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Design for Circular Economy in a Strong Sustainability Paradigm

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Abstract: Given the strategic role of design when addressing societal changes and its prominence in the circular economy (CE) discourse and practice during the past decade, a plethora of tools and methods is nowadays available to support organizations in the transition from a linear model of production to a circular one. The need for an intersection of CE, corporate sustainability, strategic design and strong sustainability is gaining momentum. Considering (a) the critical voices pointing out several limitations to the CE concept, (b) the call for linking CE to a strong sustainability paradigm and (c) the implementation mechanisms for an effective contribution to sustainable development, the focus of this research is to address the gap in CE and circular design frameworks due to missing elements therein for its successful implementation, using a Delphi method approach. Our results strongly suggest that the current CE and circular design concepts and practices are insufficient to meet the challenge of addressing strong sustainability, and new models are needed. To conclude, a new definition of design for CE in a strong sustainability paradigm and a first approach to the main elements of the new model assisted by guiding principles are proposed.

Keywords: circular economy; circular design; strong sustainability; implementation model; principles

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1. Introduction

In March 2022, the European Commission presented a package of proposals within the European Green Deal [1] to make sustainable products the norm, advance circular business models and empower consumers for the green transition [2]. The proposal establishes a framework to set eco-design requirements for specific product groups to significantly improve their circularity, energy performance and other environmental sustainability aspects. It follows the second Circular Economy Action Plan [3], which calls for "a regenerative growth model that gives back to the planet more than it takes, (. . .) keeping resource consumption within planetary boundaries" ([3], p. 2). The circular economy (CE) is considered the economic model that can make a decisive contribution to achieving climate neutrality by 2050 and decoupling economic growth from resource use while ensuring competitiveness and equity in the European Union.

Although loosely defined [4–8], CE is an umbrella concept [9] advocated as a strategy to achieve sustainable development (see, for instance, [10]). In the words of [10], it gives "a clear angle of attack to help solving environmental problems" (p. 55) by acknowledging that in a materially closed system such as the Earth, a linear use of resources ("take-make-use-dispose"), even if directed by efficiency objectives (doing more with less), is unsustainable. In a linear economic system, the depletion of resources (particularly the non-renewable ones) and the generation of waste and emissions will always occur, and environmental

management strategies like eco-efficiency, cleaner production and eco-design fail to address that since most of them focus on "less bad" products [11] and processes, rather than in "transforming products and their associated material flows such that they form a supportive relationship with ecological systems" [12]. In a CE, material flows are made up either of biological materials, which, after being discarded, are available for natural cycles in the biosphere, or of materials designed to circulate within the technosphere [13,14].

For organizations, the CE is a systemic approach to the design of processes, products/services and business models, enabling sustainable economic growth by managing resources more effectively as a result of making the flow of products and materials more circular and reducing and ultimately eliminating waste (adapted from [15]). In a CE, companies need to deliver products, which are intrinsically more durable and that can be reused, repaired, refurbished, remanufactured and recycled [16]. It also asks for offering services that provide the same or improved functionality in a more dematerialized way [17]. Since it is at the design stage that these features are mostly defined [11,18], circular design has become important in the CE debate.

The adoption of circular design by companies can be considered part of corporate sustainability, defined as "an integrated, systemic approach by business that builds, rather than erodes or destroys, economic, social, human and natural capital" ([19] p. 1). This definition places emphasis on businesses operating in a way that benefits the different types of capital rather than reducing the harm they do. This idea is also being advocated by proponents of the CE, as mentioned above. Many authors have noted that corporate sustainability, despite being adopted by an increasing number of companies, has not produced the desired effect in terms of sustainable development [20–22] since the environment continues to decline while millions of people still fall short in social minimum standards, as identified, for instance, within the UN Sustainable Development Goals [23]. More decisive action is required to overcome significant sustainability challenges, such as a climate catastrophe [24,25].

The disconnect between the increasing number of companies claiming to adopt sustainability practices and the continuous degradation in the environment (also noted by [20]) may be explained by the fact that corporate sustainability developmental models are framed around a weak sustainability perspective [22]. According to this view, natural capital can be substituted by human technology and therefore is not important to preserve [26]. A strong sustainability paradigm, on the other hand, conserves the irreplaceable stocks of critical natural capital for the sake of future generations [27]. Natural and human-made capital are complementary, rather than substitutable, in the generation of the physical basis for welfare [28,29]. Several authors argue for the need to align corporate sustainability [28,30], design for sustainability [31] and business model innovation [32] with strong sustainability. However, it is arguable that companies adopting CE principles are inherently aligned with strong sustainability, as the debate around the intersection between these concepts is open [33–35].

Moreover, existing strategies for implementing CE in organizations and value chains are more developed in identifying opportunities and designing new business model concepts, and lack methods and tools for experimenting, testing, and implementing them [36–38].

This paper aims to deal with a complex problem arising from several findings from literature and practice that are further explained in Section 2:

- The CE is expected to deliver an important contribution to sustainable development by decoupling economic growth from environmental degradation and resource exhaustion, but it has limitations, e.g., an increase in transport related to reverse logistics, energy inefficiencies related to prolonging the lifetime of some products, energy-intensive recycling processes, etc.; sufficiency is advocated as required to complement efficiency and circularity in a truly sustainable system, in which growth is in itself arguable.
- Corporate sustainability management has also fallen short in contributing to sustainable development [39], and most corporate management systems and practices are framed around a weak sustainability perspective [22,40,41]. Once CE (and particularly circular design) is embedded in corporate sustainability frameworks, there is a need to ensure that it follows a strong sustainability perspective.
- There is still a gap in CE and circular design frameworks, as they do not include the necessary elements for a successful implementation, let alone in a perspective of strong sustainability.

This research aims at contributing to fill this gap in models that support design for CE in a strong sustainability paradigm by addressing the following research questions:

RQ 1: How can design for CE in a strong sustainability paradigm be defined?

RQ 2: How do CE and strong sustainability relate to each other?

RQ 3: What is the added value of a model that supports companies in the design for CE in a strong sustainability paradigm?

RQ 4: Which are the most important elements of a model of design for CE in a strong sustainability paradigm?

This article builds upon previous research [42], which has shown that several models for sustainability (DfS) supportive models have been developed targeting products, product–service systems and societal developments and that they share common features involving action and decision-making at the strategic, tactical and operational levels. In a review paper, ref. [42] developed an analytical framework to study DfS models, informed by corporate sustainability management and design management theories. This analytical framework has shown to be adequate since it captured most of the studied models' features and also allowed for the understanding of how they varied in the approaches used to put DfS into practice, as well as to identify gaps and common elements. For this reason, the analytical framework (presented in Section 3.2) was used as a departure point for the development of the model of design for CE in a strong sustainability paradigm to be validated in the context of this research.

Positioned at the intersection of CE, corporate sustainability management, strategic design and strong sustainability at the micro level, this paper intends to respond to calls for research [16,43,44] by proposing a model whose objective is to support companies in product, product–service system and business model design for CE in a strong sustainability paradigm. The scope of the model is as follows:

1. It is meant to be applicable to all companies, regardless of their size, type and nature, involved in product, product–service system and business model design;
2. The concept of CE is considered from the perspective of sustainable development and its three concentric, hierarchical dimensions: environmental, social and economic [7,45];
3. The elements of the model should be aligned with corporate sustainability strategies placed on the strong to very strong side of the sustainability spectrum, according to [22];

Figure 1 presents the structure of this paper and the flow of information in relation to the different sections.

