

Article

A Conceptual Framework for Circular Design

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Abstract: Design has been recognised in the literature as a catalyst to move away from the traditional model of take-make-dispose to achieve a more restorative, regenerative and circular economy. As such, for a circular economy to thrive, products need to be designed for closed loops, as well as be adapted to generate revenues. This should not only be at the point of purchase, but also during use, and be supported by low-cost return chains and reprocessing structures, as well as effective policy and regulation. To date, most academic and grey literature on the circular economy has focused primarily on the development of new business models, with some of the latter studies addressing design strategies for a circular economy, specifically in the area of resource cycles and design for product life extension. However, these studies primarily consider a limited spectrum of the technical and biological cycles where materials are recovered and restored and nutrients (e.g., materials, energy, water) are regenerated. This provides little guidance or clarity for designers wishing to design for new circular business models in practice. As such, this paper aims to address this gap by systematically analysing previous literature on Design for Sustainability (DfX) (e.g., design for resource conservation, design for slowing resource loops and whole systems design) and links these approaches to the current literature on circular business models. A conceptual framework is developed for circular economy design strategies. From this conceptual framework, recommendations are made to enable designers to fully consider the holistic implications for design within a circular economy.

Keywords: circular design; design for sustainability; circular business models; circular economy

1. Introduction

Designers have a significant responsibility to shape the current status on how products and services are built. Since 1971, when Victor Papanek [1] called industrial design a harmful profession, not much change has occurred. In fact, according to research from the Royal Society for the Encouragement of Arts, Manufactures and Commerce (RSA) [2], the design of most products is far from being “circular ready”, as they follow the linear “take-make-dispose” model of resource use. However, Victor Papanek [1] also placed design as part of the solution due to designers having powerful technical and human-centred capabilities [3] that can help shape the environment in which we work, live and recreate. In the last decade, many academic and non-academic discussions have ensued for implementing a different role for design. Terms such as “eco-design”, “green design”, “design for the environment” and “sustainable design” have emerged, looking for alternative ways to deliver less damage to the environment and sometimes to wider society in general [3,4]. However, the application of these theories and methods in the development of “less bad consumer products” can have unintended consequences or re-bound effects if not considered from a whole system perspective [5] and result, for example, in the use of scrap, recycled and renewable materials, which cannot easily be recovered, disassembled or reused [6].

A circular economy enables a continuous positive development cycle that preserves and enhances natural capital, optimises resource yields and minimises system risks by managing finite stocks and

renewable flows [7]. This has the potential to address many of the complex challenges of the 21st century, including the loss of biodiversity, climate change, finite resource depletion, water stress, population growth, conflict over energy and resources, geopolitical tensions, human rights and economic failure. For design, a circular economy replaces the end-of-life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals that impair reuse and aims for the elimination of waste through the superior design of materials, products, systems and business models. In fact, the circular economy has been defined as an “industrial system that is restorative or regenerative by intention and design” [8] (p. 8). Without such a systemic change in the way that we design products, services, systems and infrastructure, the potential of a circular economy, outlined above, will never be achieved. As such, design for a circular economy has to consider different design strategies for closed loop systems as a pivotal point for its success. McDonough and Braungart [7] recognised two cycles in which resource loops flow, the “technical cycle” and the “biological cycle”. The technical cycle refers to closed loops within which materials that are inorganic or synthetics can stay in continued use without losing their properties or value. The biological cycle refers to organic nutrients or materials that can return back to the system or decompose without causing harm to the environment and provide a source of food for the wider system.

In addition to material and nutrient flows, circular design needs to consider the business model that a product is being designed for, as different kinds of product cycles take place within a circular economy. Some loops involve a business maintaining the economic value of assets throughout their lifecycle and others involve the adoption of resources that can be reintegrated into nature or fed into other supply chains [7]. Whilst there is not an ‘ideal’ business model that is preferable to achieve true circularity, tailored approaches are recommended for the successful transition into a circular economy. As such, the design of circular products needs to be ‘fit for purpose’ according to the chosen business model [8].

The role of policy is also eminent for businesses to make a transition towards developing circular products. In fact, the European Commission’s 2015 Circular Economy Strategy stressed the importance of design for end-of-life, product longevity and life extension [9]. The Commission also emphasised the importance of the revision of the Waste Electrical and Electronic Equipment (WEEE) and EcoDesign Directive to set in place regulations that drive businesses towards innovative practices for more circular products. In addition to design, policy can also help to drive the development of new business models enabling design strategies for a circular economy [8]. It is therefore necessary to consider policy and regulation as a component of the framework developed in this research and to discuss these further within opportunities for future research.

