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Review

Design of Consumables in a Resource-Efficient Economy—A Literature Review

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Abstract: Consumable products have received less attention in the circular economy (CE), particularly in regard to the design of resource-efficient products. This literature review investigates the extent to which existing design guidelines for resource-efficient products are applicable to consumables. This analysis is divided into two parts. The first investigates the extent to which general product-design guidelines (i.e., applicable to both durables and consumables) are applicable to consumables. This analysis also scrutinizes the type of recommendations presented by the ecodesign and circular product design, to investigate the novel aspects of the CE in product design. The second analysis examines the type of design considerations the literature on product-type specific design guidelines recommends for specific consumables and whether such guidelines are transferable. The analysis of general guidelines showed that, although guidelines are intended to be general and applicable to many types of products, their applicability to consumable products is limited. Less than half of their recommendations can be applied to consumables. The analysis also identified several design considerations that are transferable between product-specific design guidelines. This paper shows the importance of the life-cycle perspective in product design, to maximize the opportunities to improve consumables.

Keywords: design guidelines; ecodesign; circular product design; consumables; disposables; dissipatives; resource efficient; product design

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1. Introduction

The circular economy (CE) is a recent response to the unsustainable production, use, and disposal of products. The most common definition, according to Kirchherr et al. [1], is "an industrial system that is restorative or regenerative by intention and design" [2]. Within the CE field, much attention has been placed on durable products and how their life can be prolonged, e.g., through product design and business models allowing for reuse, repair, or remanufacturing [3–6]. Less focus has been placed on consumables and how they can be designed, offered, and planned for in a circular economy [7,8].

Consumables are a group of products that have a short lifespan and can be categorized into three main groups. Dissipative products are those that are consumed in such a manner that they are not intact as physical objects after use and hence are not available for material recycling [9]. Examples include food, fuels, and cleaning agents. Disposable products are those that are typically used once and thereafter disposed of. These products still exist as distinct objects after use. However, they usually become contaminated during use, and, in some cases, unhygienic [9]. Examples include packaging, single-use articles, and hygiene products. Short-lived components in durable products have a relatively short lifespan compared to the entire product and must be replaced several times during the product's lifetime [9]. The function of these products deteriorates at a faster pace than the remainder of the durable product. Examples include filters in vehicles, single-use batteries, and ink cartridges.

There are, however, few studies on consumables as a product group in the circular economy literature. Among these few exceptions, recent studies on fast-moving consumer goods (FMCG) and the CE can be found [10–12]. There is a partial overlap between the concepts of consumables and FMCG: Both are characterized by mass production and are inexpensive, have a short lifespan, and are bought frequently [11,13]. The concept of consumables is, however, broader in the sense of considering "non-durables" beyond retail products, whereas the FMCG concept includes semi-durables, such as fast-fashion, gifts, and gadgets [11]. Kuzmina, et al. [12] investigate future scenarios for the FMCG sector in a CE, mainly focusing on the role of business models. Haffmans, et al. [11] present circular business models and design strategies for FMCG. A different approach is taken by Stewart and Niero [10], who reviewed companies' sustainability reports in the FMGC sector, to see how they had incorporated the CE concept. They found that most reported activities related to products and their packaging, focused on end-of-life management and sourcing strategies, whereas activities related to circular product design and business model strategies were reported to a lesser extent (ibid).

In the field of design for the CE, also called circular product design [14], a growing number of frameworks, typologies, and methods have been proposed [3,5,15,16]. The characterization of circular product design differs between the authors in the same way that there is no agreed definition of the CE [1]. For instance, in their definition of circular product design, Bakker, et al. [3] state that it "Elevates design to a systems level (1), Strives to maintain product integrity (2), Is about cycling at a different pace (3), Explores new relationships and experiences with products (4) and Is driven by different business models (5)". Nevertheless, central to most designs for the CE literature is the aim to increase the lifespan of products; the circulation of products through reuse, repair, and remanufacture; and the recycling of materials [5,17]. However, although several design for CE concepts have been proposed, the extent to which the literature is applicable for the design of consumable products is not yet clear.

To a large extent, circular product design builds on its precursor, ecodesign [15]. Ecodesign is a concept that aims to minimize the environmental impact over the whole product life cycle [18,19]. Ecodesign thus enables profiling the environmental impact of products across all life-cycle phases, to identify those phases with the highest environmental impact and provide a strategic direction for design interventions [18]. Although many ecodesign concepts have existed for longer than the CE, much of their content is relevant in the CE context [17]. For example, the term "design for X", in which X represents reuse, disassembly, remanufacturing, and recycling [20], was particularly coined for design approaches that enable more circular material flows [21].

Ecodesign is, however, considered limited in its coverage of design considerations to reduce environmental impacts during use [18]. As a response to the lack of coverage of users and their possible impacts during the use-phase of products, two different design concepts have been proposed: emotionally durable design and design for sustainable behavior [18]. Emotionally durable design aims to create an emotional attachment to products (ibid), making users less prone to replace them. Design for sustainable behavior instead aims to influence users' behavior through product design [22], to reduce the environmental impact from product use. One example is to make it more difficult for the user to behave in an undesired way, by designing in obstacles that prevent errors from occurring [23].

There are many types of methods within design that aim to improve the environmental performance of products, for instance, guidelines and checklists, diagram tools, computer-aided design (CAD) integrated tools, life-cycle assessment (LCA) tools, and designs for X approaches [24]. The term "guideline" is commonly used to indicate a procedure or method to orient the decision-making process towards a given goal [25]. Design guidelines for resource efficiency thus means to orient the decision-making process in product design, with the aim to minimize the environmental impact and resource use. Generic design guidelines, such as those by Bocken, et al. [16] and Luttropp and Brohammer [26], are applicable for all types of products. They are useful at a conceptual level and for educational purposes, but are less useful in product design applications [25]. To be useful in such practical contexts, it has been argued that design guidelines need to be specific to certain product types or able to be customized to different product types [25,27]. There is therefore a plethora of design guidelines specific to different categories of products, such as food (e.g., Thrane and Flysjö [28]), packaging (e.g., Lewis [29]), and hygiene products (e.g., Gaasbeek [30]) among others. However, Böckin, et al. [7] showed that product characteristics are decisive in determining the measures that can be taken to increase the resource efficiency of products, and that such characteristics can be shared between several product types. This indicates that products that share product characteristics can also share design guidelines, which suggests that product type-specific design guidelines can be transferable between product groups.

This paper aims to investigate which existing design guidelines for resource-efficient products are applicable to consumables. This is examined in a literature review in which two types of analysis were conducted. The first investigates the extent to which general product-design guidelines (i.e., those considered applicable to many types of products, both durable and consumable) are applicable to consumables. This analysis also scrutinizes the type of recommendations presented by ecodesign and circular product design, to investigate the new aspects the newer CE concept applies to product design. The second analysis examines the type of design considerations that are recommended in the literature on product-type specific design guidelines for consumables. More specifically, the following are examined:

- To what extent do general product-design guidelines (i.e., applicable to many types of products, both durable and consumable) within ecodesign and circular product design, apply to consumable products?
- Which design consideration are transferable between guidelines for specific product groups?
- What aspects are decisive for whether design guidelines are transferable between categories of consumable products?

The first question is related to the first analysis; the second question is linked to both analyses and the third question is connected to the second analysis. This paper focuses on consumables and improvements in resource efficiency of these products. Improvements in resource efficiency (RE) are considered to include reductions both regarding use of natural resources and environmental impact. Consumables are, in some cases, used in durable products as, e.g., fuels, auxiliaries, or cleaning agents. It should be noted that design of durable products to use such consumables more efficiently is not included or analyzed in this study. Another limitation is that the paper focuses only on dissipative and disposable products and omits short-lived consumables used in durable products.

