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Business models for the reuse of construction and demolition waste

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Abstract

The construction sector is the largest contributor to waste in Europe. Approximately one-third of all waste originates from construction and demolition. In Europe, most construction and demolition waste (CDW) is recycled as backfilling and only limited amounts of construction materials are reused for their original purpose. There is a current policy push by the European Commission (EC), as well as several EU member states, focused on lifting waste up the European waste hierarchy from recycling to reuse to help preserve resources and reduce the environmental impacts of CDW, which is considered a priority waste stream. This article explores the potential and the barriers to the increased reuse of CDW and describes several business models for reuse based around the intersection between public authorities, waste companies and private companies involved in the construction and demolition sector. The article is empirically based on a study of various reuse schemes operated by waste companies, municipalities and private waste operators in Denmark. Using a mixed-methods approach, in which survey methods are combined with company visits and qualitative interviews, the article analyzes the potential and the barriers to the creation of direct reuse schemes for CDW. Based on the findings from these, four generic business models for the direct reuse and recycling of CDW are synthesized specifically targeting the CDW fractions that are waste managed at public recycling stations. Finally, the article discusses how market conditions, environmental issues and quality can influence emerging reuse schemes.

Keywords: Business models, waste, construction, demolition, recycling

1 Introduction

The demands of modern society for materials and energy, with ever-increasing consumption and production, are having significant negative impacts on the global environment. Increasing industrialization, urbanization, economic growth, and population growth, etc. are leading to a range of environmental issues, including climate change, acidification of the ocean, loss of biodiversity, land degradation and resource scarcity. According to the UN's International Resource Panel (IRP), global resource consumption increased from 26.7 billion tonnes per year to 75.6 billion tonnes per year in the period from 1970 to 2010 (Bringezu et al., 2017). In 2005, the construction industry alone used approximately 23 billion tonnes of raw materials (Haas et al., 2015), and construction and demolition waste (CDW) is the largest waste stream in the EU in terms of mass, with 374 million tonnes generated in 2016 (EEA, 2019). Furthermore, the building industry accounted for 39% of global energy and process-related greenhouse gas (GHG) emissions in 2018 (GlobalABC et al., 2019). Over the last decades, the increasing implementation of energy efficiency measures (e.g. in renovations) has significantly improved the environmental footprint of buildings, with energy savings of 50%–90% achieved in many existing buildings worldwide (Lucon et al., 2014). Moreover, many new technologies have been introduced, improving the energy intensity and reducing the total energy used in heating, lighting and appliances (GlobalABC et al., 2019). However, while the energy efficiency of buildings has generally improved, cities worldwide are rapidly expanding, thus increasing the demand for virgin materials and energy. Such a scenario is not sustainable and thus there is a need to also consider material resource efficiency.

As a major user of resources and a major waste producer, the construction sector has a key role to play in improving material resource efficiency and there is clearly a need to rethink the current construction and demolition practices to reduce the generation of waste and the consumption of virgin resources. In this regard, extending the lifespan of buildings and introducing secondary materials in new buildings and renovations are key strategies. However, the application of secondary materials is not straightforward and faces a number of challenges. Nußholz et al. (2019) found that access to quality secondary materials in the current industry set-up is insufficient and the market is dominated by a few market actors with low incentives for cooperation. Furthermore, the current waste management infrastructure and separate collection is inefficient (Kabirifar et al., 2020). These conditions make it difficult to increase sales and market share to promote circular business cases (Nußholz et al., 2019). To fully enable business model innovation, buildings should be designed for deconstruction with an aim to lower the end-of-life demolition operation costs and increase the quality of the possible resource output that can be recovered (Salama, 2017). This can be promoted by introducing Design for Disassembly (DfD) principles, thus rethinking the practices applied for the documentation, design and construction methods used for constructing buildings to facilitate their end-of-life demolition and the recovery of materials and systems, while supporting better labour practices, productivity and safety (Rios et al., 2015). It is also essential that the number of companies engaged in the promotion of secondary material use should be increased, e.g. by improving certification schemes, or by making management plans for CDW obligatory to improve the sorting, collection and treatment of such waste (Nußholz et al., 2019).

Selective demolition has been presented as an alternative to conventional demolition, focusing on optimizing the reuse and recycling of building materials in the demolition process (Christensen et al., 2022). By the systematic deconstruction of a building, it would be possible to sort out the resources and thereby maximize their reuse and recycling (Gálvez-Martos et al., 2018). However, while this process would increase the environmental performance of the building, the economic feasibility will vary depending on several factors, such as labour costs, market prices and tipping fees (Ghisellini et al., 2018; Silva et al., 2017). In a comparative study of demolition methods, Hoang et al. (2022) demonstrated that the higher costs for labour, machinery and hazardous abatement must be accommodated by the resale value of the recovered, reused and recycled materials. When a building is dismantled, waste management should focus on sorting materials based on their nature and characteristics (Christensen et al., 2022). Materials should moreover be categorized in different classes to match the quality requirements of aggregates and the grade of application (Silva et al., 2017). The certification of recycled aggregates could be supported by setting up common rules and standards for producers, thereby systematizing and improving the methods for sorting and providing a measure of quality control in the production of aggregates. Assuring the quality of aggregates would increase the confidence of users, and hence support a maturing market for secondary materials (Gálvez-Martos et al., 2018; Silva et al., 2017). Overall, there is a critical need to establish effective practices for demolition, processing, design and logistics that could secure the quality, purity and traceability of materials to prepare for their reintegration into the value chain through reuse or recycling (Nussholz & Milios, 2017; Wahlström et al., 2020).

Therefore, the promotion of circular economic practices in construction and demolition calls for systemic innovation throughout the value chain (Ness & Xing, 2017) and collaboration among the various value chain actors. To achieve environmental and social value creation while ensuring economic benefits, such innovation needs to be embedded in proven business models. Thus, to create value for a network of stakeholders not relying on an increased flow of resources, the current business models need to be redesigned (Leising et al., 2018).

1.1 Sustainable business model innovation

A business model is a conceptual tool that illustrates how a firm does business by describing how all elements of the business as a system work together, linking the firm’s strategy to its activities. A business model can thereby also provide feedback from every activity for managers to make conscious decisions in how they operate their business (Magretta, 2002; Osterwalder et al., 2005).

