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Circular product design: strategies, challenges and relationships with new product development

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Abstract

Purpose – Although product design is a fundamental element in the transition towards the circular economy, the knowledge of practices, methods and tools oriented to circular product design has not been widely developed. This study aims to contribute to the circular economy research area by investigating and analyzing the main design approaches to circular products and their relationship to new product development.

Design/methodology/approach – The authors conducted a systematic review and qualitative analysis of 120 articles. In these studies, the authors analyzed aspects such as design strategies used, the barriers to the adoption of circular product design and the relationships between the phases of new product development processes with circular product design studies.

Findings – The findings revealed that the circular product design approach has added new design strategies to those already recommended by ecodesign, such as multiple use cycles, emotional durability and biomimicry. Furthermore, the results showed that most circular product design articles focus on the planning and concept development phases of the new product development process.

Originality/value – In this article, the authors systematized the findings of an emergent research area: the development of new products for the circular economy. Its main contributions lie in the identification of design strategies, the classification of Design for X approaches, analysis of such approaches during the new product development process and discussion of their main barriers. Finally, this study presents contributions for managers and designers who are starting the transition to a circular strategy.

Keywords Sustainability, Management, Circular economy, Ecodesign, Framework

Paper type Research paper

1. Introduction

Sustainability has an increasingly important role in organizations due to growing concerns and global discussions on pollution, climate change, loss of biodiversity, depletion of finite resources and the environmental awareness of consumers and governments (Halstenberg *et al.*, 2019). International meetings, such as the Kyoto Protocol, the Copenhagen Accord and

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the Paris Agreement, which all featured discussions on climate and sustainability, have indicated growing concern about environmental sustainability (Oliveira *et al.*, 2021).

In this respect, several studies have shown the relevance of new product development (NPD) as a way of improving the environmental sustainability of companies (e.g. Singh and Ordoñez, 2016; Kaddoura *et al.*, 2019; Alnajem *et al.*, 2021). Recently, and given the prominence received by the circular economy (CE) (Ghisellini *et al.*, 2016; Lahane *et al.*, 2021), circular product design (CPD) has been presented as an approach for NPD that integrates the principles of CE (Den Hollander *et al.*, 2017; Sassanelli *et al.*, 2020). Moreover, CPD has also been considered a fundamental element in the adoption of circular business models (Bocken *et al.*, 2016). Despite the recognized importance of product design activities to the adoption of CE (Shahbazi *et al.*, 2020), knowledge about CPD is still in a nascent phase (Kane *et al.*, 2018). Furthermore, the products and components currently available in the market were not designed for this purpose (Shahbazi and Jönbrink, 2020).

Moreno *et al.* (2016) pointed out that there was an initial evolution from "green design" to "design for sustainability" and that, more recently, there has been a concern with "design for circularity". In addition to being considered an advance of ecodesign (Moreno *et al.*, 2016; McAloone and Pigosso, 2017), CPD aims to support the biological and technical cycles of materials (Mestre and Cooper, 2017; Urbinati *et al.*, 2019) by preserving the natural capital (Moreno *et al.*, 2016). CPD also aims to avoid as much extraction of virgin raw material from nature as possible (Ghisellini *et al.*, 2016; Den Hollander *et al.*, 2017).

Furthermore, as noted by Den Hollander *et al.* (2017), the economic and environmental value of products developed under CE principles should be preserved as long as possible so that their life cycle is prolonged or they are returned in their original state to the market. Thus, it is relevant to consider the CE principles of regeneration, sharing, optimization, recycling, remanufacturing and virtualization (Mendoza *et al.*, 2017) in the early phases of NPD. However, due to these design aspects, the processes and practices related to CPD are recognizably different from those of traditional NPD (Subramanian *et al.*, 2019).

Although the CE is already considered a research field in environmental sustainability (Sauvé *et al.*, 2016; Sauerwein *et al.*, 2019), the knowledge of practices, methods and tools oriented to CPD has not been widely developed (Kane *et al.*, 2018; Sassanelli *et al.*, 2020) and deserve further study. Based on a systematic and qualitative review of 120 articles, this study aimed to deepen understanding of the CPD approach. For this, we identified and analyzed (1) the current trends and design approaches used, (2) the main challenges and barriers to CPD adoption, and (3) the strategies and relationships applicable to the NPD phases. In addition, this article aimed to answer the following research questions, which still need further clarification: *What are the main design approaches for CPD? How are CPD approaches related to NPD phases? What are the main barriers to the adoption of CPD?*

By addressing these questions, this study offers several contributions, both practical and theoretical. We expand the body of knowledge about CPD, systematizing the circular design strategies, the challenges of CPD adoption and the relationship of CPD with the phases of the NPD process. Furthermore, the findings and frameworks developed are a helpful guide for managers and designers in comprehending the possible strategies and approaches to design products to support a CE.

The paper is organized into six sections. Section 2 presents a theoretical background on CPD. Section 3 contains the research methodology. Section 4 addresses the research results. Section 5 presents a discussion. Finally, Section 6 presents the research conclusions.

2. Circular product design

Influenced by the conceptual approaches of cradle-to-cradle, industrial ecology, biomimicry, blue economy and natural capitalism (Hofmann, 2019), the CE is a system of production and consumption that focuses on maintaining products, components, materials and energy in circulation in order to maintain, add and recreate value as long as possible (Sihvonen and Partanen, 2016). The CE aims to replace the concept of "end-of-life" through the reuse, recycling and recovery of materials (Ghisellini *et al.*, 2016) so as not to depend on the extraction of virgin resources from nature (Sauvé *et al.*, 2016).

At the micro-level of the CE (Ghisellini *et al.*, 2016), CPD is derived from circular models (Lüdeke-Freund, 2020) and applied to design and NPD processes (Mestre and Cooper, 2017; Moreno *et al.*, 2016). Although CPD is based on other existing design approaches, Asif *et al.* (2021) suggest that design for sustainability and ecodesign guide development work primarily from a linear economy perspective. Indeed, Sumter *et al.* (2021) point to three factors that differentiate design for the CE from other design approaches to sustainability: with an emphasis on value, quality in the circulation of materials and the use of circular business models.

Cayzer *et al.* (2017) highlight several ways to improve circularity at a product level, such as increased durability, modularization, remanufacturing, component reuse and products, which are designed with fewer materials, are free of toxic chemicals and are able to be recycled or composted. Other studies emphasize principles relating to production, such as energy efficiency and the use of renewable energy sources (Urbinati *et al.*, 2019; Ghisellini *et al.*, 2016; Singh and Ordoñez, 2016), the optimization of processes and products for the efficient use of resources and the use of waste as a resource (Urbinati *et al.*, 2019). Zhou *et al.* (2021) underscored the importance of having the proper infrastructure to develop products aligned with CE principles relative to, for example, the expansion of renewable sources of energy, such as windy and solar energy, and the consequent decrease in the use of natural resources through the different phases of the product life cycle.

From the perspective of CPD, designers must consider aspects of circularity in the early phases of NPD (Ackermann, 2018; Shahbazi *et al.*, 2020; Shahbazi and Jönbrink, 2020) through an analysis of repairing, remanufacturing, recycling (Shahbazi *et al.*, 2020) and by investigating the possibility of product sharing during useful product life (Jabbour *et al.*, 2020). Den Hollander *et al.* (2017), Sinclair *et al.* (2018), and Sumter *et al.* (2020) have also noted that the objective of CPD is not only to maintain the physical but also the emotional integrity of products in order to ensure that they can be used and reused by different users in multiple cycles.

Considering the resource loop in NPD, Bocken *et al.* (2016) propose three fundamental CPD categories for resource cycling: narrowing, slowing and closing. These design approaches can also be classified for technical and biological cycles. Technical cycle design involves approaches, such as recycling, disassembly and emotional durability (Mestre and Copper, 2017). Biological cycle design involves NPD solutions inspired by natural ecosystems, adopting a biomimetic approach and bio-inspired loop strategies (Mestre and Copper, 2017). Along the same lines, multiple life cycle design also includes technological and biological cycle design (Sassanelli *et al.*, 2020).

