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Design and collaboration strategies for circular economy implementation across the value chain

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Abstract

Based on circular economy readiness assessments of six value chain layers, 18 design strategies and five collaboration strategies for circular economy were identified. The design strategies have many applications, from the design of materials, products, and processes to business models, and while some are specific to determined layers, others can be addressed by companies in multiple layers. Furthermore, collaboration across the value chain was found to affect positively the employment of circular economy design strategies, contributing to the fulfilment of solutions' circularity potential.

Keywords: circular economy, design strategy, value chain, collaboration

1. Introduction

Transitioning to a Circular Economy (CE) is a process with several economic, societal, and environmental benefits. CE could unlock $4.5 trillion of economic output (Lacy and Rutqvist, 2015), save material-related costs (up to $700 billion annually in complex industries) (EMF, n.d.), create millions of jobs globally (S4YE, 2021), and contribute to tackling the climate challenge by addressing product manufacturing (EMF, 2019).

Nevertheless, manufacturing companies still struggle to address circularity and to successfully transition to a CE, due to the high complexity of the transition process (Jackson et al., 2014), which is related to changes in business model configurations (Pieroni et al., 2019), product design and development (Bocken et al., 2016), and consumer acceptance (Camacho-Otero et al., 2018), among others.

To address these challenges and enhance the potential success of CE implementation in manufacturing companies, Pigosso and McAloone (2021) developed a CE readiness self-assessment tool to enable the evaluation of the CE readiness of product manufacturers. The CE readiness assessment evaluates the company's ability to take action to transition to CE across several areas, providing a clear identification of strengths and improvement opportunities for the CE transition (Pigosso and McAloone, 2021).

Nonetheless, despite the importance of CE readiness at the company level, the transition to CE can only be achieved as a joint value chain effort (Eisenreich et al., 2022), including both upstream and downstream companies. But despite the high importance of value chain collaboration for CE implementation (Ritzén and Sandström, 2017), the CE readiness of more than 600 companies indicates that less than 15% of the companies have already established key partnerships and/or set strategic collaborations for CE implementation.

To address the value chain complexity in the CE transition, a more comprehensive overview of the CE transition process is needed with a holistic consideration of the readiness of key value chain layers of product manufacturers (i.e., materials providers, component manufacturers, packaging manufacturers, logistic providers, product retailers & wholesalers, maintenance & repair services, and value recovery

companies). Furthermore, the role of each value chain layer in the implementation of circular design strategies should be further addressed for higher value creation (Sumter et al., 2021).
Taking circular readiness assessments as a starting point, this paper explores the role of design strategies for the implementation of CE across six value chain layers, demonstrating the key differences and similarities in circular design strategies across the layers, as well as further exploring how value chain collaboration affects the implementation of CE design strategies.
The next section presents the research methodology for the development of the CE readiness assessments for each value chain layer (Section 2, Research Methodology). Section 3 (Results and Discussion), discloses and discusses the identified design strategies for CE across the six value chain layers, as well as the key findings on the collaboration opportunities across layers. Finally, the key outcomes are summarised in Section 4 (Conclusions and Future Work), along with the highlighted potential for future research.

2. Research methodology

The methodological framework to identify the key aspects and dimensions for evaluating the readiness of companies transitioning to a CE is comprised of two cycles: (1) theoretical development through literature review and (2) empirical evaluation by experts, resulting in the consolidated version of the dimensions and aspects for evaluating CE readiness in each value chain layer (Figure 1).