Previous work from Bocken et al. [10] brings together existing literature on consumer product design and circular business models and develops a framework of strategies. This framework is limited, however, and does not consider the wealth of the extant and valuable literature on Design for Sustainability (DfX), considered in this paper as the precursor to circular design. There is a need to provide design practitioners, industry stakeholders and product developers with recommendations of how to think about particular design strategies for different circular business models. The aim of this paper is therefore to systematically analyse previous literature on DfX, link previous approaches to the current literature on circular business models and develop a conceptual framework on design strategies for a circular economy. From this conceptual framework, recommendations are made to enable designers of consumer products to fully consider the holistic implications of design within a circular economy.

2. Method and Concept of the Study

In order to develop the proposed framework for circular design, the following three steps were undertaken:

- Step 1: Identification of the state of the art principles contributing to circular design to enable the development of a revised taxonomy of DfX approaches,
- Step 2: Identification of the state of the art classification of circular business models,
- Step 3: Synthesis and development of a conceptual framework for circular design.

2.1. State of the Art Principles for Circular Design

For this step, it was important to conduct a state of the art review on how environmental philosophies permeated the design realm and how these discussions transcended over the years, resulting in a range of DfX approaches. For the purposes of this paper, the work of Go et al. [11] is referenced. In this work, DfX is defined as “a combination of eco-design strategies including Design for Environment and Design for Remanufacture, which leads to other design strategies such as Design for Upgrade, Design for Assembly, Design for Disassembly, Design for Modularity, Design for Maintainability and Design for Reliability”. Since the topic of environmental design has been well reviewed by scholars, e.g., [10–14], this review focused on the historical evolution of green design to DfX, to develop a new taxonomy of DfX approaches based on previous work by De los Rios and Charnley [15], which is the only classification to date that looks into a full transition from DfX to circular design. The taxonomy is based on the following DfX approaches: (a) design for resource conservation; (b) design for slowing resource loops; and (c) whole systems design.

To conduct the literature review, the following academic databases were used: Scopus, Google Scholar, EBSCO Information Services Host and ProQuest. Keywords included evolution and history plus a variation on terms such as: green design, eco-design, design for the environment, environmental design, sustainable design, design for sustainability, circular design, cradle to cradle design, design for X, DfX, design for closed loops, design for remanufacture, product service system, whole system design. The literature search generated articles on conceptualising the evolution of green design through to circular design and DfX strategies. This exercise untapped new strategies, methods and tools that were not considered by De los Rios and Charnley [15]. Table 1 shows an overview of the literature that is considered to contribute to the new taxonomy.

Table 1. Categorisation of Design for Sustainability (DfX) approaches according to the existing literature.

DfX Approach	Authors
Design for resource conservation	Allwood et al. [16,17]; Bocken et al. [10]; Chertow and Ehrenfeld [18]; Lieder and Rashid [19]; Rashid et al. [20]
Design for slowing resource loops	Ashby and Johnson [21]; Accorsi et al. [22]; Bakker et al. [23,24]; Bhamra and Lofthouse [12]; Bocken et al. [10]; Bogue [25]; Boothroyd [26]; Chapman [27]; Claypool, et al. [28]; Cooper [29]; Clark et al. [14]; Edwards [30]; Ijomah et al. [31]; Johansson [32]; Kimura et al. [33]; King et al. [34]; Lofthouse [35]; Morelli [36]; Hatcher et al. [37]; RSA [2]; Sundin and Lindahl [38]; Van Nes and Cramer [39]; Vezzoli and Manzini [13]
Whole Systems Design	Benyus [40]; McDonough and Braungart [7]; Braungart et al. [41]; Charnley et al. [5]; Nagel et al. [42]; Schenkel et al. [43]; Vincent et al. [44]; Wells and Seitz [45]

2.2. Identification of State of the Art Classification on Circular Business Models

Research towards the circular economy has primarily focused on developing taxonomies to understand what circular business models would look like. Lewandowski [46] presented the most up to date and complete compilation of taxonomies developed in this space. Not all of the typologies mentioned by Lewandowski [46] were considered in this review due to the fact that the purpose of this state of the art review was to focus on the taxonomies that consider the value creation of a circular economy. The review revealed that the circular business model taxonomies developed by Accenture [47], Bakker et al. [23], Bocken et al. [10,48], Stahel [49] and Tukker [50] have a discourse founded in economic terms of value generation, activities and sources of revenue. As such, these were used to revisit and complement the work of De los Rios and Charnley [15], as they categorise the different taxonomies on business models in relation to economic gains. The review on circular

business models adopted a similar approach as described in Section 2.1 using the same databases, but with keywords such as: circular economy, circular business model, sustainable business model. In addition, a manual search was conducted on the websites of the contributors to a circular economy to complement the search with further reports, books and academic papers.