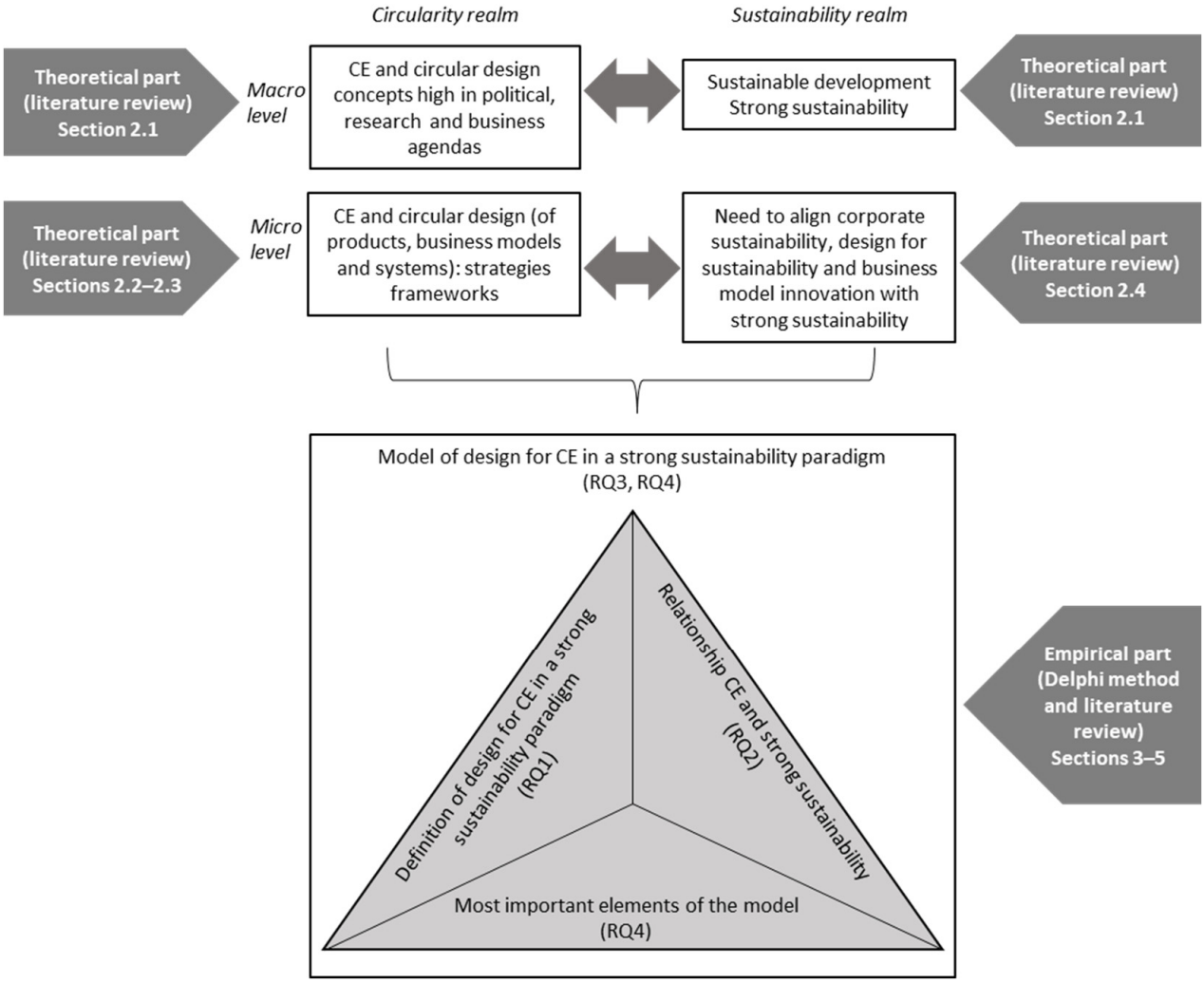


Figure 1. Overview of the structure and flow of information of this paper. The next sections of this article are organized as follows: Section 2 (theoretical background) discusses the concepts of CE and circular design, analyses circular design strategies and existing frameworks to support companies in implementing CE and discusses the need to link CE and circular design to strong sustainability. Section 3 presents the research method and how it was designed to answer the research questions. Section 4 presents the results and discussion: after a description of the sample, Sections 4.2–4.5 provide the results of the work in relation to each of the research questions and a synthesis in Section 4.6. Section 5 responds to the objective of the paper, as enunciated above: a model of design for CE in a strong sustainability paradigm. The article is closed with conclusions and perspectives for future research in Section 6.

2. Theoretical Background

2.1. CE and Circular Design: Concepts and Limitations

The CE offers a fundamental alternative to the still predominating linear take-make-consume-dispose economic model. The linear model assumes that natural resources are available, abundant, easy to source and cheap to dispose of, but there is undeniable evidence of the unsustainability of this way of producing and consuming. On the other hand, the CE is a resource-based [46] operational concept to reconfigure the currently linear system into circular and regenerative socio-economic models.

A CE requires the implementation of three basic principles driven by design [47]:

1. Preserve and enhance natural capital by controlling finite stock and balancing renewable resource flows.
2. Optimise resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles.
3. Foster system effectiveness by revealing and designing out negative externalities.

Different disciplines (such as ecology, economy, engineering, design and business) have contributed to the development of the CE concept [48], resulting in different foci and definitions. The author of [6] analyzed nothing less than a sample of 114 definitions and proposed their own definition, which reads (p. 229)

> "(CE is) an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers."

This definition was presented as an effort to provide a conceptual foundation for future work on CE [6]. Taking it, as well as definitions later published in the literature [46,48–54], an analysis of overarching objectives, CE strategies, identification of enablers and indication of different scales to which CE applies (Table S1) was performed, revealing the diversity of understandings behind this concept. Most of the analyzed definitions place CE in terms of contribution to sustainability (mostly environmental sustainability) and include CE strategies and enabling factors (i.e., indicating not only what CE is but also how to achieve it). The most comprehensive framework of CE strategies is proposed by [55], the so-called 9Rs, including R0 (refuse), R1 (rethink), R2 (reduce), R3 (reuse), R4 (repair), R5 (refurbish), R6 (remanufacture), R7 (repurpose), R8 (recycle) and R9 (recover), in which the highest circularity corresponds to R0 (make the product redundant by abandoning its function or by offering the same function with a radically different product) and the lowest corresponds to R9. In this framework, recycling (i.e., processing materials to obtain the same or lower quality) is close to a linear economy.

Given the limited conceptual grounding of CE [56], there are different views on the relationship between CE and sustainability. While some authors argue that CE is a precondition to sustainable development, since resource use and waste are reduced, others point out that such vision is simplistic and disregards trade-offs that always occur [57] and the social dimension of sustainability [58]. In an extensive literature review, ref. [4] reported views according to which CE is seen as the main solution for a transformation to a sustainable system or at least a necessary, even if not sufficient, condition for sustainability. On the other hand, the same study concluded that CE can also lead to negative outcomes related to technical unfeasibility and the required energy of a closed circle.

When reflecting on the weak relationship between CE and sustainable development, ref. [56] point out that, for instance, industrial symbioses may be sustainable, but (1) they can also lead to locking in unsustainable material systems, such as the network of petrochemical industry infrastructure, (2) the exploitation of the decarbonization potential of CE requires system thinking to avoid shifting emissions from one system to another and (3) a larger use of biological materials to substitute mineral resources can demand water resources beyond sustainable levels of supply.

The CE is seen as an instrument to decouple economic growth from environmental impacts and depletion of resources [47]. The need for decoupling has been pointed out by scientists and policy-makers for many years [59–64], although several authors point out the need to complement efficiency with sufficiency [65]. According to ([8] p. 2), "The question of growth is perhaps the largest elephant in the room for the CE". This is at odds with

the view that a CE leads to a desired growth that comes from "within" by capturing the value in existing economic structures, products, and materials, as advocated by the Ellen MacArthur Foundation [47]. This is contested because indefinite recycling and reuse of resources is not possible, and there is no evidence that CE could lead to absolute decoupling of economic growth from environmental degradation ([66], as quoted by [8]).

2.2. Circular Design Strategies

CE represents a new way of understanding value in the economic system, in which companies deliver products whose value can be maximized over time, which are intrinsically more durable and can be reused, repaired, refurbished and remanufactured, and whose materials can be recycled [67].

It is at the design stage that these features can be mostly defined [11,18]. Designers can create products that are built to last because of their robustness or by creating a symbolic attachment with the user; they can develop modular and standardized products that can be reconfigured to fulfil different functions; they can also design for dis- and reassembly, thus facilitating repair and refurbishment [68,69]. Indeed, circular design has become very important in CE development, not only at the product level but also at the business model (BM) and system levels [70–75]. All these scopes are relevant for positioning the CE as a systemic transformation, and this research is concerned with the role of design in supporting such transformation.

Like what happens with the concept of CE, there is no agreed definition of design for CE, especially when embracing the different scopes, ranging from product to ecosystem design. Most of the existing definitions focus on circular product design [11,68,76]. (Ref. [52] p. 31): "Design for Circular Economy is the design and development of products, services and product–service systems that replaces the conventional end-of-life concept by closing, slowing and narrowing the resource flows in production, distribution and consumption processes. It is enabled by innovation and novel business and organizational models and aims to accomplish sustainable development through supporting of ecosystem functioning and human well-being, and through responsible production and consumption."

The systematization of circular design strategies proposed by several authors (e.g., [16,77]) (Table S2) misses the social dimension of this definition, unlike what happens in the work of [78]; on the other hand, the regeneration of resource loops and the use of information technology as a support strategy (in addition to closing, slowing and narrowing) is included in the work of [77]. Table S2 ([16,77,78]) shows that there are remarkable differences in the degree of development of circular design strategies: the work in this area is more mature for products and business models than for ecosystems; on the other hand, strategies related to closing, slowing and narrowing resource flows are more developed than those related to regeneration of resource flows, which need to be taken into account from a strong sustainability perspective.

2.3. Existing Frameworks to Support Companies in the Transition towards CE

There is a wealth of publications on methodologies and tools to support CE transition, focusing on business models, assessment and metrics, product design and the creation of organizational capabilities such as experimentation, value chain innovation and other human factors [38,79]. For our work, the frameworks of interest are those that support the process of transforming products, services and business models into more circular ones. Therefore, we performed a literature review by using the Web of Science platform and the Google Scholar search engine to find research articles, using the following keywords in various combinations: "circular economy", "circular design", "framework", "method", "tool" and "model". Additionally, we considered the British Standard BS 8001:2017 a guide for implementing circular economy in organizations [15].

As a result, in Table S3, eight different frameworks are described [15,37,77,79–83], illustrating different perspectives that exist and, at the same time, uncovering gaps to be filled in by research.

These frameworks are highly diverse in terms of required effort from companies (from short sessions to complete management systems), activities (from assessment to visioning to full implementation of CE transitioning processes) and focus (products, business models or ecosystem design and innovation, as well as organizational management aligned with CE). They tend to coincide in the adoption of a systemic, multistakeholder approach and in addressing the environmental, social and economic dimensions of sustainability. However, none of these frameworks was developed with the explicit concern of aligning CE with a strong sustainability view, which, in our perspective, is critical to a meaningful contribution to sustainable development, as explained in the following section.