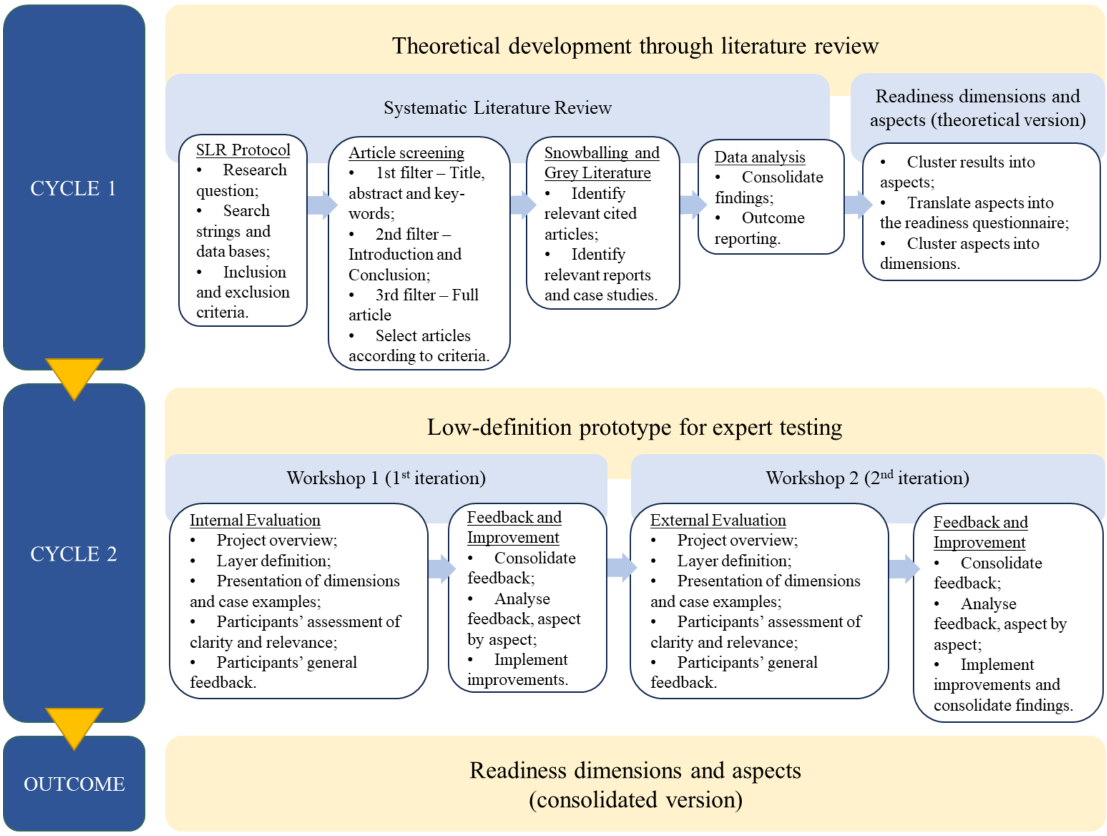

Figure 1. Methodology for consolidating readiness dimensions and aspects for value chain layers

The first cycle starts with a Systematic Literature Review (SLR), based on Kitchenham's (2004) guidelines and following Biolchini et al. (2005) research protocol. The goal of the SLR is to identify the aspects (i.e., critical criteria for the transition to CE) that determine companies' CE readiness for each value chain layer. The selection of search strings and studies are conditioned to the specific value chain layers. Table 1 described the six value chain layers investigated in this research.
The CE readiness aspects resulting from the SLR are then clustered into dimensions (i.e., related themes connected to specific business processes, such as product & service innovation, or life cycle stages, such as repair & maintenance). Furthermore, the aspects are translated into questions to be answered by

companies using a CE readiness scale (Pigosso and McAloone, 2021). The search strings and key data insights related to Cycle 1 for each value chain layer are detailed in Figure 2.

