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Six Business Model Types for Circular Building Component Reuse Actors

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Abstract: While circular business models are receiving increasing academic attention, the business models of real circular building companies remain underexamined. This paper builds upon existing conceptual proposals and general overviews of reuse actors to investigate how these organizations capture and create value within the constraints of the marketplace. Using data from case studies of 25 organizations involved in the reuse of construction waste streams, the business model of each case is described and compared using Osterwalder and Pigneur's Business Model Canvas. The authors propose six categories of circular construction business model types: upcyclers, component-specific suppliers, material resellers, reuse platforms, reuse consulting offices and deconstruction companies. The key findings include the studied organizations' consolidation of multiple waste and new product streams, the strategic minimization of hard assets, the cultivation of diverse revenue streams and an emphasis on private market solutions.

Keywords: circular business models; circular economy; construction and demolition waste; reuse; building materials; architecture

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1. Introduction

The desire to better manage global resources has given rise to an interest in the circular economy (CE), defined by the Ellen MacArthur Foundation as a "system where materials never become waste" [1]. Bocken et al. [2] suggest three ways in which this might be achieved: "slowing resource loops" by prolonging their usable lives, "closing resource loops" by recycling materials so that they may be used again and "narrowing resource loops" by reducing the quantity of resources required. This "looping" of resources contrasts with the movement of material goods in the present "linear" economy in which we extract resources from the earth to make products that are then disposed of after their use, the so-called "take-make-waste" model [1].

The construction sector is responsible for an enormous amount of waste and may therefore benefit from participating in the CE. In the European Union, the construction industry produced the most waste of any economic sector in 2018, while the United States generated over 547 million tons of construction and demolition waste in 2015 [3,4]. Although much of this waste is from demolition sites, demolition contractors typically only salvage items that are both easy to remove and of high value; the remaining materials move down the waste hierarchy and are either recycled or landfilled [5,6]. The construction and demolition industry therefore generates a vast quantity of material with the potential to be reused, but reusing building components is logistically challenging. Existing studies have identified several obstacles to construction waste reuse: the economic infeasibility of "like-for-like" reuse, the lack of quality assurance for/legal compliance of salvaged products and the uncoordinated demand and supply, among others [7–10].

Several scholars have identified "circular" business models (CBMs) that serve to facilitate value exchange in the circular economy. A business model (BM) "describes the rationale

of how an organization creates, delivers and captures value" [11]. A number of authors have developed matrices and templates by which to conceptualize BMs that slow, close and narrow resource loops. Lewandowski [12] expanded Osterwalder's Business Model Canvas (see Section 2.2) to include take-back systems and adoption factors, considerations which are of particular importance to circular businesses. Bocken and Ritala [13] developed a framework for circular BMs that uses a 2 by 3 matrix to categorize models according to their resource strategy (slowing, closing and narrowing loops) and their innovation strategy (open or closed). Other literature has attempted to categorize existing models. Bocken et al. [2] analyzed 26 businesses working in the CE across several industries and identified six major types of offerings: those focused on repair and maintenance, reuse and redistribution, refurbishment and remanufacturing, recycling, cascading and repurposing and organic feedstock. Rosa et al. [14] followed a similar approach but categorized each model based on its fit with the Ellen MacArthur Foundation's ReSOLVE framework. Whalen [15] examined the BMs of 56 product-based circular businesses and categorized these based on their levels of interaction with the products sold: "facilitators" have no physical interaction with the products, "redistributors" physically interact with products but do not alter them and "doers" refurbish products before they are sold.

Although CBMs in general are increasingly a topic of academic publications, research on CBMs for the reuse of construction waste streams is still limited. The published literature is largely conceptual or does not explicitly consider the BMs of the proposed solutions. Cai and Waldmann [8] proposed a "material and component bank" that enables the reuse of materials by refurbishing, storing and certifying salvaged materials and offering design advice. Their paper describes an asset-intensive business model that requires storage and refurbishment infrastructure, but the authors do not detail how the bank generates enough revenue to cover its costs, other than through support from the government. Rose and Stegemann similarly suggested governmental support for the establishment of a reused component database and stockpile given the limited profitability of this service, although the authors conceded that upcycling waste into high-value products may be financially feasible. The authors noted the need for further research into methods of adding value to waste streams, particularly via upcycling business models [7]. The literature on enabling technologies for the CE suggests new models for managing and extracting value from construction products and data but does not identify the business case for such models in depth. Çetin et al. described additive manufacturing, material passports and building information modeling as beneficial technologies for circularity but left discussions of "implementation or economic viability" to later papers given the nascent nature of the technologies [16]. Several papers developed the concept of a digital "material brokerage." The material brokerage concept follows the notion of an "information brokerage" that fosters communication between forward and reverse logistics supply chains [17]. However, discussions of operationalizing such a brokerage have been left for later research. Wijewickrama et al. mentioned the potential of Ali's [18] proposal for the addition of a "reuse consultant" as an information broker on project teams and suggested conducting further research into the "feasibility" of such a consultant [17]. Other research has conceptualized different models of material brokerages: as e-commerce systems funded by commissions on sales and advertising revenue, as waste exchange platforms run by material recyclers, as online trading platforms supported by government assistance and as extended producer responsibility models in which steel companies can track and manage their components in the building stock using RFID tagging [19–22]. These models were proposals at the time of their publication and thus remained untested; none were operational businesses. Some recent works have attempted to list and categorize CBMs for existing digital component reuse platforms but did not extend its analysis to the business models of the platforms, focusing instead on the impact of digitalization on each business. Sivers et al. [23] classified digital component reuse platforms into nine categories based on an analysis of 746 "solutions" and investigated their online presence. The grey literature includes an analysis of existing salvaged construction product brokerages, but this review is limited to digital trading

platforms [24]. Dutch "circular construction hubs," which serve to store and transform secondary construction materials, have also been summarized in the grey literature, but their BMs have not been analyzed [25].

