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Product design and business model strategies for a circular economy

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The transition within business from a linear to a circular economy brings with it a range of practical challenges for companies. The following question is addressed: What are the product design and business model strategies for companies that want to move to a circular economy model? This paper develops a framework of strategies to guide designers and business strategists in the move from a linear to a circular economy. Building on Stahel, the terminology of slowing, closing, and narrowing resource loops is introduced. A list of product design strategies, business model strategies, and examples for key decision-makers in businesses is introduced, to facilitate the move to a circular economy. This framework also opens up a future research agenda for the circular economy.

Keywords: Circular business model; circular design; circularity; sustainability; closed loop

1. Introduction

Governmental organizations as well as business representatives report an increasing pressure on our global resources and the climate due to human activity [30,57]. The circular economy is viewed as a promising approach to help reduce our global sustainability pressures [23,24]. The Ellen MacArthur Foundation [23] has helped popularize the move to a circular economy with businesses. Europe and China have adopted Circular Economy principles as part of their future strategies [24,51]. For example, the European Commission [24] associates the move to a more circular economy with strategies such as: boosting recycling and preventing loss of valuable materials; creating jobs and economic growth; showing how new business models, eco-design and industrial symbiosis can move Europe toward zero-waste; and reducing greenhouse emissions and environmental impacts.

The idea of a circular economy is not new and was given a theoretical foundation in the field of industrial ecology in the early 1990s [2]. Robert Ayres (in [2]) introduced the idea of industrial metabolisms:

> At the most abstract level of description, then, the metabolism of industry is the whole integrated collection of physical processes that convert raw materials and energy, plus labor, into finished products and wastes in a (more or less) steady-state condition. ([2], p. 23)

The ambition level of an industrial ecology is to achieve an ideal state, one which resembles nature most. Such a system would be characterized by “complete or nearly-complete internal cycling of materials” ([2], p. 6).

Ayres (in [2]) also observes that such a closed cycle of flows can only be sustained as long as its external energy supply lasts. A logical consequence of striving to create closed loop systems is that there are only two possible long-run fates for waste materials: either recycling and reuse, or dissipative loss (for resources such as for lubricants or detergents) [2]. Later work by McDonough and Braungart [38] recognized the importance of closing “technical” and “biological” loops in a “cradle-to-cradle” or circular (rather than cradle-to-grave or linear) economy. In addition, Stahel [50] for the technical loop distinguished between the recycling of materials and the reuse of goods. Their work on the cycling of resources builds on earlier key work, such as Rachel Carson’s “Silent Spring” first published in 1962 [12], Kenneth Boulding’s Essay on “The Economics of the coming spaceship earth” [9], and Barry Commoner’s “Four Laws of Ecology” [17].

The recognition of the limits to planetary resource and energy use, and the importance of viewing the world as a “system” where pollution and waste are viewed as a defeat, lay at the foundations of circular economy thinking. As Commoner notes “We must learn how to restore to nature the wealth that we borrow from it.” ([17], p. 300).

The circular approach contrasts with the traditional linear business model of production of take-make-use-dispose and an industrial system largely reliant on fossil fuels, because the aim of the business shifts from generating profits from selling artifacts, to generating profits from the flow of materials and products over time [4]. Circular business models thus can enable economically viable ways to continually reuse products and materials, using renewable resources where possible.

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Since the first use of the concept of the circular economy, the terminology around the "circular economy" has been diverging rather than converging and the terms closed loop and circular economy are often used in parallel. The new paradigm of a circular economy requires new concepts and tools to describe and support this paradigm. Hence, it is argued that at the product design level and the strategic level of business model innovation, a more coherent terminology is necessary to facilitate the move of businesses to a circular model.

In this paper, a range of strategies for product design and business model innovation for a circular economy are developed based on the literature, to give clarity and direction to designers and strategic decision makers in businesses that want to pursue a circular business model. The following research question is addressed: What are the product design and business model strategies for businesses wanting to move to a circular economy model?

2. Literature review on circular design and business model strategies

The literature review brings together the relevant literature on circular product design and circular business models to develop a terminology and a framework of strategies for closed loop design and business models for a closed loop.

2.1. *Resource cycles: slowing, closing, and narrowing loops*

This section introduces the terminology of slowing, closing, and narrowing resource loops. To distinguish circular economy models from linear models, we categorize the design and business model strategies according to the mechanisms by which resources flow through a system, building on the work by Stahel [48–50] and Braungart et al. [10,38].

When comparing linear and cyclical approaches for the development of products and systems, Braungart et al. [10] distinguish between "cradle-to-grave" flows of materials and cyclical, "cradle-to-cradle" flows. This distinction clearly marks a difference in resource flow patterns that characterize linear and circular models. In addition, Stahel ([49], p. 179; [50]), who refers to "closed loop systems" instead of cyclical systems, distinguishes two fundamentally different types of loops within a closed loop system: (1) reuse of goods, and (2) recycling of materials.