Table 1. Overview of the investigated value chain layers

Value Chain Layer	Short Description
Materials Providers	Companies which mostly focus on sourcing and processing materials, which are provided for the manufacture of components, parts and/or products.
Component Manufacturers	Companies which mostly focus on creating components and sub-assemblies out of materials and smaller components, primarily for sale to and use by manufacturing companies in the manufacture of products.
Product Manufacturers	Companies which mostly focus on creating finished products out of combinations of components, sub-assemblies, and materials to use by final users (incl. other companies, state organisations, or end consumers).
Packaging Manufacturers	Companies which mostly focus on creating and manufacturing primary, secondary and/or tertiary packaging solutions to contain, store, protect and/or promote goods. Packaging Manufacturers may be present across the entire value chain.
Product Retailers & Wholesalers	Companies which mostly focus on sourcing, stocking, and providing finished products and consumer goods to customers (incl. to other companies, governments, or end consumers). Product Retailers and Wholesalers may set the CE requirements in the value chain and promote circular solutions to customers.
Value Recovery Companies	Companies which mostly focus on (1) processing end-of-use products and/or components through remanufacturing, refurbishment, or repurposing; and/or (2) recovering materials from end-of-life products through cascading, recycling, or energy recovery.

	CYCLE 1				
	Theoretical development through literature review				
	Systematic Literature Review			Readiness dimensions & aspects	
Layer	Search String	# of retrieved studies	# of selected studies	# of aspects	# of dimensions
Material Providers	(TITLE-ABS-KEY ("resources flows" OR "materials flow" OR "materials suppliers" OR "materials providers" OR "raw materials") AND TITLE ("circular economy"))	587	16	33	6
Component manufacturers	(TITLE ("circular") AND TITLE-ABS-KEY ("component*" OR "part*" OR "element*" OR "packag*" OR "sub-assemb*" OR "modul*" OR "product*") AND TITLE ("*manufactur*" OR "compan*" OR "suppl*" OR "produc*" OR "provider*" OR "firm*" OR "assembl*" OR "industr*" OR "organi?ation*" OR "entreprise*"	606	69	34	9
Product manufacturers	TITLE (("circular economy" OR circular?) AND (implementation OR transition OR change OR practice OR business OR application OR pursuit OR deployment OR execution))	82	61	25	5
Packaging manufacturers	(TITLE ("circular") AND TITLE-ABS-KEY ("component*" OR "part*" OR "element*" OR "packag*" OR "sub-assemb*" OR "modul*" OR "product*") AND TITLE ("*manufactur*" OR "compan*" OR "suppl*" OR "produc*" OR "provider*" OR "firm*" OR "assembl*" OR "industr*" OR "organi?ation*" OR "entreprise*"	606	69	30	7
Product retailers & wholesalers	TITLE ("circular*") AND TITLE-ABS-KEY ("retail*" OR "wholesal*" OR "store" OR "stores" OR "shop*" OR "outlet*" OR "reseller*" OR "e-commerce" OR "electronic commerce")	298	81	34	8
Value recovery companies	(TITLE-ABS-KEY ("value recovery" OR "waste management" OR "scavengers" OR "waste recovery") AND TITLE ("circular economy"))	361	24	26	7

Figure 2. Cycle 1: detailed figures for the theoretical development of the aspects & dimensions

The second cycle comprises the evaluation of the aspects, questions, and dimensions through two workshops. Both workshops have the same structure, starting with an overview of the project and a presentation of important definitions (e.g., CE and readiness). Next, the dimensions are presented along with case examples that illustrate how the identified aspects are implemented by the investigated value chain layer. The participants assess the clarity, relevance, and completeness of the aspects and examples through online forms that record all answers. During the Internal Evaluation Workshop, the results are assessed by academic experts (i.e., research assistants, PhD and postdoc researchers, and professors) in the Design for Sustainability field. The collected feedback is analysed, aspect by aspect, and changes are implemented. Afterward, the External Evaluation Workshop is carried out with industry experts (professionals working with sustainability and CE, such as designers, quality coordinators, sales managers, heads of sustainability, and C-level executives), representing different companies in the investigated layer. Once again, the feedback is collected, and changes are implemented to guarantee the assessment is clear, relevant, and complete. As a result of the Cycle 2, the CE readiness aspects are defined, including the strategies concerning product and service design, as well as value chain collaboration. Detailed information about Cycle 2 for each value chain layer is presented in Figure 3.