While previous studies have sought to either describe a conceptual approach for component reuse [8,19–22] or to compile the variety of reuse organizations currently operating [24,25], these existing analyses have yet to investigate the multiple interacting features of existing organizations that collectively comprise their BM. This paper aims to address this lack of empirical research on the BMs of circular building component reuse actors by describing the BMs of 25 case study organizations, each of which is part of the formal economy in Northwestern Europe. Section 2.1 describes how information was collected for each case study using information obtained online and through interviews. Section 2.2 explains how case study data were analyzed using the Business Model Canvas. In Section 3.1, the authors categorize the studied BMs into identifiable "types," which are mapped to the case studies in Section 3.2, illustrated with specific examples in Section 3.3 and analyzed across specific BMC criteria in Section 3.4. Section 4 highlights common themes and key differentiators between the models and the literature. These findings serve to highlight the challenges and opportunities facing reuse actors and to validate or expand upon the existing literature with evidence from practice.

2. Materials and Methods

This research uses case study analyses and business modeling to understand and compare the operations of Northwestern European circular building component reuse organizations. Information was collected for 25 case study organizations facilitating construction component reuse. Interviews served as the primary source of data and were supplemented with online data where necessary. To analyze the collected interview data, the structure of each organization was plotted on the Business Model Canvas (see Section 2.2) and compared. This comparison led to the classification of six general BM "types." Finally, each model was analyzed based on two characteristics of circular reuse actors commonly mentioned in the literature: asset intensity and involvement in different stages of the supply chain. The results of the analysis were then plotted on a chart and grouped by type to draw out relationships between the models.

2.1. Information Gathering

Information on the CBMs was gathered from case study research. Potential cases were identified from web sources and selected based on their demonstration of a circular practice and their proximity to the authors' place of research in the Netherlands. The latter criterion was chosen to allow for in-person interviews and project visits. A total of 148 firms were identified and received an interview request sent via email. A total of 46 organizations agreed to an interview at a scheduled time, although 3 of these were later canceled. Of the 43 organizations that completed interviews, 19 of these worked directly with salvaged construction component reuse as part of their BM and were selected for inclusion in this article. From this set of nineteen interviews, ten were conducted in person, and the remaining nine were conducted via video conference. Each interviewee reviewed and signed an informed consent form that explained the nature of the research and how their data would be stored and used. Interviewees were given a chance to ask questions and make clarifications before signing. Interviews were conducted with an employee from each organization and lasted for approximately half an hour to one hour long. The interviews were semi-structured and based around a set of 20 questions, each of which was developed to assess specific criteria the authors felt were necessary for understanding successful reuse operations and completing the Business Model Canvas for each organization (see Appendix A). Participants were asked about their organizations' circular activities, financial model and the opportunities and challenges of operating in the construction component reuse sector. Notes from these interviews were sent to interviewees who were able to review them and provide comments and clarifications. These notes were used to generate

the BMs of each organization using the Business Model Canvas (BMC). Each organization's website was then reviewed to check for elements of their BM that were not discussed in the interview. When relevant information was found, these data were added to the BMC.

Some firms did not participate in interviews but were nevertheless included in the research. Six organizations had unique BMs but did not respond to requests for an interview. Instead, the BMCs of these six organizations were completed using data from their websites and, in the case of Superuse Studios and New Horizon, articles written about the company from external sources. The data sources for each case are summarized in Table 1.

Table 1. Data sources for each case study.

	Personal Interview	Company Website	External Articles
Maximum Paris (1)	X	X	
BC Materials (2)	X	X	
General Metal Re-Edition (3)	X		
Cleveland Steel & Tubes (4)		X	
London Reclaimed Brick Merchants (5)		X	
Insert (6)	X	X	
Cirkla (7)	X		
Sirkulaer Ressurssentral (8)	X		
OPALIS (9)	X	X	
Concular (10)	X	X	
Omtre (11)	X		
Rotor DC (12)	X	X	
Ombygg (13)	X		
Genbyg (14)	X	X	
Jan Kattein Architects (15)	X		
Superuse Studios (16)		X	X
Si Architectes (17)	X		
Bobi Réemploi (18)	X	X	
Remix (19)	X		
Lendager Group (20)		X	
Bellastock (21)	X	X	
Material Index (22)	X	X	
Zirkular (23)	X	X	
New Horizon (24)		X	X
Lagemaat (25)		X	

One other case study, the OPALIS website, is a mostly unmanaged information platform and therefore did not have a dedicated staff member available to provide an interview. However, OPALIS was developed by employees from two of the other case study organizations, Rotor and Bellastock. The interviews with both Bellastock and Rotor included a brief discussion of their work on OPALIS.

The BMs of Cirkla and Sirkulaer Ressurssentral include key activities (the Central Alarm supply/demand matching system and a digital platform, respectively) that have

not yet been implemented by either firm but exist as works in progress. These activities were included because they illustrate a business model type not captured by the other organizations in the study. The BMs of the other organizations only include implemented projects. For example, Omtre proposed, but at the time of publication did not yet complete, a "Re-Sawmill" that could place its BM more in the category of component-specific suppliers should the transformation of waste wood into valuable new products become its core business activity. This activity is not included in Omtre's BMC because the project is not yet implemented.

2.2. Analysis Tools

This paper uses Osterwalder and Pigneur's [11] Business Model Canvas (BMC) to describe the BM of each case study organization. The BMC was chosen because it captures the operations of an organization with enough depth to understand the complexity of the model while still facilitating comparison between the models. The BMC explains an organization using nine categories: customer segments, customer relationships, value propositions, key activities, key resources, channels, key partnerships, cost structure and revenue streams. Richardson [26] further grouped these categories into three elements—value proposition, value creation and delivery system—which Bocken et al. [27] mapped to the categories of the BMC.

Our analysis of the studied organizations began by plotting data from the interviews, organization websites and, where necessary, external articles onto a BMC for each of the studied organizations. The organizations were then compared based on similarities between the nine categories of their BMs. Where at least two individual models shared common characteristics across at least two of the nine canvas categories, these models were grouped together into a "type." A total of six types were identified. Once each organization had been assigned to a type, that type was given a name that reflected the activities of the various organizations within it. The key resources and key activities of each BMC were then analyzed across all six types. All assets and activities identified across the BMs were listed on a table, and the presence of each asset and activity in any individual organization was identified. Finally, key themes were extracted by analyzing the characteristics of the six types and the plot of resources and activities.