> The reuse of goods means an extension of the utilization period of goods through the design of long-life goods; the introduction of service loops to extend an existing product's life, including reuse of the product itself, repair, reconditioning, and technical upgrading, and a combination of these. The result of the reuse of goods is a slowdown of the flow of materials from production to recycling. … Reusing goods and product-life extension imply a different relationship with time. [49]

In earlier work, Stahel ([48], p. 74) referred to this loop as the "slow replacement system" and to "long life products." The second loop is related to recycling: "The recycling of materials means simply closing the loop between post-use waste and production. Recycling does not influence the speed of the flow of materials or goods through the economy" [48].

Building on Stahel [49,50], McDonough and Braungart [38] and Braungart et al. [10] the following two fundamental strategies toward the cycling of resources are introduced in this paper, illustrated in Figure 1:

(1) *Slowing resource loops*: Through the design of long-life goods and product-life extension (i.e. service loops to extend a product's life, for instance through repair, remanufacturing), the utilization period of products is extended and/or intensified, resulting in a slowdown of the flow of resources.
(2) *Closing resource loops*: Through recycling, the loop between post-use and production is closed, resulting in a circular flow of resources.

These two approaches are distinct from a third approach toward reducing resource flows:

(3) *Resource efficiency or narrowing resource flows*, aimed at using fewer resources per product.

In the 1990s, the influential book "Factor Four" was published [55], which sought to inspire businesses to adopt drastic resource efficiency measures, using fewer resources to achieve the same purpose. Resource

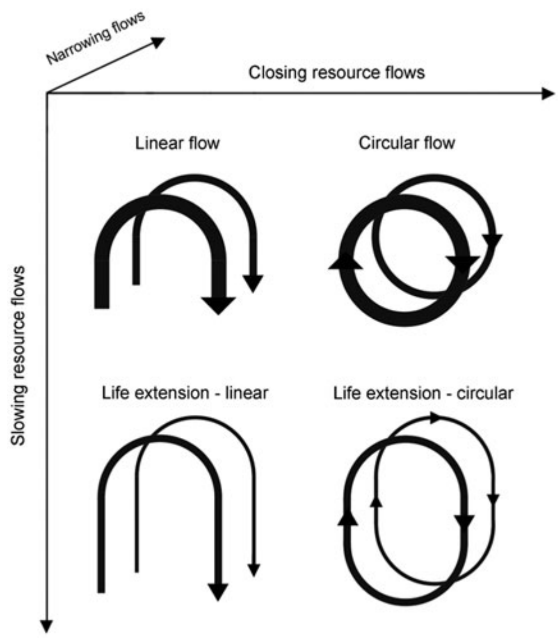

Figure 1. Categorization of linear and circular approaches for reducing resource use. Based on, and expanded from [10,38,49,50].

efficiency is not aimed at the cyclic use of products and materials, but an approach to reduce resource use associated with the product and production process, represented by Braungart et al. [10] as an eco-efficient cradle-to-grave material flow.

In summary, "slowing" is about prolonged use and reuse of goods over time, through design of long life goods and product life extension, whereas closing loops is about reuse of materials through recycling. Narrowing loops is about reducing resource use associated with the product and production process.

The "narrowing loops" approach is different from approaches for slowing resource loops, as it does not influence the speed of the flow of products and does not involve any service loops (e.g. repair). Resource efficiency has been applied successfully within a linear business model, and existing strategies for resource efficiency can be used in conjunction with both product-life extension and recycling within a circular system. As "narrowing resource flows" does not address the cycling of goods, this strategy is not addressed further in this paper. It should be noted that the end result of "slowing" and "narrowing" could be the same (less resources flowing through the system). However, "slowing" invokes a different relationship with time, whereas "narrowing" accepts the speed of resource flows. This is one of the critiques of following an efficiency approach that only considers "narrowing": if we do not address the time dimension, resource efficiency can easily lead to further speeding up of linear resource flows (selling more of a more efficient product), resulting in very little overall savings.

Building on the two basic strategies for the cycling of resources, the literature and relevant product/process standards were reviewed to retrieve product design and business model strategies for a circular economy. In the subsequent sections, product design and business model strategies are described for closing and for slowing resource loops.

2.2. *Circular product design strategies*

Integrating circular economy concerns at an early stage in the product design process is important, because once product specifications are being made, only minor changes are usually possible – it is difficult to make changes, once resources, infrastructures, and activities have been committed to a certain product design [6]. This section describes the product design strategies relevant to slowing and closing loops, and provides an overview of the terminology of relevant terms as described in the literature.

2.2.1. *Design strategies for slowing resource loops*

Extending the utilization period of products can be a highly effective strategy for reducing the use of resources. As argued by John Donahoe, at the time of writing CEO of eBay Inc.: "The greenest product is the one that already exists, because it doesn't draw on new natural resources to produce" [21].