2. Method

A literature review was conducted to answer the research questions noted above. An overview of the literature search protocol is presented in Table 1. The main criteria for selecting the literature, defined before the search was conducted, were as follows: works from the literature that covered design guidelines or presented design recommendations, with the aim to improve the products' resource efficiency; and works from the literature that aimed to cover all products (general guidelines), consumables in general, and specific consumable product-groups. Studies concerning only durable products were excluded.

- An initial literature search was conducted in Scopus during January–March 2020. Thereafter, the literature was complemented with searches in Google Scholar and Google, to include grey literature, such as product-type specific design guidelines.
- In a first screening, the titles were checked, and the abstracts were skimmed through, to see if they seemed relevant to the criteria and keywords (see Table 1).
- In a second screening, the abstracts were read in detail and the whole papers skimmed through to see if they presented design guidelines, design recommendations, or similar.

- To identify additional relevant works in the literature, forward and backward snowballing was used, starting from the already identified works in the literature.

Table 1. Overview of the sample search protocol.

Refine Type	Description	No.
Inclusion criteria	Studies that focus on design considerations for consumable products for improved resource efficiency. Studies with design considerations for all product types, aiming for resource efficiency. Studies written in English (or Swedish). Studies published by June 2020. Studies published in peer-reviewed academic journals, conference proceedings, books, or grey literature.	
Consumables keywords	Consumables, short-lived products/component, consumer goods, disposable/single-use/dissipative product, medical/hygiene/healthcare product/article, house-care/cleaning product/article, food, beverage, packaging, and products.	-
Design keywords	Design guideline, product design, and ecodesign.	-
Resource efficiency keywords	Resource efficiency, environmental, circular, green, and sustainable.	-
Keyword search	Online database Scopus with the defined keywords for consumables, design, and resource efficiency in combinations: Studies that include these keywords in their title, abstract, or list of keywords.	1948
Filtering I	Checking relevance of content from title, abstract, and keywords.	154
Filtering II	Checking relevance of content by reading the whole paper.	18
Backward and forward snowball approach	References of and works that cited the studies from filtering II were checked.	8
Complementary search for relevant grey literature	Online search in Google Scholar and Google with the defined keywords for consumables, design, and resource efficiency in combinations: Studies that include these keywords in their title, abstract, list of keywords, and presented design guidelines were selected.	6
Final sample		32

The method for analyzing the literature was characterized by mapping and categorizing. The selected literature was first sorted according to whether it dealt with general or product-type specific design guidelines. Then, the design guidelines and their design considerations (suggestions on how a measure can practically be achieved during design) were sorted according to where in the life cycle the measure would take place and mapped against a typology of RE measures presented in Böckin, et al. [7] (see Table 2 for descriptions of the measures). Based on the content of the studied design guidelines, the typology was complemented with a few measures in the analyses. The design considerations within the guidelines were also mapped against each other and grouped to identify common denominators. Similarly, the general design considerations were categorized according to the type of consumable they were applicable to, i.e., dissipative, disposable, or to specific product groups such as food or packaging. Mentioned barriers for design of consumables were also noted. The general product-design guidelines were also mapped according to whether they emanated from the ecodesign field or the field of circular product design. In addition, the design considerations in the guidelines were counted and used as a proxy for how well covered the different consumable product types were in a particular guideline.

The product-type specific guidelines were analyzed separately to allow for investigation of the transferability of design considerations between product groups.

Table 2. Description of resource efficiency measures adapted from Böckin et al. [7].

Life-Cycle Phase	Resource-Efficiency Measures	Description
Extraction and production	Reduce losses in production	Reducing losses in production involves reducing losses of both material and energy in production, e.g., by re-introducing scrap and energy flows into the production process.
	Reduce material quantity in product	Reducing material quantity in a product means reducing the material in the product without material substitution.
	Change material in product	Changing materials in a product can be done by, e.g., substituting fossil-based materials and hazardous, scarce or critical, or primary materials for less environmentally burdensome materials.
Use	Use effectively	Using a product effectively means ensuring that the appropriate function is provided for the user's needs, as well as reducing losses during use.
	Reduce use of auxiliary materials and energy	This means reducing the resource consumption of either the energy or auxiliary materials in the use-phase.
	Share	Sharing a product means that a product is used by several users regularly through, e.g., a product-pool, a library, or a renting service.
	Use more of the technical lifetime	Using more of the technical lifetime means using more of an existing product either by the same user or a new one (denoted as reuse).
	Increase technical lifetime (by design)	Increasing the technical lifetime by design means redesigning a product to last longer.
	Shift to multiple use	Shifting to a multiple use product means that a single-use product is redesigned as a multiple-use (reusable) product.
	Maintain	Maintenance involves activities where products are inspected, maintained, and protected before breakdown or other problems occur.
	Repair	Repair takes place after the wear, malfunction, or failure of a product.
	Remanufacture	This is the process of restoring a non-functional product to a functional state (as good as new or better) through disassembly, repair/exchange of components, re-assembly, and quality assurance.
	Repurpose	Repurposing means reusing a product with a different function than the original design.
Post-use	Recycle material	Recycling restores materials and returns them to use.
	Digest anaerobically/Compost	Digesting anaerobically means digesting biodegradable materials without oxygen to generate biogas and digesting material that can be used as fertilizers. Compost is an aerobic digestion process that digests organic materials and generates a soil enhancer.
	Recover energy	Recovering energy involves the combustion of materials (incineration) with energy recovery (electricity and heat).
	Treat wastewater	Wastewater treatment handles waste collected via sewers and sometimes recovers energy and plant nutrients

3. Results

The results from the literature review are divided into two sections. Section 3.1 presents the analysis of the literature on general product-design guidelines, i.e., design guidelines that are applicable to all types of products. Section 3.2 presents and analyzes the literature covering product type-specific design guidelines.

3.1. General Product-Design Guidelines of Relevance for Consumables

Table 3 shows the selected design guidelines together with a reference code assigned to each source that is used throughout the results section for identification. The guidelines are sorted according to whether they emanate from the ecodesign field or the field of circular product design. When the same guidelines appeared in the literature in several editions, the most recent one was chosen for analysis. This applies to the following: Vezzoli and Manzini [31] and Vezzoli [32]; Telenko, et al. [33] and Telenko, et al. [34]; and also Luttropp and Lagerstedt [27] and Luttropp and Brohammer [26].

Table 3. Identified general design guidelines for resource efficiency that are applicable to all types of products and the sources reference codes.

Source	Reference Code
Ecodesign	
Brezet and van Hemel [35]	1
Lewis, et al. [36]	2
Wimmer, et al. [37]	3
Luttropp and Brohammer [26]	4
Telenko, et al. [34]	5
Vezzoli [32]	6
CE Design	
van den Berg and Bakker [14]	7
Moreno, et al. [15]	8
Bocken, et al. [16]	9
Haffmans, et al. [11]	10
Bovea and Perez-Belis [17]	11
Willskytt and Brambila-Macias [9]	12
Shahbazi and Jönbrink [38]	13
Go, et al. [39]	14

Those design considerations found in the general design guidelines that were identified as being applicable to consumables are presented in the following section. They are sorted according to where in the life cycle the guidelines apply: production, use, transport, and post-use. The design considerations are also analyzed whether applicable to dissipative, disposable or both. This is based on the nature of the design consideration. For instance, if the design considerations concern the product structure, the suggestion is analyzed whether it could be applied to products with a dissipative nature (dissipatives) such as liquids or products that are physically intact after use (disposables). Specific design considerations regarding the packaging are categorized to be applicable to both product types. General considerations such as material choices are generally regarded applicable to both. Design considerations that are deemed applicable to disposables-made-reusables reflect simple durable products (e.g., no considerations for complex product structures and electronic components). The following sections are structured by first presenting design considerations in connection to the resource efficiency measures from the design guidelines. Thereafter, the general findings for each life-cycle phase are summarized.