2.3. Synthesis and Development of a Conceptual Framework for Circular Design

Most of the academic and grey literature on the circular economy has focused primarily on the development of business model structures, with a small number of studies addressing design strategies for a circular economy that look at past literature in the area of resource cycles and design for longer product life. The reason for this is because the circular economy discourse focuses on closed loops for materials, especially in recovering and recycling to keep materials circulating through the economy [51]. As such, these studies primarily consider a limited spectrum of the technical and biological cycles where materials are recovered and restored and nutrients (e.g., materials, energy, water) regenerated [5], providing little guidance to designers and a lack of clarity on how designers are to design for new circular business models. In addition, Gregson [52] argues that moral considerations should be taken into account when there is a revalorisation of keeping material flows into the economy. To address the identified gap, Step 3 of the systematic literature review links all of the identified DfX approaches, strategies, methods and tools (considering the three dimensions of sustainability-environmental, social and economic) to the classification of circular economy business models according to the value provision, source of revenue and economic activities. From this synthesis, a conceptual framework was developed followed by recommendations for circular design practice.

3. Circular Design Principles

Design is a discipline that has been taught and practiced following the linear economy of take-make-dispose, which has been modelled by industry to be time-bound and limited to its desirable life and function [53]. Following the Great Depression, planned obsolescence was introduced as a strategy to stimulate the market [54]. This strategy dramatically differed to the mind-set of consumers in World War II when the practices of making do and mending (reusing and repairing) and salvaging (recycling) were commonplace due to government policy and restrictions, through rationing, on the availability of products and resources [55]. Following WWII, through the 1950s, planned obsolescence was steadily adopted by industry designing products that could become rapidly obsolete and replaced by consumers, helping companies to increase profits [56]. Conversely, planned obsolescence contributed significantly towards damaging the environment. As the consequences of environmental impacts became clear, academics and practitioners started to explore alternative design frameworks to influence the impact that products have on the environment and society. In fact, since the democratization of design in the 19th Century and its effects for economic prosperity in the 20th Century, designers started to recognize their role and responsibilities as being the interlink between industry and consumers. As such, they were able to influence the decisions people make about what they buy and why [56], hence the birth of consumerism using the field of industrial design as the driver following World War II [55]. Designers are also recognized to play an integral part right at the beginning of the conception of a new consumer product, and as such, they can determine its environmental, social and technological costs [1,4].

By recognizing designers' responsibility, over the years, environmental philosophies have evolved from green design to design for sustainability and, more recently, design for circularity or circular design. The first approaches of integrating sustainable principles into the design process emerged from the idea of using lifecycle assessment tools to evaluate the environmental impacts at each stage of the product lifecycle [4,57]. Figure 1 represents a historical evolution of green design to DfX and describes the focus of each. Green design and eco-design have been criticised by McDonough and Braungart [7] as having the same linear approach with only attempting to "be less bad". Results from these approaches are the use of scrap, recycled and renewable materials, which often make

further recovery and regeneration impossible. Subsequently, sustainable design took a step forward by considering social issues, including usability, socially responsible use, sourcing and designing to address human needs [12]. However, this approach still follows a linear process. DfX, then, is a term used to describe the creation of physical objects and services to comply with social, economic and ecological needs within a given context. DfX is used as a description for both preventive approaches (green, design, eco-design) and design for closed loop cycles. However, DfX covers a range of strategies that could be adopted to design for a circular economy, as in some cases, it takes a more holistic and radical approach towards product development (e.g., design for Product Service Systems PSS) [50]. DfX is the most commonly-used term to represent a holistic approach and most representative of ‘circular design’; however, it can be argued that the wide usage of this term does not permit a fair representation of the implications for design within a circular economy. Thus, it was necessary to map out all of the possible DfX strategies against the most current assembly of circular business models.