Table 1 includes the typical design strategies to slow resource loops: creating long-life products (see [13,40]) and extending the product's life, once in use [4,11]. Long-life product design is supported by design for attachment and trust (i.e. emotional durability) [13] and 60 reliability and physical durability [40]. Design or product life extension can be facilitated through design for: maintenance and repair; upgrading and upgradability; standardization and compatibility; and dis- and reassembly (see [11,34]).

The terminology is briefly explained here at a high level. It should be noted that within each design strategy there might be a range of design strategy options.

2.2.1.1. *Designing long-life products.* "Designing long-life products" is the first major design strategy defined in this paper to slow resource loops. It is concerned with ensuring a long utilization period of products. Within this categorization, "Designing for attachment and trust" refers to the creation of products that will be loved, liked or trusted longer. This is also referred to as "design for emotional durability": 75 a situation where "users and products flourish within long-lasting empathic partnerships" [13]. "Design for durability" relates to physical durability, for example, the development of products that can take wear and tear without breaking down. Material selection for durability is an important part of the design process. "Design for reliability" refers to designing for a high likelihood that a product will operate throughout a specified period without experiencing a chargeable failure, when maintained in accordance with the manufacturer's instructions. ([40], p. 17). Product testing to mimic normal use can help test the reliability of the product.

2.2.1.2. *Design for product-life extension.* The second major design strategy to slow resource loops is "Design for product-life extension." This strategy is concerned with the extension of the use period of goods through

Table 1. Overview of design strategies to slow resource loops.

Design strategies to slow loops
Designing long-life products
• Design for attachment and trust
• Design for reliability and durability
Design for product-life extension
• Design for ease of maintenance and repair
• Design for upgradability and adaptability
• Design for standardization and compatibility
• Design for dis- and reassembly

the introduction of service loops to extend product life, including reuse of the product itself, maintenance, repair, and technical upgrading, and a combination of these.

"Design for Maintenance and Repair" enables products to be maintained in tip-top condition. Fairphone for example allows its users to easily repair and replace broken parts [42]. Maintenance is the performance of inspection and/or servicing tasks (technical, administrative, and managerial; [22]) to retain the functional capabilities of a product ([34], p. 1814). Repair is about restoring a product to a sound/ good condition after decay or damage ([34], p. 1813). After repair, the product is expected to be in a usable state, but assurances of performance are generally limited to the repaired part [11]. A second strategy is designing products to allow for future expansion and modification. Upgradability is defined as the ability of a product to continue being useful under changing conditions by improving the quality, value, and effectiveness or performance (…) (based on [34], p. 1814). Third, "Design for standardization and compatibility" is about creating products with parts or interfaces that fit other products as well [4]. Fourth, "Design for dis- and reassembly" is about ensuring that products and parts can be separated and reassembled easily [4]. It is a strategy that can be applied to increase the future rates of material and component reuse [18]. This strategy is also vital for separating materials that will enter different cycles (biological or technological).

2.2.2. *Design strategies for closing resource loops*

The Cradle to Cradle design philosophy, propagated by McDonough and Braungart [38] has inspired many companies and designers to apply an ambitious circular approach to product design [5,19]. With the introduction of design strategies aimed at circular flows of materials, a more detailed understanding of the concept of recycling has been propagated. According to Ayres [2], there are only two possible long-term fates for waste materials: either recycling and reuse, or dissipative loss (e.g. lubricants or detergents). Similar to the work of Ayres [2], McDonough and Braungart [38] developed two distinct strategies for product design: dissipative losses are to be made compatible with biological systems, fit for the "biological cycle"; whereas other materials are to be completely recycled, fitting a "technological cycle." Products that mix materials of both cycles and thereby inhibit the recovery of the materials are referred to as "monstrous hybrids" [9]. Table 2 summarizes the Design Strategies for Closing Loops defined in this paper.

Table 2. Overview of design strategies to close resource loops.

Design strategies to close loops
• Design for a technological cycle
• Design for a biological cycle
• Design for dis- and reassembly

Note: Design for dis- and reassembly fit both strategies for closing and slowing loops.

2.2.2.1. *Design for a technological cycle.* This design strategy is suitable for "products of service," i.e. products that deliver a service (as compared to products of consumption). When designing for a technological cycle, designers aim to develop products in such a way that the materials ("technical nutrients") can be continuously and safely recycled into new materials or products [9].

To establish continuous flow of resources in the technological cycle, the "waste" resources are to be recycled into material having properties equivalent to those of the original material. This requires either "primary recycling" or "tertiary recycling" of materials (see Table 3) as only these forms of recycling can generate materials with equivalent properties. Also, McDonough and Braungart stress that material quality is to be maintained, and distinguish between "upcycling" and "downcycling" to demonstrate that downcycling does not enable a cyclical flow of resources, but only delays the linear flow of resources from production to waste [38]. "Downcycling" thus implies that a material is reprocessed into a "low" value product [33]. In line with this distinction, processes that can be labeled as quaternary recycling or thermal recycling (Table 3) do not fit within a circular approach to product design. Table 3 summarizes the definitions for the different types of recycling.