	CYCLE 2			
	Expert testing			
	Workshop 1 (1st iteration)	Workshop 2 (2nd iteration)		
Layer	# of participants	# of participants	# of consolidated aspects	# of consolidated dimensions
Material Providers	11	8	32	6
Component manufacturers	36	5	31	7
Product manufacturers	25	50	25	5
Packaging manufacturers	36	5	31	7
Product retailers & wholesalers	9	9	34	7
Value recovery companies	15	14	26	7

Figure 3. Cycle 2: detailed figures for the empirical testing of the aspects & dimensions

Subsequently, a qualitative comparison of the aspects gathered from the CE readiness assessment of the six value chain layers is carried out for the identification of the CE design strategies (i.e., strategies aiming to slow and/or close resource loops (Bocken et al., 2016)) across the value chain layers. Lastly, the aspects related to the collaboration across value chain layers are further identified and evaluated to assess how the establishment of partnerships and collaborations is perceived across layers, as well as their potential implications on the success of CE design strategies and the transition to CE.

3. Results and discussion

3.1. Design strategies for CE

The design strategies that drive companies towards the CE transition across the six investigated value chain layers are described in Table 2. It is important to notice that the CE design strategies are not restricted to products and services, but also considered relevant for materials, technologies, processes, and business models.

Table 2. Circular Economy design strategies across value chain layers

Layer	Code	Design Strategies	Key Reference
Materials Providers	MP1	***New Materials:*** To develop new materials that can support a higher circularity of products (e.g., less complex materials, materials with improved recyclability and degradability, materials without harmful chemicals)	Stephanopoulos, et al. (2022)
	MP2	***Smart Materials:*** To develop smarter materials that can support higher circularity (e.g., self-healing materials, materials with repairability properties, materials that increase the ease of disassembly and reassembly)	Stephanopoulos, et al. (2022)

Materials Providers	MP3	***Updating Existing Materials:*** To update the portfolio of existing materials in alignment with CE (e.g., integrating recycled content into your materials)	Gaustad et al. (2018)
Component Manufacturers	CM1	***Lifetime Extension:*** To design components for a long life (e.g., design for reuse, design for modularity, design for repair)	Brissaud and Zwolinski (2017)
	CM2	***End-of-Life Strategies:*** To design components considering End-of-Life (e.g., design for recycling, design for disassembly, design for remanufacturing)	den Hollander et al. (2017)
	CM3	***Resource Usage:*** To design components with minimised resource consumption (e.g., design for sharing, design for minimal material usage, design for multifunction)	Gaustad et al. (2018)
	CM4	***Standard Design:*** To design standardised components (e.g., design for multiple Original Equipment Manufacturers, design for standard interface)	Kerwin et al. (2022)
Product Manufacturers	PM1	***Product/Service-Systems:*** To develop Product/Service-Systems (e.g., services supporting the product use, subscription systems, sharing solutions)	Pieroni et al. (2018)
	PM2	***Design for Life Extension:*** To develop products and services considering extended lifetime (e.g., design for maintenance, design for modularity, design for change of spare parts)	den Hollander et al. (2017)
	PM3	***Design for End-of-Life:*** To develop products and services considering End-of-Life (e.g., design for disassembly, design for remanufacturing, design for recycling)	Sundin (2018)
	PM4	***Design for Sharing:*** To develop products and services that can be shared with other users (e.g., design for resource management, design for durability)	den Hollander et al. (2017)
Packaging Manufacturers	PK1	***Multiple Uses:*** To design packaging for multiple uses (e.g., design for reuse, design for refill, design for sharing, design for multifunction)	Foschi and Bonoli (2019)
	PK2	***End-of-life Strategies:*** To design packaging considering their end-of-life (e.g., design for recycling, design for disassembly, design for single-material use)	Foschi and Bonoli (2019)
	PK3	***Logistic Efficiency:*** To design packaging to improve logistics efficiency (e.g., design for weight reduction, design for flexibility, design for modularity)	Gaustad et al. (2018)
	PK4	***Contextual Feasibility:*** To design circular packaging considering its feasibility in the local context (e.g., designing packaging that can be collected and recycled using the existing reverse logistics programmes and recycling facilities, designing packaging using materials that can be processed by the separation technology in place)	Nemat et al. (2019)
Product Retailers & Wholesalers	R&W	***Communication Strategy:*** To develop CE communication strategies using insights from consumer behaviour (e.g., design CE communication strategies according to customer segments, design in-store signs to inform customers about CE initiatives, design communication strategies to enhance customer engagement towards CE)	Fuchs and Hovemann (2022)
Value Recovery Companies	VRC	***Technology and process innovation:*** To develop processes/technologies for value recovery (e.g., design processes/technologies for disassembling, design processes/ technologies for sorting and processing)	Karakutuk, et al. (2021)
Cross-layer	CL	***New Value Proposition:*** To offer value proposition aligned with CE (design Business Model(s) to create, deliver, and capture circular value)	Pieroni et al., 2019