Product development models based on product–service systems (PSSs) and a sharing economy can also be used to achieve these resource-looping strategies (Holtström *et al.*, 2019; Kjaer *et al.*, 2019). They favor the use of services associated with product consumption by increasing life cycles, thus reducing the need for consumption, production and the distribution of materials, components and products (Jabbour *et al.*, 2020). With respect to incorporating product design characteristics that favor closing, slowing and narrowing the cycles of materials, CPD is considered more complex than the traditional NPD (Subramanian *et al.*, 2019).

Recent CE studies indicated that the adoption of Industry 4.0 technologies boosts not only CE (Tseng *et al.*, 2021) but also NPD projects (Halstenberg *et al.*, 2019; Ghoreishi and Happonen, 2020). These technologies contribute to optimizing, closing loops and reducing the use of materials and components during the entire life cycle of the products (Jabbour *et al.*, 2020; Tseng *et al.*, 2021). Thus, CPD also depends on the new skills of designers involved in the development of products and services (Sumter *et al.*, 2020). In addition to knowing how and having the ability to manage CE cycles, designers also need skills in technologies such as big data, smart goods development and additive manufacturing (Sousa Jabbour *et al.*, 2019; Yang *et al.*, 2019).

3. Research method

To achieve the objectives of this research, we carried out a literature review. First, we used a systematic analysis to structure the main trends of the research field. Then, we supplemented this initial phase with a qualitative review, in which all articles were fully read to obtain deeper insights into the quantitative results.

3.1 Data collection

The search for articles was achieved through the Scopus database, which is recognized for holding a large collection of high-quality journals (Fernandes *et al.*, 2020). To collect the greatest number of articles, we used a variety of keywords directly associated with the CPD field: "circular economy", "product design", "product development", "new product development", "design process", "product development process", "circular product design", "circular product development", "circular design", "design for the circular economy", "design in a circular economy" and "product-level circularity" (Figure 1). Following the

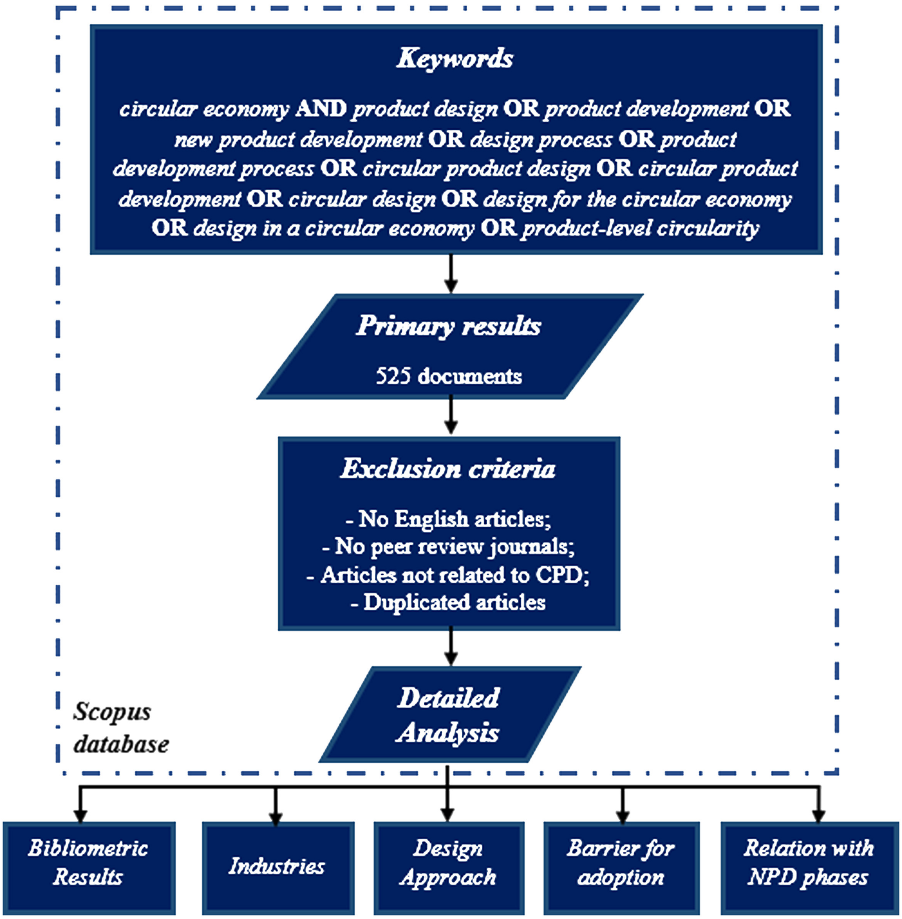

Figure 1.
Summary of research stages

recommendation of Marrucci *et al.* (2019), we used a variety of synonyms to obtain a greater number of relevant results, given the difficulty in identifying a set of keywords capable of understanding all the aspects under the CE concept. We used the "Article Title, Abstract, Keywords" field on Scopus. The database searches were updated until May 2021.

In the initial search, 525 documents were identified. It is worth mentioning that since CE is a recent topic under investigation, the search was not limited to a specific timespan. This initial list was reduced to 312 titles by considering only articles published in journals and written in English. Therefore, we excluded books, book chapters and conference articles. In the following step, after reading the titles, abstracts and, in some cases, the articles in full, we also excluded those not oriented to NPD, for instance, those focused on supply chain management and the chemical area. Articles that were unavailable to download were also excluded. The final number of articles for analysis was reduced after applying these criteria. As a result, from the initial number of 525 documents, our final sample consisted of 120 articles. A full list of these articles can be found in Appendix.

3.2 Data analysis

All 120 articles were reviewed and systematized. The contents were encoded according to geographic scope, methodological approach, keyword analysis, industries investigated, design approach, challenges and barriers to CPD, and the relationship between the phases of the NPD process with the CPD studies.

The data analysis was carried out first in Microsoft Excel. To understand the main themes related to CPD, we mapped the co-occurrence of keywords using the VosViewer software (Van Eck and Waltman, 2017). To relate the phases of the NPD process to the CPD studies, we adopted the product development process proposed by Ulrich and Eppinger (2012), which consists of six main phases: (1) planning, (2) concept development, (3) system-level design, (4) detail design, (5) testing and refinement and (6) production/ramp-up.

Figure 1 shows the steps taken for the selection of articles.

4. Results

4.1 The panorama of CPD research

Figure 2 shows the temporal evolution of publications in the sample. Clearly, CPD is a recent topic. Since the first publications, which appeared in 2014, there has been an increasing trend. It is important to note that there are a smaller number of articles from 2021 because the sample does not represent that entire year; our database searches were last updated in May 2021.

Figure 3 shows the geographic location of publications, indicating the number of documents published per country. The origin of each publication was identified through an analysis of the first author's institutional affiliations.

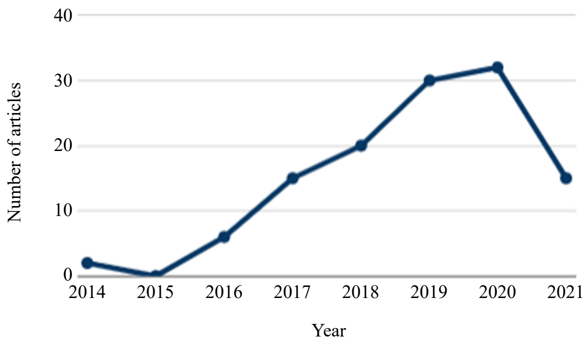

Figure 2.
Evolution of publications

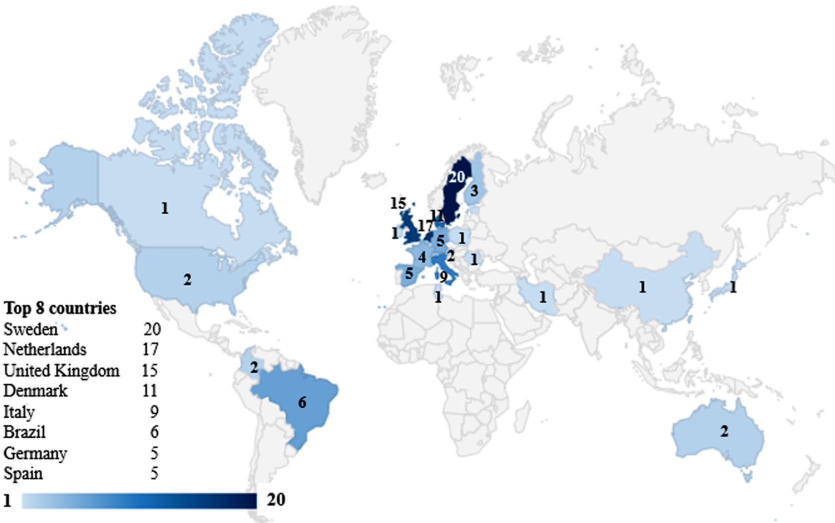

Figure 3.
Distribution of CPD articles by country

Figure 3 shows that the highest level of research on CPD is in Europe, especially in Sweden, the Netherlands, the United Kingdom and Denmark. However, several other countries have research in this field. Brazil has the greatest number of published articles outside Europe. Figures 4–6, respectively, show the main journals, methodological approaches and industries that have been investigated.