2.2.2.2. *Design for a biological cycle.* "Design for a biological cycle" is suitable for "products of consumption," i.e. products that are consumed or wear during use (resulting in a dissipative loss of resources). With this strategy, products of consumption are designed with safe and healthy materials ("biological nutrients") that create food for natural systems across their life cycle [38]. In a biological cycle, materials are biodegraded to start a new cycle. Biodegradability is the capability of being degraded by biological activity [54], compositing is a related process, in which organic matter is biologically decomposed, performed by microorganisms, mostly bacteria and fungi [54]. When viewed from a recycling perspective, composting can be regarded an example of tertiary recycling [28] (see Table 3).

2.2.2.3. *Design for Disassembly and reassembly.* Finally, "Design for Disassembly" is a strategy, which is overlapping with, and contributing to Design for a Technological and Biological cycle. It is about ensuring that products and parts can be separated and reassembled easily [4]. This strategy is also vital for separating materials that will enter different cycles (biological from technological).

Table 3. Overview of recycling definitions, based on plastic recycling terminology [28].

Recycling method	Definition
Primary recycling [1], also referred to as closed-loop recycling	Mechanical reprocessing into a product with equivalent properties [28]. "Upcycling" is concerned with retaining or improving the properties of the material, the latter concept being relatively new and underexplored; see e.g. [39])
Secondary recycling, also referred to as downgrading or downcycling	Mechanical reprocessing into products requiring lower properties [28]. In secondary recycling, material is reprocessed into a "low" value product, such as industrial grade rubber being reprocessed into a general grade rubber [33].
Tertiary recycling, also described as chemical or feedstock recycling (depolymerisation & re-polymerization)	Recovery of the chemical constituents of a material (based on [28]). More extensively defined by Kumar et al. [32] as the structural breakdown of materials into their original raw core components (for instance depolymerisation) and consecutive buildup (repolymerisation) of material with properties equivalent to the original material.
Quaternary recycling, also described as thermal recycling, energy recovery, and energy from waste.	The recovery of energy from materials [28]. Within a circular economy, this category is not considered as recycling, as only part of the energy content of a material is used again, thereby fitting a linear system.

2.3. *Circular business model strategies*

This section discusses the potential business model strategies for a circular economy. It should be noted that the examples given in Table 4 do not necessarily present full business model innovations, but rather, key elements of business model strategies that contribute to a circular business.

Business models define the way a firm does business [37] and they are viewed as an important driver for innovation (e.g. [15,52,58]). Business model choices define the architecture of the business and expansion paths, but once established, companies often encounter great difficulty in changing business models [52]. As Chesbrough [15] observes: companies commercialize product and technology innovations through their business models and while they may allocate extensive investments to this, they often have limited capability to innovate the business models through which these innovations will pass. Following "dominant business model logic" can lead firms to miss valuable uses of an innovation [15,44]. The same technology or product innovation pursued through different business models will yield different economic outcomes [15]. Hence, according to Teece [52] every new product development effort should be coupled with the development of the business model, which defines its "go to market" and "capturing value" strategies, because technology or products by themselves do not guarantee business success.

The move to a circular economy model is an example of a radical change, which will require a new way of thinking and doing business. The more radical the technical or product innovation, the more challenging and the greater the likelihood that changes are required to the traditional business model [35]. Based on the business model frameworks of Bocken et al. [8] and Bakker et al. [4] key business model strategies are identified that fit the approaches of slowing and closing resource cycles, in Table 4.

2.3.1. *Business model strategies for slowing resource loops*

In line with the Section 2.2, business models to slow resource loops encourage long product life and reuse of products through business model innovation. Four key models are described: access and performance, extending product value, classic long life, and sufficiency (Table 4). These models are explained using the three-box business model framework, including the (1) value proposition (product/ service offering), (2) value creation and delivery (how value is provided), (3) value capture (how the firm makes money and capture other forms of value [7].

2.3.1.1. *Access and performance model.* The "access and performance model" [4] is concerned with providing the capability or services to satisfy users' needs without needing to own physical products. Similar terms include "Product Service Systems" (e.g. [53]), a combination of products and services that seek to provide this capability or functionality for consumers while reducing environmental impact is often used to refer to this type of business model [27] and "deliver capability rather than ownership" [8].

The value proposition is focused on the delivery of the service (access and performance) rather than ownership. The "hassle" of service and maintenance is taken over by the manufacturer or retailer (value creation and delivery). The user can enjoy the benefits of performance and access to a service (e.g. car sharing, launderette). With regard to the way value is captured, the pricing is per unit of service (e.g. time, number of uses, performance). This business model allows companies to capture financial benefits from going circular, which they would not be able to achieve in a linear model. For example, additional costs for life extension are offset by additional revenues, because the company can use the product longer.

Table 4. Business model innovations to slow and close resource loops. Developed from Bocken et al. [8] and Bakker et al. [4].