2.4. A Call to Link CE and Circular Design to Strong Sustainability in Corporate Sustainability Management

Ref. [21] notes that although there is an increase in the adoption of sustainability practices by companies, paradoxically, environmental degradation worsens. Ref. [22] built on their work and proposed a new unified model of corporate sustainability stages that draws heavily from ecological economics science. It was used to analyze 22 corporate sustainability, corporate social responsibility, environmental management and sustainable development models at the micro-level, concluding that these are framed around weak sustainability, as opposed to strong sustainability and, according to [22], this provides an explanation to the above-mentioned paradox. The key idea in weak sustainability is that natural capital and other types of capital (e.g., manufactured) are interchangeable, whereas, in strong sustainability, the substitutability of natural capital is severely limited [27,84].

The unified model proposed by [22] is organized into five stages in the sustainability spectrum at the firms' level, ranging from very weak sustainability to very strong sustainability:

- Stage 1 (very weak sustainability): Compliance—firms are defensive and react to external demands, such as regulation.
- Stage 2 (weak sustainability): Business-centred—firms adopt sustainability initiatives for the business case, exploit nature for industrial gain and are technocentric; this stage is growth- and consumption-oriented; sustainability is understood to mean "less bad".
- Stage 3 (intermediate sustainability): Systemic—adopts an environmental, economic and social perspective of sustainability; views businesses as part of a larger industry and community and pursues systemic change but continues to seek increased growth, production and consumption; sustainability is understood as doing "more good".
- Stage 4 (strong sustainability): Regenerative—looks beyond growth and consumption, seeks no increase in scale, integrates environmental and ecological science, and acknowledges limits. It seeks to repair the damage of the industrial consumer economy with activities such as restoring and regenerating nature, reconciliation of species, repair of the commons and creating diversity.
- Stage 5 (very strong sustainability): Coevolutionary—adopts a view of "participating" cooperatively in the symbiosis and self-management of consumption and use of resources. For businesses, this means adopting an ecological science-based view in which there are planetary boundaries, a view of interdependency and the pursuit of a steady state with limited or no quantitative growth. Business becomes a fertilizer for life. Landrum did not find any micro-level model that corresponds to this stage but states that it is critical to addressing the paradox.

Given the objectives of the present research, it is worthy to reflect on the positioning of CE principles and practices across the sustainability spectrum, considering the understanding and frameworks presented in Section 2.2 and 2.3. This is presented in Table 1, indicating that there is a closer alignment with features of the systemic stage (intermediate sustainability).

Table 1. Characteristics of the CE when compared to Landrum's [22] unified model of stages of corporate sustainability.

	Descriptors of the Stages of Corporate Sustainability [22]				
	Orientation	**Understanding of Sustainability**	**Relationship to Natural World**	**Economic Growth**	**Sustainability Concerns**
CE features (own evaluation following Landrum's description [22])	Economic science, business oriented.	"Do more good". Business is part of a larger industry and community working together towards systemic change.	Part of the natural world, operate within planetary boundaries, manage and repair.	Pursuit of production, consumption and growth.	May focus on one or more realms of sustainability (economic, environmental, social) rather than the three of them.
Classification (highest level according to Landrum's description [22])	Systemic (intermediate sustainability)	Systemic (intermediate sustainability)	Regenerative (strong sustainability)	Systemic (intermediate sustainability)	Business-centred (weak sustainability)

Given the multitude of CE discourses [8], for this analysis, we took the most "advanced" views of CE as displayed in Table S1. We can conclude that CE is better positioned in the sustainability spectrum than the models analyzed by [22] (something that the author acknowledges, p. 303), although, in our analysis, it does not fulfil all the requirements of strong (let alone very strong) sustainability stages. The authors of [85] concur as they state that even if CE shares principles with strong sustainability, the latter is not evident in the existing CE frameworks; it needs to be clear that businesses are subject to the irreversible, hierarchical relationships between the environment, society and economy of the strong sustainability model.

3. Research Method and Design

3.1. The Delphi Method

The Delphi method is a systematic, interactive tool defined as "... a method for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" ([86] p. 3). Via a programme of sequential individual questionnaires (rounds) intermixed with information and feedback derived from the previous phases [87], the same experts assess the same matters towards the collective build-up of informed conclusions [49]. It is well suited to the present research, given its complexity and transdisciplinary character.

The method has four characteristic features: (i) anonymity, (ii) iteration with controlled feedback, (iii) statistical group response, and (iv) expert input [88].

The limitations of the method include the fact that it aggregates subjective input, lacks a conventionally agreed design and can raise concerns as for the choice of experts, questionnaires building and consensus nudging [49]. In the following subsections, the methodological choices to address such limitations are presented.

3.2. Panel Composition

According to [89], there is no standard when it comes to the size of the panel of experts, but panels typically fall between 10 and 100 experts and consist of either two or three expert groups, depending on stakeholders' interest in the subject of the research. In this case, the experts were required to have a diverse background and a good understanding of CE and (strong) sustainability at the organization's level. The criteria for selecting the members of the panel are presented in Table 2.

Table 2. Identification of experts for the panel.

Types of Stakeholders	Criteria for Identifying Panel Members
Academia	• Identified in CE, circular design and/or (strong) sustainability literature. • Participants in scholarly events on the above-mentioned subjects. • Snowball identification.
Business, NGO's and public administration	• Participants in workshops on CE, circular design and/or sustainability, including those organized within the KATCH_e project. [1] • Snowball identification.

[1] KATCH_e: Knowledge Alliance on Product–Service Development towards Circular Economy and Sustainability in Higher Education (project n° 575793-EPP-1-2016-1-PT-EPPKA2-KA). (www.katche.eu accessed on 29 October 2023).

3.3. Delphi Design

The Delphi method normally follows four distinct phases [86]:

1. Exploration of the subject, wherein each expert contributes with additional information they find pertinent to the issue.
2. Reaching an understanding of how the group views the issue.
3. If there is a significant disagreement, explore that disagreement to bring out the underlying reasons for the differences and evaluate them, if possible.
4. A final evaluation is when all previously gathered information has been analyzed, and the evaluations have been fed back for consideration.

Figure 2 displays the Delphi process used in the research.

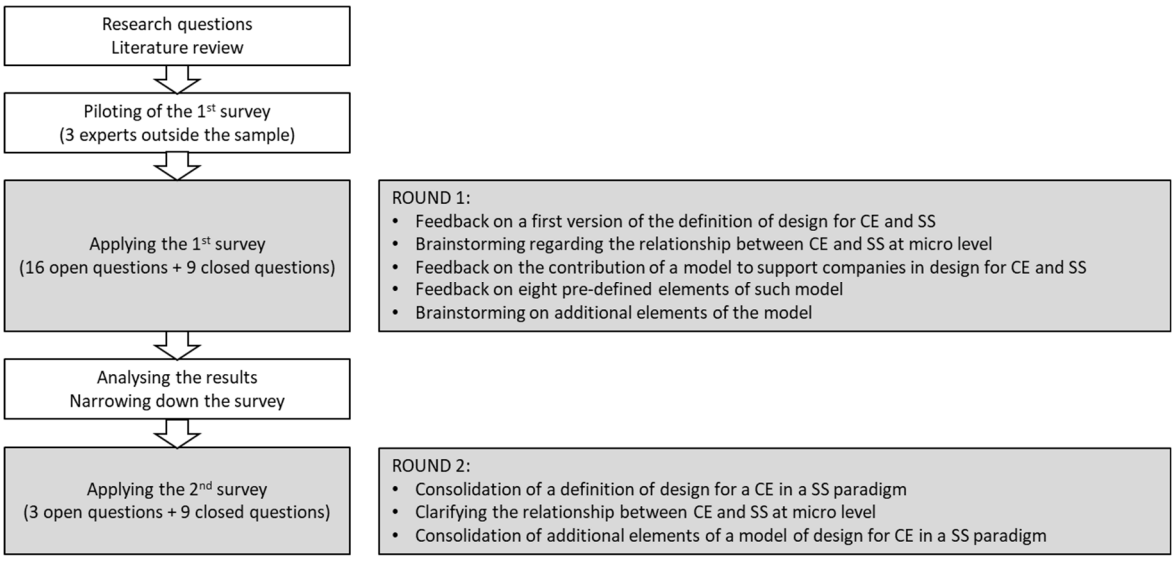


Figure 2. Overview of the Delphi process used in the present research.

Before the first round, a literature review of the subjects pertinent to the research questions was conducted (Section 2). Then, the first round was defined (Table 3), and the first survey was tested by three experts outside the panel.

Table 3. Organization of the Delphi questionnaire (1st round) and justification.

Part	Justification
1. Definition of design for circular economy and strong sustainability (version 1)	Attempt to capture the relationship between design, circular economy and strong sustainability in a definition that can provide a sound framework for the model (RQ 1).
2. Circular economy and strong sustainability	Identification of features that are aligned and conflict between the two concepts (RQ 2), given the lack of consensus in the literature regarding the contribution of circular economy to sustainable development, especially from a strong sustainability point of view.
3. Contributions of the model	Understanding the added value of a model that supports companies in the design for CE in a strong sustainability paradigm (RQ 3), given the existence of circular economy and circular design frameworks, as well as design for sustainability frameworks [42].
4. Elements of the model	The aim was to gather the experts' views on the relevance of a preselected set of elements that are present in most design for sustainability models [42] in the context of circular economy and strong sustainability. Such elements were organized into three levels: strategic, tactical and operational. In addition, the experts were given the opportunity of identifying any missing element at the three levels (RQ 4).