Figure 5 shows that most of the articles (69%) adopted a qualitative methodological approach, corresponding to case studies, theoretical reviews and framework proposals. Among the articles analyzed, 16% adopted a quantitative approach through the application of surveys, simulation and optimization models. Only 18 articles opted for mixed research, combining qualitative and qualitative approaches.

Figure 6 indicates that the CPD investigations focused mainly on the electric and electronic industries and machinery and equipment (such as washing, food processing and coffee machines). The plastic, furniture and clothing industries have also been investigated in CPD. In the "other" category, we grouped sectors that were represented less than three times by the articles identified, such as steel, aerospace and glass.

Table 1 shows the five most cited articles from the sample analyzed using the Scopus database, until May 2021.

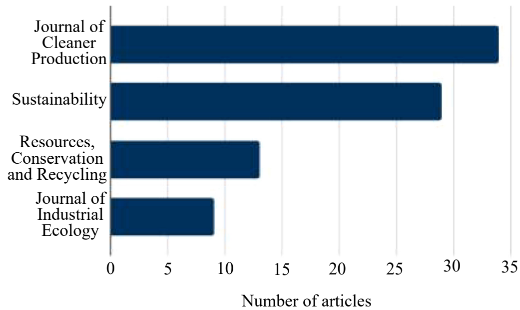

Figure 4.
Main journals

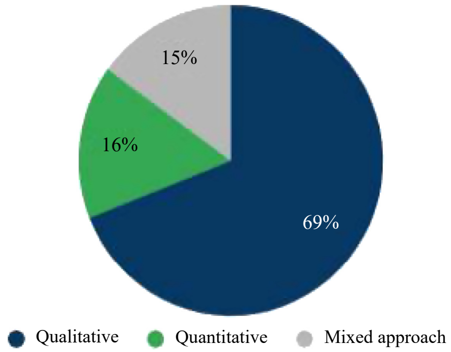

Figure 5. Methodological approach

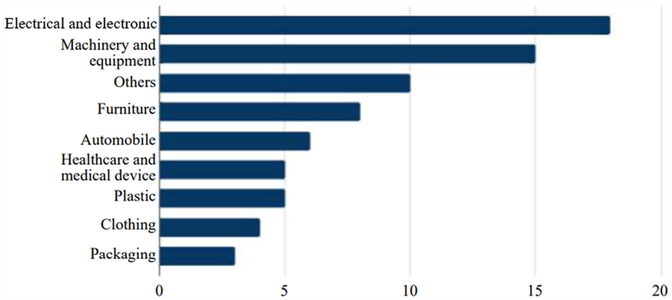

Figure 6. Industries investigated

Table 1. Five most cited articles in circular product design

References	Title	Journal	Citations
Bocken *et al.* (2016)	Product design and business model strategies for a circular economy	Journal of Industrial and Production Engineering	623
Bakker *et al.* (2014)	Products that go round: exploring product life extension through design	Journal of Cleaner Production	259
Singh and Ordoñez (2016)	Resource recovery from post-consumer waste: important lessons for the upcoming circular economy	Journal of Cleaner Production	154
Moreno *et al.* (2016)	A conceptual framework for circular design	Sustainability	152
Den Hollander *et al.* (2017)	Product design in a circular economy	Journal of Industrial Ecology	150

The study of Bocken *et al.* (2016) stands out among the papers with almost twice the Scopus citations of the second-placed one (Bakker *et al.*, 2014). Bocken and colleagues developed a framework of strategies to guide designers and business strategists in the move from a linear to a CE, based on the terminology of slowing, closing and narrowing resources. In this regard, a list of product design strategies, business model strategies and examples for key decision-makers in businesses is introduced (Bocken *et al.*, 2016). In Figure 7, the authors' keywords and index keywords with at least four co-occurrences were combined to build a network, using the VOSviewer software.

Respecting this restriction in the number of co-occurrences, three clusters were generated: given in green, red and blue (Figure 7). The main core terms of the map are "circular

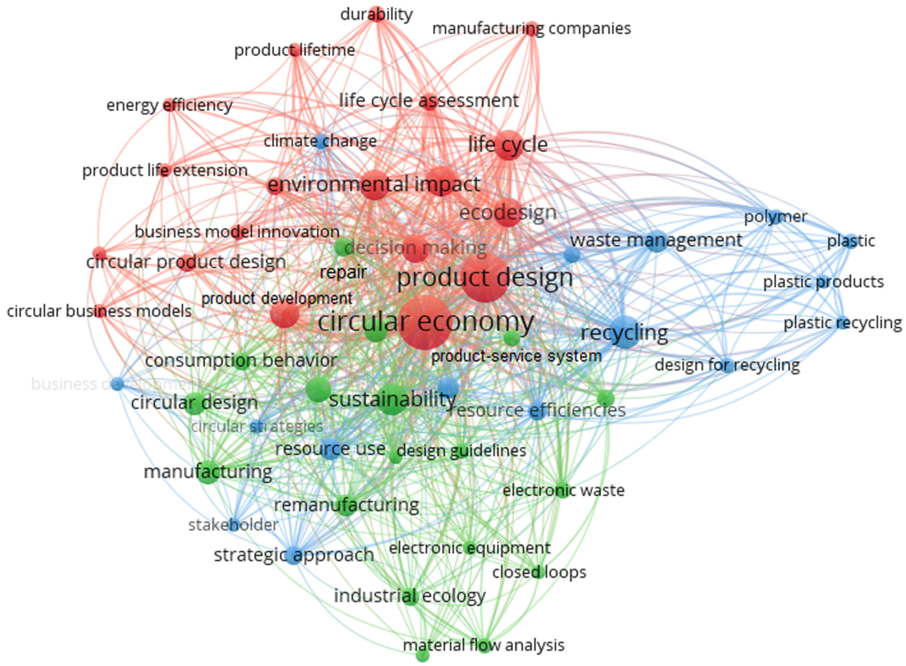

Figure 7.
Authors' keywords and index keywords with at least four co-occurrences

economy", "product design", "environmental impact", "sustainability" and "recycling". The red cluster is directly related to circular business models, addressing topics such as product life extension and energy efficiency. It reveals that much research has investigated the role of life cycle assessment (LCA) as a fundamental tool in the CPD field, identifying which phase of the product lifetime is responsible for which environmental impact. The cluster in blue shows keywords from studies dealing with recycling and design for recycling, investigating resource efficiencies and waste management practices. It can be seen that much research has focused on plastic products and their recycling. Finally, the green cluster involves other practices, such as repair and remanufacturing, relating to the studies approaching the electronic sector.

4.2 Design strategies and barriers to the adoption of CPD

Through the qualitative analysis of the articles, we identified and interpreted 40 design strategies commonly applied in CPD. We also organized these strategies into a unique framework, according to the approaches proposed by De Los Rios and Charnley (2017) and Moreno *et al.* (2016), as shown in Table 2.

Figure 8 shows the distribution of the design approaches that are cited by at least five articles.