3. Results

3.1. Six Business Model Types

The models of each of the 25 organizations in this study are grouped based on their common characteristics into six main types, each of which are listed in Table 2 and illustrated with examples from the cases in Section 3.3. The six main types are as follows:

- Upcycler: This type turns waste into new, higher-value products;
- Component-specific supplier: This type specializes in the sale of both reused and new elements of a specific product line;
- Reuse platform: This type connects industry actors to make the search for reused products easier;
- Material reseller: This type brokers and processes salvaged elements;
- Reuse consulting office: This type shares knowledge on circular practices to aid specific building projects in implementing reuse;
- Deconstruction company: This type specializes in the careful dismantling of buildings to harvest these buildings' components.

Each type is unique from the others in at least two of Richardson's three categories (see Table 2; key differences are highlighted in bold). Table S1 in the Supplementary Materials lists the BMC of each studied organization and demonstrates the characteristics it shares with its type (the characteristics unique to that model are listed in italics). While Wahlen [15] suggested that circular BMs may be understood as operating across two dimensions (the interaction between the organization and the supplier of waste products and the interaction between the organization and the customers who purchase products from it), this paper

only considers the organization/customer relationship to enhance comparability given that not all types feature a supplier/organization interaction. The organization's sourcing activities are listed on the canvas as a key activity, and its suppliers are listed as key partners.

Table 2. The six business model types plotted on Osterwalder and Pigneur's [11] Business Model Canvas and grouped according to the three model categories proposed by Richardson [26]. The lines in bold show features that are unique to that model type.

		Upcycler	Component-Specific Supplier	Reuse Platform	Material Reseller	Reuse Consulting Office	Deconstruction Company
Value Proposition	**Customer Segments**	Private market; industry	Building owner/project developer	Building owner/project developer	Building owner/project developer	Building owner/project developer	Building owner/project developer
	Customer Relationships	At purchase via website	At purchase via website	Procurement	Procurement	Design AND/OR pre-demolition; demolition; procurement; construction	Pre-demolition; demolition; procurement
	Value Propositions	Improve sustainable credentials; **design**	Improve sustainable credentials; product expertise; **lower price;** reputation; **large inventory**	Improve sustainable credentials; **make searching for reused products easier**	Improve sustainable credentials; **provide quality assurance; make salvaged component integration simple**	Improve sustainable credentials; **improve competencies**	Improve sustainable credentials; **dismantling expertise**
Value creation and delivery	**Key Activities**	Acquisition; **product design of new products;** production Sales	Acquisition; cleaning; **refurbish old products of a specific type; provide new products to satisfy demand;** logistics; sales	**Provide visibility to reuse actors;** coordinate demand and supply	Acquisition; **process salvaged materials;** logistics; Sales	**Technical consulting on reuse;** coordinate demand and supply; logistics planning	Pre-demolition audits; **building dismantling;** coordinate demand and supply; sale of reused products
	Key Resources	Manufacturing space/workshop; design process; designers; artisans; waste products	Large stock; warehouse; marketplace website; machines; knowledge of craftspeople; national reputation	Public marketplace	**Storefront;** warehouse; employees	Employees	Knowledge of deconstruction; networks; machines
	Channels	Website; social media	Website; social media	Online marketplace	Website; storefront; social media	Website; social media; project meetings	Website; social media; project meetings; online platform
	Key Partnerships	Industry providing waste	Sourcing partners; testing labs	Salvaged products providers	Sourcing partners	Contractors; material partners	Network of organizations taking material
Value capture	**Cost Structure**	**Production costs;** procuring waste materials; employee expenses; cost of warehouse	**Refurbishment costs;** procurement costs; employee expenses; logistics costs	Employee expenses	Procurement costs; employee expenses; equipment and warehouses	Employee expenses	Employee expenses; **demolition expenses**
	Revenue Streams	Sale of products	Sale of products	**Subscription fees**	Sale of products	Consulting fees	**Demolition fees;** sale of products

Some BM elements are intentionally defined broadly to enhance comparability among models and thus aid in their assignment to types. Building owners/project developers is used as a broad category for the customer segments of all BM types except upcyclers and includes developers, contractors purchasing on behalf of project owners (who ultimately bear the cost), housing associations and private customers. This general category also serves to capture the diverse customer segments that were not always systematically listed by interviewees and thus to avoid excluding an important customer group. For example, an organization may have primarily mentioned serving landlords in its interview but also

provides services for developers. By only listing landlords as this organization's customer segment, we risk unintentionally excluding an important customer group just because this group was not explicitly mentioned in the interview. Where more specific customer segments are listed on organizational websites, these are included in the individual business models. For similar reasons, the key partners of the component-specific suppliers and material resellers BM types are listed as "sourcing partners" to represent the variety of organizations and individuals that provide these businesses with material.

3.2. Classification of Cases According to BM Type

Table 3 summarizes the classification of each studied BM into one of the six types. The reuse consulting office is the most represented type in the case studies, while upcyclers and deconstruction companies are the least represented.

Table 3. The classification of each studied BM into the six identified types.

	Upcycler	**Component-Specific Supplier**	**Reuse Platform**	**Material Reseller**	**Reuse Consulting Office**	**Deconstruction Company**
Maximum Paris (1)	X					
BC Materials (2)	X					
General Metal Re-Edition (3)		X				
Cleveland Steel & Tubes (4)		X				
London Reclaimed Brick Merchants (5)		X				
Insert (6)			X			
Cirkla (7)			X			
Sirkulaer Ressurssentral (8)			X			
OPALIS (9)			X			
Concular (10)				X		
Omtre (11)				X		
Rotor DC (12)				X		
Ombygg (13)				X		
Genbyg (14)				X		
Jan Kattein Architects (15)					X	
Superuse Studios (16)					X	
Si Architectes (17)					X	
Bobi Réemploi (18)					X	
Remix (19)					X	
Lendager Group (20)					X	
Bellastock (21)					X	
Material Index (22)					X	
Zirkular (23)					X	
New Horizon (24)						X
Lagemaat (25)						X
	2	3	4	5	9	2

The categorization of Jan Kattein Architects and Si Architectes into the reuse consulting BM is based on these firms' work on a specific reuse project. However, these offices have either also completed other reuse projects or are developing new ones and are therefore continuing to grow this service as a part of their BMs.

3.3. Detailed Description of Business Model Types with Illustrative Cases

The six identified business model types are described in more detail below.