In the first round, the following definition of *design for the CE and strong sustainability* was presented to the experts (adapted from [52]), which was the basis for the first part of the questionnaire:

> *Design of products, product–service systems and business models that create positive, environmental, social and economic value and contribute to a society operating within the planetary boundaries, while promoting social well-being and equity.*
>
> *This is accomplished through closing, narrowing, slowing and regenerating resource flows in production, distribution and consumption processes, extracting the highest value and usefulness of materials, equipment and goods for the longest possible time, in cycles energised by renewable or otherwise sustainable energy sources, with a systemic view.*

Part 4 of the questionnaire consists of the eight elements of design for sustainability models that resulted from the literature review undertaken by [42], presented in Figure 3.

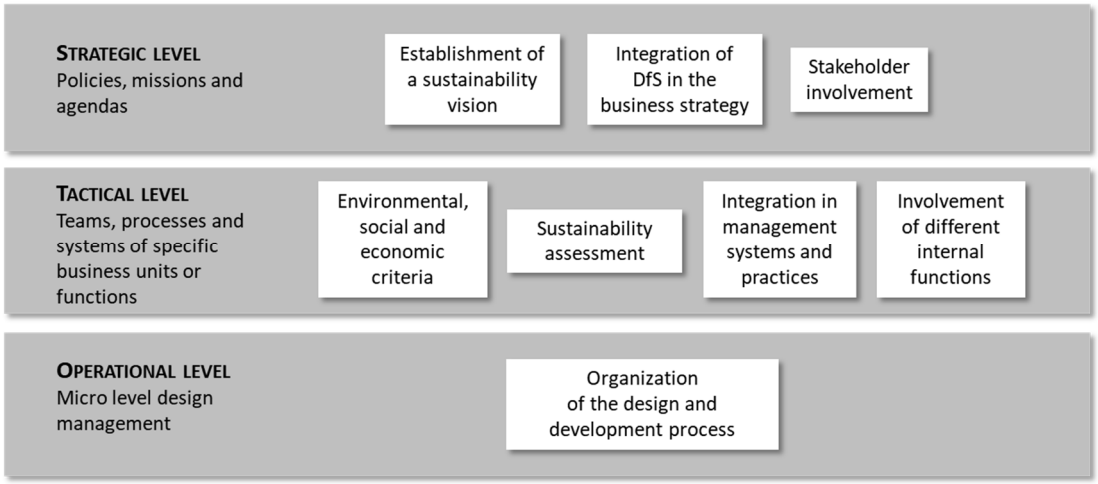


Figure 3. Analytical framework applied to DfS models (adapted from [42]), used as a basis for the development of the new model.

After the analysis of the first round's responses (which provided an overview of experts' opinions on the main subjects), a second questionnaire was developed, checking back and ranking findings. Only two rounds were considered necessary (the recommended number is two or three, according to [90]), as it was assumed that further rounds would not enhance the results and could have fatigued participants and caused them to withdraw. The questionnaires of rounds 1 and 2 are available in Supplementary Material S4 and Supplementary Material S5, respectively.

3.4. Data Collection and Analysis

The questionnaires were developed and answered using the free version of the *SurveyHero* (www.surveyhero.com accessed on 11 April 2022) software. The statistical analysis of the quantitative answers included the calculation of mean, median, standard deviation, inter-quartile range (IQR), and Kendall's W. This research is focused on gathering knowledge and reaching consensus, and therefore the following assessment metrics were used to ascertain consensus [49]:

- Over 50% agreement within two categories on a five-point Likert scale.
- Mean item ranking, share (%) of experts placing an item in the top half of their list, and Kendall's W (see Table 4).
- Measures to quantify the amount of variation of dispersion. The authors of [49] noted that different authors recommend different analyses and thus used the mean, the median, the IQR and the standard deviation in their work; such procedure was replicated here. A low standard deviation of 1.64 is proposed by some authors, whereas others consider 1.5. An IQR of around 1 indicates agreement, and larger values indicate less agreement.

Table 4. Kendall's concordance degree scale [91].

W	Interpretation
0	No agreement
0.10	Weak agreement
0.30	Moderate agreement
0.60	Strong agreement
1	Perfect agreement

4. Results and Discussion

4.1. Description of the Sample

Of the 44 questionnaires sent, 17 were completely answered in the first round, which corresponds to a 39% response rate, in line with the typical value of 40% [92]; 15 experts within this group answered the questionnaire of the second round (88% response rate, well above the minimum of 70% recommended by [93]).

One of the advantages of Delphi is that there are no limits to the geographic coverage. In this case, it was only possible to obtain answers from Europe and North America (with a total of seven countries, Figure 4), although invitations were also sent to experts from Brazil, China, South Africa and Australia, seeking broader coverage. Ideally, the geographical coverage should be better distributed, given the prevalence of Portuguese and Danish experts in the sample, but this is not expected to have a significant impact on the results, given that the knowledge about CE and strong sustainability is not context-dependent.

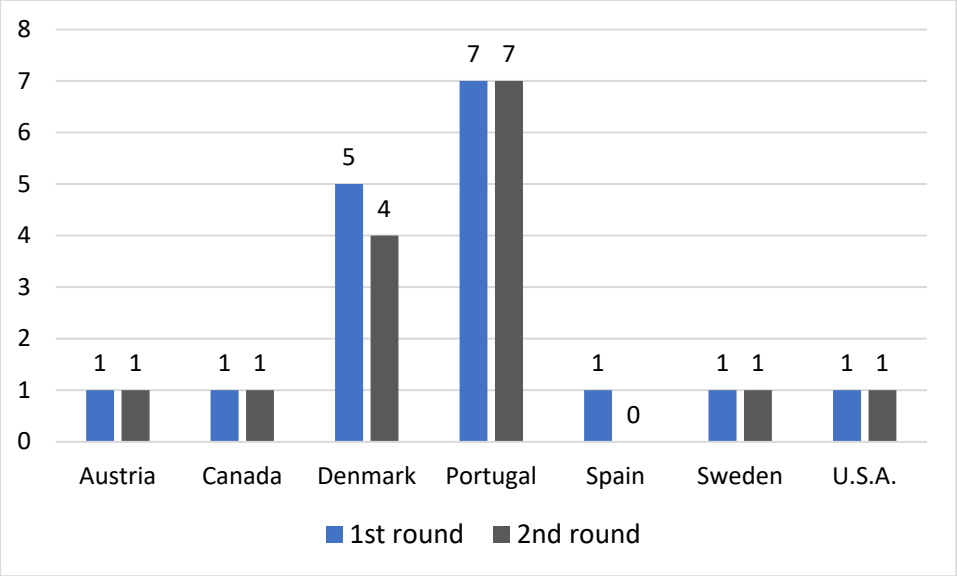


Figure 4. Geographic distribution of the respondents per round (total number).

The participants of the different organizations (Figure 5) self-defined their areas of expertise to enable an accurate panel categorization (Figure 6).

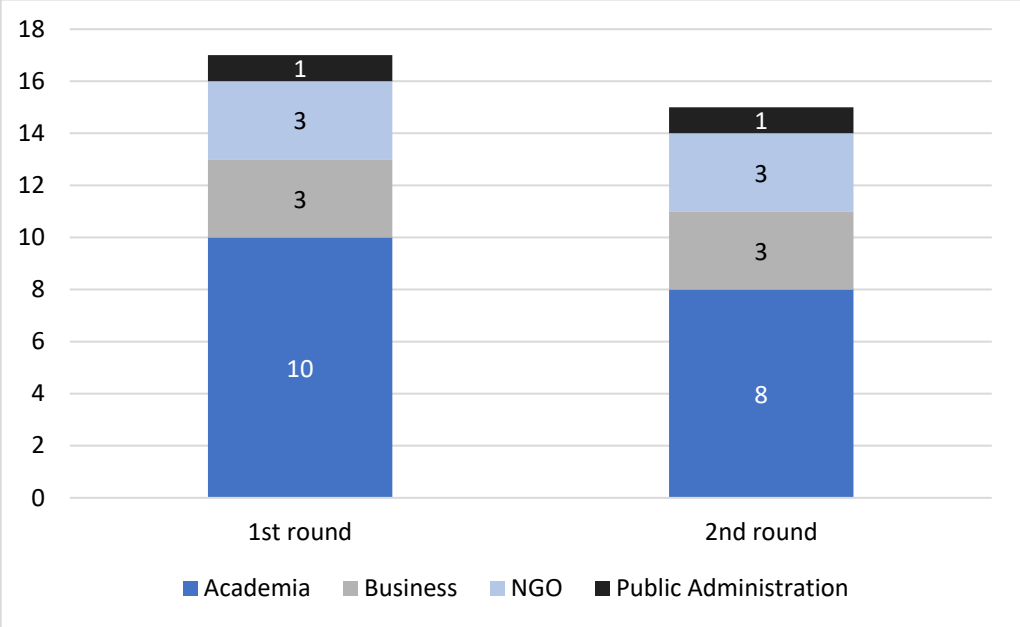


Figure 5. Type of organization of the respondents per round (total number).