The designs for recycling, repair, PSS, reuse, disassembly and durability have been extensively investigated by the literature on CPD (Table 2 and Figure 8). Although these approaches are the most frequently presented, some others have been less cited, including design for biomimicry (Moreno *et al.*, 2016; Mendoza *et al.*, 2017; Sauerwein *et al.*, 2019), design for emotional durability (Moreno *et al.*, 2016; Den Hollander *et al.*, 2017; Haines-Gadd *et al.*, 2018), design for upcycling (Moreno *et al.*, 2016; Flood *et al.*, 2020), design for refurbishing (Moreno *et al.*, 2016; Den Hollander *et al.*, 2017; Shahbazi and Jönbrink, 2020), design for fault

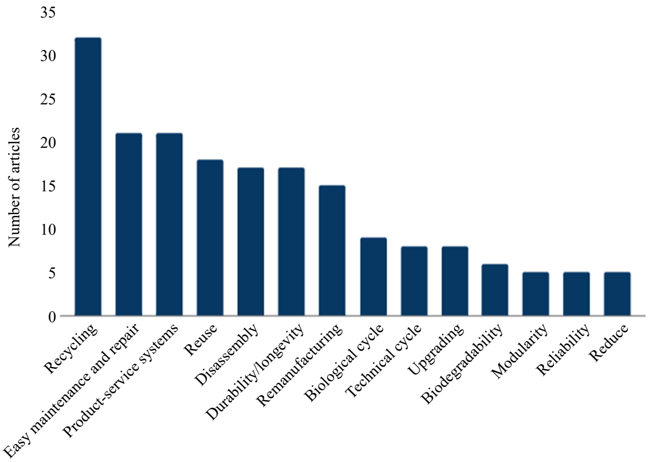

Figure 8.
Main approaches of circular product design

diagnosis (Arcos *et al.*, 2020) and design for multiple use cycles (Sinclair *et al.*, 2018; Selvefors *et al.*, 2019; Sassanelli *et al.*, 2020; Sumter *et al.*, 2020).

In terms of the last five years, Figure 9 shows the evolution of design approaches. Design for recycling appears to be the most applied strategy. Among the tools used for the adoption of CPD, there has been an emphasis on the LCA (Niero and Olsen, 2016; Almeida *et al.*, 2017; Stewart and Niero, 2018; Mesa *et al.*, 2018; Bech *et al.*, 2019; Halstenberg *et al.*, 2019; Kaddoura *et al.,* 2019; Richter *et al.*, 2019; Urbinati *et al.*, 2019). The life cycle cost analysis (Kaddoura *et al.*, 2019; Richter *et al.*, 2019) and the CPD oriented checklist (Bovea and Pérez-Belis, 2018; Halstenberg *et al.*, 2019) are also tools mentioned in some studies in the CPD field.

The adoption of the CE depends on organizational and technical innovations (Jabbour *et al.*, 2020) and is often treated as a radical innovation (Ritzén and Sandström, 2017). As such, there are barriers and challenges to adopting the CE in companies (Jesus and Mendonça, 2018). Therefore, our study also identified the barriers found in the literature for the adoption of CPD (Figure 10).

Figure 10 shows that the main barriers presented by CPD research are technological (a lack of technology or insufficient knowledge to adopt CPD), financial (investments required for the adoption of circular practices), company cultural changes related to CPD adoption and the possibility of losing market share due to customers not wanting CE approach-based products (for example: reused, remanufactured, recycled, shared or with higher prices than those using virgin raw materials).

4.3 Relationships between the CPD and NPD phases

Table 3 summarizes the relationship between studies on CPD and the phases of the NPD process (Ulrich and Eppinger, 2012). Research studies were categorized into four groups: framework, method, model and review:

"*Framework*" includes research oriented at proposing or establishing a theoretical framework or knowledge base. These works discuss implementation criteria, drivers and barriers; and they establish the theory required to implement CE strategies. Frameworks also provide knowledge useful to designers and practitioners during the implementation of new product design projects and facilitate the understanding of all implications derived from adding CE criteria into the design development process.

Table 2.
Framework for circular product design approaches

Approach	Design for X	References
Design for slowing resource loops		
Design for resources recovery	Design for cascade use	Moreno *et al.* (2016), Shahbazi and Jönbrink (2020)
	Design for remanufacturing	Bocken *et al.* (2016), Moreno *et al.* (2016), Singh and Ordoñez (2016), Atlason *et al.* (2017), Den Hollander *et al.* (2017), De los Rios and Charnley (2017), Mendoza *et al.* (2017), Charnley *et al.* (2019), Haziri and Sundin (2019), Jabbour *et al.* (2019), Niu *et al.* (2019), Urbinati *et al.* (2019), Haziri and Sundin (2020), Sassanelli *et al.* (2020), Shahbazi and Jönbrink (2020)
	Design for disassembly	Bocken *et al.* (2016), Moreno *et al.* (2016), Almeida *et al.* (2017), De los Rios and Charnley (2017), Talens Peiró *et al.* (2017), Mendoza *et al.* (2017), Bovea and Pérez-Belis (2018), Mandolini *et al.* (2018), Mesa *et al.* (2018), Vanegas *et al.* (2018), Franco (2019), Halstenberg *et al.* (2019), Urbinati *et al.* (2019), Belhadj *et al.* (2019), Sousa Jabbour *et al.* (2019), Koszewska and Bielecki (2020), Sassanelli *et al.* (2020)
	Design for reassembly	Moreno *et al.* (2016), Mesa *et al.* (2020)
	Design for upcycling	Moreno *et al.* (2016), Flood *et al.* (2020)
	Design for refurbishing	Moreno *et al.* (2016), Den Hollander *et al.* (2017), Shahbazi and Jönbrink (2020)
	Design for recycling	Bakker *et al.* (2014), Bocken *et al.* (2016), Moreno *et al.* (2016), Singh and Ordoñez (2016), Atlason *et al.* (2017); De los Rios and Charnley (2017), Mestre and Cooper (2017), Hildebrandt *et al.* (2017), Mendoza *et al.* (2017), Bovea and Pérez-Belis (2018), Bovea *et al.* (2018a), Hannula *et al.* (2018), Milios *et al.* (2018), Ragaert *et al.* (2018), Stewart and Niero (2018), Subramanian *et al.* (2019), Eriksen and Astrup (2019), Holtström *et al.* (2019), Franco (2019), Leissner and Ryan-Fogarty (2019), Ford and Fischer (2019), Sousa Jabbour *et al.* (2019), Urbinati *et al.* (2019), Cooper *et al.* (2020), Flood *et al.* (2020), Jugend *et al.* (2020), Koszewska and Bielecki (2020), Parajuly *et al.* (2020), Sassanelli *et al.* (2020), Shahbazi and Jönbrink (2020), Thompson *et al.* (2020)
	Design from recycling	Leal *et al.* (2020), Veelaert *et al.* (2020)
	Design for end of life	Moreno *et al.* (2016), Sabaghi *et al.* (2016), Mestre and Cooper (2017), Parajuly and Wenzel (2017), Sassanelli *et al.* (2020)
Design for extending product life	Design for reuse	Bocken *et al.* (2016), Singh and Ordoñez (2016), Almeida *et al.* (2017), Atlason *et al.* (2017), De los Rios and Charnley (2017), Mendoza *et al.* (2017), Talens Peiró *et al.* (2017), Bovea and Pérez-Belis (2018), Bovea *et al.* (2018a), Subramanian *et al.* (2019), Stewart and Niero (2018), Holtström *et al.* (2019), Franco (2019), Urbinati *et al.* (2019), Koszewska and Bielecki (2020), Parajuly *et al.* (2020), Shahbazi and Jönbrink (2020), Joustra *et al.* (2021)
	Design for easy maintenance and repair	Bocken *et al.* (2016), Moreno *et al.* (2016) Singh and Ordoñez (2016), Den Hollander *et al.* (2017), Mestre and Cooper (2017), Talens Peiró *et al.* (2017), Ackermann (2018), Bovea *et al.* (2018a), Haines-Gadd *et al.* (2018), Mesa *et al.* (2018), Sousa-Zomer *et al.* (2018), Stewart and Niero (2018), Sumter *et al.* (2018), Franco (2019), Jabbour *et al.* (2019), Halstenberg *et al.* (2019), Holtström *et al.* (2019), Arcos *et al.* (2020), Parajuly *et al.* (2020), Sassanelli *et al.* (2020), Shahbazi and Jönbrink (2020)
	Design for durability/longevity	Bocken *et al.* (2016), Moreno *et al.* (2016), Mestre and Cooper (2017), Bovea and Pérez-Belis (2018), Bovea *et al.* (2018a), Haines-Gadd *et al.* (2018), Mesa *et al.* (2018), Sumter *et al.* (2018), Sousa-Zomer *et al.* (2018), Selvefors *et al.* (2019), Singh *et al.* (2019), Ingemarsdotter *et al.* (2020), Mesa *et al.* (2020), Sassanelli *et al.* (2020), Stegmann *et al.* (2020), Stamminge *et al.* (2020), Cordella *et al.* (2021)
	Design for upgrading	Bocken *et al.* (2016), Moreno *et al.* (2016), Den Hollander *et al.* (2017), De los Rios and Charnley (2017), Mestre and Cooper (2017), Haines-Gadd *et al.* (2018), Mesa *et al.* (2018), Shahbazi and Jönbrink (2020)
	Design for product attachment and trust	Bocken *et al.* (2016), Mesa *et al.* (2018)
	Design for emotional durability	Moreno *et al.* (2016), Den Hollander *et al.* (2017), Haines-Gadd *et al.* (2018)
	Design for multiple use cycles	Sinclair *et al.* (2018), Selvefors *et al.* (2019), Sassanelli *et al.* (2020), Sumter *et al.* (2020)
	Design for pre and post-use	Selvefors *et al.* (2019)
	Design for circular behavior	Wastling *et al.* (2018)