3.1.1. Design Considerations Related to Production

Reduced resource use in production and associated reduced waste generation is recommended on a general level, e.g., by Wimmer et al., 2004 [37] and Vezzoli, 2018 [32]. More specifically, this can be accomplished through designing the product for minimal material waste in production [9], especially in processes such as sawing, turning, and punching [35].

Many recommendations, however, refer not so much to product design as to the design and operation of production processes. For instance, it is recommended to choose processes that make the most efficient use of materials, such as powder coating instead of spray painting [35], and to operate production processes as efficiently as possible [9]. Another material optimization consideration is to recycle production residues within the company [35] or externally [9]. Energy efficiency in production is recommended by several authors, in addition to the use of energy from renewable sources [32]. Similarly, efficiency in the use of production auxiliaries is recommended in addition to use of less harmful auxiliary substances and production techniques that generate low emissions [35].

Considering the design of the product, there are several guidelines related to improving the resource efficiency of products by reducing the material quantity and choice of low environmental impact material. Reducing the material quantity in products can be achieved by making products smaller or reducing their weight [15]. More specifically, this can be achieved by structural changes such as reinforcement, rails, frames, or folds [26]. Other suggestions include minimization of the thickness of components and avoidance of components with little functionality [32]. Design changes at a system level include replacing the material with an non-material substitute that fulfils the same function [35] and design for product-service systems [15,34].

Changing the materials in the products from high impacting to low impacting is suggested in general [37]. Avoidance of hazardous [35,37], scarce, and critical materials is suggested [9]. Use of renewable materials [35] and biodegradable materials [9] is also recommended. It is also suggested to use materials with efficient recycling technologies in place [32] or recyclable material [17], and to use recycled materials to increase their market demand [35].

System design was mentioned by a few authors and covers design for the whole product system. Examples include design that aims to reduce environmental impact over the whole life cycle [32], and design for regenerative systems and biomimicry [15].

The overview of the identified design guidelines in Table 4 shows that the applicability to dissipative and disposable products is similar. However, it can be noted that structural product changes can mainly be applied to disposables and that only dissipative products can be made into concentrates. Moreover, it is also clear that the literature from the ecodesign field provides more detailed insights into how design can improve production and reduce material quantity in products. Regarding material selection, avoidance of hazardous materials is mentioned to a greater extent in ecodesign, whereas recommendations to use biodegradable materials are more common in the CE literature. Furthermore, although all of the ecodesign literature provided design suggestions relating to production to some degree, there was a smaller contribution from the CE literature. For instance, van den Berg and Bakker [14] and Bovea and Perez-Belis [17] provided only one design suggestion for this life-cycle part.

Table 4. Measures for resource efficiency and design considerations at production, together with their relevance for respective consumable type and reference code.

Measure for Resource Efficiency	Design Consideration	Relevant for Dissipative, Disposable, or Both	Mentioned by Ecodesign	Mentioned by CE Design
Reduce losses in production	General consideration	Both	1, 2, 3, 4, 5, 6	8, 9, 12, 14
	Cleaner production	Both	1, 2, 5	12,13, 14
	Close material loops for solvents	Both	1, 2, 5	12
	Increase material and energy efficiency	Both	1, 2, 3, 4, 6	8, 12, 13
	Use renewable energy	Both	1, 5, 6	12, 13, 14
	Technology optimization (improve process control, redesign processes, reducing production steps)	Both	1, 5, 6	8, 12
	Industrial symbiosis	Both		12
	Product design to reduce production losses, i.e., avoiding complex product structure	Disposable	1, 5	12
Reduce material quantity in product	General consideration	Both	1, 2, 3, 4, 5, 6	8, 9, 10, 12, 14
	Dematerialization (use less material for a specific function)	Both	1, 2, 3, 5, 6	8, 10, 12
	Dematerialization (use other material or introduce a service for a specific function)	Both	1, 2, 4, 5	8, 10, 13, 14
	Structural product changes	Disposable	1, 4, 5, 6	10, 12
	Eliminate unnecessary components	Disposable	1, 2, 5, 6	10
	Design concentrate	Dissipative	6	10, 12
	Design out/reduce the need for packaging	Both	1, 2, 3, 5,6	10, 12
Change material in product	General consideration	Both	1, 2, 3, 4, 5, 6	7, 8, 9 10, 11, 12, 13, 14
	Avoid hazardous materials	Both	1, 2, 4, 5, 6	12, 13, 14
	Avoid scarce materials	Both		11, 12
	Use low impact materials	Both	1, 2, 5	12, 13, 14
	Use bio-based materials	Both	1, 2, 5, 6	10, 12, 13, 14
	Use bio-degradable materials	Both	5, 6	8, 9, 10, 12, 14
	Use recycled material	Both	1, 2, 5, 6	7, 8, 9, 10, 12, 13, 14
System design	Design for the entire value chain	Both	1, 2, 5, 6	8
	Design for regenerative systems or design for biomimicry	Both	5, 6	8, 9

CE: circular economy.

3.1.2. Design Considerations Related to the Use-Phase

A reduction in resource use associated with product use [16] is generally recommended, i.e., use effectively. One approach is to ensure that product functionality and product use are matched and optimized [9]. Calibration marks on the product [34] and IT-supported feedback mechanisms and sensors are also suggested to help the user consume only the needed product quantity [9,34]. Information about desired user behavior is also suggested to be provided on the product [26]. Another means of reducing losses during use is to make the default state the most desirable from an environmental perspective [35].

Some disposables can be redesigned into a reusable product. Relevant design considerations for such products are in general the same as for other durable products, although, in addition, recommendations for maintenance, such as cleaning, are relevant. Fewer authors mention specific design considerations for designing a product for reuse, with the exceptions of Lewis, et al. [36], Vezzoli [32], and Willskytt and Brambila-Macias [9]. For instance, Lewis, et al. [36] state that the product needs to be durable enough to withstand repeated collection, handling, washing, and refilling.

The user's perception and willingness to reuse products is suggested to be of relevance for reusable goods [9]. Emotional durability through timeless and classic design could thus be relevant [16]. In addition, ensuring that it feels hygienic to reuse the product could be considered through the product design [9].

Periodic preventive maintenance activities, such as cleaning and refilling, are a prerequisite for reusable products. To reduce the need for maintenance, the products are suggested to be designed to avoid dirt from accumulating [17,32]. Design for reducing energy consumption during use is also considered relevant [26,37]. It is also suggested to consider which actor will perform maintenance and/or refilling, i.e., the manufacturer, the retailer, or the user, and that the cleaning meets relevant standards [36]. This is suggested to be relevant for food, beverages, and cosmetic products.

The overview in Table 5 indicates that the design considerations for use effectively apply to the same extent to dissipative and disposable products. It can also be noted that there are fewer concrete design considerations mentioned by the CE literature, with the exception of Willskytt and Brambila-Macias [9], in comparison with the ecodesign literature, in which Brezet and van Hemel [35] and Telenko, et al. [34] contributed the largest number of relevant design considerations.

It can also be noted that, even though design considerations to reduce impacts during use largely involve design for sustainable behavior (DfSB) strategies, few of the guidelines mention DfSB as a design concept. In the CE literature, DfSB is addressed by Willskytt and Brambila-Macias [9] and, in the ecodesign literature, it is mentioned as a design concept by Vezzoli [32], although only one such design consideration was included in their design guidelines.