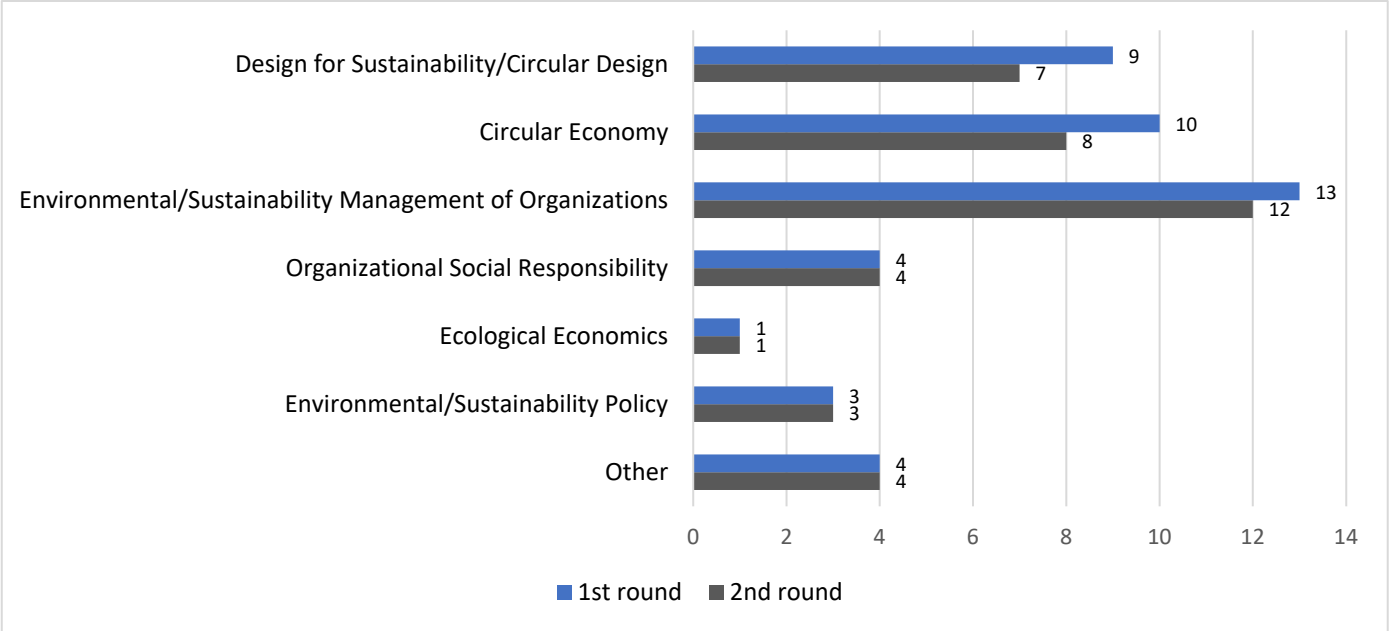


Figure 6. Areas of expertise indicated by respondents per round (multiple choice).

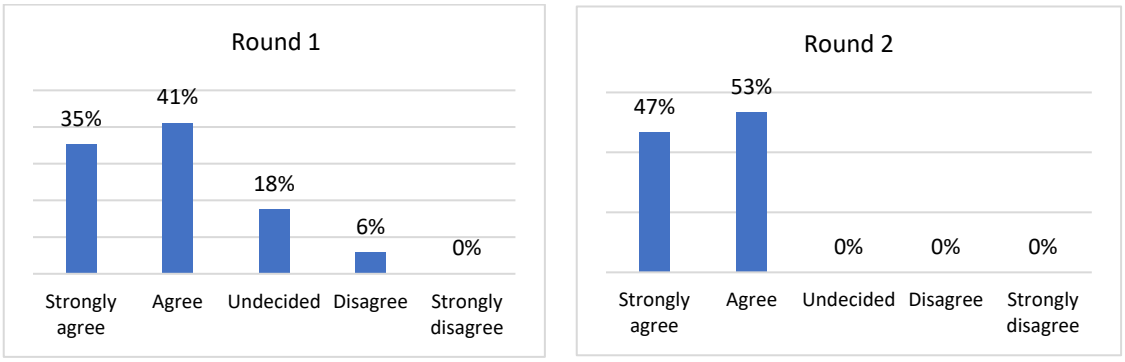
4.2. Definition of Design for CE in a Strong Sustainability Paradigm

Following the definition of design for CE and strong sustainability, as described in Section 3.3, Figure 7a and Table 5 show that the level of agreement with the proposed definition was good, but respondents indicated the following reasons for not (strongly) agreeing with it:

- On a more fundamental level, there was criticism regarding the concept itself: the relationship between CE and strong sustainability (as one expert put it, "what is to be included in the 'and'?").
- Other points of criticism concerned the issue of the creation of positive environmental, social and economic value: one expert considered that whether humans can have a positive environmental impact depends on the baseline and that the environmental impacts are captured by the condition of "operating within the planetary boundaries", whereas another expert pointed that according to the strong sustainability view, protection of human health and the environment are goals; keeping economy as a goal could lead to less protection (sub-optimization) from a human health and nature protection perspective. Furthermore, it was noticed that in the second paragraph of the definition the social dimension of sustainability was missing.
- Some respondents expressed concerns about the need to focus on regenerating systems and not only resource flows and emphasized the shift from non-renewable to renewable resources.

Table 5. Statistical analysis of the level of agreement of respondents to the proposed definitions of design for CE and strong sustainability/in a strong sustainability paradigm in the first and the second rounds.

	Round 1	**Round 2**
Mean	4.06	4.47
Median	4	4
Standard deviation	0.90	0.52
Inter-quartile range	1.0	1.0
	76%	100%



(**a**) (**b**)

Figure 7. Level of agreement of respondents to the proposed definitions of design for CE and strong sustainability/in a strong sustainability paradigm in the first (**a**) and the second (**b**) rounds.

An attempt was made to address all these concerns and suggestions, and thus the following definition of *design for CE in a strong sustainability paradigm* was presented in the second round of the Delphi method:

> *Design of products, product–service systems, business models and production-consumption systems that contribute to a society that thrives within the planetary boundaries, while stimulating social well-being and equity.*
>
> *This is accomplished through the following:*

- *Closing, narrowing and slowing resource flows and regenerating natural systems in production, distribution, consumption and post-consumption processes in cycles energized by renewable sources;*
- *Retaining and creating the highest value and usefulness of materials, equipment and goods for the longest possible time, preferably at the local human scale;*
- *Contributing to a social foundation of well-being derived from stakeholders' needs and expectations and internationally agreed social standards.*

The statistical analysis of the results from round 2 (Figure 7a,b, and Table 5) shows an improvement in the level of agreement when compared to the first round, with 100% of respondents agreeing within the top two categories on the five-point Likert scale.

These results indicate that experts agreed with the second version of the definition, which is an advancement on the conceptualization of the link between design, CE and strong sustainability and provides the foundations for the development of the model. The definition shares several elements with the concept of circular design:

- Moving away from a product-focused approach towards a business model and a system approach [11,68,94];
- Closing, narrowing, slowing and regenerating resource flows [16,77];
- Creating and retaining value [68].

The agreed definition, however, introduces new elements that reflect a more mature understanding of circular design and the challenge of pursuing a "strong sustainability paradigm":

- The idea that design should support a thriving and inclusive society functioning within planetary boundaries;
- Favouring a local human scale as opposed to a global scale;
- The consideration of the needs and expectations of stakeholders.

These aspects are at the core of the discussion around CE and sustainability and are further discussed in Section 4.3.

4.3. Relationship between CE and Strong Sustainability

Although the questions concerning definitional aspects were expected to shed light on the relationship between CE and strong sustainability, experts were directly inquired about such a relationship, with the aim of guiding the development of the model. In the first round, respondents were asked to openly state features of both concepts that are aligned and features that are conflicting. All experts responded with a minimum of one and a maximum of three features. After analysis and elimination of redundancies, a list of 10 potential alignments and 10 potential conflicts was elaborated, which respondents were asked to rank in the second round (Tables 6 and 7).

Table 6. Potential alignments between CE and strong sustainability, in order of ranking (from higher to lower rank).

Potential Alignments between CE and Strong Sustainability
Attempt to stay within planetary boundaries;
Reduced consumption of virgin feedstock by keeping resources in closed loops;
Positive environmental value via strengthening ecological regeneration;
Preserving the value of products, materials and resources as long as possible;
Shift to renewable energy;
Degrowth;
Resource efficiency;
Job creation and social sustainability;
Shift to renewable materials;
Sustaining capital stocks over time.

Note: The cells in grey indicate that the feature scored above the average.

Table 7. Potential conflicts between CE and strong sustainability, in order of ranking (from higher to lower rank).

Potential Conflicts between CE and Strong Sustainability
CE is still focused on creating economic benefits and business opportunities. As such, it does not provide much incentive to invest in nature conservation without a business model.
CE does not imply acting in nested circles: business (and economic activity) fully within social, then all within environmental limits, whereas this is required in strong sustainability.
CE does not necessarily include the social sustainability dimension.
Increased circularity does not necessarily lead to a decrease in global environmental impacts. And even if a decrease in impacts is achieved, it may not be rapid enough to meet global goals.
The CE features do not necessarily recognize that there are critical natural capital stocks that need to be safeguarded and that there are limits to the substitution of capital.
CE is not addressing a radical change in consumption patterns, which is required for strong sustainability.
CE still promotes GDP growth.
With a higher resource efficiency resulting from CE, rebound effects can occur, which will lead to an even higher resource use.
Circularity might entail keeping toxic substances in the loop.
The energy needed for the closing loops is not always included in CE approaches.

Note: The cells in grey indicate that the feature scored above the average.

Figures 8 and 9 present the results of the ranking of potential alignments and conflicts between CE and strong sustainability (the theoretical interval ranges from 150 to 15) and the average value (67.5). The statistical analysis of these answers is given in Tables 8 and 9.