To describe a model of a firm and its functioning, Richardson (2008) condensed the business into a system with three main components: i) value proposition, which describes what the firm will deliver to its targeted customers and why the customers will value the offering. In sustainable business models, value proposition focuses on balancing economic, social and ecological values (Boons et al., 2013); ii) value creation and delivery, which are the processes for putting the proposed offering into action. These describe and link all the activities involved in creating, producing, selling and delivering the firm’s offering. It illustrates the structure of the organization, including the capabilities and resources within the firm, and moreover the key partners and channels for creating and delivering value. In sustainable business models, value creation is broadened out to not only focus on aspects within the firm but also on the firm as part of a larger system (Boons et al., 2013) and how it can also create value in its supply chain relations and for customers and the public (Lüdeke-Freund, 2010); iii) value capture, which concerns how the firm can produce revenue from the value that it has created and delivered, while also considering the cost structure in terms of how it can achieve a profit margin while recovering its costs. Sustainable business models also require a balance in costs and revenue for all actors involved (Boons et al., 2013) but may challenge traditional value chain relations, e.g. by introducing concepts like product-service-system (PSS) models, in which value capture is focused on delivering a service rather than ownership of a product (Bocken et al., 2014).

According to Schaltegger et al. (2012), some firms may react to sustainability concerns by adopting a defensive strategy, focusing on regulatory compliance, to protect the firm against costs and risks or proactively by integrating sustainability in the firm. When addressing sustainable innovation within a firm, the scope can vary from incremental optimization, like operational efficiency schemes, to a fundamental shift in the purpose of the firm, thus also addressing organizational change and the search for new market opportunities by creating shared value (Adams et al., 2016). The concept of shared value recognizes a move in defining markets from internal economic incentives to societal needs. This requires internal actions, such as integrating sustainability in the definition of the mission of a firm and in its decision-making, and external ones, such as taking part in new forms of collaboration with stakeholders (Porter & Kramer, 2011). Furthermore, Stubbs and Cocklin (2008) emphasized the importance of addressing both structural (e.g. processes, structures and practices) and cultural (e.g. norms and values) attributes.

1.2 Circular business models for CDW

As a subcategory of sustainable business models (Geissdoerfer et al., 2018), circular business models embed circular economy principles in the core business strategy. Bocken et al. (2016) proposed a typology distinguishing circular strategies that target slowing-, closing-, or narrowing resource flows. Strategies that target narrowing resource flows aim at using fewer resources per product, which in this paper are recognized as efficiency-targeted schemes. This type of strategy usually does not imply a fundamental shift in business purpose, and thereby neither challenges business as usual nor promotes radical innovation in construction and demolition. Business models to slow resource loops focus on extending product use by extending the life of a product, such as through PSS, refurbishment, improved durability and repair, and by encouraging sufficiency and designs for long-life products. Business models for closing resource loops involve activities like collecting and sourcing, establishing take-back systems, industrial symbiosis, and design for cycling and reassembly. The target is to address innovation that promotes recycling and thereby can secure a circular flow of resources.

As circular strategies in construction and demolition often require an implementation in multiple phases, usually involving several stakeholders, along the project life (Nussholz & Milios, 2017), a multi stakeholder approach is usually essential to succesfully recirculate building materials. Furthermore, Nussholz and Milios (2017) discovered in a case study that developing new resources and capabilities within firms is essential for circular business model innovation. To apply circularity, they found that some firms had developed certification schemes to assure quality, gained knowledge in reuse and recycling solutions, and had developed a new customer base and supplier network to gain access to materials. They also discovered that some of firms acted beyond their traditional position in the value chain, e.g. as retailers, to also operate in demolition.

Circular business models in construction and demolition can be embedded at various stages of a building lifecycle, targeting different phases of the value chain, including i) material production, ii) design, iii) constrution, iv) use and v) end-of-life (Adams et al., 2017; Wahlström et al., 2020). The current practice in Europe is for most CDW to be used as backfilling (EEA, 2019). It is therefore crucial for the transformation to a circular economy to develop business models that can assist the looping of CDW back into the construction of new buildings rather than simply using as backfilling. There exist only a few academic articles about circular business models for CDW (e.g. Nussholz & Milios, 2017), and this article hopes to deepen the academic understanding of how such business models can be organized. The business models presented in this paper therefore mainly represent the end-of-life phase, focusing on the intersection between waste management and transformation, albeit innovation in the material production phase is also partly targeted, as some of the business cases seek to integrate a high amount of recycled content in material production. As described in this paper, innovation in the end-of-life phase must target both demolition, waste management and the transformation of resources, hence presenting the following value chain (Figure 1):

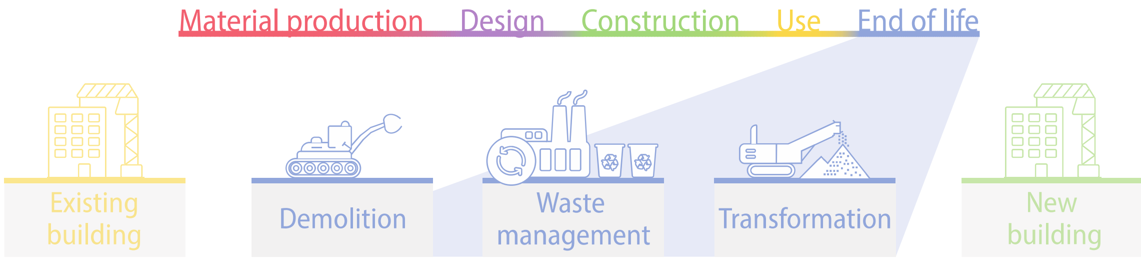

Figure 1 Illustration of the construction and demolition value chain based on Adams et al. (2017) and Wahlström et al. (2020), elaborating the end-of-life phase that is the focus of this study.

Based on empirical data obtained from a mixed methods study performed in Denmark, this article analyzes a number of circular business models for CDW.

2 Research Question and Methods

This article explores a number of business models for the reuse of CDW considering the intersection between public authorities, publicly owned waste companies and private businesses in the construction and demolition sector. The article investigates existing schemes for the direct reuse of CDW, synthesizes generic business models based on findings from the investigated schemes, and finally discusses the key barriers to further promote the market for secondary construction materials. As a basis for the study, three key research questions were posed:

Research questions:

1. What types of business models exist for the direct reuse of CDW and how do they operate?
2. How could one develop a typology for business models for the direct reuse of CDW?
3. What are the main factors that could promote the direct reuse of CDW?