The overview also indicates that the CE literature does not provide more concrete recommendations for the design of reusable product system, although the CE literature in general advocates reusable products rather than disposable ones [2]. However, the CE literature provides more insights into emotionally durable design.

3.1.3. Design Considerations Related to Transportation

Design for reducing the impact of transport includes both decisions on product design and the transport mode/logistics [35]. In regard to the former, transport energy can be minimized if products have a space-saving shape or structure [34]. Examples of such designs include compact and concentrated products with high storage density [11], down-scaled products, and reduced packaging weight [32]. Selection of local materials and energy sources is suggested to reduce impacts from transport during production [32]. Suggestions for out-bound transportation include transport of the product as components, leaving the final assembly to the user, which allows for more dense packaging, or reusable bulk packaging [35]. To reduce impacts from transport at post-use, it is suggested that the discarded product is designed for compressibility and stackability [32].

Decisions for the energy-efficient transport mode and logistics include selecting environmentally benign forms of transport, co-distribution of goods, and use of standardized transport packaging (e.g., euro-pallets) [35].

As shown in Table 6, the design considerations related to transportation are applicable to the same degree as those for dissipative and disposable products. Moreover, Table 6 indicates that design for improving transportation is less prominent in the CE literature than in the ecodesign literature.

Table 5. Measure for resource efficiency and design considerations at use-phase production, together with their relevance for respective consumable type and reference code.

Measure for Resource Efficiency	Design Consideration	Relevant for Dissipative, Disposable, Disposable-Made-Reusable, or All Three	Mentioned by Ecodesign	Mentioned by CE Design
Use effectively	General consideration	All three	1, 3, 4, 5, 6	9, 12, 13, 14
	Match product functionality with user needs	All three		12
	Product shape to reduce waste and enable consumption of only needed product quantity	All three	1, 5	12
	Use feedback mechanisms or sensors for consumption reduction	All three	4, 5, 6	12, 13
	Calibration marks for correct product quantity	All three	1, 5	12
	Information and clear instructions	All three	1, 4	12, 13
Shift to multiple-use product	General consideration	Disposable-made-reusable	1, 2, 3, 4, 5, 6	7, 8, 9, 10, 12, 13, 14
	More materials/change to durable materials	Disposable-made-reusable	2, 3, 4, 6	7, 8, 12, 13, 14
	Reliability/eliminate weak links in product structure	Disposable-made-reusable	1, 2, 6	7, 9 11, 12, 13, 14
	Make part of product reusable	Disposable-made-reusable	6	12
	Product design that handle maintenance	Disposable-made-reusable	2, 5, 6	7, 11, 12, 14
Emotional durable design	General consideration	Disposable-made-reusable	1, 5, 6	7, 8, 9, 11, 12, 13
	Classic product design	Disposable-made-reusable	1, 5	7, 8, 11, 12, 13
	Adaptable design	Disposable-made-reusable	5, 6	
	Design for hygiene (feel hygienic to reuse)	Disposable-made-reusable		12
	Design for pleasurable experience	Disposable-made-reusable	1	8
Maintain	General consideration	Disposable-made-reusable	1, 2, 3, 5, 6	7, 8, 9, 11, 12, 13, 14
	Product design to reduce maintenance	Disposable-made-reusable	1, 2, 5, 6	7, 12, 14
	Avoid dirt accumulation	Disposable-made-reusable	5	11, 14
	Ensure cleaning process meet relevant standards	Disposable-made-reusable	2	
	Energy and resource-efficient maintenance	Disposable-made-reusable	1, 2, 5, 6	12
	Clean energy	Disposable-made-reusable	2, 6	12, 13

Table 6. Measures for resource efficiency and design considerations related to transport, together with their relevance for the respective consumable type and reference code.

Measure for Resource Efficiency	Life-Cycle Phase	Design Consideration	Relevant for Dissipative, Disposable, or Both	Mentioned by Ecodesign	Mentioned by CE Design
Improve transport	Production	General consideration	Both	1, 3, 4, 5, 6	8, 10, 12, 13, 14
		Space saving product shape or structure (e.g., foldable or concentrate)	Both	1, 4, 5, 6	10, 12
		Lightweight products	Both	1, 4, 5, 6	10
		Nest components	Both	1, 5	
		Select local materials	Both	5, 6	8
		Standardized transport and bulk packaging	Both	1	
		Energy-efficient transport mode	Both	1, 5	
	Post-use	General consideration	Both	5, 6	8, 13
		Space saving product shape or structure (compressibility and stackability)	Both	5, 6	

3.1.4. Design Considerations Related to Post-Use

The collection of the discarded products can be facilitated by designing the product in compliance with retrieval systems and providing the user with information about the recommended waste treatment of the product [11,26].

Design for recycling is recommended at a general level [15,37]. The technical recyclability of the material in products is related to the choice of materials. It is recommended to use only one or a few materials in products [32], and to use materials compatible with recycling [17,38]. In addition, it is suggested to avoid materials that are difficult to separate, such as laminates and composites [35], and minimize the use of hazardous materials [26]. To enable material recycling, collected discarded products may require cleaning [15,38] in addition to identification [39] and separation of materials [16].

For products that cannot be recycled, Vezzoli [32] suggest they can be designed for incineration. This includes choice of materials with a high energy content [32] and avoidance of materials and additives that emit dangerous substances during incineration [9]. If the product instead contains biodegradable materials, anaerobic digestion and composting can be suitable post-use treatments. To facilitate such treatment, it is suggested to select materials that degrade in the expected end-of-life environment and avoid combinations with non-degradable materials [32]. Designing biodegradable products is mentioned as particularly suitable for products that risk being littered [9].

Table 7 shows that there are significantly fewer measures related to post-use that are suitable for dissipative products than for disposable ones. This is expected because dissipative products are not intact after use and hence not as readily available for post-use treatment other than wastewater treatment. The CE and ecodesign literature appear to cover design for post-use treatment to a similar extent, although more detailed recycling considerations appear to be provided in the ecodesign literature, such as on how different materials should be recycled [36].

Table 7. Measures for resource efficiency and design considerations at post-use, together with their relevance for respective consumable type and reference code.

Measures for Resource Efficiency	Design Consideration	Relevant for Dissipative, Disposable, or Both	Mentioned by Ecodesign	Mentioned by CE Design
Post-use	Facilitate collection and cleaning	Both	5, 6	8, 13
	Facilitate identification of materials	Both	2, 4, 5, 6	7, 10, 11, 12, 14
	Facilitate separation of materials and components	Disposable	1, 2, 5, 6	7, 11, 12, 13, 14
Recycle material	General consideration	Disposable	1, 2, 3, 4, 5, 6	7, 8, 9, 10, 11, 12, 13, 14
	Few or uniform materials (locate same materials together)	Disposable	2, 4, 5, 6	10, 11, 12, 14
	Avoid molding, fusing incompatible materials	Disposable	1, 2, 5, 6	7, 10, 12, 13, 14
	Easily liberated materials, e.g., use snap fits instead of adhesives	Disposable	1, 2, 5, 6	7, 12, 13, 14
	Avoid hazardous materials	Disposable	1, 2, 5, 6	7, 10, 11, 12, 13, 14
Digest anaerobically/compost	General consideration	Both	5, 6	8, 9, 10, 12, 14
	Select materials that degrade in the expected end-of-life environment	Both	6	12
	Avoid combining with non-degradable materials or facilitate separation	Both	6	10, 12
Incinerate with energy recovery	General consideration	Disposable	1, 6	12
	Strive for completely combustible products to reduce slag	Disposable	6	12
	Avoid hazardous metals and halogens	Disposable	6	12
Treat wastewater	Design that makes sure only things that are supposed to end up in toilets end up there	Dissipative		12

3.2. *Product-Type Specific Design Guidelines*

In the following section, the product-type specific design guidelines are presented. These cover packaging, food, medical, and cosmetic products (Table 8). Packages can have several functions and are classified into three categories (Pålsson [40] as cited in Mahmoudi and Parviziomran [41]): Primary packaging is the packaging that envelops and holds the product; secondary packaging is an outer packaging layer of the primary packaging and could be used to bundle primary packages together; and tertiary packaging is used for bulk handling, warehouse storage, and transportation purposes. Food products are considered here to include both food and beverages, including their packaging. The medical products category in this work covers both products that are classified as medical devices according to the EC [42], such as catheters, surgical aprons, and incontinence products, and hygiene products, such as diapers, sanitary napkins, and wet wipes. Cosmetic products are considered to range from everyday personal-care hygiene products, such as soap, shampoo, deodorant, and toothpaste, to luxury beauty items, including perfumes and makeup [43]. Cosmetic products are considered here to include their packaging.

