Product Design in a Circular Economy

Development of a Typology of Key Concepts and Terms

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Summary

In a circular economy (CE), the economic and environmental value of materials is preserved for as long as possible by keeping them in the economic system, either by lengthening the life of the products formed from them or by *looping* them back in the system to be reused. The notion of *waste* no longer exists in a CE, because products and materials are, in principle, reused and cycled indefinitely. Taking this description as a starting point, the article asks which guiding principles, design strategies, and methods are required for circular product design and to what extent these differ from the principles, strategies, and methods of eco-design. The article argues that there is a fundamental distinction to be made between eco-design and circular product design and proceeds to develop, based on an extensive literature review, a set of new concepts and definitions, starting from a redefinition of *product lifetime* and introducing new terms such as *presource* and *recovery horizon*. The article then takes Walter Stahel's Inertia Principle as the guiding principle in circular product design and develops a typology of approaches for Design for Product Integrity, with a focus on tangible durable consumer products. The newly developed typology contributes to a deeper understanding of the CE as a concept and informs the discussion on the role of product design in a CE.

Introduction

The field of eco-design is well developed and recognized. It provides product designers with a range of guiding principles, eco-design strategies, and methods (Pigosso et al. 2015; Bovea and Pérez-Belis 2012; Luttropp and Lagerstedt 2006; Brezet and van Hemel 1997). The recent attention for the circular economy (CE) has led design researchers to question the validity of these guiding principles, strategies, and methods when attempting to design for a CE. This article argues that there is a fundamental distinction to be made between eco-design and circular product design, and this means that circular product design requires a new, or at least an adapted, set of principles, strategies, and methods.

Although there are many alternative descriptions and definitions of the CE, the description used here is based on material flow concepts developed in the field of industrial ecology (IE) (Ayres 1994; Stahel 1994, 2010; Lifset and Graedel 2002): In a CE, the economic and environmental value of materials is preserved for as long as possible by keeping them in the economic system, either by lengthening the life of the products formed from them or by *looping* them back in the system to be reused. It follows that the notion of *waste* no longer exists in a CE, because products and materials are, in principle, reused and cycled indefinitely. Although there will always be a certain amount of unavoidable dissipation (Ciacci et al. 2015), the intention of a CE is to work toward a closed loop. In order for a CE to become

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fully sustainable, the vast majority of the energy inputs should be derived from renewable sources (Ayres 1994).

The goal of this article is to identify guiding principles and to provide a basis for the development of design strategies and methods that could underpin product design for the CE, taking as a starting point the notion that eco-design and circular product design differ on a fundamental level. The current guiding principles, strategies, and methods as proposed by eco-design are rooted in the here and now (which is the linear economy). Eco-design is the systematic integration of environmental aspects into product design with the aim to improve the environmental performance of the product throughout its whole life cycle (EC 2009a). Eco-design is what Faber and colleagues (2005) and de Pauw (2015) refer to as a *relative* approach. It "starts with the present state of affairs and identifies existing problems, which people subsequently attempt to solve. Improvements take place incrementally . . . . In contrast to the absolute approach, the focus of this relative approach is not the good, but the less worse or better" (Faber et al. 2005, 8). It is precisely this focus that was critiqued (e.g., de Pauw 2015), because how can designers come up with truly sustainable or circular innovations if the current methods only lead them to optimize what is already there? It led design thinkers such as McDonough and Braungart (2002), Benyus (1997), and Webster (2015) to propose more absolute approaches. These imply notions of ideal states (i.e., the CE as an ideal state) and challenge designers to strive for such an ideal state, thus opening up a wider solution space and an increased likelihood of finding innovative solutions (de Pauw 2015). To meet these challenges, however, product designers need guiding principles, strategies, and methods to guide the conceptualization and embodiment of their designs.

So far, *absolute* approaches have been viewed by many as utopian, impractical, and unnecessarily normative. Nobody knows what the real form of a truly CE is and whether or not it could work. Nevertheless, designers should be expected to explore new avenues and promising directions. The urgency of this was expressed by the CEO of design consultancy IDEO, Tim Brown (Brown and Katz 2011, 3): "It is hard to imagine a time when the challenges we faced so vastly exceeded the creative resources we have brought to bear on them."