3.3.1. Upcycler

Upcyclers turn waste into new higher-value products. Their business model is unique among the types for its emphasis on good design as a value proposition and product design as a key activity. Relying on waste requires upcyclers to both identify organizations that discard materials and to convince these suppliers to sell at least some of these discarded materials for repurposing. Suppliers mostly come from industry: BC Materials (BC) uses waste soil from excavation projects, and Maximum Paris uses production waste from manufacturers. Suppliers are incentivized to sell their waste products for several reasons: they avoid waste handling fees, receive payment (sometimes more than a recycler will pay them) and can boast about their sustainable credentials. The combination of high design and sustainable credentials allows upcyclers to sell their products at a cost premium, but the product-focused nature of the model also requires asset investment. BC attempts to minimize this cost burden by collaborating with production partners, who rent factory space and capacity to BC so that it may avoid the investment of building its own production space. This strategy allows BC to avoid the problem they felt other circular products companies faced: their products were too expensive because they were not mass-produced, but the products could not be mass-produced because they were too expensive (and so demand was low). Upcyclers may also support the continued circulation of their products. Maximum Paris offers to perform repairs on its items, and BC is developing a takeback program.

3.3.2. Component-Specific Supplier

Component-specific suppliers specialize in the reuse of a specific product line (such as steel members) but provide the unique service of mixing new and salvaged material streams. This combination of selling salvaged items when possible and making up any shortfalls with new items when necessary requires these organizations to keep a large inventory, but also means they are often able to compete with dealers of new materials on price given the lower cost of the salvaged materials. This large inventory is accumulated using several strategies. Both London Reused Brick Merchants (LRBM) and General Metal Re-edition (GMR) aid their sourcing activities by conducting deconstruction activities and facilitating the logistics of reusing deconstructed elements themselves. Other companies share the expense of keeping a large stock with others; GMR is able to draw upon the resources of its founding company, General Metal Edition, while Cleveland Steel shares its stock with the other steel companies in the Bianco Group, the steel distribution network of which it is a part. Not all component-specific resellers use price as a competitive advantage. LRBM instead relies on its large inventory to provide customers with a product uniquely suited to match the historic brickwork of the city. These companies' limited product variety allows them to develop deep expertise about their offering and a strong reputation, which are two other characteristics of this business model type.

3.3.3. Reuse Platform

Reuse platforms connect actors to make the search for reused products easier. These platforms often use a material brokerage model that allows them to match supply and demand without interacting with products directly and therefore require few assets. This model also requires the organization to find ways of generating revenue unrelated to the product transaction, which may take place off the platform. The reuse platform rectifies this by charging subscription fees for its services. However, these organizations are not always

for-profit entities and sometimes serve more as consortiums created by interested actors. Relying on such a founding group allows the platform to immediately benefit from the network effects of a platform model. For example, Insert is a non-profit organization formed by 12 demolition companies who wanted a central space to list their salvaged components. Sirkulaer Ressurssentral and Cirkla primarily provide for knowledge sharing between partners and are partially financed by donations or are considering seeking investors, respectively. OPALIS is a unique case in that it does not make money and finances its development costs by relying on EU funding. Other revenue streams, such as consulting, may serve to cover the costs of managing these platforms.

3.3.4. Material Reseller

Material resellers perform similar brokerage activities to reuse platforms but physically interact with the salvaged components. This model performs similar material processing activities to component-specific suppliers but primarily deals with salvaged products (in contrast to component-specific suppliers, which also provide new ones). The salvaged products these organizations reclaim and sell are often donated from demolition projects wishing to minimize waste and avoid handling fees, but they may also come from private individuals (as is the case with Genbyg) or product manufacturers providing products from incorrect orders (Ombygg). Other supply models exist as well. For high-value products, Ombygg provides the product supplier the ability to sell on consignment and therefore realize some of the revenues from the sale. While traditional "salvage yards" may be included in the material reseller category, material resellers often supplement the revenues from the sale of their products with other services, such as consulting, deconstruction, storage space rental, software products and furniture rental. Some organizations, like Rotor DC and Genbyg, collaborate with designers to upcycle their products, similar to the upcycler BM type.

Resellers process materials both by acquiring information about them to aid in their sale and through refurbishment, both of which lead to the unique value propositions of this type. Unlike reuse platforms, which cannot provide a guarantee of quality given their lack of interaction with the product, resellers foster trust and provide quality assurance by performing almost all the steps to transform a product from a demolition material to an item ready to be reused. This makes component integration simple as the customer often does not have to prepare the salvaged component further before integrating it into their design. Given the more traditional retail nature of this type, these organizations often have physical storefronts, although the material reseller Concular is a highly digital business.

3.3.5. Reuse Consulting Office

Reuse consulting offices share knowledge on circular practices to aid building projects in implementing reuse. These models require minimal hard assets and therefore rely heavily on employee knowledge and experience to generate value. This BM is unique from reuse platforms, which often also offer technical consulting on reuse, in that reuse consulting offices' knowledge sharing activities are primarily carried out for the benefit of a single client and are thus specific to that client's building project or organizational model. Similarly, while reuse consulting offices sometimes rely on a network of materials partners to provide the material brokerage services listed earlier under reuse platforms (Section 3.3.3), these services are specific to a client project (a reuse consulting office will find clients for salvaged products from a specific building the client is demolishing or will source salvaged products for a client's new building, for instance). This consulting model appears in a variety of formats consistent with the variety of services that reuse consultants can provide. Reuse consulting may be offered as part of a larger architectural office, as is the case with Jan Kattein Architects, Si Architectes and Lendager Group. When this is the case, the consulting office is often also the project architect. Some reuse consulting businesses are spinoffs from architectural offices after these offices decided they wanted to provide their circular knowledge to architectural projects other than their own, as is the

case with Zirkular (a spinoff of Baubüro in situ) and Remix (a spinoff of Encore Hereux). Other businesses, such as Bellastock and Material Index, primarily serve to manage the flow of materials from demolished buildings to new uses by providing pre-demolition audits. A novel case is Bobi Réemploi, whose reuse consulting practice includes "reuse material qualifier" activities. Bobi Réemploi defines a framework for the considered use of the salvaged components it provides for new projects that, if followed, enables Bobi's insurance to cover the provision of these materials to the project.