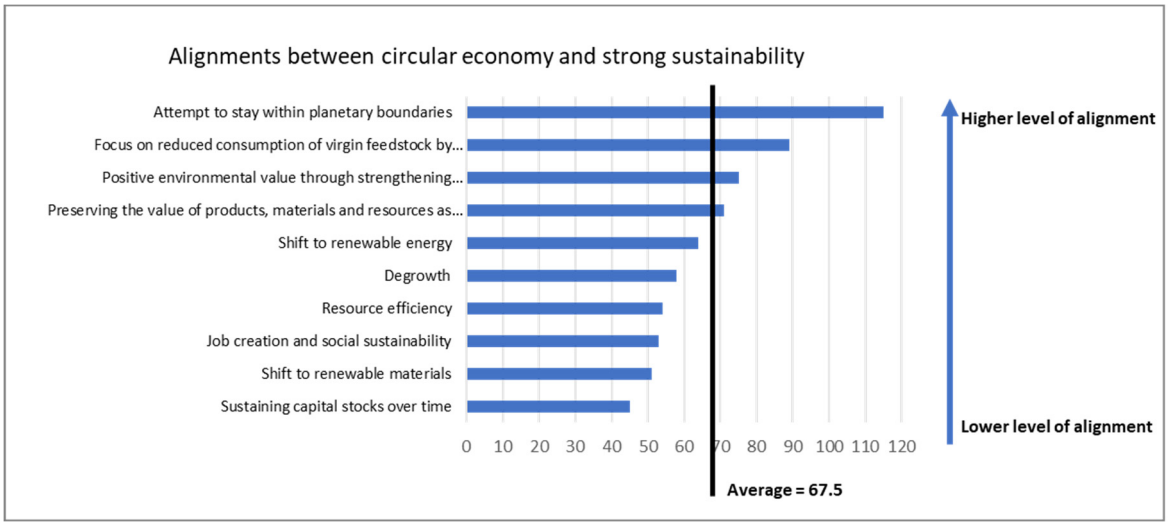


Figure 8. Results of the ranking of potential alignments between CE and strong sustainability (second round).

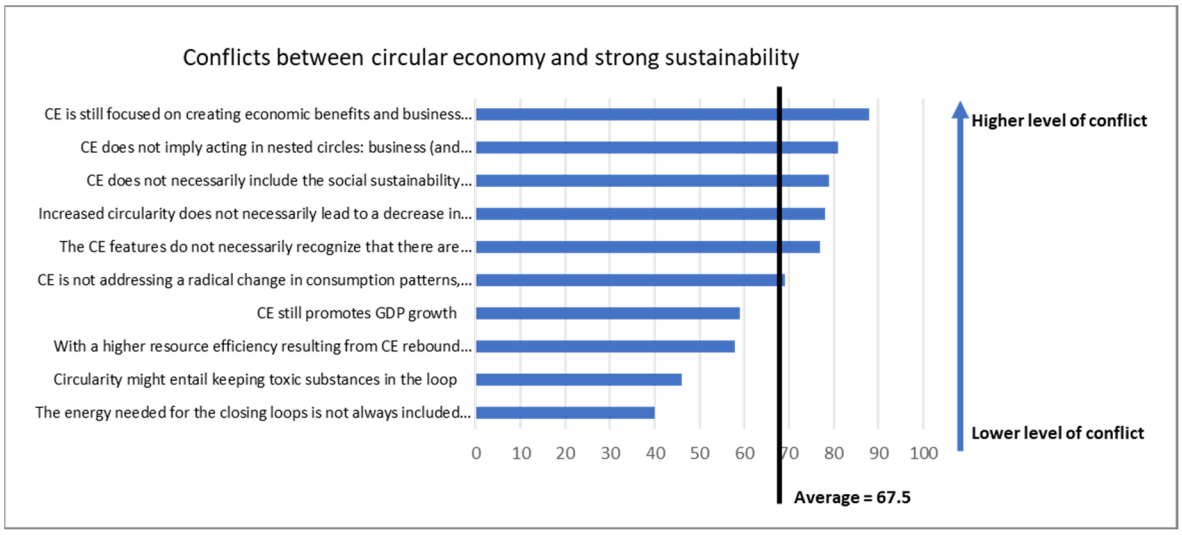


Figure 9. Results of the ranking of potential conflicts between CE and strong sustainability (second round).

Given the low level of agreement between experts regarding the questions of alignment and conflict between CE and strong sustainability, on a second step, we limited a statistical analysis to the features that scored above average, i.e., those in grey in Tables 6 and 7; for that end, we redefined the scoring (from 1 to 4 in the case of the four alignments and from 1 to 6 in the case of the six conflicts, respecting the ranking that had been awarded by the experts). We observed that the level of agreement regarding the alignments increased, reaching the "moderate agreement" level (Table 10), but as for the conflicts between CE and strong sustainability, the level of agreement decreased (Table 11).

Table 8. Potential alignments between CE and strong sustainability (second round).

Alignments Ranking [a]	Mean	Median	% [b]	Standard Deviation	Inter-Quartile Range	Kendall's W
Attempt to stay within planetary boundaries	8.67	10	87%	2.41	1.50	0.22
Reduced consumption of virgin feedstock by keeping resources in closed loops	6.93	7	80%	2.28	3.00	
Positive environmental value via strengthening ecological regeneration	6.00	6	53%	2.67	2.50	
Preserving the value of products, materials and resources as long as possible	5.73	6	60%	2.02	2.50	
Shift to renewable energy	5.27	6	60%	2.99	4.50	
Degrowth	4.87	3	47%	3.56	6.50	
Resource efficiency	4.60	4	33%	3.11	5.50	
Job creation and social sustainability	4.53	4	27%	2.13	2.00	
Shift to renewable materials	4.40	4	27%	1.92	3.00	
Sustaining capital stocks over time	4.00	4	27%	2.70	4.00	

[a] from higher to lower in average. [b] % of experts placing an item in the top half of their list.

Table 9. Potential conflicts between CE and strong sustainability (second round).

Conflicts Ranking [a]	Mean	Median	% [b]	Standard Deviation	Inter-Quartile Range	Kendall's W
CE is still focused on creating economic benefits and business opportunities. As such, it does not provide much incentive to invest in nature conservation without a business model.	6.87	8	67%	2.56	4	0.12
CE does not imply acting in nested circles, i.e., the business (and economic activity) fully embedded in society and both within environmental limits, whereas this is required in strong sustainability.	6.40	7	53%	3.50	6	
CE does not necessarily include the social sustainability dimension.	6.27	6	67%	2.63	3	
Increased circularity does not necessarily lead to a decrease in global environmental impacts. And even if a decrease in impacts is achieved, it may not be rapid enough to meet global goals.	6.20	7	67%	2.83	5	
The CE features do not necessarily recognize that there are critical natural capital stocks that need to be safeguarded and that there are limits to the substitution of capitals.	6.13	7	67%	2.92	4	
CE is not addressing a radical change in consumption patterns, which is required for strong sustainability.	5.60	6	60%	2.72	4	
CE still promotes GDP growth.	4.93	4	33%	2.96	5	
With a higher resource efficiency resulting from CE, rebound effects can occur, which will lead to even higher resource use.	4.87	5	33%	2.07	2.5	
Circularity might entail keeping toxic substances in the loop.	4.07	2	27%	3.13	5	
The energy needed for the closing loops is not always included in CE approaches.	3.67	3	20%	2.19	3.5	

[a] from higher to lower in average. [b] % of experts placing an item in the top half of their list.

Table 10. Statistical analysis of the potential alignments between CE and strong sustainability, limited to the items that scored above average (second round).

Alignments Ranking [a]	Mean	Median	Standard Deviation	Inter-Quartile Range	Kendall's W
Attempt to stay within planetary boundaries.	3.47	4	1.06	0.5	0.33
Reduced consumption of virgin feedstock by keeping resources in closed loops.	2.47	3	0.99	1.0	
Positive environmental value via strengthening ecological regeneration.	2.40	3	1.06	1.5	
Preserving the value of products, materials and resources as long as possible.	1.67	2	0.62	1.0	

[a] from higher to lower in average.

Table 11. Statistical analysis of the potential conflicts between CE and strong sustainability, limited to the items that scored above average (second round).

Conflicts Ranking	Mean	Median	Standard Deviation	Inter-Quartile Range	Kendall's W
CE is still focused on creating economic benefits and business opportunities. As such, it does not provide much incentive to invest in nature conservation without a business model.	4.00	4	1.56	1.5	0.03
CE does not imply acting in nested circles, i.e., the business (and economic activity) fully embedded in society and both within environmental limits, whereas this is required in strong sustainability.	3.67	4	2.13	4	
CE does not necessarily include the social sustainability dimension.	3.47	3	1.88	3	
Increased circularity does not necessarily lead to a decrease in global environmental impacts. And even if a decrease in impacts is achieved, it may not be rapid enough to meet global goals.	3.40	3	1.68	2	
The CE features do not necessarily recognize that there are critical natural capital stocks that need to be safeguarded and that there are limits to the substitution of capitals.	3.53	4	1.55	2.5	
CE is not addressing a radical change in consumption patterns, which is required for strong sustainability.	2.93	3	1.53	1.5	

These results must be carefully analyzed due to the lack of consensus on the conflicts between CE and strong sustainability, but it is worthwhile to contrast them with the literature that deals with the relationship between the two concepts.