The three research questions were analyzed using a mixed-methods approach (Johnson et al., 2007), in which a social survey research design is combined with site visits and semi-structured interviews (Bryman & Bell, 2011). A pre-structured qualitative survey was thus conducted (Jansen, 2010) to be carried out by telephone interviews, to explore the diversity of the business model characteristics in emerging reuse schemes for CDW among the study cohort, followed up by semi-structured interviews for more in-depth discussions.

The study cohort comprised municipalities, public waste companies and private businesses operating in Denmark, which were selected after a screening of the Danish waste sector and were identified as companies and municipalities with systems for the direct reuse of CDW. Through a web search, 18 companies were initially identified. Next, those with either no or too immature a scheme, or who were not interested in participating in the study were excluded, leaving a total of 11 organizations, comprising six waste companies (owned by municipalities), three municipalities and two commercial companies operating in the waste sector. An overview of the 11 respondents is illustrated in Table 1.

Table 1 Overview of the respondents based on the type of organization.

Municipalities	**Waste companies**	**Private companies**
Albertslund	AVV	Solum
Bornholm	RenoDjurs	GenByg
Hedensted	ARWOS	
	Sønderborg Forsyning	
	ARC	
	AffaldPlus	

In the survey, a representative from each of the 11 organizations was interviewed over the telephone and a short summary note of the interview was completed. The data from the interviews were later codified and the results compiled in a table. Some of the 11 municipalities and waste companies were additionally contacted by email afterwards and asked to clarify potential misunderstandings and to supply additional data. The survey covered how their reuse schemes were organized, the type of CDW covered by the scheme, the main suppliers and buyers of the CDW, the economic transactions involved with the scheme, the quality of the CDW, the environmental aspects associated with the handling of the CDW, and finally the capacity of the reuse scheme. The findings from this survey were then used to synthesize four generic business models for different modes of operation.

After the survey phase was completed, field visits were organized to five of the waste companies/municipalities (Argo, Solum, Genbyg, AffaldPlus, and Albertslund recycling station). The field visits were conducted to gain first-hand impressions of the types, quality and quantity of the CDW collected and handled for reuse and the physical organization of the reuse systems. Photos and notes were taken during the field visits. Also, during some of the field visits (Solum, Genbyg, AffaldPlus and Albertslund recycling station), qualitative interviews were conducted with key personnel involved in the direct reuse schemes. The qualitative interviews focused on understanding why and how the systems had been established and what the key barriers had been in terms of the legal aspects, market conditions (supply and demand), quality and environmental issues, as well as more practical and organizational aspects of their established business models. The research approach is summarized in Figure 2.

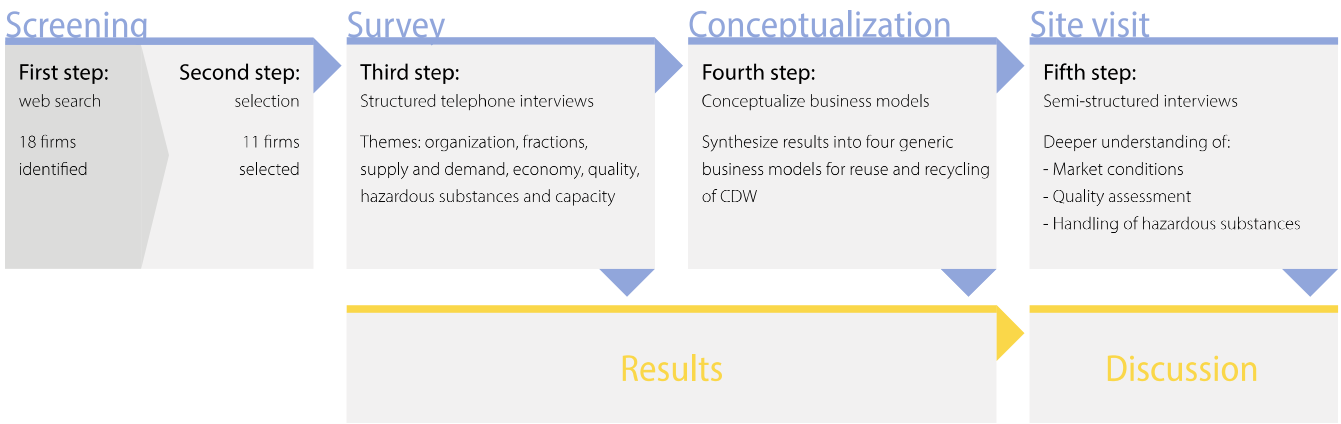

Figure 2 Overview of the study methodology.

3 Current Danish Waste Management System

In Denmark, CDW accounted for approximately 40% of all waste in 2019, amounting to a total of 5 million tonnes (Danish Environmental Protection Agency, 2020); of which, 5% of the CDW was deposited at landfills, 7% was incinerated, 36% was recycled and 52% was used as backfilling. Although Denmark complies with the objective of the EU Waste Framework Directive (2008/98/EC) by reaching at least 70% recycling by 2020, the current recycling practice implies that the majority of CDW is downcycled and used as road base and filling material (i.e. backfilling), instead of being reused for its original purpose in the construction of new buildings – similar practices can be found in most European countries.

The legal Danish framework for handling CDW is based on the EU Waste Framework Directive (WFD), which includes the so-called waste hierarchy, which indicates the preferred way to prevent and handle all types of waste. The hierarchy is divided into five levels based on priority: 1) prevention, 2) preparation for reuse, 3) recycling, 4) other recovery, including energy recovery, and 5) disposal, including landfill.

For this study, it was essential to clearly distinguish between levels 2 and 3, i.e. preparation for reuse and recycling. Preparation for reuse according to the WFD includes activities such as checking, cleaning and doing minor repairs to construction materials to enable their reuse without further processing, where reuse is defined in this context as a process in which the construction material is utilized for the same purpose for which it was originally created. Recycling, as level 3, includes processes where construction materials are processed into new products, materials or substances that can be used for the purpose they were originally intended or for other purposes.

The responsibility for waste management in Denmark is split between several levels of government. The national government is responsible for waste prevention, while the 98 municipalities in Denmark are responsible for waste management. Source-separated industrial waste is liberalized in the sense that private companies, for example in construction, can choose a private waste contractor to handle their CDW. The government's Executive Order on Waste (BEK nr 2159 af 09/12/2020) determines that construction projects generating less than 1 tonne of waste can use municipal recycling stations without the waste needing to be reported to the local authority. This allows small-scale contractors in the construction sector (e.g. carpenters, bricklayers and plumbing companies) to use public recycling stations, whereas large-scale construction companies typically must use private contractors instead.