3.3.6. Deconstruction Company

Deconstruction companies specialize in the careful dismantling of buildings to harvest these buildings' components. Many of these components are reusable and can be upcycled, refurbished or sold by the other BM types mentioned above. A deconstruction company may also process and sell these items itself, as is the case for New Horizon Urban Mining, which transforms demolition waste into aggregate for new concrete. This BM type is unique from component-specific suppliers and material resellers that offer deconstruction services in that its primary revenues and costs are related to the deconstruction operation. Deconstruction services may be offered as the core service of the company (New Horizon) or as an additional service provided by a more traditional demolition company (Lagemaat).

3.4. Analysis of Key Resources and Key Activities

The models were further analyzed across two qualities emphasized in the literature: involvement throughout the supply chain [8,22,25] and asset intensity [15]. Heavy supply chain involvement is frequently described for reuse models in the literature (especially conceptual models) [8,22,25] without explicit discussions of the assets (and thus capital expenditures) potentially required for the model to partake in so many stages of the supply chain. For example, Cai and Waldmann's [8] proposed material and component bank is involved in "almost all main phases of a construction" and, although involvement in some of these stages is limited to information brokerage, the bank's involvement in assessment, conditioning and storage would all likely require hard assets such as testing equipment, machinery for refurbishment and warehousing, respectively. To understand whether increased involvement necessitates the use of increased assets in practice, the authors chose to analyze the supply chain involvement of each case study so that it could be compared to that case's asset requirements. Asset intensity was then analyzed due to its assumed correspondence with initial capital investment; models that require more assets would likely involve higher upfront costs and are therefore more challenging to launch. Asset intensity has also been previously demonstrated to impact reuse effectiveness: Whalen [15] finds higher "firm–product interaction" leads to greater resource efficiency. Whalen's [15] categorization of CBMs according to their level of product interaction corresponds roughly with asset intensiveness; "doers" need the necessary space and equipment to refurbish the product they sell, while "facilitators" do not require corresponding assets to enable the transaction. Each organization's BM is thus given a score from 0 to 5 based on the assets it requires to conduct its business (see Table 4). The asset categories were generated by listing the assets under key resources in the case studies' BMCs, which include the following categories:

- Warehouse/storage: This is a physical space to temporarily store materials;
- Inventory: This includes physical building materials, both salvaged and new, stored by the reuse actor;
- Equipment: This includes physical assets for transforming materials through deconstruction, manufacturing and/or reclamation;
- Transportation infrastructure: This includes vehicles owned or contracted by a business to move products between locations;
- Storefronts: These include physical locations where customers may come to view and purchase materials;
- Employees: This refers to human labor used to run the business.

The use of any individual asset category adds one point to the score. Businesses with the highest scores therefore rely on the most assets. All considered asset categories except employees are "hard" assets; no other "soft" assets are considered. The use of an asset category must be part of a company's regular business operations for that business to receive a point; for example, although Lendager maintains a yard where it conductsmaterial tests, this yard does not seem to be a consistent part of its provision of architectural services for most projects, and thus Lendager does not receive a point for warehouse/storage. Organizations receive a point for rented assets if these are regularly used for operations.

Table 4. The assets used regularly by the studied organizations.

	Warehouse/ Storage	Inventory	Equipment	Transportation Infrastructure	Storefront	Employees	#
Maximum Paris (1)	X	X				X	3
BC Materials (2)	X	X	X			X	4
General Metal Re-Edition (3)	X	X	X	X		X	5
Cleveland Steel & Tubes (4)	X	X	X			X	4
London Reclaimed Brick Merchants (5)	X	X	X	X		X	5
Insert (6)						X	1
Cirkla (7)						X	1
Sirkulaer Ressurssentral (8)	X					X	2
OPALIS (9)							0
Concular (10)	X	X				X	3
Omtre (11)	X	X				X	3
Rotor DC (12)	X	X	X		X	X	5
Ombygg (13)	X	X	X			X	4
Genbyg (14)	X	X	X		X	X	5
Jan Kattein Architects (15)						X	1
Superuse Studios (16)						X	1
Si Architectes (17)						X	1
Bobi Réemploi (18)						X	1
Remix (19)						X	1
Lendager Group (20)						X	1
Bellastock (21)						X	1
Material Index (22)						X	1
Zirkular (23)						X	1
New Horizon (24)	X	X	X	X		X	5
Lagemaat (25)	X	X	X	X		X	5

Each organization also receives a score based on its level of involvement throughout the component reuse supply chain (see Table 5). This paper maps each organization to its involvement in the five steps in this supply chain described by Cai and Waldmann: "(1) global planning of demolition and deconstruction, (2) reasonable extraction and collection of recyclable and reusable materials and components, (3) assessment and improvement

of the quality of materials and components in a factory or center shop of the [reuse organization], and (5) certification of materials and components" [8]. Organizations receive an additional point if they are involved in that supply chain stage; higher scores are given to organizations involved in more stages. Organizations who do not physically interact with a product at a relevant stage may still receive a point if they facilitate the stage; for example, several reuse consulting offices (see Section 3.3.5) do not store products but arrange for their storage and thus receive a point.

Table 5. The involvement of the studied organizations in the reuse supply chain stages proposed by Cai and Waldmann [8].

	Deconstruction Planning	Dismantling and Collection	Assessment and Refurbishment	Storage and Sale	Certification	#
Maximum Paris (1)			X	X		2
BC Materials (2)				X	X	2
General Metal Re-Edition (3)	X	X	X	X	X	5
Cleveland Steel & Tubes (4)			X	X	X	3
London Reclaimed Brick Merchants (5)	X	X	X	X	X	5
Insert (6)	X			X		2
Cirkla (7)				X		1
Sirkulaer Ressurssentral (8)				X		1
OPALIS (9)				X		1
Concular (10)	X	X	X	X	X	5
Omtre (11)	X	X		X	X	4
Rotor DC (12)	X	X	X	X	X	5
Ombygg (13)	X	X	X	X	X	5
Genbyg (14)	X	X	X	X	X	4
Jan Kattein Architects (15)			X	X		2
Superuse Studios (16)	X	X	X	X	X	4
Si Architectes (17)	X		X	X		3
Bobi Réemploi (18)	X	X		X	X	4
Remix (19)				X	X	2
Lendager Group (20)				X	X	2
Bellastock (21)	X			X	X	3
Material Index (22)	X			X		2
Zirkular (23)	X	X		X	X	4
New Horizon (24)	X	X	X	X		4
Lagemaat (25)	X	X		X		3

The organizations' scores across both dimensions are mapped onto a scatter diagram for analysis (see Figure 1). It should be noted that the assignment of a score does not imply a value judgment; higher scores do not indicate "better" BMs.