This article therefore asks the question: If we accept the *absolute* idea of a CE as described above, how would this affect the way we design products in a CE? This article takes a first step toward answering this question by critically evaluating the key concepts and terms we currently use when discussing a product's lifetime and end of life (EoL).

Method and Scope

A literature review is done in order to create a comprehensive overview of the key concept and terms that might be relevant for product design for a CE. The literature review is based on the procedures described by Hagen-Zanker and Mallet (2013) and draws predominantly from the fields of IE, eco-design, and sustainable product design, and includes (mostly gray literature) on CE. The initial body of literature is compiled from the search results returned by Google Scholar, for search terms related to sustainable product design, eco-design, and CE. The initial list of search terms consists of (combinations of): "closed loop," "definition*," "description*," "terminology," "standard," "product," "product life*," "maintenance," "obsolescence," "planned obsolescence," "product design," "recondition*," "recover*," "refurbish*," "remanufactur*," "recycl*," "reuse," "renewable energy," "repair," "resource*," "reverse logistics," "upgrad*," and "waste." Using snowballing, new keywords that emerge are added to the initial set.

The results of the searches are scan-read for relevance and irrelevant articles discarded. In total, over 400 articles are studied in order to identify the *seed literature* (works of research on the topic considered as fundamental in the specific field) and to detect similarities, discrepancies, inconsistencies, and/or contradictions (Hart 2011). This article represents an abbreviated report of the synthesis of this literature review. A more extensive description will be provided in a Ph.D. thesis (den Hollander Forthcoming). Using the findings from the literature review, the article then develops a new typology for Design for Product Integrity. The typology is intended for durable consumer products: That is, tangible durable consumer goods that may or may not be accompanied by intangible services. Single-use consumer goods, like toilet paper or single-use packaging, are out of scope.

Eco-Design versus Circular Product Design: Fundamental Differences

One of the guiding principles of eco-design is the waste hierarchy, described in the European Waste Framework Directive (EC 2009b). The waste hierarchy details a priority order for managing waste, moving from prevention of waste (the preferred option), to reuse, recycling, other recovery (e.g., energy recovery), and disposal (the least preferred option). For eco-design, the goal is to strive for prevention over reuse, and for reuse over recovery, etc. Waste is defined in the Waste Framework Directive as "any substance or object which the holder discards or intends or is required to discard."

The current definitions of prevention, reuse, recovery, and recycling all hinge on the assumption that a product at a certain point in time inevitably will become waste. The waste hierarchy, for instance, defines prevention as: "measures taken before a substance, material or product has become waste." The definition of reuse is: "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived," and the definition of recovery is: "any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy." This shared reliance on waste as a central defining entity renders them virtually meaningless in context of a CE, where waste does not exist. It provides a clear indication of the need to examine the underlying concepts these terms aim to express and, if so, to reconsider and adjust their wording accordingly.

The waste hierarchy has been critiqued by Behrens and colleagues (2007) for not necessarily having a positive impact on dematerialization and decoupling, given that it focuses only on waste and does not address material inputs directly, nor consider economic output. Van Ewijk and Stegemann (2014), in addition, provides a critique relating to the hierarchy's priority orders. First, they argue, inclusion of an option in a priority order legitimizes its existence (i.e., disposal). Second, the common understanding is that one needs to move up the hierarchy rather than necessarily achieve the highest outcome. It is about the direction of change rather than the end goal, which illustrates the relative nature of the waste hierarchy (and of eco-design).

With the Inertia Principle, Walter Stahel introduced a guiding principle for circular design: "Do not repair what is not broken, do not remanufacture something that can be repaired, do not recycle a product that can be remanufactured. Replace or treat only the smallest possible part in order to maintain the existing economic value of the technical system" (Stahel 2010, 195). For product designers, the Inertia Principle is about product integrity, which we define here as the extent to which a product remains identical to its original (e.g., as manufactured) state, over time. The starting point is the original product, and the intention of the Inertia Principle is to keep the product in this state, or in a state as close as possible to the original product, for as long as possible, thus minimizing and ideally eliminating environmental costs when performing interventions to preserve or restore the product's added economic value over time. This illustrates the absolute nature the Inertia Principle (i.e., it is aimed at a utopian goal).