From the six analysed layers, the CE design strategies were clustered according to their similarities, in four design main areas: business model, materials, products & services, and process & technology.

3.1.1. Design of circular business models

The design business models (CL) according to CE principles (eliminate waste and pollution; circulate products and materials; regenerate nature - EMF, 2021b) was found to be relevant across all value chain layers analysed. Companies transitioning to a CE, regardless of their value chain position, should be able to create, deliver and capture circular value; that is, share with all the business ecosystem stakeholders the generated gains and benefits decoupled from resource consumption (Bertassini et al., 2021; Pieroni et al., 2019). Nonetheless, organisations might choose different circular business models (CBM). *Materials Providers*, for example, might choose to offer exclusively renewable materials. Arkema (2023) argues that the design of new materials (e.g., bio-based resins) (MP1) can enable a CBM based upon renewable feedstock. Manufacturers (*Component*, *Product*, *Packaging*) can opt to offer their products as a service, by implementing strategies to extend product lifetime (PM2) and to share products (PM4) (Signify, 2023). Furthermore, *Product Retailers & Wholesalers* can adopt digital CBM (e.g., Levi's Second Hand (n.d.) digital platform that raise consumer awareness (R&W) on circular denim); Additionally, *Value Recovery Companies* might offer sorting services (e.g., Trebo (2022) has developed a technology (VRC) to sort material fractions from complex waste streams). Regardless of the CBM approach, organisational competence to design circular business models is crucial to implement the CE on a micro-level (Lewandowski, 2016).

3.1.2. Design of materials

The design of materials that support a higher circularity across the value chain is a key focus for *Materials Providers*. The choice of materials can affect how easy or difficult it is to remanufacture, recycle, or compost components, products, and packaging (Markevičiūtė and Varžinskas, 2022). Therefore, *Materials Providers* can design new materials that are less complex (e.g., using a single substance) and have improved degradability (MP1), or smart materials that can improve the ease of disassembly (MP2). Moreover, *Materials Providers* can improve the circularity of materials, for instance, by integrating recycled content into materials and by using alloys that can be recycled together (MP3). Natural Cotton Color (2021), for example, phases out toxic elements from cotton fabrics, making the reuse, shredding, and value recovery easier and less cost-intensive.

3.1.3. Design of products & services

The design of products & services within *Component, Product* and *Packaging Manufacturers* involves a number of CE design strategies, such as enhancing the durability of components, products, and packaging. For components and products, it might be beneficial to design for maintenance and repair (CM1, PM2) for instance. As for the packaging, manufacturers can choose to design for multiple uses, such as design for reuse and design for sharing (PK1). These manufacturers can also improve the circularity at the End-of-Life through CE design strategies, such as design components for disassembly (CM2), design products for remanufacturing (PM3), and design packaging for recycling (PK2).
However, circular design strategies, apart from these cases, presented themselves differently from layer to layer, as following described:

- *Component Manufacturers* can design components that enhance the circularity of products during the use phase, for example, designing for minimal energy and water usage (CM3). Moreover, standard design (CM4) can play an important role in the circularity of an entire value chain or product portfolio. Components such as cables, ports and interfaces can have standard designs, increasing their use by several Original Equipment Manufacturers, and making it easier for maintenance providers and end-consumers to find and replace, when needed, only the components, instead of the whole product. In the EU, for example, a new directive establishes that portable electronic devices should have a single charging port (EC, 2021), enforcing standard design on Component Manufacturers in the electronics sector.
- *Product Manufacturers* can design entire products and services to be shared among a variety of users (PM4), as well as design Product/Service-Systems (PSS) (PM1). These design strategies can enhance the use rate of products, reducing resource inefficiency. If aligned with service-based business models, the product ownership relies on the manufacturers, who can combine

other CE design strategies (PM2 and PM3) to improve the products' overall durability and value recovery potential at the end-of-life. Kaer, for instance, offers cooling as a service by designing air conditioning products with extended lifetime and optimised repairability (EMF, 2021a).

- *Packaging Manufactures* also have opportunities to address CE design strategies in the development processes. Designing modular, flexible and lightweight packaging (PM3), for instance, could have a great impact on forward and reverse logistics operations. The Euro Pool System (n.d.) offers reusable, light, and foldable trays to the European fresh supply chain, reducing 86% of the volume in return trips. Furthermore, designing packaging in accordance with the contextual feasibility (PM4) of processes and technologies is essential to guarantee the circularity of resources. For example, a company can design packaging made with materials that can be processed by country's A existing collection and sorting infrastructure, but not by country B. Instead of delivering to country's B market this same packaging, the packaging manufacturer should analyse the existing infrastructure and technology to develop a feasible solution to that context.

This result confirms the importance of looking into how distinct value chain actors pursue the CE transition within their own context so to allow for the development of interventions and recommendations that are both tangible and relatable.

3.1.4. Processes and technology

Products and services designed using CE strategies must be accepted by customers, who should also play a role in the end-of-life strategies (e.g., maintaining, repairing, sorting for waste collection), to continue to fulfil their circularity potential (Chamberlin and Boks, 2018). *Product Retailers & Wholesalers* play an important role in engaging customers in circular behaviours, by designing communication strategies (R&W) that raise customers' awareness concerning the circularity of products, inform customers on how to maintain and extend the durability of products, favour the acceptance of circular products, among others. Nudie Jeans (2023), for example, designs the majority of its communication strategies (displayed in physical stores, labels, website, social media, etc.) promoting and guiding circular behaviour. Furthermore, when products reach end-of-life, *Value Recovery Companies* should be prepared to keep the resources' value at the highest level possible. For that, these organisations should be able to design processes and/or technologies (VRC) to handle different materials, components, products, and packaging, including those that were not designed for CE. *Value Recovery Companies'* efforts might include designing processes for recycling "new" materials (e.g., ReMatch Turf Recycling), designing technology to separate mixed materials (e.g., Trebo), and others.

3.2. The role of collaboration across value chain layers

The employment of CE design strategies is relevant for all value chain layers analysed; however, how do they influence the overall value chain circularity? The CE readiness aspects that address collaboration between value chain actors are described in Table 3.

Looking into the aspects that address the collaboration across the value chain, it can be noted that design activities in the upstream and downstream value chain affect each other, and should be approached as a joint effort, to the largest extent possible. Establishing partnerships across the value chain (VC2) has been indicated as important to enable a circular business across all layers. Partners can boost the market readiness for products and services, share insights and knowledge, and define how design strategies can be pursued collaboratively.

Moreover, by engaging its value chain (VC1), an organisation can set circular procurement requirements, push for circular design strategies among materials providers and packaging manufacturers, or even design together communication strategies to address customers' barriers concerning circular products and services. Fairphone (2023) has engaged its value chain in the CE transition, by establishing material requirements, collaborating with the component manufacturers, encouraging customers to repair products, and supporting the recovery of materials at the end-of-life.