In Denmark, there are around 400 recycling stations, where citizens and private companies can hand in bulky waste for recycling. The recycling stations vary in size and design and in the number of fractions they handle and how they handle those waste fractions. Most of the waste managed at the recycling stations is recycled, while a smaller part is incinerated, and a minor part is deposited at landfill sites. Only very limited amounts of the waste at recycling stations are reused (Winkler & Nyborg, 2021).

The quality (understood as the ability for the materials to be reused or recycled without adding significant amounts of labour and energy) of these fractions varies, but it is likely that some part of these waste materials will have the potential for reuse. Moving waste from recycling to reuse, however, often requires different waste handling processes, including its preparation for reuse (Dalhammar et al., 2021). Recently, several Danish recycling stations have established reuse schemes for CDW, but so far only limited knowledge about these systems has been compiled (Milios & Dalhammar, 2020; Moalem et al., 2022). The Danish government reached political agreement for a plan covering also the structure of the future Danish waste management system in June 2020 and as part of this, all recycling stations must implement reuse schemes (Danish Government, 2020).

4 Results from the Survey and Interviews

The following section presents the results of the study following some general qualitative considerations from the respondents surveyed in the study. These considerations cover the collected fractions, their potential and how they are handled, as well as some reflections on how the different reuse schemes are organized. The data from the survey is summarized in Table 2.

Table 2. Overview of the analyzed data organized by organization, type of scheme and investigated themes.

Organization	Albertslund Municipality	RenoDjurs	ARWOS	AffaldPlus	Sønderborg Utilities	AVV	Bornholm Regional Municipality	Genbyg	Hedensted Municipality	Solum	ARC
Type (1–4)	Swap system (1)	Swap system (1)	Retailing at waste company (2)	Retailing at waste company (2)	Retailing at waste company (2)	Retailing at waste company (2) /commercial retailer (3)	Reuse through commercial retailer (3)	Reuse through commercial retailer (3)	Reuse through commercial retailer (3)	Reuse through commercial retailer (3)	Recycling via the material's producer (4)
Waste fractions	Insulation materials, wood products, doors, roofing tiles, vapour barriers	Paving stones, doors, windows, wood products	Paving tiles, stones, wood products, sanitation, interior doors, insulation materials	Wood products, paving stones, windows, doors, sanitation, insulation materials, metal products	Wood products, windows, doors, insulation materials	Wood products, tools, paving tiles, tiles, windows, interior doors, sanitation, furniture	Wood products, bricks	Doors, windows, lamps, electrical items, wood products, flooring, tiles, paving tiles, bricks roofing tiles, sanitation	Wood products	Interim wood	Wood products, luminaires, concrete
Suppliers	Private users (primary) and SMEs (minor)	Private users (primary) and SMEs (minor)	Private users (primary) and SMEs (minor)	Private users (primary) and SMEs (minor)	Private users (primary) and SMEs (minor)	Private users (primary), SMEs (minor) and bricks from demolition contractors	Demolition contractors	Demolition contractors	Demolition contractors	Contractors	Demolition contractors
Buyers	Consumers	Consumers	Consumers	Consumers	Consumers	Consumers (bricks to business)	Businesses (start-up phase)	Consumers and SMEs (minor)	SMEs	Consumers and businesses	Businesses (internal experiment)
Organizational structure	Managed by the municipality without extra employees	Managed by RenoDjurs without extra employees	Managed by ARWOS w/ separate account and employees	Managed by AffaldPlus w/ separate account and 14 employees	Managed by SF w/ separate account and 2–3 employees	Managed by AVV w/ separate account. Social enterprise for bricks	Storage at the recycling station. Establishing value chain	Contractor managing store and webshop with 12–14 employees	Facilities and storage for entrepreneurs managed by the municipality	Distribution and sales by retailer. Sorting and packing by Solum.	Project managed by ARC
Economy	Financed through waste fees (no sales)	Financed through waste fees (no sales)	Financed through sales. Generates savings from reduced treatment fees	Financed through sales. Generates savings from reduced treatment fees. Profit used to balance waste fees	Financed through sales	Financed through sales. Generates savings from reduced treatment fees. Profit used for new initiatives	Projects not yet commercialized	Free access to materials via soft stripping	Financed by the municipality and entrepreneurs	Value capture shared between the value chain partners	Projects not yet commercialized
Fees	Private users: public fee. For businesses: €31/vehicle	Private users: public fee. For businesses: €27/visit	Private users: public fee. For businesses: €30/visit	Private users: public fee. For businesses: fee exemption for reuse	Private users; public fee. For businesses: €27/visit	Private users: public fee. For businesses: depends on yearly visits	not relevant	not relevant	not relevant	not relevant	not relevant
Quality	No special assessment	No special assessment	No special assessment	No special assessment	No special assessment	CE-certified bricks	Resource screening	No special assessment	No special assessment	No special assessment	Concrete class assessment
Environment	Pragmatic assessment	Pragmatic assessment	Pragmatic assessment	Pragmatic assessment	Pragmatic assessment	Pragmatic assessment	Mandatory screening	Mandatory screening	Mandatory screening	Visual screening	Mandatory screening
Capacity	Small barn allocated at the recycling station	5 open shipping containers	Small extension to secondhand store at the recycling station	1000 sqm decentralized store	Store at the recycling station	180 sqm store at recycling station	3 shipping containers at the recycling station	6000 sqm total in store and decentralized storage	1000 sqm facilities and storage	National retailers central storage	not relevant

SF: Sønderborg Forsyning; w/: with; w/o: without. SME: small and medium-sized enterprise. CE: Conformité Européenne

4.1 Waste fractions

The CDW collected by recycling stations can be divided into two main flows: 1) new and unused construction materials that become waste during construction projects and 2) used construction materials that typically result from demolition processes or are generated as a by-product from construction or renovation processes. Construction materials submitted at the recycling stations must be source separated, but the specific fractions differ between recycling stations. In Copenhagen Municipality, for example, CDW for recycling must be sorted into 14 different fractions (Copenhagen Municipality, 2022).