(*continued*)

Table 2.

Approach	Design for X	References
Design for dematerializing/ repurposing products	Design for PSSs	Moreno *et al.* (2016), Mendoza *et al.* (2017), Ackermann (2018), Bressanelli *et al.* (2018), Sinclair *et al.* (2018), Bech *et al.* (2019), Franco (2019), Halstenberg *et al.* (2019), Holtström *et al.* (2019), Sousa Jabbour *et al.* (2019), Kaddoura *et al.* (2019), Kjaer *et al.* (2019), Kristensen and Remmen (2019), Tunn *et al.* (2019), Chen (2020), Fernandes *et al.* (2020), Jabbour *et al.* (2020), Jugend *et al.* (2020), Sassanelli *et al.* (2020), Stegmann *et al.* (2020), van der Laan and Aurisicchio (2020)
	Design for exchange	Selvefors *et al.* (2019)
	Design for adaptability	Sassanelli *et al.* (2020)
	Design for repurpose	Shahbazi and Jönbrink (2020)
	Design for remake	Sassanelli *et al.* (2020)
	Design for recontextualizing	Den Hollander *et al.* (2017)
Design for resource conservation		
Design for reduce resource consumption	Design for production quality control	Moreno *et al.* (2016), Mestre and Cooper (2017), De los Rios and Charnley (2017)
	Design for reliability	Bocken *et al.* (2016), De los Rios and Charnley (2017), Mesa *et al.* (2018), Sousa-Zomer *et al.* (2018), Sassanelli *et al.* (2020)
	Design for reduce weight/ miniaturization	Moreno *et al.* (2016), Stewart and Niero (2018)
	Design for fault diagnosis and failure modes	Arcos *et al.* (2020), Kimita *et al.* (2020)
	Design for energy efficiency	Mestre and Cooper (2017), Mendoza *et al.* (2017), Sassanelli *et al.* (2020)
	Design for environment	Urbinati *et al.* (2019), Sihvonen and Partanen (2016), De los Rios and Charnley (2017)
	Design for sustainability	Sassanelli *et a*l. (2020)
	Design for modularity	Talens Peiró *et al.* (2017), Mendoza *et al.* (2017), Halstenberg *et al.* (2019), Chen (2020), Sassanelli *et al.* (2020)
	Design for standardization and compatibility	Bocken *et al.* (2016), Mendoza *et al.* (2017), Mesa *et al.* (2018), Sassanelli *et al.* (2020)
	Design for reduce	Moreno *et al.* (2016), Mestre and Cooper (2017), Stewart and Niero (2018), Subramanian *et al.* (2019), Koszewska and Bielecki (2020)
	Design for demand or on availability	Moreno *et al.* (2016)
Design for closing resource loops	Design for biodegradability	Bocken *et al.* (2016), Singh and Ordoñez (2016), Moreno *et al.* (2016), Mendoza *et al.* (2017), Mesa *et al.* (2018), Razza *et al.* (2020)
Design for systems change		
Design for regenerative systems	Design for biomimicry	Moreno *et al.* (2016), Mendoza *et al.* (2017), Sauerwein *et al.* (2019)
	Design for biological cycle	Bocken *et al.* (2016), Moreno *et al.* (2016), Franco (2017), Mestre and Cooper (2017), Mendonza *et al.* (2017), Mesa *et al.* (2018), Stewart and Niero (2018), Julianelli *et al.* (2020), Stegmann *et al.* (2020)
	Design for technical/technological cycle	Bocken *et al.* (2016), Moreno *et al.* (2016), Franco (2017), Mestre and Cooper (2017), Mendonza *et al.* (2017), Mesa *et al.* (2018), Stewart and Niero (2018), Julianelli *et al.* (2020)
	Design for entire value chain (circular supply)	Moreno *et al.* (2016), Mestre and Cooper (2017), Sassanelli *et al.* (2020)

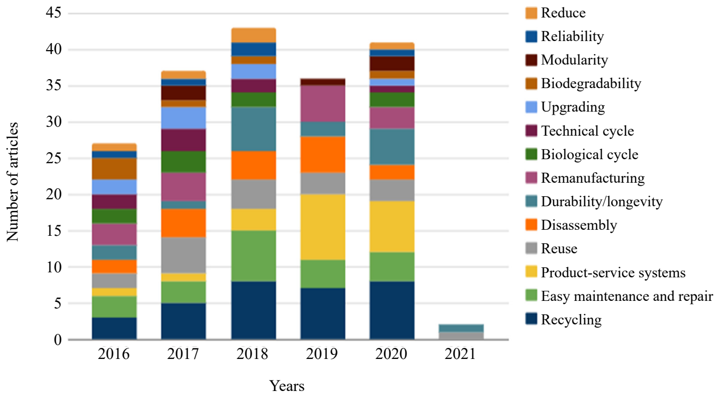

Figure 9.
Circular product design approach per year

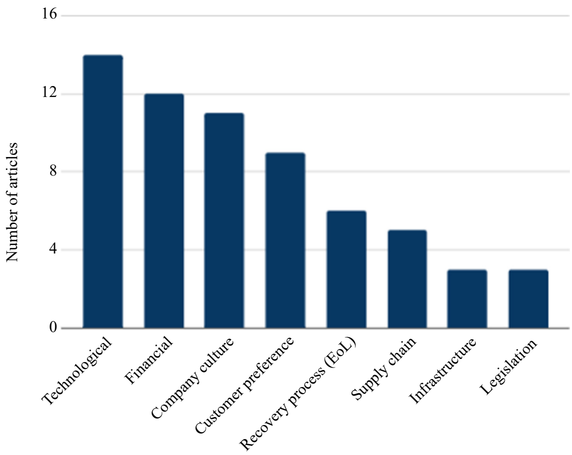

Figure 10.
Most frequent circular product design barriers

"*Method*" consists of research works that propose a methodological contribution to the inclusion of CE principles in the product design process. A method also includes the definition of new indicators, additional design steps, verification checklists and the integration of CAD/CAE technologies to reduce design mistakes and improve the overall quality of products in terms of sustainability. LCA approaches were included in this category. The measurement of impacts from design is a valuable methodological contribution and provides useful feedback for the design process.

"*Model*" comprises research efforts focused on measuring and predicting the behavior of products in terms of financial, environmental and reliability impacts. This can be accomplished by modifying design attributes, such as geometry and materials, or approaching post-design issues, such as reverse supply chains, the behavior of remanufactured products and material recovery.

"*Review*" includes literature analyses oriented to the evolution and future directions of particular topics related to CE. Reviews summarize previous works and facilitate the identification of key research, entailing an initial background to help concentrate future research efforts.