Table 3. Aspects for enhancing collaboration across value chain layers

Layers	Code	Collaboration strategies
Materials Providers Component Manufacturers Product Manufacturers Packaging Manufacturers Product Retailers & Wholesalers Value Recovery Companies	VC1	***Value chain engagement*** To develop upstream and downstream collaboration to allow closed loops (e.g., setting circular procurement requirements, establishing processes to recover post-consumption resources, addressing consumers barriers towards the CE transition)
	VC2	***Partnerships*** To establish partnerships across the value chain to enable a circular business
Materials Providers Component Manufacturers Product Manufacturers Packaging Manufacturers Value Recovery Companies	VC3	***Co-development of solutions*** To establish partnerships to develop circular solutions (e.g., designing materials in collaboration with materials providers and manufacturers, developing takeback systems as a collaboration between manufacturers and waste collectors)
Materials Providers Component Manufacturers Packaging Manufacturers Product Retailers & Wholesalers	VC4	***Transparency*** To share technical data and information across the value chain (e.g., employing supply chain traceability, adopting digital product passports, disclosing clear information to customers
Materials Providers Component Manufacturers Product Manufacturers Packaging Manufacturers	VC5	***Industrial symbiosis*** To participate in industrial symbiosis (e.g., using 3rd parties' waste streams as raw material, providing waste as raw materials to other systems)

With a transparent flow of data and information across the value chain (VC4), organisations can design and develop products together, from material selection, and component and packaging traceability, to product design, retail engagement and value recovery take-back systems. In a collaborative circular value chain, the upstream and downstream stakeholders work towards the same goals, intertwining CE design strategies to fulfil the circular potential of resources (VC3). Moreover, the application design strategies can consider the participation in industrial symbiosis schemes (VC5), by using or providing waste streams from/to other industries as a resource.

4. Conclusion and final remarks

To enable the enhanced readiness of product manufacturers and related value chain layers, this research consolidated 18 design strategies that contribute to enhancing the circularity readiness of companies across six value chain layers. The design strategies are employed across a varied range of application areas, from the design of materials, products and services, processes and technologies, to the development of business models. While some CE design strategies are specific to determined layers (e.g., standard design and logistic efficiency), others might be addressed by companies in multiple layers (e.g., design for lifetime extension and design for end-of-life).

Furthermore, the importance of value chain collaboration to the success of circular initiatives was discussed. A material designed to be circular might not have been recovered at end-of-life due to poor product design, for instance. At each value chain stage, the circularity potential can be hindered or boosted, depending on the lack or presence, respectively, of the ideal CE design strategy. The CE transition of entire value chains requires that stakeholders across layers address the challenges and opportunities of the CE in collaboration. A comprehensive and holistic approach for addressing CE design strategies in the value chain can drive the readiness towards the CE transition.

By tackling the CE readiness and mapping out design strategies for CE across a number of value chain layers, this research contributes to enhancing the theoretical understanding of how CE design should be approached by companies with distinct positions in the value chain. In addition, this research provides practitioners an inspirational path towards circular value chain transition. By identifying and understanding CE design strategies across the value chain, companies can establish collaboration with key partners (e.g., sharing learnings and co-developing solutions) and diversifying their circular solution portfolio, by pursuing opportunities to address layer-specific CE strategies (e.g., tackling circularity in the material, component, product and packaging development and retail and value recovery operations), engaging more and more stakeholders in the CE transition.

Although the focus of the research was the CE design strategies and collaboration across value chain layers, the complete assessments present several aspects that are equally important to develop a CE transition path, including, but not limited to, organisational leadership commitment, CE business strategy, new cost structures and revenue streams, and market readiness. Future research will focus on the development of two additional layers: *Logistic Providers* and *Maintenance & Repair Services*. Moreover, the evaluation of CE readiness at a value chain level will be further explored, to provide collaboration guidance for establishing a network of organisations ready to make the circular transition.

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