Table 8. Identified design guidelines for resource efficiency that are applicable to specific product groups and the sources reference codes.

Source	Reference code
Packaging	
Lewis [29]	A
González-García, et al. [44]	B
van Sluisveld and Worrell [45]	C
Lofthouse and Bhamra [46]	D
Youhanan, et al. [47]	E
Ellen MacArthur Foundation (EMF) [48]	F
Svensk Plastindustriförening (SPIF) [49]	G
EMF [50]	X
Food Products	
Urbinati, et al. [51]	H
Thrane and Flysjö [28]	I
Wikström, et al. [52]	J
Keoleian and Spitzley [53]	K
Medical Products	
Gaasbeek [30]	L
Leissner and Ryan-Fogarty [54]	M
Kane, et al. [55]	N
Moultrie, et al. [56]	O
Cosmetic Products	
L'Haridon, et al. [57]	P
Lofthouse, et al. [58]	Q

In the following, the identified design considerations from the different product-type specific design guidelines are presented according to where in the life cycle they apply.

3.2.1. Design Considerations Related to Production

Table 9 presents an overview of the design considerations for reducing losses in production, material selection and reducing material quantity. It can be noted that the design guidelines for packaging provides the most design considerations, which is expected because this was the product group for which most design guidelines were identified. Cosmetic products was the product group for which the fewest design guidelines were identified.

Most studied guidelines mention several design considerations aiming to reduce losses in production. However, although relevant for all product groups, no such design considerations were mentioned in the guidelines for cosmetic products [57,58].

For resource efficiency measures aiming to reduce the material quantity in products, it can be noted that, for the disposable products, i.e., packaging and medical products, more concrete design considerations are mentioned as compared to the dissipative products, i.e., food and cosmetic products. This can be explained by the fact that it is not possible to influence the physical structure of dissipative products to the same degree as for disposable products. For instance, it is suggested to eliminate unnecessary components and void space [29,44,45], and carry out structural product changes such as down-gaging, and strengthening or weakening components [29,45], which are most applicable to disposable products. However, design concentrate [46,48,50] involves redesign of a dissipative product, but is not mentioned by any of the design guidelines for the dissipative products, food and cosmetics. Another proposed means of reducing the material quantity of products is to remove the need for packaging [29] (e.g., by designing solid personal-care products [50]) or make the product redundant [30]. For instance, Gaasbeek [30] suggests that the need for diapers could be reduced by toilet-training children earlier.

Table 9. Measures for resource efficiency and design considerations at production mentioned in design guidelines for packaging, food, medical, and cosmetic products, with respective reference code.

Measures for Resource Efficiency	Design Consideration	Packaging	Food Products	Medical Products	Cosmetic Products
Reduce losses in production	General consideration	A, B, G	H, I, J	L, M, O	
	Cleaner production	A, B	I		
	Increase material and energy efficiency	A, B	H, I, J	L, O	
	Use renewable energy	A, B	H, I	O	
	Technology and production optimization	B	I, J	L	
	Internal recycling/Industrial symbiosis	B, G			
Reduce material quantity in product	General consideration	A, B, C, D, F, X	H, I	L, O	Q
	Dematerialization (less material for a specific function)	A, B, C, X	H, I	L	
	Structural product changes (down-gauge, or strengthen or weaken components)	A, C		L	
	Different product sizes	A, C, D, X	I		
	Design concentrate	A, C, D, F, X			Q
	Eliminate unnecessary components, void space	A, B, C, X		L, O	
	Design out the packaging	A, X			
	Product-packaging system optimization	A, C, X	I	O	
Change material in product	General consideration	A, B, G, X	H, I	L, O	P
	Avoid hazardous/scarce materials	A, B, X		O	P
	Use low impact materials	A, B, X	H, I	L, O	P
	Use bio-based materials	A, B, X	H, I	L	
	Use responsible (sourced) materials	A, X			
	Use bio-degradable materials	A, X	H	L	P
	Use edible coating/packaging	X			
	Use wasted raw material		H, I		
	Use recycled material	A, B, G, X	H	L, O	

It can be noted that changing the material content in products to more environmentally benign materials is suggested by the design guidelines for all four product types to some degree [28,49,56,57]. For instance, for food products it is suggested to use ingredients with less climate impact, such as vegetables instead of meat [28].

3.2.2. Design Considerations Related to the Use-Phase

Table 10 shows an overview of the design considerations for reducing impacts during use through more effective use and shifting to a multiple-use product. It can be noted that the design guidelines for packaging provide the most examples of "use effectively" design considerations, followed by those for food products. These design guidelines provide design suggestions both related to the packaging and the product it contains. For instance, for the groups of dissipative products, food and cosmetics, it is recommended that packaging is designed to allow for liquids to be poured without spillage, in a way that allows the packaging to be completely emptied and so that only the needed amount is dispensed [28,29,46,49,52]. The dissipative product itself is instead proposed to be given rheological properties, making it easier to pour from the packaging [29,49].

Table 10. Measures for resource efficiency and design considerations at use-phase mentioned in design guidelines for packaging, food, medical, and cosmetic products, with respective reference code.

Measures for Resource Efficiency	Design Consideration	Packaging	Food Products	Medical Products	Cosmetic Products
Use effectively	General consideration	A, B, C, G, X	I, J	L, N	Q
	User centered design (understand the user and needs)	A		L	
	Match product functionality with user (e.g., optimize product quantity and user, and packaging size)	A, X	I, J		
	Product shape to reduce waste and correct amount (dispense all)	A, D, G, X	I, J		Q
	Modifying the rheological properties (to enable dispense)	A, G			
	Use feedback mechanisms or sensors for consumption reduction	X	J	N	
	Calibration marks for correct amount	A, X			
	Increase product functionality	X		L	
	Increase shelf life (e.g., modify atmosphere, aseptic packaging)	A, C, G	I, J		
	Inform about shelf life		I, J		
	Information and clear instructions (e.g., about preferable behavior)	A, B, D, G, X	I, J	L	Q
Reduce energy during use	Information and clear instructions (appropriate storage and energy efficiency during use)	A, G	I		
Shift to multiple-use product	General consideration	A, B, C, D, E, F, G, X	I, K	L, N, O	Q
	Durable Product	B, C, D, F, X		L, N, O	Q
	Optimal product lifetime (labels of use cycles left)	C		N	
	Refillable product	A, C, D, X			Q
	Make reusable option preferable, engage user in reuse	E, X		L	
	Consider the actor and system/setup for refilling/maintenance (manufacturer, distributor, or user)	A, C, E, F, X		L, N	Q
Maintain	Design product according needed maintenance	C, X		N	Q
	Provide information about cleaning	X			
	Design for easy/energy-efficient maintenance	A, D, E		L	Q

Among the design considerations mentioned specifically for food products is design for increased shelf life, i.e., the period the commodity may be stored before it is unfit for use [28,45,52]. This is suggested to be achieved by modifying or controlling the atmosphere packaging. Information about shelf life is also considered important. Product packaging optimization is also mentioned particularly in relation to food products, for which it is suggested that for food with high environmental impact it makes sense to increase the material content in packaging to ensure long shelf life [52].