Type of approach	Planning	Concept development	System-level design	Detailed design	Testing and refinement	Production ramp-up
Framework	Sihvonen and Partanen (2016), Den Hollander *et al.* (2017) Mendoza *et al.* (2017), Ackermann (2018), Bressanelli *et al.* (2018), Kane *et al.* (2018) Lin (2018), Sihvonen and Partanen (2018) Sousa-Zomer *et al.* (2018), Sumter *et al.* (2018) Haziri *et al.* (2019), Holtström *et al.* (2019), Ingemarsdotter *et al.* (2019), Jabbour *et al.* (2019), Niu *et al.* (2019), Selvefors *et al.* (2019), Subramanian *et al.* (2019) Tunn *et al.* (2019), Richter *et al.* (2019), Hagejärd *et al.* (2020), Haziri and Sundin (2020), Jabbour *et al.* (2020), Julianelli *et al.* (2020), Stegmann *et al.* (2020), Sumter *et al.* (2020), van der Laan and Aurisicchio (2020), Veelaert *et al.* (2020), Dokter *et al.* (2021), Kravchenko *et al.* (2021), Sumter *et al.* (2021)	Bakker *et al.* (2014), Moreno *et al.* (2016), Niero and Olsen (2016), Sihvonen and Partanen (2016), Singh and Ordoñez (2016), Baxter *et al.* (2017), De los Rios and Charnley (2017), Den Hollander *et al.* (2017), Franco (2017), Mestre and Cooper (2017), Parajuly and Wenzel (2017), Sherwood *et al.* (2017), Ackermann (2018), Bovea *et al.* (2018a), Milios *et al.* (2018), Sihvonen and Partanen (2018), Sousa-Zomer *et al.* (2018) Bech *et al.* (2019), Haziri *et al.* (2019), Jensen *et al.* (2019), Kaddoura *et al.* (2019), Kjaer *et al.* (2019), Kristensen and Remmen (2019), Richter *et al.* (2019), Sauerwein *et al.* (2019), Selvefors *et al.* (2019), Singh *et al.* (2019), Subramanian *et al.* (2019), Urbinati *et al.* (2019), Chen (2020), Cooper *et al.* (2020), Haziri and Sundin (2020), Jugend *et al.* (2020), Julianelli *et al.* (2020), Shahbazi and Jönbrink (2020), Sumter *et al.* (2020), van der Laan and Aurisicchio (2020), Kravchenko *et al.* (2021), Sumter *et al.* (2021)	Whalen and Peck (2014) Moreno *et al.* (2016), Den Hollander *et al.* (2017), Sousa-Zomer *et al.* (2018), Haziri *et al.* (2019), Sauerwein *et al.* (2019), Selvefors *et al.* (2019), Jugend *et al.* (2020)	Whalen and Peck (2014), Niero and Olsen (2016), Hildebrandt *et al.* (2017), Eriksen and Astrup (2019)	Bakker *et al.* (2014), Hildebrandt *et al.* (2017), Bech *et al.* (2019), Kaddoura *et al.* (2019), Niu *et al.* (2019), Richter *et al.* (2019), Urbinati *et al.* (2019), Chen (2020)	Holtström *et al.* (2019), Subramanian *et al.* (2019)

(*continued*)

Table 3. Characterization of the application of research works regarding product development phases in circular product design

Type of approach	Planning	Concept development	System-level design	Detailed design	Testing and refinement	Production ramp-up
Method	Atlason *et al.* (2017) Bovea and Pérez-Belis (2018), Haines-Gadd *et al.* (2018) Sinclair *et al.* (2018) Charnley *et al.* (2019), Halstenberg *et al.* (2019), Alamerew *et al.* (2020) Linder *et al.* (2020), Ingemarsdotter *et al.* (2020), Vihma and Moora (2020)	Bocken *et al.* (2016), Atlason *et al.* (2017) Linder *et al.* (2017), Bovea and Pérez-Belis (2018), Haines-Gadd *et al.* (2018), Sinclair *et al.* (2018), Vanegas *et al.* (2018), Charnley *et al.* (2019), Dobrotă *et al.* (2019), Albæk *et al.* (2020) Kimita *et al.* (2020), Neramballi *et al.* (2020) Asif *et al.* (2021), Boyer *et al.* (2021), Ruiz-Pastor *et al.* (2021)	Bocken *et al.* (2016), Almeida *et al.* (2017), Linder *et al.* (2017), Talens Peiró *et al.* (2017), Bovea and Pérez-Belis (2018), Haines-Gadd *et al.* (2018), Mandolini *et al.* (2018), Mesa *et al.* (2018), Vanegas *et al.* (2018) Cong *et al.* (2019), Favi *et al.* (2019), Ford and Fisher (2019), Albæk *et al.* (2020), Arcos *et al.* (2020), Leal *et al.* (2020), Neramballi *et al.* (2020) Razza *et al.* (2020), Asif *et al.* (2021), Cordella *et al.* (2021), Desing *et al.* (2021)	Sabaghi *et al.* (2016) Almeida *et al.* (2017), Cayzer *et al.* (2017), Lieder *et al.* (2017), Talens Peiró *et al.* (2017), Mandolini *et al.* (2018), Ragaert *et al.* (2018), Belhadj *et al.* (2019), Cong *et al.* (2019), Favi *et al.* (2019) Ford and Fisher (2019), Leissner and Ryan-Fogarty (2019) Koszewska and Bielecki (2020), Leal *et al.* (2020), Mesa *et al.* (2020), Desing *et al.* (2021), Joustra *et al.* (2021)	Sabaghi *et al.* (2016), Cayzer *et al.* (2017), Lieder *et al.* (2017), Bovea *et al.* (2018b), Belhadj *et al.* (2019), Dobrotă *et al.* (2019), Ford and Fisher (2019), Stamminger *et al.* (2020), Joustra *et al.* (2021)	
Model	Franco (2019), Rossi *et al.* (2020)	Franco (2019)		Franco (2019), Martínez *et al.* (2019)	Hannula *et al.* (2018) Ameli *et al.* (2019)	
Review	Stewart and Niero (2018), Wastling *et al.* (2018), Pinheiro *et al.* (2019), Bressanelli *et al.* (2020), Fernandes *et al.* (2020), Flood *et al.* (2020), Parajuly *et al.* (2020), Sassanelli *et al.* (2020), Thompson *et al.* (2020), Diaz *et al.* (2021), van Loon *et al.* (2021), Willskytt (2021)	Stewart and Niero (2018), Wastling *et al.* (2018), Pinheiro *et al.* (2019), Bressanelli *et al.* (2020), Thompson *et al.* (2020), van Loon *et al.* (2021), Willskytt (2021)	Corona *et al.* (2019), van Loon *et al.* (2021)			

Table 3.

Most of the studies in CPD concentrate on the initial phases of the NPD process (planning and concept development). However, few works address the last phase of this process (production ramp-up) (Table 3).

5. Discussion

CPD is an emerging field of research. Articles about it have only been published with any degree of frequency since 2017. This could explain why the majority of studies on CPD are qualitative (Figure 5). The initial concepts of CPD are still are being explored, mainly through case studies and framework proposals. Yet, it can be seen that CPD is being developed as a fundamental means for the adoption of CE.

Europe is currently the main center of studies on CPD, particularly in Sweden, the Netherlands, the United Kingdom and Denmark. Among the most investigated industrial sectors, there is an emphasis on electric, electronic, machinery and equipment. This interest likely occurs because they are highly polluting sectors and therefore harbor potential for CPD approaches, such as designs for reuse, disassembly, remanufacturing, recycling and updating, among others (Bressanelli *et al.*, 2020).

An analysis of the keywords co-occurrences map (Figure 7) reveals that "product design," "circular economy," and "product development" are highlights. The keywords network shows the division of the CPD field into three clusters. The blue cluster concentrates on work oriented to recycling, plastic products (plastic recycling) and waste management design. The green cluster integrates studies on electronic waste, remanufacturing, repair, consumption behavior and PSS; it also shows research related to economic and numerical analysis for decision making in CPD, such as material flow analysis. Finally, design strategies and methods such as ecodesign, product life extension, durability, energy efficiency and LCA are concentrated in the red cluster.

Among the design approaches, the map shows the importance of "recycling". This result is in line with the main design approaches of CPD (Figure 8), in which design for recycling is the approach most mentioned by the studies in the field. Furthermore, the map of keyword co-occurrences highlights those topics such as LCA, climate change and consumer behavior are also related to CPD.