Because the Inertia Principle starts from the highest level of product integrity, it is understood that moving down the hierarchy may be inevitable in the real world, but is not the preferred direction. From a product design perspective, recycling is the least preferred option given that it involves the destruction of a product's integrity. The recycling process involves the dismantling and disintegration of a product and its constituent components and the subsequent reprocessing of the product's materials.

If we accept that product design for a CE, hereafter *circular product design*, is guided by the Inertia Principle and the concept of product integrity, the next step is to develop a set of key concepts and terms that incorporate these principles and that include the fact that a product can, in principle, not become waste.

Key Concepts for Circular Product Design

For a CE to mimic a closed-loop system as closely as possible from a material flow perspective, resources that have entered the CE have to remain accounted for at all times: before, during, and after their lifetime as useful products. It follows that product lifetime is a key concept in a CE.

Products Become Obsolete/Product Use Cycle/Product Lifetime

Product lifetime is often equated with the time span during which a product is functional (e.g., Murikami et al. 2010). However, functionality is considered an insufficient criterion for two reasons. First, many products are discarded while still in perfect working order (Oswald and Reller 2011; Bayus 1991; Van Nes 2003). Second, products can be temporarily out of order without immediately being discarded. A flat tire is no reason to discard a bicycle. We therefore propose to define product lifetime in terms of obsolescence. A product becomes obsolete if it is no longer considered useful or significant by its user (Burns 2010). The literature distinguishes different types of obsolescence or reasons for products being discarded. Burns (2010), for instance, discerns aesthetic obsolescence (i.e., products that have become outmoded), social obsolescence (i.e., products that have become outlawed), technological obsolescence, and economic obsolescence. Further examples include logistical and functional obsolescence (Cooper 2010; Bartels et al. 2012; Tomczykowski 2001; Feldmann and Sandborn 2007).

However, reduced to its essence, all obsolescence ultimately is a loss of perceived value (i.e., desire or affinity) of the product and/or system, triggered, in some instances, by reduced functionality at the product and/or system side (Box 1983). The state of obsolescence does not have to be permanent. It can often be reversed, giving a product a new lease of life. Expressing product lifetime in terms of obsolescence and acknowledging that obsolescence can often be reversed leads to the following newly synthesized definitions:

Product use cycle is the duration of the period that starts at the moment a product is released for use after manufacture or recovery, and ends at the moment a product becomes obsolete.

Product lifetime is the duration of the period that starts at the moment a product is released for use after manufacture and ends at the moment a product becomes obsolete beyond recovery at product level.

Recovery is a term for any operation with the primary aim of reversing obsolescence. Note that this definition of recovery rather differs from the one presented in the Waste Framework Hierarchy (see the section *Eco-Design versus Circular Product Design: Fundamental Differences* in this article).

From the above definitions, it follows that products can have one or more use cycles, but only one lifetime. As long as a product's obsolescence can be reversed, a new use cycle can be started. If, however, resources can only be recovered at the expense of permanently destroying product integrity, that is, through recycling at material level, the product lifetime ends. By using the term obsolescence in the definitions of product use cycle and product lifetime, it is acknowledged that the duration of product use cycles and product lifetime are not solely determined by the physical properties of the isolated product, but rather by the perceived value within its wider context. Interventions to deliberately lengthen a product's overall lifetime can thus be aimed at modifying the physical properties of the product, as well as at altering the product's position relative to its wider context.

Presource/Leakage/Recovery Horizon

Until now, the term assigned to obsolete products and their embedded resources in a linear economy mostly depended on their location. Unused products, tucked away in people's homes, are said to be hibernating (Oswald and Reller 2011) or called stock (Graedel et al. 2013) and are destined to become waste. To redefine obsolete products and their embedded resources in a CE, making their designation independent of location and distinguishing them from virgin resources, we propose a newly synthesized definition for these obsolete products awaiting recovery. The new term is a contraction of *product* and *resources*, reflecting their lineage and potential economic value for production:

Presource is a term for obsolete products awaiting recovery.

The concept of presource pertains to the whole product as it became obsolete and as such does not discriminate between components, parts, or materials. Depending on the intervention that is applied to recover the obsolete products awaiting recovery, presource is converted into products or components (e.g., through, repair, refurbishing, and remanufacturing) or materials (e.g., recycling).

