., Garlito, R. G., Gómez, L. S., & Prieto, E. G. (2021). Artificial intelligence in the sorting of municipal waste as an enabler of the circular economy. *Resources*, *10*(4), 28. https://doi.org/10.3390/resources10040028

Wynstra, F., Spring, M., & Schoenherr, T. (2014). Service triads: A research agenda for buyer-supplier-customer triads in business services. *Journal of Operations Management*, *35*(1), 1–20. https://doi.org/10.1016/j.jom.2014.10.002

A

Barriers

A.1 Theoretical barrier examples

Categories	Theoretical Barrier Examples
Organizational	Narrow focus of existing sustainability strategies (Guldmann & Huulgaard, 2020) Incompatibility with existing (linear) operations and development targets (Tura et al., 2019) Conflicts with existing business culture and lack of internal cooperation (Tura et al., 2019)
Supply Chain	Strong industrial focus on linear models (Tura et al., 2019) Lack of tools and methods to measure (long-term) benefits of CE projects (Tura et al., 2019) Lack of network support and partners (Tura et al., 2019) Lack of collaboration and resources (Tura et al., 2019) Conflicting interests between actors in the supply chain (Vermunt et al., 2019) Lack of consideration on circular design from supply chain actors (Vermunt et al., 2019) Bad re-use practices/reluctance of third parties (Vermunt et al., 2019)
Technological, knowledge and informational	Lack of technical know-how and expertise(Vermunt et al., 2019; Bianchini et al., 2019) Lack of information and knowledge (Tura et al., 2019) Lack of technologies and technical skills (Tura et al., 2019) Ability to deliver high quality products (Vermunt et al., 2019) Design challenges to create durable products (Vermunt et al., 2019) Adoption of specific technologies (e.g., recycling technologies) for the redesign of circular products and production systems maintaining the same quality level (Bianchini et al., 2019)
	Continued on next page

Table 16 – continued from previous page

Categories	Theoretical barrier examples
	Lack of information sharing through enhanced information management technologies, e.g. platforms (Tura et al., 2019)
Institutional	Lack of CE know-how of political decision-makers (Tura et al., 2019) Ineffective recycling policies (Vermunt et al., 2019) Public procurement policies not sustainability oriented (Guldmann and Huulgaard, 2020)
Economic and financial	Costly management and planning processes due to more complex practices (Bianchini et al., 2019) Higher costs related to the new CEBM (e.g. costs of collection and segregation of components) (Vermunt et al., 2019) High costs and lack of financial capability and support (Tura et al., 2019) High up-front investment costs (Vermunt et al., 2019) Unclear financial business case (Vermunt et al., 2019)
Market	Low price of virgin raw materials compared to recycled materials (Guldmann and Huulgaard, 2020; Vermunt et al., 2019) Lack of consumer interest/non-acceptance of CEBMs (Vermunt et al., 2019)

Table 16: Barrier categories with example barriers gathered from CEBM literature (Bianchini et al., 2019; Guldmann & Huulgaard, 2020; Tura et al., 2019; Vermunt et al., 2019)

A.2 Empirical barrier examples

	Barrier descriptions	Illustrating examples from interviews
Economic & financial	Low financial impact of improved plastic handling process	Efficient waste handling does not significantly affect construction project economics – C1
		Plastic materials are cheap compared to other building expenses – RI2
	Incineration flows are currently more cost-effective than CEBMs	Lower cost of incineration with energy recovery – WSP1
		It's often more expensive to recycle than to incinerate it – T2
	Plastic recycling is a complex process where logistic cost is a critical issue	Sorting in more fractions often gives additional logistic costs – C2
		Transportation of plastic waste is very costly – R3
		The most critical issue for take-back management of plastic, for example EPS, is the transport – M2
		Plastics are very low density, making them expensive to transport – T3
Organizational	Difficult to organize for effective on-site sorting into many fractions	The challenge of sorting plastic into many fractions at the construction site is a crucial reason for the low recycling rate. – C3
		No standard operational procedures for sorting different plastic fractions at the site – RI2
		Planning for recycling is not included in early stages resulting in too little space and time – T2
		Many different actors on construction sites makes sorting harder – RI3
	Narrow focus of existing sustainability strategies	Sustainability focus have historically been on limiting dangerous waste and not recycling of non-dangerous waste – T1

Table 17: Economic & financial, and Organizational barriers

	Barrier descriptions	Illustrating examples from interviews
Supply chain	Lack of network support, partners and needed resources	There is a lack of off-site sorting possibilities – C1
		Lack of recycling plants that can receive plastics for sorting – RI3
	Supply chain actors lacking incentives for handling plastic waste	Supply chain is focused on material flows into the site and not out – RI1
		Lack of incentive for sub-contractors to sort waste – M1
		Lack of incentive to sort plastic waste – R1
	Collaboration and communication issues	It is difficult to establish collaborations between manufacturers and waste contractors. – M2
		Lack of communication between actors – RI3
		It's hard to communicate with smaller construction companies – T2
Institutional	Ineffective legal obligations	The legal requirement of one plastic fraction is not enough – T2
		Only one plastic fraction legally required is insufficient – RI2
		There is a lack of legal obligations for sorting plastic waste – R1
		There is a lack of legal requirements for manufacturers to make sure that the products they put into the construction industry are possible to recycle. – C3
		Lack of law supervision, could be a consequence of low knowledge on how to supervise – T3
	Lack of procurement regulations that generate demand pull	Lack of legal instruments that drive demand – T1
		Producers have no quota obligation for recycled plastic. This is needed to be able to have a stable market. – R3