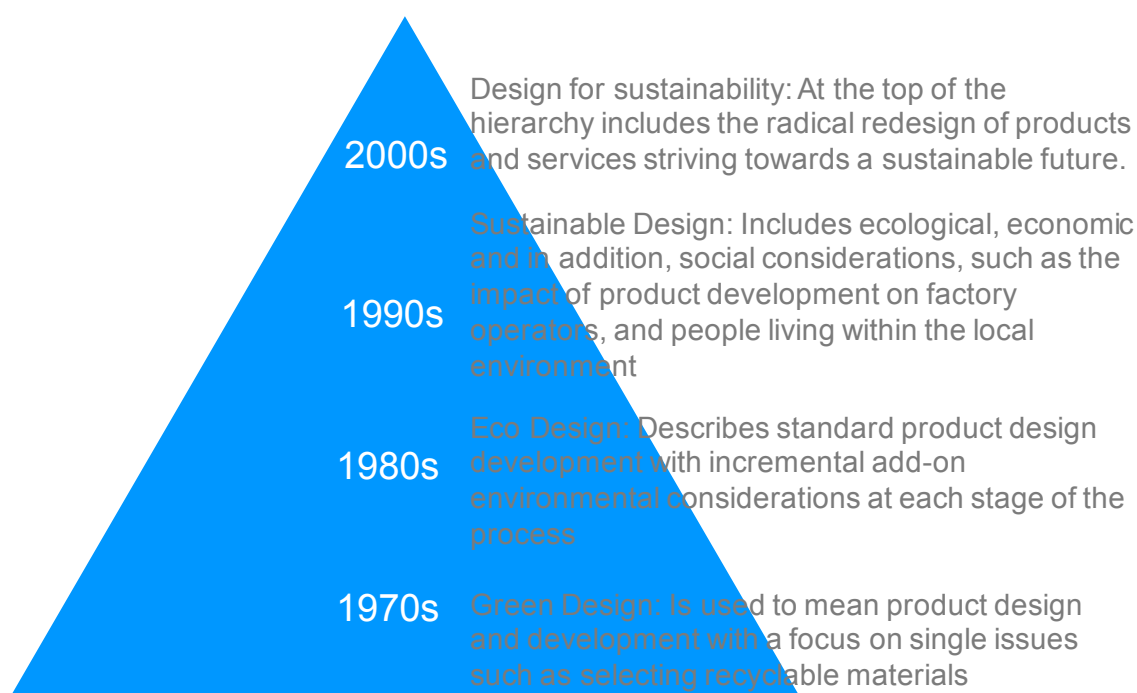


Figure 1. Historical evolution of environmental philosophies applied to design.

From DfX to Designing for Circular Cycles

Multiple authors argue against a direct link between sustainability and a circular economy stating that sustainable growth should not be about reduction and restraint over consumption [8,58] and that we should still be entitled to live in an enjoyable world, where resources are restorative. However, an ever-growing array of design principles, methods and tools from disciplines historically linked to sustainability exists to support the design and development of products for closed loops, hence the decision to consider them within this research. In fact, early thinkers on the concept of designing for circular cycles, such as Benyus [40], looked into how resources could become a nutrient for the next generation of living organisms. Other initial proposers of this concept include McDonough and Braungart [7] with their cradle to cradle approach in which outputs (waste) from one system become the inputs (resources) for other systems. Additionally, scholars, such as Walter Stahel [49,59–61], thought about dematerialisation (reducing material input, while maintaining performance), which gave life to new forms of business models, namely the sharing economy and collaborative consumption, which are integral to the circular economy as we currently know it. Despite the prominence of such concepts within what we understand as a circular economy, the link between the evolution of sustainability and

the circular economy is not universally accepted and should be acknowledged as a working position based on the literature reviewed within this research.

The most up to date literature describing design considerations for a circular economy suggests necessary changes to incorporate restoration and recovery at different levels, e.g., energy, products, materials, elements or molecules [7,8], as well as the technical characteristics of modularity, disassembly and repair-friendly features into products [25,26]. To give a better understanding of where the current DfX strategies are in relation to design for circular cycles, the taxonomy built by De los Rios and Charnley [15] was revisited, which considers the latest approaches to designing for multiple lifecycles, as well as to achieve holistic circular design (Table 2).

Through revisiting the recent literature, a new configuration of the strategies proposed by De los Rios and Charnley [15] was developed. This new taxonomy focuses on understanding how the sum of DfX approaches and “systems thinking” can be integrated to change the role of design within the circular economy. This taxonomy takes into consideration that design will be mindful and that in order to implement circular design, designers will successfully adapt circular resources to user needs both for function and pleasure, as an evolutionary role of design for closed loops. As such, this new taxonomy does not include design for behavioural change (e.g., Boks et al. [62]; Lilley [63]) as a strategy, as it is assumed that if a true circular design is applied, design will not need a palliative strategy to influence more sustainable behaviour. Piscicelli and Ludden [64] argue that influencing consumer acceptance would be important to scale up circular business models into the market. However, circular design goes beyond the traditional design process following the linear model of take-make-dispose, in which by considering the system as a whole, designers learn to be system thinkers. System thinking involves unique human cognitive capabilities that could help create meaningful design that would be more broadly accepted. As such, designers could make informed decisions about which circular strategies to use according to the business model and, at the same time, consider the transition processes and socio-cultural aspects in which the circular model will be implemented [65]. By applying systems thinking, designers have the potential to influence consumer perceptions and consumption patterns to help industry and society to not only move away from careless resource depletion [12], but transition towards an abundant, innovative and prosperous future, enabling a true adoption of circular design.