CDW handed in at recycling stations owned by waste companies are typically recycled at private companies for the production of new materials and products. The usability and economic value of the fractions vary significantly. Establishing a scheme for reuse therefore depends on which fractions potential users assign value to. The respondents in the study mainly pointed to wood products as the type of materials with the highest demand and value potential. Typically, wood products include different types of planks, laths and plywood that originate both from construction projects and demolition projects. Some recycling stations remove nails and the like from wood products to increase the value of the waste, but such procedures can require substantial effort and labour. Based on the survey, the following CDW materials were identified as the main products that would be most likely suitable for reuse:

- Wood products
- Insulation materials
- Newer windows and interior doors

• Tiles, paving stones and bricks

• Sanitation products

The selection and prioritization of CDW fractions vary between the surveyed waste companies. For example, the reuse scheme established by AffaldPlus receives both new and used construction materials, while in Albertslund Municipality, a swap scheme (without sales) has been established, focusing mainly on unused construction materials that have been turned in as waste at the recycling station.

Most of the studied reuse schemes receive construction materials from private enterprises involved in the construction sector. Five of the surveyed systems receive CDW for reuse from larger demolitions, but in most cases, this is done on a project basis and they have not yet developed sustainable business models to cover such flows. The Solum and Genbyg cases are the only ones in the surveyed schemes where formal agreements have been made with several construction and demolition companies.

4.2 Organization

The surveyed reuse schemes are organized in different ways, with some using shop facilities, swap schemes or systems based on a collaboration between waste companies and private retailers and/or private material producers. Among the 11 companies surveyed, two have organized reuse schemes based on a swap system. For example, the waste company RenoDjurs has set up five shipping containers at the recycling station and designed a special area dedicated to reusing building materials, furniture and the like. Meanwhile, 4 of the 11 surveyed schemes have organized shop facilities for reuse. In this type of scheme, a shop is set up at the recycling station.

At the waste company AVV, a warehouse has been established to host a 180 sqm reuse shop facility. Meanwhile, the waste company AffaldPlus invested in the renovation of an old commercial property to host a 1,000 sqm construction market (including furniture sales and workshop facilities). The property also hosts a facility for textile recycling, where textiles are sorted and packed. In total, 8 of the 11 surveyed systems have established (or are in the process of establishing) schemes for the reuse of construction materials handed in as waste.

The survey also identified some reuse schemes exclusively organized by private waste companies. The private construction goods retailer Stark and the waste company Solum have entered into a collaboration for the reuse of interim wood. Interim wood is used at construction sites for various purposes, such as railings, shields, stairs. Often wood products come in standardized sizes and quality. In this collaborative scheme, Stark organizes the transport and sales, while Solum is responsible for the sorting and packaging to ensure a uniform quality.

The waste company Amager Resource Center (ARC) is working on several projects focused on the recycling of CDW in collaboration with private material producers. These activities include projects for the recycling of crushed concrete, where, after an environmental and quality screening procedure, the concrete is transferred to the producer, via a waste handling company, where the recycled concrete is treated, to then be used in the production of new concrete.

5 Business Models for the Direct Reuse of CDW

The previous section presented some general considerations according to the organization of different types of schemes for the direct reuse and recycling of building materials. It was concluded that these schemes can be organized in many ways. Based on the analysis of the surveyed reuse schemes, we synthesized the findings into four generic business models for the direct reuse or recycling of construction materials. By synthesizing the data presented in Table 1 in accordance with Richardson's (2008) representation of a business model, the four generic models illustrate how the proposed value can be distributed and captured in the value chain, what resources and capabilities are needed to establish and run the business models, and what societal value can be gained through the schemes.

5.1 Model #1: Swap system

The first business model covers the direct reuse of construction and demolition materials as organized at recycling stations through non-sale swap schemes. This business model is typically organized as an integrated part of the conventional recycling station, as illustrated in Figure 3. It is designed in such a way that users supply construction and demolition materials they consider reusable and other users/customers can take the materials free of charge. This type of scheme is typically financed by the municipal waste fee and does not require additional staffing. Thus, the schemes can be operated by the existing staff at the recycling station. The staff guide users at the recycling stations and carry out a simple quality control primarily aimed at avoiding the diffusion of hazardous substances that may be in some construction materials placed in the swap system. Signs at the recycling station guide users to the swap system, while the staff also encourage the recycling station users with reusable construction and demolition materials to offer the materials in the swap system instead of placing them in the otherwise designated recycling containers.

Figure 3 Illustration of business model #1 "Swap system", including the organizational resources, value capture, suppliers and buyers, and the potential societal value.

The construction and demolition materials in this business model are typically supplied by private users and smaller private companies that deliver volumes less than 1 ton, thus constituting construction and demolition waste which is not subject to notification under the Danish Executive Order on Waste (BEK nr 2159 af 09/12/2020). The smaller quantities of materials at these schemes also mean that it is primarily the private users of the recycling stations that take construction materials back that are targeted. Commercial projects require strict quality documentation in line with the Construction Product Regulation (305/2011) standards, which the organizations operating swap schemes typically cannot provide. Thus, only a limited number of businesses can use this scheme, usually for small renovations. Customized IT systems are rarely used in connection with the swap schemes (ideally, such IT systems could be developed in the future), although the schemes are typically communicated through social media (primarily Facebook).

Example of model #1: The main flow of waste is handed in for either recycling or energy recovery. Operated as a side activity, materials for reuse are voluntarily placed by users in a reserved area and are sporadically assessed by the recycling station personnel – mainly for the removal of suspected contaminated materials (e.g. lead in paint or polychlorinated biphenyl (PCB) in varnish or grout). Thus, the personnel should receive some, even minor, training in pragmatic environmental assessment. Private users have unlimited access to the recycling station included in the basic waste management fee, while business users are charged approximately €30/visit. Products for reuse are collected by users with no check carried out by personnel. Materials for reuse are exempted the waste treatment fee for the waste company.

5.2 Model #2: Retailing at the waste company

This type of scheme is shown in Figure 4 and has been established in connection with some recycling stations, but is primarily aimed at establishing a store for the commercial sale of construction materials. Thus, retailing waste companies operating this system require a higher degree of organization and logistics compared to the case with operating a simpler swap system (Model #1).