Other design considerations that are relevant to disposable products include increasing the functionality of products, so they do not require to be changed as often [30]. Other suggestions, relevant to all consumables, include optimizing the product quantity to different users by supplying the product in different packaging sizes [29]. Moreover, provision of information and clear instructions about correct product handling and preferable user behavior is suggested by most design guidelines [30,44,52,58].

Few guidelines mention the possibility to influence energy usage during use. For example, Thrane and Flysjö [28] recommend information is given on food products on their need for cold storage and Lewis [29] suggests information on cleaning products regarding the required water temperature and quantity during product use.

All consumables' design guidelines mention design of reusable products to a certain extent. However, it can be noted that it is only mentioned as a general consideration in the food guidelines. Having a durable product design is generally suggested [45,55,58]. For instance, Ellen MacArthur Foundation (EMF) [50] provides several concrete examples of reusable packaging solutions. In addition, for refillable products the structure or the product must allow for it [29,46,58]. Many design guidelines also mention it as important to consider the actor, the system setup and business model for refilling and/or maintenance of the product [47,48,50,55]. For instance, creating incentives for users to return reusable packaging is mentioned [50].

Maintenance, usually cleaning or sterilization, as in the case of medical products, is stated as being central to design considerations for reusable products. For instance, the level of cleaning or sterilization influences how the product needs to be designed to withstand the maintenance activity. In addition, the product design can reduce the need for maintenance if the product has, for instance, a smooth surface [55]. It is also suggested that the maintenance should be as energy efficient [47] and easy [29] as possible.

The user perception is suggested to be relevant for reusable products. For instance, Lofthouse, et al. [58] recommend the maintenance experience to be clean and hygienic, and Youhanan, et al. [47] advocate that reusable options be made attractive.

3.2.3. Design Considerations Related to Transport

Design considerations regarding transportation are mentioned to a lesser degree in the product-group-specific design guidelines (see Table 11). Structural product changes, such as lightweight products, concentrates, and packaging that can be flattened, are mainly mentioned [29,53]. In addition, eliminating the need for transport and implementing low-emission transport are suggested [28,56].

Table 11. Measures for resource efficiency and design considerations at transport stage mentioned in design guidelines for packaging, food, medical, and cosmetic products, with respective reference code.

Measures for Resource Efficiency	Design Consideration	Packaging	Food Products	Medical Products	Cosmetic Products
Improve transport	General consideration	A, B, C, X	I, K	O	
	Eliminate/reduce need for transport	C, X		O	
	Lightweight products, concentrates of products, and flat packaging	A, B, X	I, K		
	Improve fuel efficiency/low-emission transport	A, B	I	O	

3.2.4. Design Considerations Related to Post-Use

Table 12 shows an overview of the identified design considerations related to post-use. Clearly, the design guidelines for food and cosmetic products provides less considerations compared to those for packaging and medical products.

Table 12. Measures for resource efficiency and design considerations at post-use mentioned in design guidelines for packaging, food, medical, and cosmetic products, with respective reference code.

Measures for Resource Efficiency	Design Consideration	Packaging	Food Products	Medical Products	Cosmetic Products
Post-use	Inform user about correct disposal	A, B, D, G, X	I	M, N, O	
	Facilitate collection and cleaning	A, X		L, N, O	
	Facilitate identification of materials	A, B, X		M, N	
	Facilitate separation of materials and components	A, B, C, X		M, O	
Recycle material	General consideration	A, B, C, G, X	H, I	L, M, N, O	Q
	Few or uniform materials (locate same materials together)	A, C, G, X		L, M, N, O	
	Avoid different colors	G, X			
	Avoid molding or fusing incompatible materials	A, X		M, O	
	Avoid hazardous materials and contamination	A, X			
Digest anaerobically/compost	General consideration (biodegradability)	A, B, C, G, X	H	L	
	Select materials that degrade in the expected end-of-life environment	A, G, X	H		
Design for litter reduction	General consideration	A, G			
	Minimize the number of separable components that can be littered	A, G			
	Dissolvable packaging	X			Q
	Use of a biodegradable material certified to a relevant standard	A, X	H		

Informing the user about correct disposal is something that is generally mentioned [49,56]. Furthermore, recycling in conjunction with design that facilitates identification and separation of materials are mentioned by most guidelines. Use of uniform and few materials, avoidance of molding different materials and laminates, and avoidance of coloring materials are examples of suggestions to enable recycling [29,50]. It can also be noted that the design guidelines for packaging provide most detailed design considerations for post-use, particularly regarding material recycling [29]. For medical products, it is particularly noted as important that the recycling process can break down pathogens and medicine [30].

Design for litter reduction is a specific concern mentioned in the packaging design guidelines by Lewis [29] and Svensk Plastindustriförening (SPIF) [49]. Suggestions include minimizing the number of separable components that can be littered (e.g., straws, trays, and cutlery) [49]. Dissolvable packaging is suggested by Lofthouse, et al. [58] and packaging made of biodegradable material by Lewis [29]. However, SPIF [49] notes that there are limitations with biodegradable plastic materials because most of these can only be degraded at an industrial scale.

4. Analysis of Design Guidelines

In this section, the general product-design guidelines and the product-type specific design guidelines are analyzed in regard to their transferability between different consumable product types and to identify gaps in the different guidelines.

4.1. General Design Guidelines

Comparing the general product-design guidelines with the product-type specific guidelines, it is possible to identify some design considerations they are lacking. Generally, design considerations to reduce losses during use were limited in the general guidelines. For such considerations, the packaging related guidelines provide additional insights. For instance, understanding of how the user will use the product [29], i.e., user-centered design, is relevant for all products, but it is not mentioned in the general design guidelines, except by Willskytt and Brambila-Macias [9]. Another relevant design consideration that is missing in the general guidelines is dispensing all of the product [29]. Recommendations about information on the products and packaging regarding desirable use, e.g., for energy efficiency, is also missing in the general design guidelines. There are also limited design considerations on how to redesign single-use products to multiple uses in the general guidelines, as found in most of the product-type specific design guidelines. In particular, Kane, et al. [55] provide insights into the cleaning and sterilization of reusable goods, and the design of reusable products for an optimal lifetime.

In some of the general design guidelines, the design considerations are mentioned on a rather abstract level, e.g., system design or design for regenerative systems through biomimicry or biological cycles [15]. For such considerations, the product-type specific guidelines provide considerably more concrete suggestions. For instance, Thrane and Flysjö [28] in their design guidelines for food products, suggest making use of otherwise wasted raw materials and ingredients, which is a recommendation that applies to all products. In addition, Lewis [29] and Wikström, et al. [52] provide concrete examples of how system design can be undertaken in regard to a total packaging system and the product. The general design guidelines by Willskytt and Brambila-Macias [9] propose a design to reduce littering, but further detailed suggestions on this topic can be added from Lewis [29] and SPIF [49], such as minimization of the number of separable components that can be discarded.

To conclude, the product-type specific design guidelines can contribute both additional design considerations to the general guidelines, in addition to providing more concrete examples of the design.

4.2. Packaging

The packaging design guidelines are, in general, very thorough and provide concrete design considerations of relevance to packaging design in specific application areas.

4.3. Food Products

Several design considerations exist for food and beverages that may be transferred both from the general design guidelines and from other product-type specific guidelines. From the general design guidelines, the recommendation by Haffmans, et al. [11] to allow the product to be made into a concentrate is of relevance to the design of the food product.