Table 2. Taxonomy of DfX approaches based on De los Rios and Charnley [15].

DfX Approach	Circular Design Strategy	Design Focus	DfX Method/Tool	Literature Sources
Design for resource conservation	Design for circular supplies	Design for closing resource loops	Design for biodegradability	Bocken et al. [10]; McDonough and Braungart [7]
			Design with healthy /smart processes/materials	Bocken et al. [10]; Benyus [40]; McDonough and Braungart [7]
	Design for resource conservation	Design for reduce resource consumption	Design for production quality control	Boothroyd [26]; Allwood et al. [16]
			Design for reduction of production steps	Allwood et al. [16]; Vezzoli and Manzini [13]
			Design for light weighting, miniaturizing	Allwood et al. [16]; Vezzoli and Manzini [13]
			Design for eliminating yield losses /material/resources/parts /packaging	Allwood et al. [16]; Vezzoli and Manzini [13]
			Design for reducing material/resource use	Ashby and Johnson [21]; Allwood et al. [16,17]; Clark et al. [14]; Vezzoli and Manzini [13]
Design for slowing resource loops	Design for long life use of products	Design for reliability and durability	Design on demand or on availability	Bhamra and Lofthouse [12]; Chapman [27]; Clark et al. [14]; Vezzoli and Manzini [13]
			Design the appropriate lifespan of products/components	Bakker et al. [23,24]; Bhamra and Lofthouse [12]; Bocken et al. [10]; Chapman [27]; Clark et al. [14]; Cooper [29]; Lofthouse [35]; Van Nes and Cramer [39]
		Design for product attachment and trust	Create timeless aesthetics	Bakker et al. [23,24]; Bhamra and Lofthouse [12]; Bocken et al. [10]; Chapman [27]; Lofthouse [35]
			Design for pleasurable experiences	Bhamra and Lofthouse [12]; Bocken et al. [10]; Chapman [27]; Lofthouse [35]
			Meaningful design	Bhamra and Lofthouse [12]; Bocken et al. [10]; Chapman [27]; Clark et al. [14]; Lofthouse [35]
		Design for extending product life	Design for repair/refurbishment	Bakker et al. [23,24]; Bocken et al. [10]; Chapman [27]; Kimura et al. [33]; Van Nes and Cramer [39]
	Design for easy maintenance, reuse and repair		Bakker et al. [24]; Bocken et al. [10]; Bogue [25]; Chapman [27]; Johansson [32]; Edwards, [30]; Van Nes and Cramer [39]	
	Design for dematerialising products	Design for upgradability and flexibility	Bakker et al. [23]; Bocken et al. [10]; Bogue [25]; Chapman [27]; Johansson [32]; Edwards [30]; Van Nes and Cramer [39]	Bakker et al. [24]; Bocken et al. [10]; Bogue [25]; Chapman [27]; Johansson [32]; Edwards [30]; Van Nes and Cramer [39]
			Design for product-service systems	Bakker et al. [24]; Clark et al. [14]; Morelli [36]; Sundin and Lindahl. [38]; Tukker [50]; Vezzoli and Manzini [13]
	Design for multiple cycles	Design for resource recovery	Design for swapping, renting and sharing.	Bakker et al. [24]; RSA [2]; Tukker [50]
			Design for easy end-of-life cleaning, collection and transportation of recovered material/resources	Vezzoli and Manzini [13]
			Design for cascade use	Accorsi et al. [22]; Vezzoli and Manzini [13]
			Design for (re)manufacturing and dis- and re-assembly	Bakker et al. [24]; Bocken et al. [10]; Bogue [25]; Chapman [27]; Edwards [30]; Hatcher et al. [37]; Johansson [32]; Kimura et al. [33]; Sundin and Lindahl [38]; Van Nes and Cramer [39]
	Whole Systems Design	Design for systems change	Design to reduce environmental backpacks	Design for upcycling/recycling
Design for the entire value chain				Charnley et al. [6]; Chertow and Ehrenfeld [18]; Claypool et al. [28]; Vezzoli and Manzini [13]; Wells and Seitz [45]
Design for Regenerative Systems			Design for local value chains	Wells and Seitz [45]; Vezzoli and Manzini [13]
			Design for biomimicry	Benyus [40]; Nagel et al. [42]; Schenkel et al. [43]; Vincent et al. [44]
			Design for biological and technical cycles	Bocken et al. [10]; McDonough and Braungart [7]; Braungart et al. [41]