Business Model Strategies	Definition	Examples of cases
Business model strategies for slowing loops		
1 Access and performance model	Providing the capability or services to satisfy user needs without needing to own physical products	• Car sharing • Launderettes • Document Management Systems (e.g. Xerox, Kyocera) • Tuxido hire • Leasing jeans • Leasing phones
2 Extending product value	Exploiting residual value of products – from manufacture, to consumers, and then back to manufacturing – or collection of products between distinct business entities	• Automotive industry – remanufacturing parts • Gazelle offering consumers cash for electronics and selling refurbished electronics (gazelle.com) • Clothing return initiatives (e.g. H&M, M&S' Shwopping)
3 Classic long-life model	Business models focused on delivering long-product life, supported by design for durability and repair for instance	• White goods (e.g. Miele's 20 year functional life span of appliances; [4]) • Luxury products claiming to last beyond a lifetime (e.g. luxury watches such as Rolex or Patek Philippe)
4 Encourage sufficiency	Solutions that actively seek to reduce end-user consumption through principles such as durability, upgradability, service, warrantees and reparability and a non-consumerist approach to marketing and sales (e.g. no sales commissions)	• Premium, high service and quality brands such as Vitsœ and Patagonia [7] • Energy Service Companies (ESCOs)
Business model strategies for closing loops		
5 Extending resource value	Exploiting the residual value of resources: collection and sourcing of otherwise "wasted" materials or resources to turn these into new forms of value	• Interface – collecting and supplying fishing nets as a raw material for carpets • RecycleBank – providing customers with reward points for recycling and other environmentally benign activities (recyclebank.com)
6 Industrial Symbiosis	A process- orientated solution, concerned with using residual outputs from one process as feedstock for another process, which benefits from geographical proximity of businesses	• Kalundborg Eco-Industrial Park (http://www.symbiosis.dk/en) • AB sugar and other sugar refiners – internal "waste = value" practices [46]

Examples include launderettes, car clubs, and clothing hire models (e.g. tuxedo hire). The advantage of the Access and Performance strategy is that it can introduce economic incentives for slowing resource loops, both with manufacturers (increasing profits from e.g. durability, energy efficiency, reusability, reparability) and users (reducing costs when reducing use, e.g. thinking before using a car) and potentially reduces the total need for physical goods. In this way, this type of business model can contribute to slowing resource loops.

2.3.1.2. *Extending product value.* "Extending product value" is concerned with exploiting the residual value of products. An example of a business model is the case where the remanufacturing operation would simply recover products which have ceased to function, with no new net consumption of materials, other than those consumed during transport and processing [56]. In this type of business model, remanufacturing typically becomes the activity of the original manufacturer. Refrigerators and other white goods in the EU are examples of products whose development is driven by Extended Producer Responsibility and the WEEE Directive. Other examples are business models, where third parties focus on exploiting the residual value of a manufacturer's, brand or retailer's products (e.g. Stuffstr, Gazelle or Gone!).

The value proposition in this case is centered around manufacturers exploiting the residual value of products and are able to deliver the customer an affordable "as new" product through remanufacturing or repair or through other product life extension design strategies. For instance, entrepreneurs can offer a platform to allow customers to exploit the residual value of their products (e.g. eBay). The "value creation and delivery" includes take-back systems and collaborations (e.g. with retailers, logistics companies, and collection points) to enable consistent product returns (e.g. a deposit system at retail in the case of soda bottles). The firm can capture new forms of value through reduced material costs (while potentially increasing labor and logistics cost), which can lower overall cost and make this an attractive option for manufacturers. Whereas gap exploiters [4] exploit products from other companies as they see an untapped opportunity, in an ideal case, manufacturers themselves develop business models that support reuse and remanufacture.

2.3.1.3. *Classic long life model and encourage sufficiency.* The "classic long life model" [4] is concerned with long-product life, supported by design for durability and repair for instance. The value proposition focuses on high-quality, long-lasting products, and high levels of service (reparable, reusable over time). Value creation and delivery focuses on durable product design and high customer service levels (e.g. repair, maintenance). The upfront price is often "premium," which would typically cover the long-term service and product warrantee cost over the product lifetime absorbed by the manufacturer (value capture).

Similarly, "encourage sufficiency" [8] is about long-lasting products. However, for sufficiency business models a "non-consumerist approach to sales" is emphasized [7]. It includes solutions that actively seek to reduce end-user consumption, in particular through a non-consumerist approach to promotion and sales (e.g. not overselling, no sales commissions) [8]. The main principle of "encourage sufficiency" is to make products that last and allow users to hold on to them as long as possible through high levels of service. The manufacturer creates high-quality durable products and offers high levels of service (value proposition). In addition, the company takes a non-consumerist approach to selling – fewer high-end sales rather than "built-in obsolescence" (value creation & delivery). Sufficiency-based business models to date are often premium business models – they are high end and the price premium justifies "slower sales" and higher service levels (value capture).