Although the CE knows no waste, in reality there will always be dissipative losses. These are defined by Ciacci and colleagues (2015) as the flows of materials from the anthroposphere (i.e., human systems) to the biosphere (i.e., environment) in a manner that makes their future recovery extremely difficult, if not impossible. Examples of such dissipative losses are platinum and cerium released from autocatalytic converters, the wear of rubber tires, and the evaporation of chemicals contained in solvents, lubricants, and coolants. In this article, building on the description of dissipative losses by Ciacci and colleagues (2015), we propose the term leakage:

Leakage is a term for products or their components/materials that flow from the circular economic system to the biosphere, and that cannot be recovered at the present time.

The integration of the temporal aspect in the above definition of leakage suggests that what is considered leakage today, could tomorrow be recovered, given that recovery methods, processes, and facilities are likely to evolve over time. This leads to the concept of recovery horizon. Recovery horizon is defined as:

Recovery horizon is the present limit beyond which products or their components cannot be recovered.

Summarizing, the goal of a CE is to have as many resources as possible remain part of the economic system and, when needed, to return them from the obsolete state (presources) to the nonobsolete state as quickly and efficiently as possible, while all the time minimizing leakage and pushing the recovery horizon.

Design for Product Integrity: A Typology of Design Approaches

Following the Inertia Principle and the concept of product integrity, designers in a CE should first aim to prevent a product from becoming obsolete and, second, make sure that presources can be recovered with the highest level of integrity (i.e., reversing obsolescence). These two goals can be pursued at the level of products and components (this will be referred to as *design for product integrity*) or at the level of materials (referred to as *design for recycling*). Circular product design includes both design for product integrity and design for recycling (see figure 1). When designing for recycling (either conventional or biocycling), the product's integrity is lost. The designer's goal is to ensure that the product's materials can be recycled as efficiently and effectively as possible and can be looped back into the economic system.

In the remainder of this article, the focus will be on *design for product integrity*, because *design for recycling* is an established concept that has been reasonably well described in the literature (see, for a recent review, De Aguiar et al. [2017]).

Designers can help prevent a product from becoming obsolete by creating products with a high physical and emotional durability, that are intended to be used for a long time. In other words, such products *resist* obsolescence. An example could be a comfortable, sturdy pair of leather boots. Designers can also create products that are easy to maintain and/or upgrade, thus enabling extended use. Leather boots are relatively easy to maintain, for instance—all they require is a regular polish. This helps *postpone* obsolescence. Design approaches for long use and extended use, that resist or postpone obsolescence, prolong a product's use cycle and thus extend its lifetime.

In order to facilitate recovery (*reversing obsolescence*), designers can create products that are, for instance, easy to repair or refurbish. A hole in a leather boot's sole renders the boot obsolete. The hole can, however, easily be repaired by a cobbler, thus giving the boot a new use cycle and extending its lifetime.

A typology for *design for product integrity* in a CE is depicted in figure 2. The different design approaches will be described and defined in more detail in the subsequent paragraphs. We will show that taking an industrial design perspective on countering obsolescence requires existing definitions to be adapted and expanded, because they need to include aspects that were not considered when product lifetime was defined exclusively in terms of functionality, such as brand (Kotler 1984; Simões and Dibb 2001), warranty (Ijomah et al. 2004), cosmetic condition (Van Nes and Cramer 2005), and the need to control access to intellectual property (Sundin 2004). References to these aspects are included in the new definitions because they significantly affect perceived use value (and thus the onset of obsolescence) as well as the range of options for design interventions.

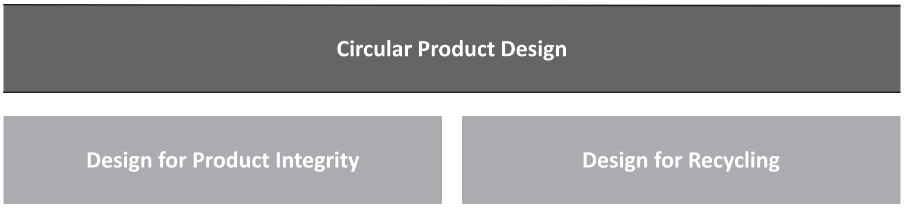

Figure 1 Circular product design encompasses both design for product integrity (aimed at preventing and reversing obsolescence at a product and component level) and design for recycling (aimed at preventing and reversing obsolescence at a material level).