4. Business Models for a Circular Economy

This section revisits the taxonomy on circular business models proposed by De los Rios and Charnley [15] in relation to economic gains, such as value flows, primary source of revenue and economic activities to close loops. This taxonomy was chosen as it resonates with Linder and Williander's [66] definition of a circular business model, which refers to "a business model in which the conceptual logic for value creation is based on utilising the economic value retained in products after use in the production of a new offering" (p. 2). As many scholars [8,10,46] have mentioned, the circular economy has been developed by many schools of thought, such as cradle to cradle, industrial ecology, biomimicry, blue economy, natural capitalism, industrial symbiosis and the performance economy [49,59–61]. The Ellen MacArthur Foundation [8] recognises that those schools of thought are complementary, and as such, they propose three fundamental principles towards the transition to a circular economy:

- Principle 1: Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows; meaning that technology and processes are chosen wisely according to their use of renewable or better-performing resources.
- Principle 2: Optimize resource yields by circulating products, components and materials at the highest utility at all times in both technical and biological cycles; meaning designing for remanufacturing, refurbishing and recycling to keep technical components and materials circulating in the economy, preserving embedded energy and other value. It also refers to encouraging biological nutrients to re-enter the biosphere in the safest way possible to become valuable feedstock for a new cycle.
- Principle 3: Foster system effectiveness by revealing and designing out negative externalities; this includes reducing damage to human utility, such as food, mobility, shelter, education, health and entertainment, and managing externalities, such as land use, air, water and noise pollution, release of toxic substances and climate change.

Following these principles, the Ellen MacArthur Foundation [8] defined four forms of value generation. These are: cycling smaller/faster with less energy and resources, cycling for longer, cascaded uses and pure regenerative cycles. The circular business model taxonomies developed by Accenture [47], Bocken et al. [10], Stahel [49] and Tukker [50] were analysed according to these forms of value (Figure 2). The taxonomies of Bocken et al. [10] and Bakker et al. [23] were reviewed, but not further analysed, as Bocken et al. [10] presents an updated version of these. It should be noted that the majority of the literature concerning circular business models does not come from business schools themselves and, therefore, brings into question whether or not this field of research is being taken seriously in practice. This remains a challenge for business model research.

The value generation companies might achieve by implementing the circular economy principles will depend on a case-by-case basis regarding the demand of resource use. If demand grows, the amount of resources needed would not be enough, and thus, a constant input of resources will be needed. In addition, keeping materials and resources circulating within the economy will require an input of extra resources. As such, Allwood [51] argues that the priority would be to reduce the rate at which material and resources are required. Scholars such as Bocken et al. [10] recall earlier schools of thought that argue for slowing, closing and narrowing the resource flows through different business strategies that will influence the design of products and services.

Circular Business Model Archetypes							
Value Flows (adapted from Bocken et al. [10] and Ellen MacArthur Foundation [8])			Primary Source of Revenue	Economic Activities to Close Loops Stahel [49]	PSS Business Models Tukker [50]	Business model innovations to slow and close resource loops Bocken et al. [10]	Business Models for Circular Advantage Accenture [47]
<div>Services</div> <div>↑</div> <div>Manufactured products</div> <div>↓</div> <div>Resources</div>	Slowing resource loops	▶ Profit from increased utilization rate of products, enabling shared use/access/ownership.	Reuse and remarket of manufactured goods		Result-oriented services	Access and performance model	Sharing Platforms
		▶ Profit from selling access to a product for a specific period of time or 'uses', and retaining material ownership.			Use-oriented services	Extending product value	Product as a service
	Cycling for longer	▶ Profit from providing maintenance services or sales of refurbished, remanufactured or repaired units	Product-life extension activities for goods	Product-based services	Classic long-life model	Product life extension	
		▶ Profit from repeated sales of consumables or services for a long-life product					
		▶ Profit from selling high quality products with a long lifespan at a high price			Encourage Sufficiency		
	Cascaded uses	▶ Profit from recovering resources/energy out of disposed products or by-products from the same or other company, upcycling or recycling them.	Material efficiency / recycling molecules		Extending resource value	Resource recovery	
Narrowing resource flows	▶ Profit from providing renewable energy, bio based- or fully recyclable input material to replace single-lifecycle inputs, and use fewer resources from products	Industrial Symbiosis			Circular supplies		

Figure 2. Categorisation of circular business model archetypes according to the value flows and primary source of revenue.

5. Circular Design Framework

To develop the circular design framework, the circular design and business model taxonomies explained above were simplified, having five main circular design strategies mapped against five circular business model archetypes. These are further explained below.