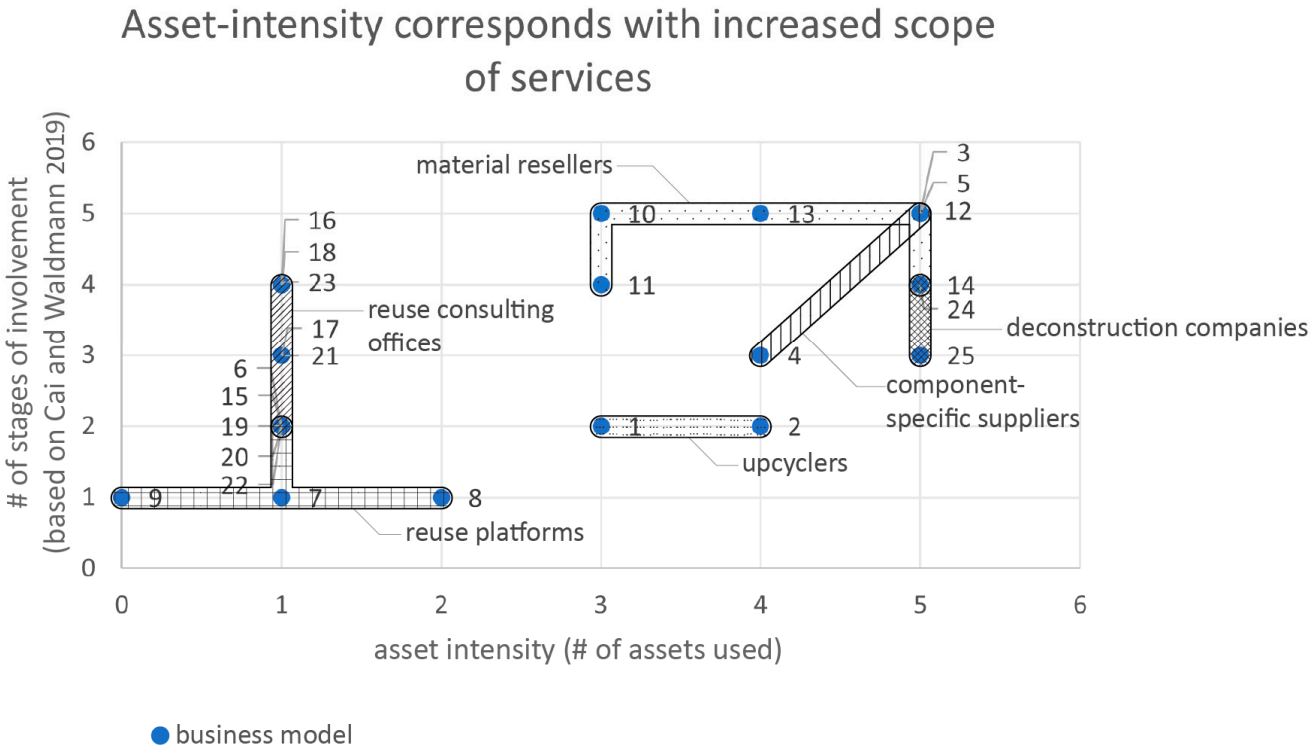

Figure 1. A scatter diagram comparing the asset intensity of each organization (from Table 4) with the number of stages of the reuse supply chain each organization is involved in (Table 5) [8].

4. Discussion

Many of these BMs include several notable features that expand upon issues previously discussed in the literature. These features include the consolidation of post-industrial, post-consumer and new component streams; the economic value proposition (or lack thereof) of reuse models; the asset intensiveness of the models; the models' diverse revenue streams and the organizations' relationship to the government [7,8,19–25].

4.1. Consolidation of Streams

A component-specific supplier's offering of both old and new streams to match demand is a unique service that has not been broadly discussed in the conceptual literature, which has instead focused on models for the trading of solely salvaged materials [7,8,19–21]. While it is theoretically possible for salvaged component streams to fulfill all demand (or for designers to shift entirely to working with available salvaged materials), stocking enough reused components to meet this requirement remains difficult and, despite this model's emphasis on large inventories, cost-intensive. The provision of old and new streams eases the cost burden of the model and eases the logistical burden on the customer, who only has to work through one supplier to complete the purchase of the provided material. The component-specific nature of the offering also integrates well into existing construction practices in which specialized subcontractors (a steel subcontractor, for instance) source and integrate their individual material into the larger building project [28]. This model is therefore exemplary for its ability to be integrated with traditional procurement processes, thus easing the burden of reuse.

Although much of the literature on component reuse emphasizes post-consumer components (those removed from existing buildings) [7,8,19–23], pre-consumer products from the manufacturing sector offer a viable alternative to new components as well. Ombygg's sale of mechanical companies' rejected systems alongside its other salvaged components demonstrates an instance of another type of material stream integration. It is not difficult to imagine component-specific suppliers integrating this post-industrial waste stream in their

offering as well, especially if their production lines do not reincorporate these materials anyway. The reuse of post-industrial components avoids some of the pitfalls of post-consumer components, including the lack of information about the product and sometimes the lack of manufacturer warranty. Intermediaries capable of coordinating all of these waste streams demonstrate a strong potential to foster component reuse.

4.2. Value Propositions

While arguments for the circular economy often use financial justification for the model (see, for instance, the Ellen MacArthur Foundation's report titled "Towards the circular economy Vol. 1: an economic and business rationale for an accelerated transition" (2013)), few of the studied business models rely on cost savings as their primary value proposition. The reused components these businesses sell are sometimes less expensive than their new counterparts, but the cost of their use tends to approach (or sometimes exceeds) the market price for new materials once the processes of refurbishment, certification and logistics are included. Some organizations are more explicit about the financial advantages of reuse. Organizations that facilitate the sale of their customers' waste streams, such as Material Index, allow customers to capture the remaining value of their sold waste materials. Cleveland Steel advertises the cost advantage of its salvaged steel and, similar to Sirkulaer Ressurssentral, only provides testing when a component will be used in a manner for which testing is necessary, such as for load-bearing applications. These organizations thus allow customers to pay only for what they need from the product.