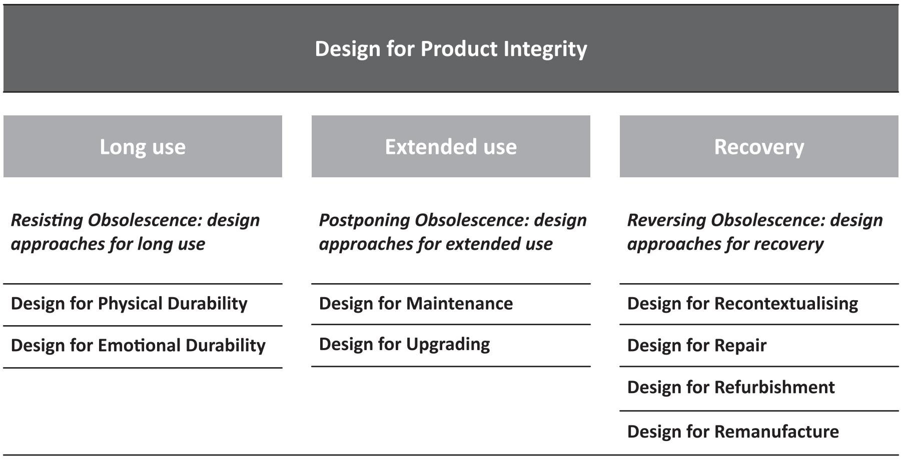

Figure 2 Typology of design approaches for product integrity.

Resisting Obsolescence: Designing for Physical and Emotional Durability

A product has a high physical durability if its performance over time degrades slower than comparable products on the market. Degradation can, for instance, be caused by wear, fatigue, creep, and corrosion and can, to a certain extent, be influenced by the design of the product and its components (Goel and Singh 1997). Durability is a physical property of a product, and *design for durability* has been researched quite extensively (see, e.g., Keoleian and Menery 1993; Bijen 2006; Vezzoli and Manzini 2008).

The opposite is true for emotional durability, where far less research has been undertaken. Page (2014) presents a review of the literature on how consumer-product relationships are formed and whether feelings of attachment influence replacement decisions. Page's research makes clear that the field of product attachment is still under development, with different schools of thought that touch or overlap to a greater or lesser extent, but do not share a common structure or framework. The overall conclusion of the review presented by Page (2014, 280) is that product attachment and emotional durability is influenced by many factors, some of which can be implemented and enhanced by designers. Many are, however, difficult to control. Page concludes: "designers must think carefully about which attachment areas are appropriate to their product and consider their relevance for each consumer's situation."

Postponing Obsolescence: Designing for Maintenance and Upgrading

The international standard EN 13306 (2010, 5) on maintenance terminology defines maintenance as the "combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function." In this definition, postponing obsolescence (i.e., retaining a product in a functioning state) and reversing obsolescence (i.e., restoring a product to a functioning state) are both considered maintenance. In practice, this led to the terms *preventative maintenance* (retaining) and *corrective maintenance* (restoring) being introduced (Moss 1985). In the typology presented in figure 2, design for maintenance is used exclusively as *preventative maintenance*.

Maintenance terminology was developed in the field of engineering, which is why (according to the standard definition) it focuses on technical and organizational issues. In addition to making adjustments to the settings of the original product, maintenance removes elements that are foreign to the original product, for example, dust and/or adds or replaces specific elements (consumables) that are required for the standard operation of the (durable) product, for example, fuel, filters, or lubricants. These maintenance activities are often characterized by their repetitive nature. When applied to consumer products, maintenance retains an aesthetic and/or hygienic condition, like in clothes laundering (washing and ironing). This is captured in the following definition:

Maintenance is the performance of inspection and/or servicing tasks at regular intervals, to retain a product's functional capabilities and/or cosmetic condition.

The definition of upgrading is an extension of the above definition of maintenance, whereby *retain* is replaced by *enhance* to express the overall intent of the process of upgrading, as defined by Flexner (1987), cited in Linton and Jayaraman (2005). Upgrading is usually done when a product is still in good working order, but the context of use changes, making it necessary to enhance the product's capabilities. As the user of a pair of sturdy leather boots grows older (i.e., changing context of use), feet may require more support. Upgrading the boots by fitting orthotics prolongs the boots' use cycle and extends their lifetime.