5.1 Design strategies and barriers to adoption

Understanding that the transition from linear to circular models requires the adoption of DfX approaches (Sassanelli *et al.*, 2020), our results advance the knowledge in CE and CPD by presenting those approaches, which are the most researched and possibly more applied. Our findings reveal that design approaches to recycling, easy maintenance and repair, PSSs, reuse, disassembly, durability and remanufacturing are the most discussed in this field.

Design approaches for recycling, reuse, reduce, disassembly, remanufacturing and maintenance are widely addressed by ecodesign (e.g. Van Hemel and Cramer, 2002; Karlsson and Luttropp, 2006), and CPD (e.g. Stewart and Niero, 2018; Sassanelli *et al.*, 2020; Shahbazi and Jönbrink, 2020). Marrucci *et al.* (2020), through an analysis of the retail sector, highlight an alignment between recycling and CE, since, in terms of CO2, recycling returns better results than incineration or disposal in landfill. CPD also frequently proposes designs for the updating, adoption of PSSs and design for multiple use cycles (Sinclair *et al.*, 2018; Selvefors *et al.*, 2019; Sumter *et al.*, 2020). In addition, unlike the ecodesign approach, new approaches are proposed and integrated into the CPD field, such as design for emotional durability, design for fault diagnosis and design for biomimicry (e.g. Moreno *et al.*, 2016; Den Hollander *et al.*, 2017; Sauerwein *et al.*, 2019; Arcos *et al.*, 2020; Sassanelli *et al.*, 2020; Shahbazi and Jönbrink, 2020).

Design for long life (Franco, 2019) and the concern with prolonging the life cycle of products or their components (Mendoza *et al.*, 2017; Sinclair *et al.*, 2018; Kaddoura *et al.*, 2019) are central to CPD and have relevant roles in slowing resource loops (Mendoza *et al.*, 2017). The adoption of these principles, allowing for the prolonged use of products (Halstenberg *et al.*, 2019), includes designs oriented to reuse, maintenance, upgrade, modularity, maintainability and reliability (Ackermann, 2018; Bovea and Pérez-Belis, 2018; Selvefors *et al.*, 2019).

Moreover, the choice of durable materials (Sihvonen and Partanen, 2018) and the emotional durability of products (Den Hollander *et al.*, 2017; Haines-Gadd *et al.*, 2018; Selvefors *et al.*, 2019) are also CPD approaches geared toward extending the lifetime of products. However, the extension of the product life cycle does not always mean less environmental impact. In some cases, trade-offs can occur: between the extension of a life cycle and an environmental impact. Richter *et al.* (2019) addressed these issues by analyzing lamps and freezers. They show how shorter life-span products are more energy efficient.

Other alternatives for prolonging the use of products include the sharing economy (Jabbour *et al.*, 2020; Stegmann *et al.*, 2020), service rental (Stewarta and Niero, 2018) and PSS (Sinclair *et al.*, 2018; Kjaer *et al.*, 2019). These alternatives, involving servitization, often depend on the support of Industry 4.0 technologies, which have already been recommended by a number of CPD studies (Lin, 2018; Halstenberg *et al.*, 2019; Jabbour *et al.*, 2020), including the application of additive manufacturing (Sauerwein *et al.*, 2019) and the development of smart products and services (Halstenberg *et al.*, 2019). The adoption of ecolabels can also contribute to the market demand for circular products (Marrucci *et al.*, 2021b).

Affecting a transition to the CE imposes challenges on companies (Jesus and Mendonça, 2018; Alnajem *et al.*, 2021). The barriers found in this study on CPD were initially aligned with those already found in other CE works (Ritzén and Sandström, 2017; Jesus and Mendonça, 2018; Kirchherr *et al.*, 2018): that is, technological, financial, consumer behavior and organizational barriers that are related to the adoption of the CE as a whole and at its micro-level are also associated with the adoption of CPD.

According to our findings, the main barrier to CPD is related to technological limitations (Holtström *et al.*, 2019; Urbinati *et al.*, 2019). In implementing newer technologies in CPD, it is important to overcome the barriers with emerging technology, especially those related to Industry 4.0 (e.g. Halstenberg *et al.*, 2019; Jensen *et al.*, 2019; Sauerwein *et al.*, 2019; Sinclair *et al.*, 2018). The findings also indicate that the need for high financial investment, especially in technologies, is a relevant barrier towards CPD (Urbinati *et al.*, 2019; Kaddoura *et al.*, 2019).

Consumer behavior was another barrier observed with CPD (Kane *et al.*, 2018; Holtström *et al.*, 2019). Bech *et al.* (2019) have pointed out that the cost of market entry is a barrier. Cong *et al.* (2019) also observed the economic viability of recycling as a barrier to overcome since the low economic return of value recovery affects decisions principally determined during product design processes. Convincing consumers who are not willing to share and buy pre-used products has also been recognized as a challenge to the adoption of CPD (Holtström *et al.*, 2019; Selvefors *et al.*, 2019; Hagejärd *et al.*, 2020).

A company's culture is another relevant barrier since it can make it difficult to adopt financially viable solutions that are aligned with the CE (Kaddoura *et al.*, 2019). In this sense, the transition to CE also depends on human resource management towards an organizational culture aligned with circular business models (Marrucci *et al.*, 2021a).

5.2 CPD and the NPD process

Compared to the phases of the traditional NPD process (Table 3), most studies in CPD are oriented to describing or proposing frameworks. Thus, research efforts have been focused on defining theoretical implications and strategies that include or adopt CE approaches.

Moreover, CPD research has concentrated on the initial phases of the NPD process (especially the planning and development conceptual stages). However, few studies have investigated the relationship between CPD and the "testing and refinement" and "production ramp-up" phases (the final stages of the NPD process). This is understandable since a product would have had to be manufactured and ready to be commercialized. However, it is necessary to investigate how circular products are perceived during the first stage of sales or pre-sales. Indeed, these are issues still to be explored by studies in the area.

Unlike ecodesign, which has already consolidated a wide range of application tools (Byggeth and Hochschorner, 2006; Knight and Jenkins, 2009), CPD research has not developed many new or different tools. The main tool mentioned in the literature is the LCA, which is also well-consolidated in environmental management and ecodesign. However, CPD studies have already presented performance indicators to measure the circularity of new product designs (e.g. Bovea and Pérez-Belis, 2018; Mesa *et al.*, 2018; Mesa *et al.*, 2020). Stewart and Niero (2018) have highlighted the importance of using key performance indicators to provide statistical information, such as the percentage of renewable material used, the percentage of recycled material used, the percentage of weight reduction, the percentage of recyclable products and the number of items collected or recycled. Thus, measuring the level of change to more durable products, modularization, remanufacturing (Saidani *et al.*, 2019), the reuse of components and the design of products with less material could be valuable indicators for CPD (Cayzer *et al.*, 2017).

6. Conclusions

This study aimed to deepen CPD understanding by addressing the current trends, strategies, design approaches, the main challenges to its adoption and its relationship with the phases of NPD. To this end, a systematic literature review was conducted through an initial quantitative investigation and an in-depth qualitative analysis of the 120 studies identified.

The main findings revealed that CPD is a recent research area that is on an upward trend. Furthermore, most of the works analyzed used a qualitative method, indicating that CPD research is currently in an exploratory phase. The main design strategies of the CPD and its evolution over the years could be identified. The results showed at least 14 design approaches that are often applied in CPD (Figure 8); the design for recycling, easy maintenance and repair, and PSS were the top strategies found. Concerning the challenges of CPD, the technological and financial factors were the most prominent. CPD strategies were found to be related to all NPD phases. Nevertheless, the findings demonstrated that the connection between CPD and NPD is mainly set during the initial phases of the NPD process.

6.1 Implications of the study

This research brings practical, theoretical and societal implications. For practice, we present a number of strategies that can be adopted for developing a CPD. In this sense, the framework of design strategies and CPD approaches summarized in Table 2 is a useful guide for practitioners aiming to comprehend possible initiatives for designing products for slowing resource loops, conservating resources and changing systems. In addition, Figure 9 and Table 3 represent substantial contributions for both theory and practice by showing the application of design strategies over the years and those most adopted and by systematizing the references concerning the relationship between CPD and each phase of the NPD process. Thus, this study offers practical insights for managers and designers starting the transition to a circular strategy in their businesses.