5.1. Circular Design Strategies

The five identified circular design strategies are:

- Design for circular supplies: This strategy focuses mainly on the biological cycles and refers to thinking of “waste equals food” in which resources are captured and returned to their natural cycle without harming the environment [40].
- Design for resource conservation: This strategy focuses on both the technical and biological cycles and uses a preventative approach in which products are designed with the minimum of resources in mind [10].
- Design for multiple cycles: This strategy focuses on both the technical and biological cycle and refers to design aimed at enabling the longer circulation of materials and resources in multiple cycles [10,23].
- Design for long life use of products: This strategy focuses on the technical cycle and refers to extending the utilisation of a product during its use through extending its life and offering services for reuse, repair, maintenance and upgrade [23], or by enhancing longer-lasting relationships between products and users through “emotional durable design” [27]. Furthermore, changing the ownership of products through services could enhance longer utilisation of products and, therefore, move to a sharing system [47].
- Design for systems change: This strategy covers the whole spectrum of value creation for both biological and technical cycles and refers to design thinking in complex systems as a whole and between its parts to target problems and find innovative solutions [5].

5.2. Circular Business Model Archetypes

By analysing the four taxonomies identified in Section 4, it was seen that the taxonomies proposed by Bocken et al. [10] and Accenture [47] were the ones that take into consideration both the biological and technical cycles and all of the sources of value generation listed above. As such, a summary was made of five circular business model archetypes.

- Circular supplies: A business model based on industrial symbiosis in which the residual outputs from one process can be used as feedstock for another process [10].
- Resource value: A business model based on recovering the resource value of materials and resources to be used in new forms of value [7,10,48].
- Product life extension: Those business models that are based on extending the working life of a product [48].
- Extending product value: Those business models based on offering product access and retaining ownership to internalise benefits of circular resource productivity [48].
- Sharing platforms: Those business models that enable increased utilisation rates of products by making possible shared use/access/ownership [48].

After defining the five circular design strategies and business model archetypes, these were mapped against each other with the purpose of delivering a tangible value through influencing industry and society (Figure 3). This resonates with the philosophy proposed by the Ellen MacArthur Foundation [8] that we should develop industrial systems that move away from careless resource depletion and at the same time gain substantial benefits by doing so [10]. In fact, many authors argue that sustainable growth should not be a matter of restraint and guilt over consumption [8,58]

and we should still be entitled to live in an enjoyable world, where material flows are restorative. As such, Figure 3 depicts the value flows against the source of revenue for each of the identified circular business models. In the upper part of Figure 3, the five circular design strategies are mapped out according to the circular business models and their position in the value chain, to aid the designer to understand which is the business model they are designing for, as different types of product cycles are considered within the circular economy [8]. The value of the framework lies in the integration of schools of thought from circular design strategies and circular business models. For the first time, this framework provides design practitioners with a holistic view of how to approach circular design, not only from a product perspective, but by taking into account the relevance and importance of the surrounding business models and how to integrate them with the design process. In addition, the framework acknowledges the role of policy and regulation in enabling circular business models, which requires exploring in future research.