There is a certain overlap between food products and packaging guidelines because several food guidelines also cover design considerations of the packaging. This is partly due to the fact that most food products cannot be stored without a package and that the package is considered to have a major role in reducing food waste [52]. For this reason, there are also design considerations from the packaging guidelines that are of relevance to food products. van Sluisveld and Worrell [45] provide suggestions of how the shelf life of food items can be increased by modifying the atmosphere in the packaging. The packaging can also be designed to be biodegradable, as suggested by Lewis [29], which would reduce the need to wash the packaging at post-use, because it can be composted. Another possibility is to design edible packaging [50], to reduce the need of post-use treatment, including the risk of litter. Reusable refillable packaging is not mentioned by most of the food and beverage guidelines, other than by Keoleian and Spitzley [53] for milk packaging. However, more detailed design considerations regarding this could be taken from the medical product guidelines because they also have strong regulations for sterilization of products.

There are impediments to implementing some design considerations for food products. For instance, recycled polymers can only be used in direct food contact if they meet stringent safety standards, with the exception of non-processed food, such as fruits and vegetables [29]. Furthermore, recycled resin that meets the US Food and Drug Administration standards has to undergo a chemical recycling process or a "super clean" mechanical process containing numerous decontamination stages [29].

4.4. Medical Products

It can be noted that design considerations for reducing losses during product use are scarce in the medical products design guidelines. For instance, in the general design guidelines by Willskytt and Brambila-Macias [9], reducing losses during use is suggested to be achieved through functionality matching, which means matching the needs of the user with the correct product. Furthermore, providing indicators of how much product/function is left during use could be relevant for these products.

Several impediments to certain design considerations are mentioned in the guidelines for medical products, particularly for product reuse, material recycling, and use of recycled materials [30,55]. These impediments are due to the fact that all medical and many hygiene products are classified as medical devices (e.g., according to the European Union Regulation (EU) 2017/745). This means, for example, that waste potentially contaminated with biological materials must be disposed of in a way that destroys the biohazard, but also that reusable products have to be sterilized according to specific procedures. These impediments can also limit the transferability of design guidelines between product types. Due to these requirements, it could be especially difficult to redesign critical single-use products into reusable products. In addition, these impediments highlight the need to know the type of maintenance or sterilization that is required when designing a reusable product.

4.5. Cosmetic Products

Comparing the investigated design guidelines for cosmetic products with the general design guidelines and other product-type specific guidelines, it is clear that several design considerations are transferable to cosmetic products. Mainly design considerations for reducing losses during use can be transferred from packaging and food design guidelines.

More specifically, suggestions to designers to prevent over-consumption, such as packing sizes adjusted to users' needs and packages that dispense a suitable amount of products, can be transferred from design guidelines for food products [52]. Losses during use can also be reduced by modifying the rheological properties of the product to ensure the all of the product can be poured from the packaging [29]. In their design guidelines for food products, Wikström et al. (2018) also suggest design to change behavior to ensure products are used optimally, which is applicable to cosmetic products. Similar to food, many cosmetic products have an expiration date [59,60], which, however, is often not clearly communicated. According to the EU Cosmetics Regulation EC 1223/2009, if the shelf life is lower than 30 months, an expiration date must be indicated on the packaging of the product. If the shelf life is longer than 30 months, no indication of expiration date is necessary on the packaging [60].

For cosmetic products, it can also be relevant to provide information on how to reduce the use of energy and water during use of the product, as suggested in the general guideline by Lewis [29].

5. Discussion

5.1. General Product-Design Guidelines and Their Applicability to Consumable Products

From the analysis of general product-design guidelines, it is clear that the ecodesign literature largely provides more detailed design considerations than the CE literature. This is especially true for Vezzoli [32], Brezet and van Hemel [35], Lewis, et al. [36], and Telenko, et al. [34]. The aims of the CE papers explain why fewer detailed design considerations are provided in the CE literature. Much of the identified CE literature aims to present strategies for circular product design rather than detailed design guidelines, and only in some cases provides examples of how these strategies can be operationalized. Of the identified CE literature, only Bovea and Perez-Belis [17] and Willskytt and Brambila-Macias [9] explicitly aimed to present design guidelines.

The papers' aims also explain the type of design strategies that are included. For instance, Bocken, et al. [16] focused on design strategies for circular loops of materials. For this reason, measures to reduce resource use during production and use were out of scope. Similarly, Bovea and Perez-Belis [17] aimed to identify design guidelines "to improve ... circularity" and thus also emitted design considerations to improve production, material selection, and material quantity. Moreno, et al. [15] and Willskytt and Brambila-Macias [9], in contrast, provided design considerations over the whole life cycle (with the exception of transportation), with the result that more design considerations relevant to consumables were addressed in their design guidelines.

Table 13 outlines the extent to which the reviewed literature contributes to design recommendations for different types of consumable products. The percentage design considerations of relevance for each type of product were calculated in relation to the total number of design considerations in each reviewed guideline. These percentages can only be seen as a proxy indicator of how well the different consumable product types were covered in a particular guideline. As expected, the percentage of relevant design considerations were the lowest for dissipative consumables, and the highest for disposable products turned into reusable products. It is also clear from Table 13 that, on average, fewer design considerations applicable to consumables were found in the CE literature.

Table 13. Percentage of relevant design guidelines for different types of consumable products in the reviewed literature.

Source	Percentage Relevant for Dissipative Consumables	Percentage Relevant for Disposable Consumables	Percentage Relevant for Disposables-Made-Reusable
Ecodesign			
Brezet and van Hemel [35]	33%	64%	73%
Lewis, et al. [36]	33%	75%	87%
Wimmer, et al. [37]	50%	54%	71%
Telenko, et al. [34]	32%	51%	66%
Luttropp and Brohammer [26]	46%	71%	77%
Vezzoli [32]	36%	50%	64%
Average Ecodesign	38%	61%	73%
CE Design			
van den Berg and Bakker [14]	0%	7%	31%
Moreno, et al. [15]	50%	62%	80%
Bocken, et al. [16]	27%	36%	64%
Haffmans, et al. [11]	32%	44%	52%
Bovea and Perez-Belis [17]	0%	19%	47%
Willskytt and Brambila-Macias [9]	41%	50%	59%
Shahbazi and Jönbrink [38]	40%	40%	74%
Go, et al. [39]	17%	21%	62%
Average CE Design	26%	35%	59%
Total Average	32%	48%	66%

Additional patterns to note are that the circular design guidelines provide more suggestions on recirculation of products and how to prolong their use, which is expected. The CE design guidelines also provide more insights on business perspectives. For instance Bocken, et al. [16], Haffmans, et al. [11], and Moreno, et al. [15] provide guidelines not only for product design for circularity, but also for circular business models. However, although redesign of disposable products into reusable products is generally advocated in the CE literature, few concrete recommendations for how to design them can be found.

Other traits shown are that the CE literature provides more insights into emotionally durable design (see Table 5). It can also be noted that fewer concrete design considerations for reducing losses during product use were mentioned by the CE literature, with the exception of Willskytt and Brambila-Macias [9]. Because the ecodesign guidelines generally have a wider scope regarding coverage of life-cycle phases, they provide more guidance on design for efficiency during production, and with regard to product structure and transport.

5.2. Transferability of Design Guidelines between Different Types of Consumables

In Section 4, it was found that several design considerations may be transferred both from the general design guidelines and from other product-type specific guidelines. This section discusses the aspects that determine whether a design consideration is transferable. The first aspect that matters is the product characteristics, i.e., whether the product is dissipative or disposable. At a general level, design considerations for products with the same product characteristic can be transferred between guidelines for different product groups. However, there are some additional aspects that inhibit or enable transferability.