The economic costs of running the shops for the reuse of construction and demolition materials are covered by the income generated from sales in the shops and therefore no waste fee is included for the operation of the stores. Additional staff are typically hired specifically to operate the stores, which in some cases creates social jobs. The number of additional staff varies, between 2–3 to 14 employees in our survey sample (Table 2), and some staff training is generally needed; AffaldPlus spent €185 on training staff in 2019 (AffaldPlus, 2020). The stores are not really aimed at generating profit, and any potential profit is utilized to stabilize existing waste fees or reinvested in the scheme. To attract private businesses to supply CDW for reuse in the shops, some of the systems offer 24/7 opening hours and free of charge disposal for private businesses to encourage them to supply reusable construction and demolition materials to the shop. This provides private companies a combined economic and practical incentive to engage with the scheme, as the companies would otherwise have to use the fee-based, conventional recycling option, which is also only open during office hours.

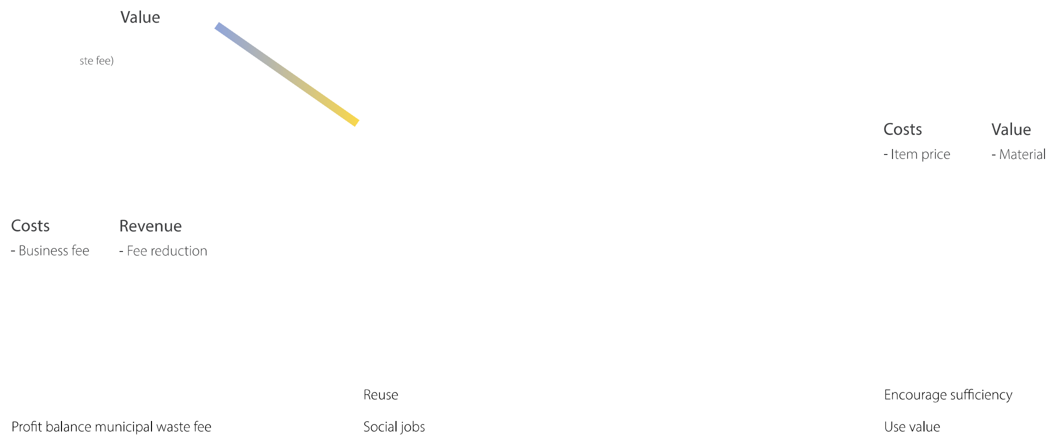

Figure 4. Illustration of business model #2 "Retailing at the waste company", including the organizational resources, value capture, suppliers and buyers, and the potential societal value.

To the waste companies that operate the recycling stations, there are additional indirect economic benefits associated with the reuse shops, as the abated recycling costs decrease. The establishment of reuse shops are in some cases also supported indirectly by the municipalities financing the buildings hosting the shops. As the sale of reusable construction materials through stores requires a higher degree of logistics compared to the swap schemes (Model #1), some of these schemes have an integrated IT system, where private companies are even offered a pick-up service for reusable materials.

The primary customers in the shops are private citizens and to a lesser degree small-scale companies in the construction sector. The fluctuating inventories and uncertainty of supply considering also the material quality are still considered barriers to a larger scale business-to-business model.

Example of model #2: Like in model 1, the main flow of waste is handed in for recycling or energy recovery. In 2019, AffaldPlus managed a total amount of approximately 194000 tonnes of waste, of which 152000 tonnes were processed for recycling and 1800 tonnes were sold for reuse (AffaldPlus, 2020). Operating as a store with a separate account, all products are handed in and assessed by personnel for quality and pragmatically for preventing the diffusion of hazardous substances before they can be placed in the store. Some materials require minor preparation for reuse (e.g. the removal of nails). The separate store makes it possible for some schemes to offer fee exemption to business users for reusable items and besides, the sales profit from the reused materials also results in reduced treatment costs (e.g. Arwos saved approximately €90000 in 2019).

5.3 Model #3: Reuse through commercial retailers

Model 3 describes a business model where a system is established to loop targeted materials from construction and demolition projects back into the construction sector via privately owned retailers. The main difference between Models #2 and #3, as illustrated in Figure 5, is that Model #2 is organized by the waste utility companies (typically owned by municipalities) and organized in relation to the recycling stations, whereas Model #3 is operated by private retailers with no affiliation to the recycling stations.

The empirical data for this article suggest there are two main approaches to establishing reuse through a commercial retailer: a) a broad strategy focused on items generated from the soft-stripping phase of demolition projects (e.g. items taken out of buildings prior to demolition, such as doors, windows, electrical equipment or sanitation) and b) a strategy focused on one specific fraction. The first approach typically involves items that are considered easily marketable among private consumers. This type of building materials is usually relatively difficult to include in standardized quality control systems due to the large variety in design, quality and function (doors and windows for example often differ in design, shape, and material composition, etc.). Businesses in the construction sector therefore tend to prefer new construction products, which are covered by standardized quality control systems, over these types of reused items. Value capture across the value chain is secured indirectly for the demolition contractor through a cost reduction associated with the soft stripping, while at the same time providing free access to materials for the retailer. The retailer generates profit through sales.

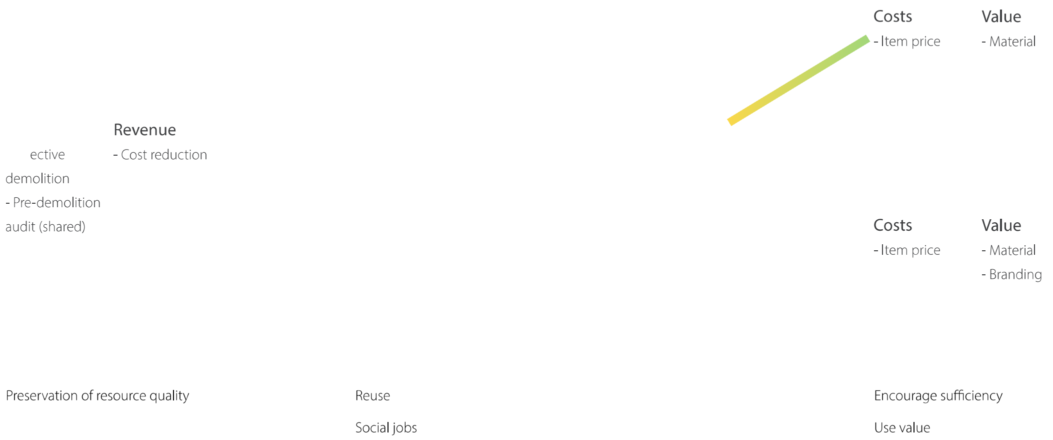

Figure 5. Illustration of business model #3 "Reuse through commercial retailers", including the organizational resources, value capture, suppliers and buyers, and the potential societal value.