Examples of premium business models include the one of the furniture company Vitsœ [25] which developed a video "against obsolescence" [26], and Patagonia [16] who developed the iconic "Don't buy this jacket" advertisement [41] to support the launch of its Common Threads Initiative to encourage repair and reuse of its clothing sold [7]. Positive impacts of encouraging sufficiency include the reduction in the consumption of resources, sustainable living and long-term customer loyalty, and new repair and service markets. Businesses may benefit from premium margins on high-quality products and high levels of customer loyalty. The principles of longer use and repair and service are aligned with the principles of a closed loop economy.

2.3.2. *Business model strategies for closing loops*

Closing loops in business model innovation is about capturing the value from what is considered in a linear business approach, as by-products or "waste." These strategies may be "micro" in scope, for example when materials are reused in manufacturing processes within a production facility [56], or more "macro" when products are eventually disposed of and the content may be recycled via an entirely independent network. This business model is already profitable for some materials such as aluminum where the energy costs of creating the material are higher than re-melting [56].

2.3.2.1. *Extending resource value.* "Extending resource value" is about the collection or sourcing of otherwise " wasted" materials and resources to turn these into new forms of value. An example of this is InterFace NetWorksTM – a program that sources fishing nets from coastal areas to clean up oceans and beaches while creating financial opportunities for people in impoverished communities and serving as a source to create recycled into yarn for Interface carpet [29].

The value proposition is focused on exploiting the residual value of resources, potentially making the product more appealing to certain customers (e.g. those with a "green" interest), while reducing material costs and the overall product price. Forms of value creation and delivery include new collaborations and take-back systems to be put in place to collect/ source materials. Value is captured by turning otherwise "wasted" resources into new forms of value. Similarly to "extending product value", gap exploiters [4] exploit resources from other companies, but in an ideal case, manufacturers themselves develop business models for resource reuse.

2.3.2.2. *Industrial symbiosis.* Similar to this, industrial symbiosis is a process-orientated solution, concerned with turning waste outputs from one process into feedstock for another process or product line [3,14]. An innovative business model example of internal symbiosis practices is the case of AB Sugar, who managed to reinvent its business model focused on sugar refining through innovation practices of industrial symbiosis, described by Short et al. [46]. These internal practices where value is created from "waste" are not uncommon, the Guitang Group in China being another example of a sugar refiner developing new business lines based on "waste" streams [59].

Whereas industrial symbiosis practices often take place at the process and manufacturing level and benefit from businesses located closely within a geographical area, "extending resource value" often happens at the product level and may happen across geographical areas (see e.g. the Interface example).

The value proposition for the business network is a reduction in overall operating cost and risks (e.g. environmental fines). Collaborative agreements can be established to reduce costs across the network, by for example sharing communal services (e.g. cleaning/ maintenance, recycling) and exchanging by-products (value creation and delivery). Value can be captured through joint cost reductions and the potential creation of new business lines based on former waste streams (see e.g. AB Sugar; [46]).

3. Conceptual framework to support the move to a circular economy

Building on the product design and business model strategies to enhance a circular economy, this section proposes a simple circular economy strategy framework to help facilitate the move to a circular economy (Figure 2).

As shown in Figure 2, it is argued that design and business model strategies need to be implemented in conjunction. Therefore, the business needs to implement or already have in place, an overall goal or vision focused on "circularity." This will empower innovators in the business to fully capture the business potential of the circular economy within the overarching objective to reduce sustainability pressures [36].

This framework is a first starting point to provide academics and practitioners with an overview and potential guidance to adopt strategies in a circular economy. It is acknowledged by the authors that the move to a circular economy is inherently complex and "systems thinking" is essential to understand the wider impact of the changes in business models and design, especially as these are interrelated. While these complexities are important to take into account, they are beyond the scope of this framework. Nevertheless, as the cases in the next chapter will illustrate, the introduction of circular strategies will have effects well beyond the company boundaries. Furthermore, the results may induce rebound effects in the usage of the products and services and may trigger customers spend their cost savings on other "polluting activities" (e.g. flights; see for example the work by Druckman et al. [20]). Further study into the application of circular business model and design strategies will be used to further develop the framework.

4. Examples of circular product design and business model strategies

In this section, a number of cases from practice are included to illustrate the different product design and business model strategies included in the framework. For each of the four main categories – slowing and closing product design and slowing and closing business model strategies – examples are given. Finally, examples of businesses taking an integrative perspective on the vision, design, and business model are included.

4.1. *Design for slowing resource loops: example of a car*

The car is a well-known example of a product that, due to its high upfront costs, has been designed for durability, maintenance, and reparability. Long car warranties are increasingly used as a sales argument, with warranty periods of seven years being offered by companies (for specific parts) to increase their market share. Moreover, the durability of cars allows for a large second-hand market of cars, car parts, and service sales. Maintenance and reparability come with an extensive network of car dealers affiliated to the manufacturers as well as independent car repair shops. To a limited extent, cars can also be adapted to meet (changing) customer requirements by means of accessories, and, with the current presence of on-board computers, software can be upgraded. The use of remanufactured parts is still limited to the automotive after-sale market [47].