For dissipative products, the shelf life and the use time (the time from when the product is opened until it deteriorates) of the product can differ. For instance, products can be perishable (milk), persistent (soap), or something in-between (facial sunscreen). This means that although some products may have a long shelf life they need to be consumed quickly once opened, whereas others can last longer in an opened packaging. Design considerations can be transferred between products with a similar degree of required packaging protection and shelf life, for instance, preserved food and cosmetics products. In addition, dissipative products with similar rheological properties can share design considerations; for example, viscosity determines what type of packaging shape is suitable.

The second aspect is connected to the type of function the product delivers. This can be especially relevant for disposable products and serves as a limiting aspect. For instance, if the function is to protect and provide hygienic care (e.g., a diaper) or if it is to provide protection to avoid damage to other products (e.g., packaging), there could be different requirements of relevance and thus also design considerations. Thus, design considerations could be transferable between products that have similar functions.

The third aspect of relevance is who handles the product, e.g., users, service personnel, or caregivers. For products used by similar actors, design considerations related to product handling are often transferable.

The last aspect of relevance which often limits the design considerations that are suitable for a product are the legal requirements relevant to the product. For instance, different considerations can be important if the product is in contact with food [61] or it is a medical device [42]. Legal requirements such as the waste directive [62] can also determine how different products should be treated at post-use. Therefore, seemingly different products, such as food and medical products, could provide more insight into how they can be designed because they both have high hygiene requirements that limit their possibilities for reuse and the use of recycled materials. For instance, Gaasbeek [30] suggests that, similar to the EU regulations for recycled plastic for food contact [63], the possibility to establish strict legislation for using recycled paper in absorbent hygiene products could be investigated.

5.3. Usefulness of General Product and Product-Type-Specific Design Guidelines

In this section, the usefulness of general product design is discussed in relation to product type-specific design guidelines. General product-design guidelines are generally considered useful for educational purposes [25] by showing a wide range of possible design recommendations. They can also be useful as inspiration, by showing design strategies that can be applied to other products. Telenko, et al. [34], however, argue that many product type-specific guidelines are solution-specific, which confines the designer to a specific technology, rather than helping the designer to create an innovative solution. Instead, they suggest that guidelines are more useful if they are applicable to a broader set of products. However, this might not always be true. Indeed, as shown in this literature review, in the general design guidelines, only a fraction of the design considerations is applicable to dissipative products.

Telenko, et al. [34] state that it is up to designers to go through the general and product type-specific design guidelines to create their version. Thus, for general design guidelines to be even more useful, they could indicate the products for which different design suggestions are suitable. For instance, Willskytt and Brambila-Macias [9], Bovea and Perez-Belis [17], and Vezzoli [32] each acknowledged that different product categories have different design constraints.

Conversely, it has been argued that design guidelines need to be specific to certain product groups or able to be customized to different product groups [25,26]. From the analysis of the product type-specific design guidelines, it can be noted that the more specific the requirements for the product, the more product-specific the guidelines (e.g., food products). Furthermore, product type-specific guidelines can provide more concrete and detailed design considerations. In addition, many note that the characteristics of environmental impacts vary by industry sector and, therefore, the opportunities for improvement also vary [25,64]. Finally, Kane, et al. [55] call for application of circular design principles to specific industries.

In summary, this literature review finds that general and product-specific guidelines are complementary to each other and indicate the importance of product type-specific guidelines.

5.4. Areas for Future Research

From the review, it was possible to identify several areas in which more research is needed. Firstly, design considerations for reducing losses in the use-phase were limited for both the general and some of the product type-specific design guidelines. More specifically, there was a limited inclusion of design considerations aiming to improve the product and packaging to ensure that all of the product could be consumed, and, design for sustainable behavior (DfSB) considerations in general. For instance, a study that investigated the cause of household food waste in Sweden [65] found that 20–25% of the food waste could be related to the packaging and that three packaging aspects dominate the reason for waste: packages that were too large, packages that were difficult to empty, and waste caused by products that were past their "best before date". They also found that environmentally educated households wasted less, particularly of prepared food, but also of products that had passed their "best before date". In addition, Wikström, et al. [52] highlight in their work that more research is needed on packaging functions and user behavior that reduce food losses. This indicates that both packaging design and information provided to consumers are important to reduce food waste (which can be undertaken by using DfSB). It can also be noted that most examples and case studies in the literature of strategies for reducing losses during use mainly concern reduction in energy, such as electricity in households and fuels in vehicles, e.g., Shu, et al. [66] and Wever, et al. [67]. Fewer cases and applications of DfSB have been related to consumables, other than energy, such as food, diapers, or soaps, which are needed to understand how such product losses can be reduced during use.

Second, this review also indicates that there is a potential for companies to learn about resource-efficient product designs from other products that share similar transferability aspects, such as for food and medical products. Research is thus needed to explore the extent to which the identified transferability aspects are determinants of the suitability of design considerations. This research could help designers filter and select relevant design guidelines.

5.5. Limitations

The first limitation concerns the method for conducting the literature search. The primary literature search to identify design guidelines was conducted by using Scopus. This can be seen as a limitation because many product type-specific design guidelines are not primarily published as scientific articles, but as reports. Attempts were made to avoid this limitation by conducting supplementary searches via Google and Google Scholar, however, more emphasis on these search engines may have resulted in additional relevant design guidelines. Another possible means of targeting product-type specific guidelines could be to search for sector organization's webpages and looking for sector-specific guidelines.

Another limitation concerns the keywords for collecting studies. For instance, the search string did not include product design methods in addition to guidelines, such as design for X and various design tools. However, such design methods are, in many cases, specialized for a certain problem or life-cycle step [34], which could have limited the study's scope. Additional keywords of specific consumables could also have provided a greater pool of papers for the product type-specific analysis. For instance, there was limited coverage of cosmetics, and consumables such as detergents and other cleaning products.

The last limitation concerns the percentage of relevant design considerations for the respective consumable types (Table 13). The numbers can be slightly misleading because the greater the number of design considerations provided by a design guideline, the lower the percentage. For instance, 36 of the total of 108 considerations were applicable to dissipative products from Brezet and van Hemel [35] design guidelines, thus accounting for 33%. By comparison, for Moreno, et al. [15], 12 of 24 (50%) considerations were applicable to dissipative products. Another difficulty was the demarcation of relevant design considerations for dissipative products because they usually consist of a product system of a dissipative product and disposable packaging. Similarly, it was difficult to demark relevant design considerations for disposables made into reusable products. To make a distinction, for dissipative products the suitability of design considerations focused on the dissipative product rather than the product-packaging system. For disposables made into reusable products, the design considerations of relevance for simple durable products and the maintenance thereof were included (thus excluding design considerations for complex durable product structures and components).

6. Conclusions

This paper aimed to study design guidelines for resource efficiency and their relevance for, and applicability to, consumable products. The analysis of the general guidelines showed that, although the guidelines are intended to be general and applicable to many types of products, their applicability to consumable products is limited. Less than half of their recommendations can be applied to consumables. Moreover, this analysis revealed that, on average, the ecodesign literature provided more design considerations of relevance to consumables. This analysis also shows that it is important to have a life-cycle perspective that includes design considerations over the entire life cycle of products, to maximize the opportunities to improve consumables.

This paper also analyzed the design considerations covered in the design guidelines of different groups of consumable products. The analysis identified several design considerations that are transferable between product-specific design guidelines. The aspects that determine the applicability of specific design considerations and their transferability between guidelines for different product groups are product characteristics, shelf life, and use time (for dissipative products), in addition to function of the product, who handles the product, and legal requirements of relevance to the product.

Finally, this research found that design considerations to reduce losses during the use of consumable products are only included in the design guidelines to a limited extent.

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