The second approach is most often used in relation to a specific type of material, such as bricks, construction wood or interim wood. Focusing on a specific (and simpler) material simplifies quality assessment and makes it possible to apply standardized quality control systems and associated labelling systems (such as CE). CE certification has, for example, been used in association with the reuse of bricks. By building a quality control system (e.g. factory production control, FPC) for reused bricks, it is possible to prepare an European Technical Assessment (ETA) and an European Assessment Document (EAD) to describe the overall technical specifications (for example, for documentation of the product's performance) for enabling them to achieve CE certification. This makes it easier for private businesses in the construction sector to apply such bricks in the construction of new buildings where certification is needed.

Most of the surveyed companies who market construction and demolition materials through a commercial retailer do not screen for environmentally hazardous substances themselves, but use data from the legal statutory environmental screening conducted during pre-demolition.

Example of model #3 based on the flow of bricks: In the second approach, to preserve the quality of materials during demolition, the contractor performs a pre-demolition audit identifying the quantities, qualities and possible hazardous substances prior to a selective demolition (European Commision, 2016). Hoang et al. (2022) identified the combined cost for labour and machinery for dismantling such materials with a sorter grab to be approximately $10/tonne more than in a conventional demolition process; however, the potential resale value increases by almost the same amount – some materials even have a potential profit factor of two times, e.g. bricks (Christensen et al., 2022). To ensure quality, the bricks are manually cleansed for removing excess mortar and assessed at an ETA approved facility for CE certification before they can be sold at the store.

5.4 Model #4: Recycling via the material producers

The fourth business model targets the large quantities of construction materials generated from demolition projects (such as steel or concrete) that are typically unsuited for direct reuse. Covering recycling processes (as opposed to Model #3 that covers reuse processes), this business model focuses on demolition materials that can be recirculated back into new constructions through a private material producer, such as a concrete producer. To ensure quality in this type of business model, it is imperative that a proven practice is established, including well-defined workflows for selective demolition. This process can be strengthened and secured through certification. In a report from the Danish Environmental Protection Agency, Dansk Byggeri's Demolition Section suggests that an ISO 9001 certification can support quality management in relation to selective demolition (Golder Associates A/S et al., 2017). High quality in recycling processes may, however, not always be achieved and recycling processes therefore need to be evaluated and differentiated according to the end-use requirements.

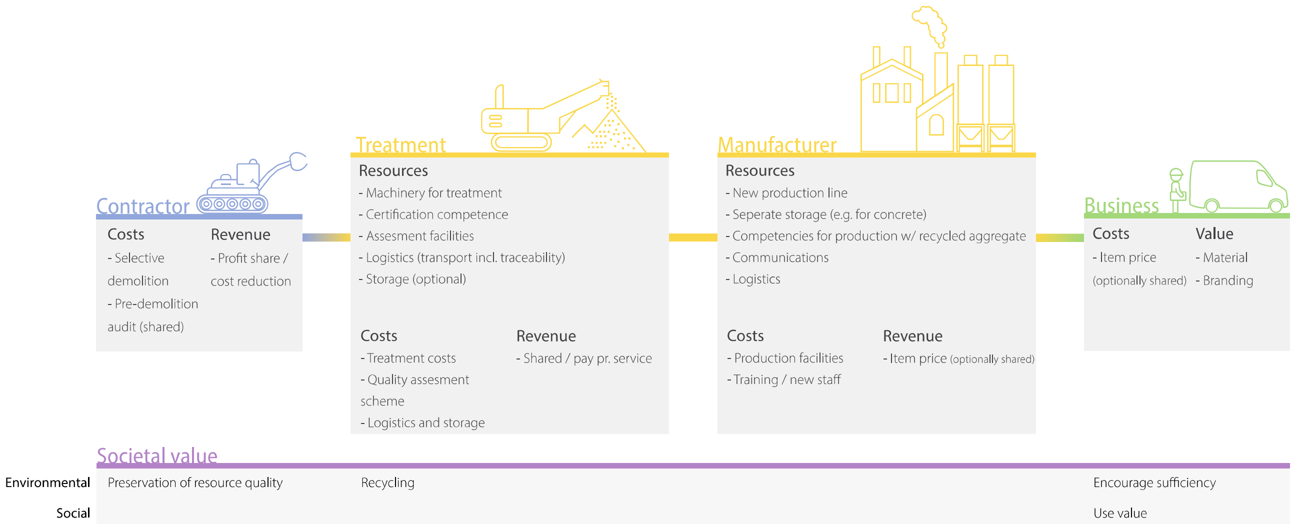

Figure 6. Illustration of business model #4 :Recycling via the material producers", including the organizational resources, value capture, suppliers and buyers, and the potential societal value.

The flow of materials and logistics can be organized in several ways, e.g. off-site through stationary recycling stations or mobile stations operated onsite. On a general level, Silva et al. (2017) found that stationary recycling stations tend to ensure the highest quality. However, the stationary recycling of, for example, concrete often implies more transportation, making it more complicated to ensure and guarantee the quality when the concrete is moved and more partners are involved at several sites. For this type of business model, it is crucial to secure close collaboration between the actors, as illustrated in Figure 6, and so value capture as well as risk management must be clearly negotiated. This can be organized through forming a consortium between the contractor, treatment company and manufacturer in the tender offer. The business represented in Figure 6 is in this case the construction client. Considering the case of the flow of concrete: Like in model #3, the concrete is first demolished and crushed either on site or at a facility, screened for soil and then separated into fractions by grain size to secure clean aggregate fractions for application (fine grain for sand aggregates and coarse for stone and gravel). The concrete is assessed to provide a performance declaration for CE certification based on drill tests prior to demolition, aggregate tests prior to manufacturing and sample tests after manufacturing (Kellermann et al., 2021). The recycled concrete must be purchased before manufacturing and matched for the right type of application in terms of the quality. Thus, the recycling of concrete is still performed on a project-to-project basis.

6 Discussion

As presented in the four business models, several factors must be addressed to successfully operate the reuse and recycling schemes, including the development of new organizational resources. To further scale circular business models for CDW, it is crucial to engage the supply and demand conditions, quality assurance and control of hazardous substances. These factors are discussed in the following.