This example of cars illustrates that design for maintenance, repair, and upgrade can be viable strategies for a wide range of products and components, including electro-mechanical systems, hydraulics, pneumatics, and electronic products for example. Furthermore, it shows that slowing resource loops can be feasible, even for energy-consuming products. However, we acknowledge that the demand for lightweight, energy-efficient vehicles (to narrow resource loops), and the related research into the application of composite materials may conflict with the other design strategy of closing resource loops.

4.2. *Design for closing resource loops: Solanyl*

In this section, we illustrate an example of "design for closing resource loops" with a biopolymer that can fit the design strategy of design for a biological cycle. Solanyl is a polymer produced by Rodenburg Biopolymers with characteristics similar to the popular engineering plastics polyethylene, polypropylene, and polystyrene. It is claimed that the bio-based Solanyl uses 65% less energy to manufacture [45] and is 10 to 50% cheaper at 0.8–1.5 €/kg compared to the three synthetic polymers

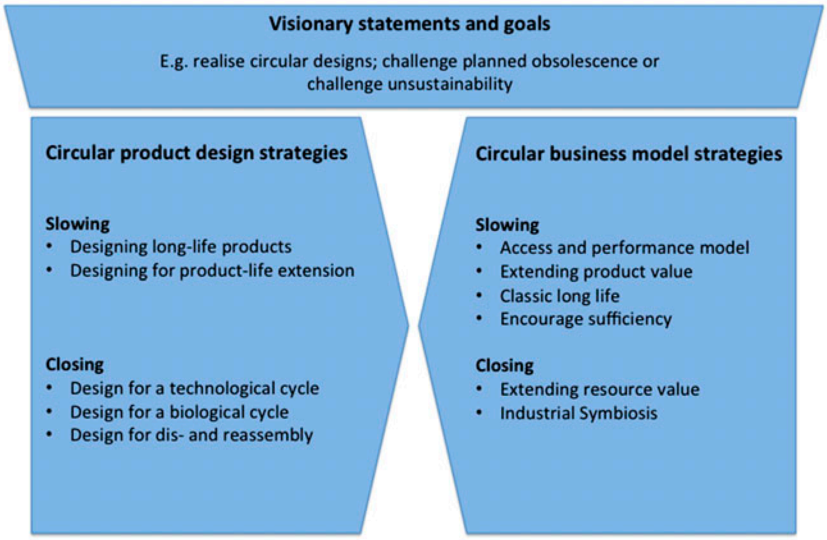

Figure 2. Circular economy product and business model strategy framework.

PE, PP, and PS [43]. Using locally abundant raw materials, potato peels left over from the production of fries and other potato products, allows for the lower price. Solanyl biodegrades in soil and can be used as nutrients by micro-organisms [47]. This makes it a suitable material for products that can end up in soil by mistake (plastic bags, disposable cutlery, festival coins) and products that deliberately dissolve during use (root guards, plant clips, potting cups).

Not all biopolymers are designed for a biological cycle. Bio-based polymers may not biodegrade (i.e. bio-based PE) and biodegradable polymers may be petroleum based (i.e. PCL). Solanyl was designed for safe and healthy use, as a nutrient for biological systems, and with a controlled degradation timespan. It also seeks to create a high-value product from a low-cost by-product. In products with a limited use life, materials such as Solanyl can offer a renewable replacement for petro-based materials in a circular economy.

As with all material cycles, the feasibility of this product within a circular economy depends on the recycling infrastructure in which the products are designed to, or are likely to end up.

4.3. *Business models for slowing loops: Miele*

To illustrate Business Models for slowing loops, an example of a durable washing machine manufacturer is provided.

The German domestic appliance company Miele is an example of "Classic Long Life" and "Encourage Sufficiency." Miele produces (among other appliances) high-quality washing machines. The company's primary revenue stream comes from the sales of these high-grade appliances. Miele's washing machines are an almost iconic example of "Classic Long Life" as a business model: their machines are guaranteed a functional lifespan of 20 years, where washing machines on average last some 10 years. In addition, Miele runs its own service company. Despite the economic recession, the company has refused to move down-market and compete on price. Miele has nearly all its manufacturing operations based in Germany and refuses to outsource to low-cost suppliers. According to the Atlantic Times [31], Miele accepts a modest growth rate ("the company does not exist to generate capital income for investors"). Hence, the company appears to pursue sufficiency-driven business model innovation. Lofthouse and Bhamra [35] identified the following design strategies employed by Miele: optimal service life (up to 20 years), design for durability, design for upgradability (service engineers can provide software upgrades), reduced energy consumption, and minimized resource use. Hence, business model innovation goes hand in hand with product innovation for circularity.