- CE and natural capital: whereas experts considered that both CE and strong sustainability aim at a society that operates within the planetary boundaries (corroborated by [35]), some agreed that the CE does not imply that there are severe limits to the substitution of natural capital. According to a strong sustainability view, human activities should integrate the nature-given, non-negotiable, physical and environmental restrictions. The society is organized along normative definitions, within which the economy is organized, understood as a constellation of actors and entities providing goods and services for the society. The deductive approach implies that economic actors have to operate within the environmental constraints [46];

- CE within a business case logic: experts stressed that the CE is focused on economic benefits and business opportunities; the business case for sustainability has been criticized since it represents a weak sustainability worldview [41], as it derives from a win-win paradigm, where the business case should achieve economic, environmental and social sustainability goals simultaneously. Given the complex nature of sustainable development, ref. [95] argue that this is rarely the case and corresponds to a simplistic view in which trade-offs between the three sustainability dimensions are ignored;
- CE and the social dimension of sustainability: it is unclear how CE might affect inequality, power relations in value chains, roles and rights of consumers, users and citizens and the distribution of resources and exploitation of labour [35];
- CE and environmental impacts at a global level: there are several arguments questioning the effective contribution of CE to reducing the negative environmental impacts at a global level [96], including Jevon's paradox: an improved efficiency in raw materials use delivered by the CE will lower the prices and result in increased demand (see for instance [46,97]). Therefore, there is a need to complement the efficiency and effectiveness delivered by the CE with sufficiency (next bullet);
- CE and the need for a radical change in consumption patterns: Respondents expressed concern about the consumption side of CE, which has been under-researched [98], and the need to address sufficiency and counter the current patterns of consumption. Several authors back up this view [99–101]. Referring to the famous IPAT equation (I (Impact) = P (Population) × A (Affluence) × T (Technology)) [101,102] show that "although population and technological advances can prove to be very helpful in achieving sustainable development, they are not sufficient in themselves if the biocapacity consumed per capita (i.e., total consumption) is not addressed" (p. 10), and the CE tends to concentrate in technological improvements [35].

Given the support for the views expressed by the experts during the Delphi exercise found in the literature, those views will be considered in the development of the model (see Section 5).

4.4. Contribution to a Model of Design for CE in a Strong Sustainability Paradigm and Recommendations

In the first round, experts answered an open question about the potential contribution of a model to support companies in developing products, product–service systems, and business models following CE and strong sustainability principles, aiming at understanding the potential added value they attributed to such model; in addition, respondents were asked what would be required (i.e., which were their recommendations) for this added-value to be accomplished.

Out of the 17 experts, only 12 replied to these questions, and all stated potential contributions to be expected from the model. These can be grouped according to four topics; the most mentioned one (5 answers) is related to translating higher level, strong sustainability and CE principles into actionable guidance/design criteria. Experts also mentioned the benefits to the environment and society, including decarbonization of the economy, job creation, less resource use, etc. Two experts proposed that the model should cope with the challenge of promoting strong sustainability in the context of the current economic system that still favours unsustainable businesses, although they recognize that contextual factors such as legislation are a necessary element in the whole picture. And finally, there were answers related to benefits at the procedural level, such as the standardization of concepts and processes, as well as the capability to monitor the progress.

Table 12 presents these results, as well as the recommendations that respondents formulated in relation to the contributions they identified.

Table 12. Contribution from and recommendations to a model of design for CE in a strong sustainability paradigm.

Contribution—Aggregated Topics	Number of Answers	Recommendations: The Model Should...
Translating higher-level, strong sustainability and CE principles into actionable guidance/design criteria	5	...include specific, measurable steps; ...be developed with a bottom-up approach, using case studies; ...include life cycle thinking.
Benefits to the environment and society	3	...promote systems thinking; ...include co-creation and involvement of all stakeholders and actors; ...be flexible to respond to the evolution of needs; ...be adjusted to the local conditions.
Coping with the challenge of aligning strong sustainability with the current economic system, which does not favour that	2	...provide for the development of business models that incorporate an understanding of ecological value beyond financial value; ...include the notion that the growth of the firm should be deliberately limited; ...should start by addressing full sustainability and then make use of circularity.
Benefits at the procedural level	2	...include representative and easy-to-assess monitoring indicators; ...have specific moments of verification, validation and adjustment in view of the constant evolution of needs.

Two experts made a comment saying that without knowing more about the model, they were not able to contribute to this part of the questionnaire, which was a valid point. We decided to record the answers received, and thoroughly consider them in the development of the model but closed these questions after round one.

4.5. Elements of the Model

In the first round, experts rated the importance of the different elements displayed in Figure 2 using a 5-point Likert scale. The results in Table 13 show that there was consensus in scoring all elements as important or very important (scores 4 and 5 on the scale, respectively) and given the high level of agreement, the related questions were closed in round 1.

An open question regarding missing elements was also posed in the first round and scored by the respondents in round 2, using the same 5-point Likert scale. The results are given in Table 14.

Although experts considered that these elements were missing from the list used in the first round of the Delphi survey, in fact, their proposals (all of which meet the consensus criterion) complement or deepen what was already included in the model (with one exception) as shown in Table 15.

Table 13. Importance of pre-defined elements of a model of design for CE in a strong sustainability paradigm, distinguishing the strategic, tactical and operational levels of design management in a company.

Pre-Defined Elements of the Model [a]	Mean	Median	Standard Deviation	Inter-Quartile Range	% Likert Scale 4–5 Consensus $\geq$ 51%
Alignment of the business strategy with the vision (strategic) (see next point)	4.76	5	0.44	0	100%
Establishment of a vision for CE and strong sustainability to which the company contributes (strategic)	4.71	5	0.47	1	100%
Integration of design for CE and strong sustainability in management systems and practices (environment, quality, social responsibility, others) (tactical)	4.65	5	0.61	1	94%
Involvement of different internal functions within a company in the design process (tactical)	4.65	5	0.61	1	94%
Stakeholder involvement in establishing the vision, co-development of circular and sustainable solutions, and sustainability assessment (strategic)	4.59	5	0.62	1	94%
Circular and sustainable design strategies and criteria covering environmental, social and economic dimensions (tactical)	4.53	5	0.72	1	88%
Organization of the design and development process for products, product–service systems and business models (operational)	4.47	5	0.72	1	88%
Sustainability and circularity assessment with a life cycle perspective (tactical)	4.35	5	0.79	1	82%

[a] from higher to lower in average.

Table 14. Importance of additional elements of the model, proposed by the experts in round 1.

Additional Elements of the Model [a]	Mean	Median	Standard Deviation	Inter-Quartile Range	% Likert Scale 4–5 Consensus $\geq$ 51%
Translating higher-level goals and principles of CE in a strong sustainability paradigm into design criteria	4.80	5	0.41	0	100%
Understanding how the products, product–service systems and business models of the organization interact with the wider socio-ecological system they are part of	4.67	5	0.49	1	100%
Establishing partnerships with stakeholders to jointly develop products, product–service systems, and business models aligned with CE and strong sustainability principles	4.40	5	0.74	1	87%
Inclusion of user and consumption perspectives into design processes to integrate them into circular and sustainable solutions principles	4.27	4	0.88	1	87%
Articulation between different individual projects (products, product–service systems, business models) and assessment of how they are interconnected at the company level	3.80	4	0.68	1	67%

[a] from higher to lower in average.

Table 15. Takeaways from the experts' proposals regarding additional elements of the model.

Proposed Additional Element of the Model	Predefined Element(s) it Relates to	Takeaways from the Experts' Proposals
• Translating higher-level goals and principles of CE in a strong sustainability paradigm into design criteria.	• Establishment of a vision for CE and strong sustainability to which the company contributes (strategic); • Circular and sustainable design strategies and criteria covering environmental, social and economic dimensions (tactical).	• The model should include not only a vision and goals but also principles; • The model should include mechanisms to transform aspirational goals into concrete design criteria.
• Understanding how the products, product–service systems and business models of the organization interact with the wider socio-ecological system they are part of.	• Establishment of a vision for CE and strong sustainability to which the company contributes (strategic); • Sustainability assessment (tactical).	• Explicitly include an analysis step required to establish a vision of CE and strong sustainability (strategic level), as well as a review to assess if the vision is being implemented.
• Establishing partnerships with stakeholders to jointly develop products, product–service systems, and business models aligned with CE and strong sustainability principles.	• Stakeholder involvement in establishing the vision, co-development of circular and sustainable solutions, and sustainability assessment (strategic).	• The proposed additional element is very similar to the predefined one.
• Inclusion of user and consumption perspectives into design processes to integrate them into circular and sustainable solutions principles.	• The same as above.	• Unlike the previous additional element, this one applies specifically to users and consumers and may imply changing consumption patterns.
• Articulation between different individual projects (products, product–service systems, business models) and assessment of how they are interconnected at the company level.	• New element.	• It can be interpreted as understanding the way new business model development (wider scope) influences the design of product–service systems and of physical products (stricter scope) and vice versa, and assess their articulation

4.6. Synthesis

In order to develop the model, it was deemed necessary to develop a definition of design for CE in a strong sustainability paradigm model (RQ1) and consensus among experts was achieved, with a good level of agreement around the definition proposed in the second round of the Delphi research. Despite this convergence, the identification of the elements of alignment and conflict between CE and strong sustainability (RQ2) proved more difficult since experts did not reach a consensus regarding the conflicts between both concepts. Nonetheless, their observations were supported by the literature and therefore considered in the development of the model and the drafting of principles included therein.

The experts that participated In "he r'search found that the most important added value of the model (RQ3) is to translate higher level, strong sustainability and CE principles into actionable guidance/design criteria.

And finally, the findings related to RQ4 have shown which are the elements of a model for the implementation of design for circular economy in a strong sustainability paradigm, with a high degree of consensus, at strategic, tactical and operational levels.