Other value propositions are more common. A common benefit these firms provide is the ability to improve the ecological image of their customers. This is beneficial from a marketing standpoint as it helps customers improve their images and fulfill corporate social responsibility requirements. One interviewee said that clients are interested in reuse because it allows their organization to demonstrate how "green" they are without investing a lot of money beyond what "business as usual" would cost, which is not the case when investing in other green technologies like solar panels. Minimizing an organization's environmental footprint is appealing from a legal perspective as well. As governments increasingly implement legislation calling for the reduction in buildings' embodied carbon emissions, these organizations provide an opportunity to fulfill these requirements by reusing components, especially in legislative environments that allow these components to count as having zero carbon impact. In areas such as France that now mandate pre-demolition audits, these businesses act as a simple way to outsource compliance.

Consistent with Whalen [15], several business model types offer financial benefits directed at suppliers. Donating waste streams to an upcycler or material reseller saves the donator from paying waste processing fees. Upcyclers often pay suppliers for their waste streams, thus furthering the benefit to the supplier. Ombygg's consignment model for high-value products is an innovative method for allowing suppliers to realize a financial gain from their salvaged components.

4.3. Asset Intensiveness

The level of assets required by different BMs is a key differentiator between types and impacts BMC categories beyond the key resources section where assets are listed. This observation is consistent with Whalen's [15] categorization of CBMs based on business/product interaction. Whalen suggests that more asset-intensive models require the sale of higher-value products so that these businesses can generate enough revenue to make a profit. This study tends to support this claim; the most asset-intensive businesses (dismantling companies, material resellers and component-specific suppliers) typically provide high-value products such as load-bearing components. Upcyclers are a good example of this phenomenon as well.

Several organizations use sharing strategies to minimize their asset requirements (and thus, according to Whalen's framework, to allow for lower product costs). Cleveland Steel's membership in the Bianco Group allows it access to the inventory of its partner companies,

thus reducing its own inventory requirements. BC reduces its own need for production space by leasing from its manufacturing partners, just as New Horizon uses existing infrastructure for storage and logistics. Shared spaces also facilitate testing. Ombygg's warehouse also serves as a site for product inspections, which can be completed on location by visiting members of labs, therefore avoiding the shipment of large components to and from testing locations. Several asset-intensive BMs rely on the assets of a parent company. GMR is able to use General Metal Edition's new material stock, and Lagemaat's deconstruction business is supported by the machinery of its existing demolition activities.

Where possible, assets are digitized. Most material resale platforms exist online and therefore avoid the cost of a physical storefront, although material resellers tend to show their products in a physical space as well. Component data are recorded digitally but are often formatted to facilitate a one-time exchange. Material Index, for instance, records material information in a shared platform, but this information is not intended to be accessible in the future lives of the product. Both Rotor DC and Ombygg provide just enough information for visitors to their storefronts to understand what is being sold, which serves both to minimize the intensive process of collecting and recording product data but also to minimize seller liability; sellers are liable for the material characteristics they advertise, so listing fewer product attributes is in a material reseller's best legal interest. Data collection and recording are therefore conducted so as to place a minimal cost burden on the organization, as intensive data processing is itself an asset-heavy strategy.

Asset intensiveness also seems to correspond with an increased scope of services, perhaps so that organizations can generate enough revenue to cover large asset investments or, in the case of product-related businesses, due to the economic efficiencies of more vertically integrated models (see Figure 1). Generally, types that require more assets to operate (dismantling companies, material resellers and component-specific suppliers) are also involved in more of the steps along the path from demolition site to product sale. These additional activities sometimes correspond to increased revenue opportunities; for example, New Horizon's involvement in material reuse goes well beyond dismantling to include the development and sale of new products made from salvaged materials. Material resellers and component-specific suppliers are perhaps involved in a larger variety of activities because of their unique expertise in the market. Rotor DC, for instance, has expertise both in demolition planning and material refurbishment but also uses its related expertise in deconstruction to source components that may not be salvaged otherwise. GMR and LRBM pursue similar strategies to acquire reused steel and bricks, respectively. Reuse platforms generally participate in the fewest number of stages but are generally quite asset-light. This asset/service relationship is less pronounced for reuse consulting offices, which, as knowledge-based businesses, require very few assets but aim to support reuse projects throughout the project process and are therefore involved in many stages.

4.4. Diverse Revenue Sources

The studied BMs draw upon a large variety of revenue sources. This pattern suggests their managers have a deep understanding of the competencies of their organizations and a willingness to exploit these competencies for different forms of potential revenue. Superuse Studios expanded into the software business by licensing its Harvest Map platform, which the organization used internally as a key resource for understanding material flows in their architectural projects. Concular employees' programming expertise is apparent in the company's material brokerage platform, and Concular relies on this expertise to similarly expand into software sales. Other revenue streams come from innovative processes that the organizations have created. Rotor DC developed a tile cleaning method to reclaim the tile installations it wished to sell in its shop and now uses this proprietary method to provide tile reclamation to external customers as well. Perhaps most common is for organizations with reuse expertise to capitalize on this expertise via knowledge sharing activities. Quite a few organizations, including Lendager Group, Superuse Studios and Insert, provide circular business consulting services alongside their more standard business activities.

Bellastock shares its expertise in an annual ticketed festival during which participants build and inhabit shelters made from reused materials.

These alternative revenue sources sometimes serve to extract more value out of a hard asset and are thus an extension of the careful asset strategies of Section 4.3. Rotor DC and Genbyg allow customers to rent some of their inventory rather than requiring an outright purchase. Organizations whose warehouse space is a key resource sometimes rent temporary storage areas to clients needing to store building materials. While both Ombygg and Concular provide this rental service, Superuse Studios ceased its warehousing activities after it became a logistical burden on the organization. The latter example demonstrates the importance of capturing potential revenue streams while ensuring these do not distract from the core value proposition of the company's BM.