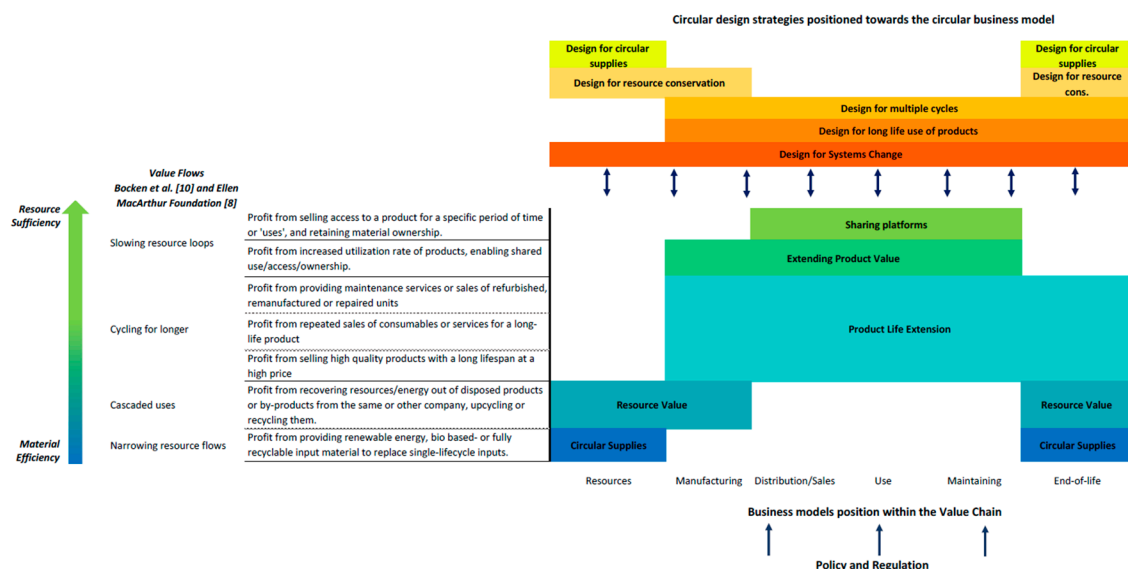


Figure 3. Circular design framework: circular design strategies mapped out against the circular business model archetypes and their value creation.

6. Recommendations for Circular Design

The advances in design strategies according to different products from Bocken et al. [10] and Bakker et al. [23] were particularly relevant for this research, as they provided the most complete and up to date description of design considerations for a circular economy. In addition, the researchers also acknowledged the efforts of the Great Recovery Project [67] which have developed a series of design principles for circular design. By looking into the academic and grey literature, related to the proposed framework, a set of recommendations for circular design was generated, with the aim of assisting designers, innovators and decision makers in the consumer goods spectrum, on their journey towards circular design. The recommendations are presented below as a set of 10 points to consider when designing for a circular economy.

- (1) Design for “systems change” when considering any circular design strategy;
- (2) Design by identifying the new circular business model that your product/service is being designed for;
- (3) Design by thinking of revolutionising the world: circular design goes beyond doing less bad;
- (4) Design for multiple cycles (short and/or long) and not only with end-of-life in mind;
- (5) Design by thinking in living and adaptive systems;

- (6) Design with different participants in the value chain, including your final user, and always keep him/her/it in mind;
- (7) Design by considering value in a broader view, not as a price tag on a shop shelf, but as an asset;
- (8) Design with failure in mind: it is better to test and prototype as many times as possible;
- (9) Design knowing where each material and part comes from and where each material and part goes to;
- (10) Design with “hands on” experiences that foster a call for action.

These recommendations aim to inspire current and future designers, inventors, innovators and decision makers in business to acquire new skills and think beyond current processes to enable a regenerative system that is created by intention and design. The change in the role of design is inevitable to cater to a dynamic society that is familiar with the reinvention of new business propositions. However, the pressing environmental and societal events in the last decade demonstrate a significant call for action to start thinking of the implications to the wider system. As such, the circular economy has been seen as a possible solution to stabilize some of these pressing issues by decoupling economic growth from resource consumption. Designers should start thinking about their contribution to the circular economy by being aware of the impact they can make by shifting their mind-set to “solution providers” rather than “object creators” [68]. As such, this paper seeks to contribute to the body of knowledge in this area by studying the evolution of DfX and its contribution to a circular economy. It should be acknowledged that the literature review conducted was based on academic research and does not interrogate to what extent the implementation of circular design strategies or business models exists in practice. Further research is required to understand how the theories discussed in this paper are permeating across industrial sectors, using tools and following recommendations such as those presented in this paper.

7. Concluding Remarks

This paper aimed to develop a framework for the evolution of DfX. Key circular design strategies were identified and mapped out against circular business model archetypes. The relationship between design strategies and multiple business models is imperative to make the transition from a linear economy of take-make-dispose to a circular one. As such, the developed framework considers the type of value creation that each business model could generate and proposes the adequate circular design strategy for each of them. The major contribution of this paper was the consideration and synthesis of decades of work in the field of DfX to propose a transition to circular design. Authors in the field might argue that not all DfX strategies were considered. However, the literature recognises that strategies overlap each other, and as such, this review presents a summary of the most relevant strategies, tools and methods derived from DfX to meet the aim of this research. Due to the majority of the literature reviewed originating in the EU, with the exception of some from the USA, it is proposed that the framework is valuable for European design. The exploration of the framework in other contexts, particularly its use within emerging economies, is a challenge for further research.

In addition, further work will include the development of a circular design tool alongside the proposed recommendations to further aid designers, inventors, innovators and decision makers to implement the identified strategies and qualitatively assess the social and environmental impacts of the proposed product/service/business model during the concept generation process. This will need to be complemented with further quantitative assessment. An assessment on how the circular design framework is applied to different products is required, as it is recognised that each identified strategy will not just be related to a business model, but also to a product category. This will help to build a product portfolio that could complement the desired tool. Finally, future work will also consider the role of policy and regulations to enable the implementation of circular business models with the appropriate circular design strategies. This work will consider the current topics of importance for the European circular economy strategy, such as regulations for the recovery of critical materials.

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