5. A Model of Design for CE in a Strong Sustainability Paradigm

The results achieved with this research indicate that the design of products, product–service systems and business models for CE in a strong sustainability paradigm requires the adoption of principles that should inform companies' practices, particularly the implementation of design strategies and criteria. In order to comply with a strong sustainability view, such principles should lead to a paradigm change as opposed to incremental efficiency improvements, which implies a long-term planning period [103].

This research indicated the need to add several aspects to existing CE principles (presented in Section 2.1) to comply with a strong sustainability model. They are derived from the agreed definition of design for CE in a strong sustainability paradigm, the experts' opinions regarding the alignments and conflicts between CE and strong sustainability and the suggestion of translating higher-level goals and principles of CE in a strong sustainability paradigm into design criteria, even though there was no specific question in the Delphi survey to this regard.

Thus, we propose a new framing for existing CE principles, as proposed by [47], and the inclusion of additional principles, as follows:

Overarching principle: Function within planet boundaries, set up science-based goals and seek a positive environmental impact at the system level when

- Preserving and enhancing natural capital by controlling finite stocks and balancing renewable resource flows;
- Optimising resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles;
- Fostering system effectiveness by revealing and designing out negative externalities;
- Developing circular business models oriented to nature conservation;
- Deliberately limiting the growth in production and consumption via innovative business models and influencing consumer practices towards sufficiency;
- Giving priority to the local human scale and shorter circular value chains;
- Stimulating social well-being by linking circular solutions to stakeholders' needs and expectations and agreed social standards (e.g., the Sustainable Development Goals).

As for the elements of the model, the results also indicate that these are adequately organized at strategic, tactical and operational levels. Furthermore, although the model is targeting individual companies, the systemic nature of CE requires cooperation and co-creation within the value network, considering and positively influencing the environmental, social and economic implications at the system level. Correspondingly, the model encompasses three dimensions, as shown in Figure 10:

- Complexity: paradigm change and practice change (inspired by [51]);
- Organizational levels: strategic, tactical and operational [42];
- Organizational width (inspired by [51]): a single company and the value network, understood as a network of interlinked value chains and interested parties [104].

Table 16 shows how the elements of the model relate to the three dimensions, and Figure 10 illustrates the concept of the proposed model operating within the principles.

The elements of the model may be explained as follows (the numbering of the bullets corresponds to the one on the table):

(1) Establishing a vision for CE and strong sustainability, to which the company contributes via its business strategy, with a long-term perspective.
(2) Understanding how the products, PSS and BM interact with the wider ecological, social and economic system.
(3) Integration of the principles of CE in a strong sustainability paradigm in the business strategy at the highest level; this implies questioning the social function of the company in a sustainable society.
(4) Adopting design strategies and criteria aligned with the principles. This implies a hierarchical approach considering giving priority to use- and result-oriented strategies, offering products as services, over the product-oriented strategies (see point 9).

(5) Involving the different internal functions and the external stakeholders, including the value network and user and consumer perspectives.
(6) Articulation between different individual projects and how they are interconnected at the company level.
(7) Sustainability assessment of individual projects and their interconnection at the company level.
(8) Integration of the model with existing management systems and practices to ensure the continuity, review and improvement of its implementation.
(9) Structuring the design and development (D&D) process to meet the remaining elements of the model, i.e., the definition of the goals, steps, responsibilities, authority and assessment criteria. It should include an explicit initial activity of questioning the function, or the need, that the product or product–service combination should fulfil.

Figure 10 presents an overview of the model informed by the principles of CE in an SS paradigm.

When compared with the initial framework (Figure 3), this model presents similar elements. Nevertheless, it is worthy to note the following:

- The strategic sustainability assessment (new element) helps companies to understand how their products, PSS and BM contribute to the sustainability vision and respond to a specific recommendation rated as very important by experts in the Delphi survey;
- A second new element, also considered important, is the articulation of projects at the company level to ensure an integrated approach and the alignment of the overall business strategy with the vision and principles;
- The stakeholder involvement element of the previous model is now consubstantiated in specific activities of co-design of products, PSS and BM;

As stated, all elements are informed by the proposed principles of CE in a strong sustainability paradigm, which is perhaps the most important feature that responds to the need to explicitly align design models and frameworks with strong sustainability.

Principles of CE in a SS paradigm

Function within planet boundaries, set up science-based goals and seek a positive environmental impact, when:

1. **Preserving and enhancing natural capital by controlling finite stock and balancing renewable resource flows.**
2. **Optimising resource yields by circulating products, components and materials in use at the highest utility at all times in both technical and biological cycles.**
3. **Fostering system effectiveness by revealing and designing out negative externalities.**
4. **Developing circular business models oriented to ecological regeneration.**
5. **Deliberately limiting the growth in production, through innovative BM and influencing consumer practices towards sufficiency.**
6. **Giving priority to the local human scale and shorter circular value chains.**
7. **Stimulating social well-being by linking circular solutions to stakeholders needs and expectations and agreed social standards (e.g., the Sustainable Development Goals).**

Dimensions / Elements of the model	Complexity		Levels			Width	
	Paradigm change	Practice change	Strategic	Tactical	Operational	Individual	Value network
Vision	✓		✓			✓	✓
Strategic sustainability assessment		✓	✓			✓	✓
Integration in business strategy	✓		✓			✓	✓
Design strategies and criteria	✓			✓		✓	✓
Co-design of products, PSS and BM		✓	✓	✓	✓	✓	✓
Articulation of projects at company level	✓		✓			✓	
Tactical sustainability assessment		✓		✓		✓	✓
Integration in m'gmt systems and practices		✓	✓	✓	✓	✓	✓
Organization of the D&D process		✓			✓	✓	

Figure 10. A model of design for the CE in a strong sustainability paradigm.

Table 16. Elements of a model of design for CE in a strong sustainability paradigm.

Dimensions	Complexity		Levels			Width	
Elements of the Model	**Paradigm Change**	**Practice Change**	**Strategic**	**Tactical**	**Operational**	**Individual**	**Value Network**
Vision (1)	✓		✓			✓	✓
Strategic sustainability assessment (2)		✓	✓			✓	✓
Integration in business strategy (3)	✓		✓			✓	✓
Design strategies and criteria (4)	✓			✓		✓	✓
Co-design of products, PSS and BM (5)		✓	✓	✓	✓	✓	✓
Articulation of projects at the company level (6)	✓		✓			✓	
Tactical sustainability assessment (7)		✓		✓		✓	✓
Integration in mgmt systems and practices (8)		✓	✓	✓	✓	✓	✓
Organization of the D&D process (9)		✓			✓	✓	

6. Conclusions and Perspectives for Future Research

There is a shift both in research and in policy development areas towards adopting strong sustainability as opposed to a weak sustainability paradigm [33,105]. This research addresses this trend by contributing to the conceptual development of circular design as well as to its practice within a framework of strong sustainability, and therefore attempting to overcome recognized limitations in the current predominant CE and circular design discourses. A more radical approach is deemed necessary when new research recently published in the journal *Science Advances* shows that six of the nine planetary boundaries are transgressed, suggesting that Earth is now well outside of the safe operating space for humanity to strive [106].

The objective and research questions of this work were dealt with via input from a group of experts obtained using the Delphi method. Although several measures were taken to avoid biases, the limitations of this method still condition our results since a Delphi study is highly contextual and difficult to replicate [49].

From a conceptual point of view, it should be highlighted that experts agreed on a new definition of design for CE in a strong sustainability paradigm and identified features that are aligned between the two concepts (CE and strong sustainability). The identification of conflicting features has proved more controversial since no consensus was reached and should be the subject of further research.

From a practical perspective, our research resulted in a new model of design for CE in a strong sustainability paradigm. The advantage of this model, when compared to existing approaches, is two-fold: (a) informed by a new set of strong sustainability-related principles that add to existing CE principles, it is expected to provide a sounder framework for companies and their value networks to develop products, product–service systems and business models that ultimately preserve and regenerate the planet and contribute to a social foundation of well-being; and (b) provides management elements that address different degrees of complexity, organizational levels and organizational width, thus attempting to tackle a gap in many CE and circular design approaches found in the literature that lack guidance on how to manage the implementation of visions and strategies.

The link between circular design and strong sustainability at the micro level, both from conceptual and practical perspectives, constitutes the novelty of this research. It should be noted that the results presented here were obtained via a consultation process of a relatively small number of experts, which constitutes a limitation of this work. Thus, as for prospects of future research, they include the further specification and testing of the model and its guiding principles in practical applications, considering multiple dimensions: their effectiveness in achieving the desired outcomes in specific organizational and value network contexts, enablers and obstacles, and success and unsuccess factors.

Furthermore, it would be interesting to study how the proposed model can be integrated into overall organizational management models, such as the European Foundation for Quality Management (EFQM) Model. Based on the link between organizations' purpose and strategy, the EFQM 2020 version is aligned with the United Nations Sustainable Development Goals and calls for effective leadership in order to understand and adopt the excellence principles in the long term with a view to future requirements, deliver performance and manage transformation, focusing on the 'ecosystem' in which the organization operates and delivering outstanding results [107,108]. It is, therefore, an interesting model whose links to the one presented in this article seem worthy of study.

Another trend that is relevant for the application of the model proposed in this article is Industry 5.0, a value-oriented, human-centred industry [109] with the aim of achieving sustainable and resilient systems [110]. The role of the model in pursuing Industry 5.0 is also an avenue for further research.

Finally, it would be important to assess the sustainability impacts of the development of products, product–service systems and business models according to the proposed model, using the Planetary Boundaries as an environmental sustainability reference [111,112] to ascertain its value in delivering sustainable solutions.

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