Upgrading is the process of enhancing, relative to the original design specifications, a product's functional capabilities and/or cosmetic condition.

Reversing Obsolescence: Designing for Recontextualising, Repair, Refurbishing, and Remanufacturing

This section describes and defines four design approaches aimed at reversing obsolescence (e.g., recovery) at product level, ordered by declining product integrity: design for recontextualizing; repair; refurbishing; and remanufacturing.

Recontextualizing is a new term, which was introduced to replace the term repurposing. From the current literature (Oakdene Hollins Ltd. 2007; Gray and Charter 2007; Watson 2008; EC 2009b; BSI 2009, 2011; EMF 2014), it is unclear whether or not repurposing, defined in BS 8887-2:2009 (BSI 2009, 5) as "utilize a product or its components in a role that it was not originally designed to perform" allows for remedial actions. In addition to these changes in role, repurposing can also denote changes in user or owner (person or organization) (Oakdene Hollins Ltd 2007). This is, however, not evident from its current definition, that further fails to explicitly accommodate for changes in the wider context surrounding the product, like, for example, business model and/or regulatory framework. In our definition of the proposed new term recontextualizing, all changes to factors *other than the tangible product as it was designed* are considered changes in context. Remedial actions, like repair, are explicitly excluded to prevent overlap with other recovery interventions. Examples of recontextualizing are the secondhand sales of a pair of sturdy leather boots (change of owner), the deployment of an older laptop computer as a thin-client server (change of role), and the use of older and previously privately owned cars as cheap rentals.

Recontextualizing is a term for use of an obsolete product (or its constituent components), without any remedial action, in a different context than it was (they were) originally designed for.

Corrective maintenance is usually equated with the term repair. This study uses a definition of repair based on Ijomah and colleagues (2004), but with the inclusion of a statement about the end condition of the product, as introduced by Stahel (2010) and Flexner (1987) in their definitions of repair. Also, as the adjectives *sound* and *good* in Flexner's (1987) definition are open to multiple interpretations, they were replaced by *working*. A statement regarding warranty is further included here as Ijomah and colleagues found that when a product's obsolescence is reversed, "a warranty serves as a guide to a product's quality" (Ijomah et al. 2004, 6). Given that manufacturers may expand their warranty coverage as part of a marketing strategy, the included statement represents the minimum warranty coverage associated with each particular type of intervention.

Repair is the correction of specific faults in an obsolete product, bringing the product back to working condition, whereby any warranty on the repaired product generally is less than those of newly manufactured equivalents and may not cover the whole product, but only the component that has been replaced.

In figure 2, refurbishing or reconditioning is placed below repair but above remanufacturing. The reason for this, as Oakdene Hollins Ltd. (2007, 20) argued, is that "unlike remanufacturing, reconditioning only requires the rebuilding of major components to a working order rather than 'as-new'; yet, unlike repair, all major components that are on the point of failure will be rebuilt or replaced, even where the customer has not reported or noticed faults in those components." Similar to repaired products, "reconditioned products tend to have a lower performance specification and associated warranty than the equivalent new product."

In the newly synthesized definition of refurbishing, we introduce a cosmetic aspect, clearly distinguishing it from repair not only by the extent, but also by the nature of interventions.

Refurbishing, or its equivalent *reconditioning*, is the process of returning an obsolete product to a satisfactory working and/or cosmetic condition, that may be inferior to the original specification, by repairing, replacing or refinishing all major components that are markedly damaged, have failed, or that are on the point of failure, even where the customer has not reported or noticed faults in those components. Generally, any warranty on a refurbished product applies to all major wearing parts, but is less than that of a newly manufactured equivalent.

Remanufacturing is often taken to be an equivalent, or a variety, of refurbishing. This article, however, argues that the two are not the same. The differences originate in the way they deal with issues concerning brand and (control of) intellectual property. Whereas brand and (control of access to) intellectual property play an important role in business and industrial design, the current definitions of remanufacturing focus on functional aspects and are not explicit with regard to the actors that can engage in manufacturing (BSI 2009; Oakdene Hollins Ltd. 2007; Sundin 2004; Ijomah et al. 2004; Amezquita et al. 1995; Haynesworth and Lyons 1987; Lund 1983). We have therefore expanded the definition proposed by Ijomah and colleagues (2004) to incorporate the aspects of brand and (control of access to) intellectual property that set remanufacturing apart from refurbishing.