4.4. *Business models for closing loops: AB Sugar*

To illustrate Business Models for closing loops, the example of AB Sugar is provided.

This case, based on Short et al. [46] includes AB Sugar as an example of "Industrial Symbiosis." AB Sugar, the UK's largest sugar producer by market share, is an example of a company, which over the past three decades, has systematically sought opportunities to turn waste and emissions from their core manufacturing processes into useful feed stocks for new product lines [46]. Whereas their core business is sugar, the business model has evolved to include a wide range of additional profitable product lines [46]. Examples include a new business line, producing animal feed from by-product bagasse (a common by-product of sugar refining), the use of latent heat and CO2 from sugar refining to heat greenhouses and grow tomatoes near its sugar refining facilities, and a new bioethanol production facility, based on fermentation of sugar (by-) products [46].

Whereas Industrial Symbiosis is not always clearly presented as a business model innovation in the literature, this case [46] demonstrates, by the sheer size and volume of new product lines, that a company can gain competitive advantage from Industrial Symbiosis and use it as a driver for business model innovation to stay competitive in a market under pressure (the sugar industry).

4.5. *An integrative perspective*

The framework introduced in Figure 2 shows that companies need to start with an overall vision before developing their circular business model and design strategies in detail.

Furniture manufacturer Vitsœ [7,25,26] and white goods manufacturer Miele (discussed in Section 4.3) for example, can be viewed as companies challenging "planned obsolescence" as part of their overall vision. Vitsœ aims to make durable timeless products which will last a lifetime or longer [25]. The company seeks to challenge "planned obsolescence" in design through the way it does business [26]. Vitsœ encourages reparability, upgradability, and emotional and technical durability in design, which are important strategies to slow resource loops. Its business model is focused on encouraging sufficiency. Similarly, Miele accepts modest growth rates, which could help slow resource loops [31]. This is supported by a (relatively) premium business model and durable design.

Mobile phone manufacturer Fairphone [42] and outdoor clothing business Patagonia [16,41] can be viewed as companies challenging corporate "unsustainability." Fairphone for example goes against the trends in smartphone design that is not easily reparable, by creating an easy-to-disassemble and -repair phone [42]. The company started off by making the supply chain for smartphones highly transparent and applying Fairtrade principles to phone manufacturing. Fairphone is an example of a company, with an integrative vision, design and business model. A second example of such a visionary company is Patagonia, which has a mature view on "sustainability" and wants to challenge unsustainability and over-consumption through the way business is done [25]. Similar to Vitsœ, Patagonia has taken action to create awareness about the unsustainability of overselling and over-consuming, illustrated by its one-off "Don't Buy This Jacket" advertisement [41]. This can be viewed as a business model strategy to slow resource loops ("encourage sufficiency"; Table 3). Patagonia furthermore encourages people to reuse clothes and buy second hand through the Common Threads Partnership with eBay [21] and pledges to support product repair and make durable products, which are strategies to "slow" resource loops.

5. Concluding remarks

This paper has sought to give insights in the current product design and business model strategies suited for the move to a circular economy. The taxonomy of slowing, closing, and narrowing resource loops was introduced building on Stahel [49,50] and McDonough and Braungart [38] and Braungart et al. [10] as can be found in Figure 1. The aim of slowing resource loops is to extend the utilization period of products, whereas the purpose of closing resource loops is to close the loop between post-use and production (i.e. recycling). Second, a simple circular economy strategy framework (Figure 2) was developed to provide a conceptual overview of the possible design and business model strategies for a circular economy.

In order to transform the economy from linear to circular, business model and design strategies will need to go hand in hand. Potentially, we will need multiple business model and design strategies, approaches, methods, and tools to support the move to a circular economy. For example, the Miele case showed a synergistic combination of business model strategies (sufficiency and classic long life) and product design strategies (e.g. product design for durability and design for upgradability).

The frameworks and definitions in this paper are developed as conceptual aids for designers, innovators, and decision-makers in businesses. Furthermore, it can provide insight into future research directions, by building on key earlier work in the broad areas of environmental science, industrial ecology and sustainability, and setting out a framework for future researchers. It should be noted that hybrid-forms of these strategies are possible and the strategies of slowing and closing (and narrowing) resource flows can be mutually reinforcing. For instance, an access and performance business model can be combined with design for a technological cycle, so that at the end of the product's final life cycle, materials can be easily reclaimed and recycled. Furthermore, "systems thinking" remains important, to remain vigilant of rebound effects [20] and the wider consequences of adopting each of the strategies, not only from the environmental and economic perspective, but also from the social perspective.

Future work will need to include other essential elements such as the supply chain, enabling technologies, and infrastructure. This includes the development of case studies to test the identified strategies. Furthermore, researchers might want to "dissect" each of the strategies into further sub strategies or develop hybrid or entirely new forms that contribute to a circular economy. Finally, methods for assessing the environmental, social, and economic sustainability of circular products and business models will need to be developed.

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