4.5. Governmental Support

Some of the literature's reliance on governmental support to fund financially challenging business models [7,8,21] does not seem to reflect the status of the reuse market, although municipal marketplaces are receiving increasing attention. Although several jurisdictions require the creation of predemolition audits prior to demolishing a building, it is much more challenging to find municipalities that require and support the reporting and management of components in a centralized database of the kind suggested by Rose and Stegemann [7]. Trading building components is, of course, challenging for government actors given their requirement to promote competition in public procurement. Component management is instead conducted privately. The decentralized nature of the sector is at least partly responsible for the reuse platform business model type, which attempts to consolidate the knowledge and product offerings of individual private actors. The non-profit model of some of these organizations, as well as other BM types' reliance on other income streams to support its material brokerage activities, suggests that this information sharing activity is perhaps more effectively served by the municipality, although it currently seems unlikely that municipalities will broadly adopt this responsibility. The inconsistent profitability of material brokerage activities is supported by Embuild's analysis of digital trading platforms [24].

Nevertheless, some municipalities are becoming involved. Zirkular has supported the municipalities of Basel and Zurich in facilitating competitions for the design of new buildings out of old structures; the municipalities support the reuse of components by providing information about available components. Zirkular is now considering licensing its supply and demand matching software to these cities. Insert already pursues a similar business model with its Insert Connect product, which provides a platform for the inventorization and exchange of building components within organizations. The city of Amsterdam uses this service to manage its assets internally. Public entities have the potential to play an important role in reusing material streams given the large stock of materials under their purview, although this role may ultimately be facilitated by private actors.

5. Conclusions

An empirical analysis of the BMs of organizations participating in the construction component reuse sector suggests six types, some of which have not yet been explored in the literature. These types—upcyclers, component-specific suppliers, reuse platforms, material resellers, reuse consulting offices and deconstruction companies—expand upon previously proposed conceptual models in depth and breadth and display several key features:

- Separation of functions: Functions that the literature propose are completed by one central organization are instead managed by a variety of actors and coordinated by reuse consulting offices (material certification, for instance, is performed by external testing agencies but coordinated by the consulting office).
- New activities: Component-specific suppliers introduce new activities, such as the collation of new and reused component streams.

- Reliance on the private market: Although occasionally bolstered by a friendly policy environment, these organizations continue to rely on the desire of their customers to improve their ecological footprints.
- Minimization of assets: Given the still-nascent nature of the market and a lack of governmental support, organizations are turning to asset-light and asset-sharing models to generate profit.

Despite the challenging environment in which they operate, these BM types provide inspirational examples of BMs that might be implemented elsewhere to foster the continued growth of the CE.

Research that further investigates the CBMs proposed in this paper may also prove informative. CBMs for the building industry may have specific traits compared to CBMs for consumer goods given the capital and labor intensity of the construction industry and the relatively long lifespans of building components. Comparing these BMs has the potential to improve our understanding of both industries while revealing strategies adopted in one sector that may prove useful in another. Modeling the growth prospects of each model could also reveal the scalability and future feasibility of different BM types. Finally, expanding the inquiry to new geographical regions and outside the formal economy (e.g., waste pickers) may reveal additional models and/or strategies worthy of broader adoption.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su16135425/s1, Table S1: Business Model Canvas of each organization. References [29–48] are cited in the Supplementary Materials.

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Appendix A

Interview questions were developed to investigate two lines of inquiry: how each organization addresses nine major issues relevant to reuse and the business model of each organization. The nine reuse issues and interview questions are listed below. Each question is then mapped to the issues it investigates and its relevant section of the BMC.

Appendix A.1. Issues Relevant to Component Reuse

1. Motivation: This indicates which project actors encourage reuse or why customers choose to patronize this reuse business.
2. Stakeholders: This refers to additional required members of the project team relative to a "standard" non-reuse project as well as how existing actors in the construction industry are impacted by reuse.
3. Design/build process: This refers to how reused components impact the construction process and when their inclusion in the project is decided.

4. Sourcing: This indicates where reused elements come from, their availability and how they are transported and stored.
5. Regulatory environment: This refers to how laws and codes impact project component reuse.
6. Quality control: This refers to the testing required for component reuse.
7. Reclamation: This refers to how salvaged components are modified to enable their reuse.
8. Financial viability: This refers to how reused components impact project costs and whether their reuse is profitable.
9. Documentation: This refers to whether and where component information is recorded and how it is used.

Appendix A.2. Interview Questions

1. Describe this organization and how it got started.
2. Who is the customer?
3. Why do customers come to you?
4. What sorts of reused components do you work with?
5. What additional actors are involved when salvaged components are used on a project?
6. At what point in the building process do customers typically come to you to integrate reused elements? Is this the ideal time?
7. How does the use of reused components impact the project process?
8. Where do the reused materials come from?
9. How are these materials transported and stored?
10. How does the regulatory environment impact your use of reclaimed materials?
11. How does using salvaged components affect the permitting and planning process?
12. Do you conduct any testing on the materials before they are used?
13. How do you decide which salvaged items to use? Do you reject any items and, if so, why?
14. What role do you play in facilitating material exchange? Which of the following steps do you partake in?
    a. Predemolition audits
    b. Demolition planning
    c. Deconstruction
    d. Transport
    e. Warehousing
    f. Testing
    g. Reclamation
    h. Documentation
    i. Design assistance/design
    j. Specification writing
    k. Installation guidance
    l. Construction
15. Do you warranty or facilitate the warranty of the salvaged materials you use?
16. How have reused materials impacted the insurance requirements of the projects you have worked on?
17. Is your business model profitable?
18. How does the cost of reused materials compare to new materials? What additional costs or cost savings exist?
19. How do you document the salvaged components you use? What features do you record?
20. How have you seen the reuse environment change over time?
21. What are the biggest challenges you're facing? Biggest opportunities you're aware of?

Table A1. Mapping of interview questions to nine criteria and BMC.

Interview Question	Relevant Criteria	BMC Categories
1	1	VP, KA
2	1	CS
3	1	VP
4		VP, KR
5	2	KP
6	1, 3	CR, Ch
7	3	KA
8	2, 4	KA, KR, KP
9	3, 4	VP, KA, KR, KP
10	5	
11	3, 5	
12	6	VP, KA, KR, KP
13	6	KA
14	2, 3, 4, 6, 7, 9	VP, KA, KR, KP
15	6, 8, 9	VP
16	8, 9	
17	8	CoS, RS
18	8	CoS
19	9	KA, Ch
20		
21		

CS: customer segments, CR: customer relationships, VP: value propositions, KA: key activities, KR: key resources, Ch: channels, KP: key partnerships, CoS: cost structure, RS: revenue streams.

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