Table 18: Supply chain and institutional barriers

	Barrier descriptions	Illustrating examples from interviews
Technological, knowledge and informational	Technological challenges	Some building materials require colored plastic packaging to protect from UV radiation, e.g, wooden materials. – C3
		There is no technology today that enables automated sorting of quality high enough to produce high-quality raw materials. IR cameras can only recognize polymer types. – R3
	Lack of collection, aggregation, and sharing of information concerning plastic waste flows	Statistics are lagging behind so hard to get progression feedback – C2
		Lack of metrics – C2
		Missing compilations on plastic recycling flows and climate savings. – C2
		Lack of efficient communication systems – C3
	Lack of knowledge and experience in waste handling	Lack of knowledge from the purchaser on what material has systems for recycling/reuse – RI1
		Many people on construction site with different experiences and information available – RI2
		Knowledge gap regarding plastic waste handling prevalent among construction site practitioners – RI2
Market	Competitive plastic market and unstable market of recycled plastics	The prices for recycled plastics are very volatile. Prices and demands can swing in a few months resulting in difficult planning – R3
		Materials are often purchased base on lowest price – RI1

Table 19: Market barriers, and barriers related to technological, knowledge and informational issues

B

Interview Guides

B.1 Interview guide 1

Background:
This study aims to map service opportunities that can increase plastic waste recycling within the Swedish construction sector. With services for plastic waste recycling, we refer to actions performed by one or several actors that make it easier for subsequent actors in the value chain to make sure that plastic waste is materially recycled. We are particularly interested in such services where one actor pays another to perform the action. Specifically, we want to investigate how services enabling increased plastic recycling could be used at large in the industry and not just on the project level. With this interview, we aim to learn how plastic recycling could be increased, to better understand the characteristics of present services for plastic waste handling, and to identify hindering factors for the provision of such services.

Recording:
In order to ensure that we capture your point of view effectively, we would like to record the interview. The recording will be kept confidential and will not be presented to anyone. Your answers will be anonymized in the subsequently published thesis.

Questions:

Background of the interviewee:

- What is your academic and professional background?
- What is your job title and how would you describe your position?
- What are you particularly passionate about at work?
- Are you currently working on a project related to plastic waste?

Issues with regard to plastic recycling in the construction industry:

- Currently, only 0.8% of plastic waste from the construction sector is recycled. What main reasons do you see that help explain this low recycling rate?

- Looking forward, what would you say are the current major challenges to increasing the rate of recycled plastics?

Services for increased rates of recycled plastics in the construction industry:
On the project level, there have been attempts to create circular loops for different types of plastics such as floors and packaging (emballage). These loops have to different extents been dependent on services such as Tarkett taking back flooring installation spillovers, "uppdukning", on-site compression of plastics, and on-site waste handling managers.

- Can you describe these, or similar, services that you have come across?
- What would you say are the challenges with regard to providing such services?
- What do you think can help explain why these services mainly are seen on the project level and not industry-wide?
- What other types of services do you see that can increase the rate of recycled plastics?

Additional remarks:

- Is there anything related to this interview that you would like to share with us?

B.2 Interview guide 2

Background:
Our study aims to map service opportunities that can increase plastic waste recycling within the Swedish construction sector. With services for plastic waste recycling, we refer to actions performed by one or several actors that make it easier for subsequent actors in the value chain to make sure that plastic waste is materially recycled. Our main focus is on such services where one actor pays another to perform the action. Specifically, we want to investigate how services enabling increased plastic recycling could be used at large in the industry and not just on the project level.

With this interview, we aim to learn how digital solutions could be leveraged to support the development of services for increased plastic waste recycling. Here, we are curious about two different perspectives. First, how digital solutions could be leveraged to improve plastic waste handling services. Second, how digital solutions could be leveraged to mitigate prevalent issues that plastic waste handling services face.

Recording:
In order to ensure that we capture your point of view effectively, we would like to record the interview. The recording will be kept confidential and will not be presented to anyone. Your answers will be anonymized in the subsequently published thesis.

Questions:

Background of the interviewee:

- What is your academic and professional background?

- What is your job title and how would you describe your position?

- What are you particularly passionate about at work?

- Are you currently working on a project related to plastic waste?

Digital solutions for improved plastic waste handling services:
Prevalent types of services for increased construction plastic waste recycling include (1) take-back management of installation residues, (2) on-site sorting of plastic waste, (3) off-site sorting of plastic waste, (4) cleaning of plastic waste, and (5) transportation of plastic waste.

- How could digital solutions increase the effectiveness or efficiency of such services?

- What other services could you see, enabled by digital solutions, that could increase plastic waste recycling?

Digital solutions for prevalent issues regarding plastic waste recycling services:

How could digital solutions improve ...

- ... the efficiency of plastic waste transportation?

- ... on-site sorting of plastic waste?

- ... off-site sorting of plastic waste?

- ... communication between actors across the construction value chain?

- ... quality assurance for recycled plastics?

Additional remarks
- Is there anything related to this interview that you would like to share with us?

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