6.1 Market conditions: supply and demand

CDW for reuse covers many different categories and inventories at the reuse schemes, with significant fluctuations. The goods in the reuse markets can therefore change, and the reuse shops are thus unable to offer the same stability as conventional construction markets. These fluctuations in supply make the reuse schemes in their present form less attractive to commercial buyers. The majority of the surveyed reuse schemes are owned and operated by municipalities. They are not allowed to earn a profit but only aim to cover the costs to operate the scheme; hence, the fluctuating flows of different construction and demolition materials are not considered an economic barrier to operate such a scheme. However, based on the data from the survey, it can be concluded that the fluctuating flow of materials has a negative influence on the shops ability to attract commercial customers, who would prefer conventional construction markets with more stable supply and inventories. Thus, to increase B2B sales, it is necessary to establish a more stable flow of construction materials, as private companies will otherwise not find it worth their effort to drive to the reuse shops at the recycling stations. In addition, a web-based marketing system would likely create a better overview of the assortment available, and create more security for business customers according to the availability of goods.

Some of the waste companies have implemented a fee exemption for business customers at the recycling stations to encourage them to use the reuse scheme instead of the recycling scheme. This economic carrot is intended to discourage companies from throwing CDW in large containers and instead encourage them to use the slightly more labour-intensive reuse scheme. However, this type of reuse scheme requires additional staffing at the recycling stations to manage the incoming materials. The waste company RenoDjurs operates a swap scheme and points out that fee exemption can risk compromising the quality of the materials submitted in the reuse scheme, since companies will have an incentive to hand in all materials regardless of its quality. The study therefore finds that fee exemption is best paired with a business model based on commercial retailing, since this model can generate income, which can pay for additional staff to monitor and select materials for the reuse scheme based on quality.

6.2 Quality assurance

Of the 11 surveyed schemes, 8 responded that they performed no special quality assessment of the construction materials, and that it is up to the customers themselves to assess the quality of the materials. Quality assurance is to an extent less vital for private citizens, but this is considered critical for the sale of used building materials to commercial customers. As Gálvez-Martosa et al. (2018) points out, quality assessment and the classification of materials is a factor that can increase the confidence in used building materials, by creating transparency and providing the possibility for them to comply with market standards. Professionals are obligated to comply with the standards laid down in the Construction Product Regulation (305/2011), hence quality assurance creates an incentive for the industry to utilize reuse schemes. Bornholm's Regional Municipality has established systems for the quality screening of building materials, as their project aims to establish a value chain based on commercial customers; however, the municipality does not guarantee the quality of the reused construction materials in strictly legal terms.

To establish a market for secondary materials, it is important to address the risks in legally guaranteeing material quality. This requires new agreements between the value chain actors, preferably early on in the process, specifically in terms of who guarantees the material quality (supported by CE certification) and how the risks are shared (Lauritzen, 2018; Wahlström et al., 2020).

6.3 Environmentally hazardous substances

A wide variety of construction materials contain environmentally hazardous substances, such as PCBs, asbestos, chlorine paraffins, lead and other metals. Materials considered a risk are separated from the other reused materials at the recycling stations to avoid the diffusion of environmentally hazardous substances. At most of the surveyed schemes that include recycling stations, the environmental assessment is based on a pragmatic assessment performed by an employee at the recycling station.

Formal environmental screening for hazardous substances is exclusively carried out in cases where the material supply comes from demolition projects, as environmental screening is mandatory in that case. For example, Bornholm's Regional Municipality aims to establish a value chain for reused/recycled construction materials through a series of demolition projects, by creating a network of actors from the construction sector (Christensen, 2021). During the demolition projects, samples are taken to test them for potential environmentally hazardous substances and resource mapping is performed to assess the quantity and quality of the materials prior to demolition.

Regarding the environmental assessment of direct reuse materials, generally no special training for personnel is undertaken beyond the general qualification, but at AVV, for example, simple environmental screening principles have been developed in relation to the risk of PCBs, mercury, etc.

7 Conclusion

The majority of CDW is presently recycled as backfilling, but since construction materials often are energy intensive to produce in the first place, there are potentially substantial environmental benefits associated with efforts to push materials up in the waste hierarchy. The present study analyzed the potentials and barriers in different business models based on the reuse and recycling of CDW, and identified the main barriers related to the economy, organization, quality and environmental issues.

Based on a survey of reuse schemes established in Denmark, the study identified diverse ways to organize closed-loop systems for CDW. Based on these diverse experiences, four generic types of business models for the reuse and recycling of CDW were synthesized: 1) Swap system, 2) Retailing at the waste company, 3) Reuse through commercial retailers and 4) Recycling via the material producers.

The study identified the main elements of the business models for end-of-life CDW and the four proposed business models illustrated in abstract terms the resources needed and the cost incentives needed to establish reuse and recycling schemes for CDW. Moreover, the study contributes to an identification of the main challenges to scale-up business models for the reuse and recycling of CDW for future research, including market engagement and value chain collaboration, quality and environmental assessment, and the relation between the waste sector and the construction sector.

The direct reuse of construction materials is a relatively new area for municipalities and waste companies. The current reuse schemes in municipalities and waste companies typically cover a high diversity of fractions, but only cover a small proportion of the total accumulated waste from construction and demolition, since the larger companies in the Danish waste sector typically use private contractors for handling and recycling their CDW. Based on the findings in this study, some perspectives for future research can be provided in terms of meeting the discussed barriers and further developing elements of the presented business models.

The study finds that a vital precondition for upscaling the studied schemes is an improved collaboration between private and public partners. Five of the studied schemes engaged in dialogue with demolition companies to increase the purity and quality of materials, including the development of selective demolition procedures. Additionally, collaboration across the value chain is a necessary condition for the development of the supply and demand for reused and recycled CDW. Future research on value chain collaboration related to risk assessment, the distribution of responsibilities and the development of organizational resources is crucial to commercialize secondary construction materials.

The studied schemes primarily target private costumers (private citizens who reuse CDW) and a further upscaling of the schemes to cover companies in the established construction industry would require the development of standardized quality systems and certification schemes. Future research on how to develop systems for the quality assessment of secondary construction materials is important. This would likely necessitate a targeted strategy for selected waste fractions as quality assessment procedures and certification are time consuming and economically expensive. Furthermore, research on the relation between the waste sector and the construction sector regarding legislation, and the key actors and processes is urged with an aim to transform the waste sector into a resource sector. A framework condition to comply with the quality criteria in the Construction Product Regulation (305/2011) is to develop national or international standards for End-of-waste criteria (2008/98/EC).

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