Our findings also indicate that the adoption of CPD needs to consider aspects of circularity in the early stages of the NPD, which would require those designers and other professionals involved in product development to acquire abilities and competencies in line with the demands of the CE. Among these skills, it is possible to highlight: (1) environmental impact analysis: designers are required to understand the consequences of selecting materials and designing geometries in terms of energy consumption, carbon footprint emissions and water consumption, among others, during the whole product lifecycle; (2) knowledge on slowing and closing the loop concepts: designers and practitioners need to understand the cycling dynamics of products and what strategy can be applied to each product or component (e.g. reuse, remanufacture, repair and recycle); (3) knowledge of technologies that allow the application of product sharing and PSS: it is also necessary that designers are cognizant with Industry 4.0 technologies and how they can be integrated into CPD, such as 3D printers (additive manufacturing), augmented reality, digitalization and the Internet of things.

In this sense, it is important to continuously prepare designers and managers, whether at universities or in companies, on the need to incorporate CE principles from product design. This preparation necessarily involves knowledge of sustainability and environmental management, new business models, and integration of new technologies (such as those from Industry 4.0) in products and processes.

Additionally, designers should create strong links between users and products to reduce the rapid replacement of products and facilitate useful long product life, even when new product versions can be released. In this respect, it is also important to awaken customer self-consciousness about the environmental impacts of products and global sustainability issues in general. As the results demonstrate, at the societal level, consumer behavior can be a challenge to CPD adoption due to, for example, an unwillingness to share or buy used and remanufactured products. Therefore, cultural changes that build population environmental awareness can be encouraged by public agents and educational institutions.

Technological barriers and the high level of financial investment are also challenges in adopting the CPD. In this sense, strengthening circular and innovation ecosystems could provide support for overcoming these barriers and moving towards business models for a CE. Thus, public policies for innovation and the environment could play a significant role in creating and coordinating the different actors in an ecosystem.

For scholars, this paper systematized the knowledge of an emergent research area and provided several future research directions. We expanded the extant literature in CE and NPD by analyzing the current CPD research landscape, presenting the design strategies that have been investigated and proposed, and the main barriers to the adoption of CPD. Moreover, this study presents new insights on the relationship between the NPD and CPD processes.

6.2 Future research and limitations

From the current literature on CPD, a number of avenues for further research in this field could be presented. Clearly, many proposed design approaches are already well known in the literature, especially those from design for sustainability and ecodesign (reuse, disassembly, remanufacturing and maintenance, for example). Thus, it is important to widen the knowledge of how other design approaches may be integrated into circular business models, such as emotional durability, biomimicry, multiple use cycles, repurposing and upgradability.

The application of the current literature has focused on the planning and concept development stages of the NPD process. However, new useful approaches to cover further stages should be proposed and developed, such as system-level design, detailed design, testing and refinement. Therefore, we suggest that future research should concentrate efforts on other product development stages to facilitate critical tasks such as the selection of materials, the analysis of assembly/disassembly complexity and measurements with respect to potential recycling, repairing, refurbishing and remanufacturing. Moreover, little is still known about how CPD can be adopted in the final stages of the NPD process (production ramp-up, product launch and sales, for example). Thus, more studies could investigate the integration of CPD in the final stages of the NPD process.

In terms of engineering, the articles selected demonstrated an imbalance between a marketing–planning–early definition and geometry–material–performance tasks. Future research directions should compensate for this imbalance by promoting more methodologies, guidelines and approaches oriented to integrating the whole NPD process.

Finally, the limitations of this article need to be addressed. Concerning research methods, the selection of specific keywords and the use of only one database are recognized limitations. In addition, the final samples and the systematization and analysis of the findings required reading and filtering, which may have added a level of subjectivity to the analysis. The fact that the research was completely theoretical and that practical situations of companies were not analyzed is another limitation that must be recognized. Future research could, therefore, continue and advance the theoretical analysis on CPD, as well as following the proposals for additional research as proposed in this paper.

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Appendix

Table A1.
Identified and analyzed articles.

Ackermann (2018)
Alamerew *et al.* (2020)
Albæk *et al.* (2020)
Almeida *et al.* (2017)
Ameli *et al.* (2019)
Arcos *et al.* (2020)
Asif *et al.* (2021)
Atlason *et al.* (2017)
Bakker *et al.* (2014)
Baxter *et al.* (2017)
Bech *et al.* (2019)
Belhadj *et al.* (2019)
Bocken *et al.* (2016)
Bovea *et al.* (2018a)
Bovea *et al.* (2018b)
Bovea and Pérez-Belis (2018)
Boyer *et al.* (2021)
Bressanelli *et al.* (2018)
Bressanelli *et al.* (2020)
Brown *et al.* (2021)
Cayzer *et al.* (2017)
Charnley *et al.* (2019)
Chen (2020)
Cong *et al.* (2019)
Cooper *et al.* (2020)
Cordella *et al.* (2021)
Corona *et al.* (2019)
De los Rios and Charnley (2017)
Den Hollander *et al.* (2017)
Desing *et al.* (2021)
Diaz *et al.* (2021)
Dobrotă *et al.* (2019)
Dokter *et al.* (2021)
Eriksen and Astrup (2019)
Favi *et al.* (2019)
Fernandes *et al.* (2020)
Flood *et al.* (2020)
Ford and Fisher (2019)
Franco (2017)
Franco (2019)
Hagejärd *et al.* (2020)
Haines-Gadd *et al.* (2018)
Halstenberg *et al.* (2019)
Hannula *et al.* (2018)
Haziri *et al.* (2019)
Haziri and Sundin (2020)
Hildebrandt *et al.* (2017)
Holtström *et al.* (2019)
Ingemarsdotter *et al.* (2019)
Ingemarsdotter *et al.* (2020)
Jabbour *et al.* (2019)
Jabbour *et al.* (2020)
Jensen *et al.* (2019)

(*continued*)

Joustra *et al.* (2021)
Jugend *et al.* (2020)
Julianelli *et al.* (2020)
Kaddoura *et al.* (2019)
Kane *et al.* (2018)
Kimita *et al.* (2020)
Kjaer *et al.* (2019)
Koszewska and Bielecki (2020)
Kravchenko *et al.* (2021)
Kristensen and Remmen (2019)
Kwant *et al.* (2021)
Leal *et al.* (2020)
Leissner and Ryan-Fogarty (2019)
Lieder *et al.* (2017)
Lin (2018)
Linder *et al.* (2017)
Linder *et al.* (2020)
Mandolini *et al.* (2018)
Martínez *et al.* (2019)
Mendoza *et al.* (2017)
Mesa *et al.* (2018)
Mesa *et al.* (2020)
Mestre and Cooper (2017)
Milios *et al.* (2018)
Moreno *et al.* (2016)
Neramballi *et al.* (2020)
Niero and Olsen (2016)
Niu *et al.* (2019)
Parajuly *et al.* (2020)
Parajuly and Wenzel (2017)
Pinheiro *et al.* (2019)
Ragaert *et al.* (2018)
Razza *et al.* (2020)
Richter *et al.* (2019)
Rossi *et al.* (2020)
Ruiz-Pastor *et al.* (2021)
Sabaghi *et al.* (2016)
Sassanelli *et al.* (2020)
Sauerwein *et al.* (2019)
Selvefors *et al.* (2019)
Shahbaz and Jönbrink (2020)
Sherwood *et al.* (2017)
Sihvonen and Partanen (2016)
Sihvonen and Partanen (2018)
Sinclair *et al.* (2018)
Singh and Ordoñez (2016)
Singh *et al.* (2019)
Soo *et al.* (2021)
Souza-Zomer *et al.* (2018)
Stamminger *et al.* (2020)
Stegmann *et al.* (2020)
Stewart and Niero (2018)
Sumter *et al.* (2020)
Sumter *et al.* (2018)
Sumter *et al.* (2021)

(*continued*)

Table A1.

Talens Peiró *et al.* (2017)
Thompson *et al.* (2020)
Tunn *et al.* (2019)
Urbinati *et al.* (2019)
van Loon *et al.* (2021)
van der Laan and Aurisicchio (2020)
Vanegas *et al.* (2018)
Veelaert *et al.* (2020)
Vihma and Moora (2020)
Wastling *et al.* (2018)
Whalen and Peck (2014)
Willskytt (2021)

Table A1.

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