Remanufacturing is a term for a series of industrial processes in a factory environment, whereby an OEM (original equipment manufacturer), an OEM contracted third party, or a third party licensed to carry the OEM brand name, disassembles obsolete products into components, to a level as far down as needed to bring as many of those components as considered eligible after testing back to at least OEM original performance specifications and recombines those components—generally originating from different used products—with as few as possible new parts, to manufacture new products of a similar type and specification, that result in a new product with a warranty that is identical to that of an equivalent product manufactured out of all new parts.

This definition is an improvement over other definitions of remanufacturing because it does not differentiate between remanufacturing and conventional manufacturing based on the end result, but is based on the process followed in procuring raw materials and semifinished products and in bringing the end result into being. It also includes an explicit statement as to the remanufacturing agent, because active involvement of the OEM in remanufacturing efforts is considered essential. When there is no active involvement, as is the case with so-called independent or third-party remanufacturers (Jacobsson 2000), it is highly unlikely that OEMs will make their intellectual property regarding product and process remanufacturing available to the level needed by third parties.

And, finally, the new definition does away with the distinction between a warranty on a product manufactured completely from new parts or a product manufactured from a combination of new parts and parts restored to at least OEM specifications as part of a remanufacturing process.

Discussion and Conclusions

In this article, we explore how the context of a CE (which is, in principle, an economy without waste) might affect the way we design products. The goal of the article is to provide a basis for the development of guiding principles, design strategies, and methods that could underpin product design for a CE, with tangible, durable consumer products as the focal point. Accepting that waste is not an option in a CE, we consider that prolonging and extending useful lifetime by preserving embedded economic value is the most effective way to preserve resources. This leads to the redefinition of product lifetime and EoL and to the introduction of the Inertia Principle and the concept of *product integrity*. The article presents a typology for *design for product integrity*, which systematically describes different interventions for extending product lifetimes, classifying these as resisting, postponing, or reversing product obsolescence. Because the interventions are ordered according to the inertia principle, for example, decreasing product integrity, the typology helps to discriminate between the different options and provides initial guidance to industrial designers on how to prioritize the various interventions in their designs.

The typology for *design for product integrity* is a first step. Several important issues have not been taken into account in this article, which need further research and development:

Product Life Extension versus Environmental Impact

The ultimate goal of *design for product integrity* is to minimize and ideally eliminate environmental costs by preserving or restoring the product's added economic value over time. Extended product lifetimes, however, do not always result in a net reduction of environmental load. Over time, newer versions of products may be developed that incorporate more efficient technologies. From that moment on, the environmental impacts that arise from the prolonged use of a product may become larger than the embedded impacts of a more efficient replacement product (Bakker et al. 2014). Because the Inertia Principle does not account for this, product designers need to understand the ecological consequences of their design interventions.

Subjectivity

It is, by definition, impossible to objectively state whether a product is obsolete or not—subjectivity is at the heart of the definition of obsolescence and therefore at the heart of the definition of product lifetime. Obsolescence is largely in the eye of the beholder. It is, for example, often the user who determines whether or not a product is due for repair. A fully functional smart phone with a crack in the screen may be considered obsolete (and thus in need of immediate repair) by someone who highly values aesthetics, whereas it may seem in perfectly good working order to someone less concerned about the product's appearance. Even when the overall intention of *design for product integrity* is clear, the subjective nature of obsolescence can make it difficult for designers to predict and determine the best design approach.

Need for a (Business) Context

A design that facilitates, for instance, maintenance or repair for one actor can turn out to be impossible to maintain or repair for the other. This is a complicating factor. Product designers aiming to design for maintenance and/or repair need to ask the question: Who will perform the maintenance or repair and where? Is it a layman user at home, a professional in the workshop, or perhaps a robot at the manufacturer? The typology proposed in this article currently does not provide answers to such questions, because these involve taking into account factors like a product's particular business context and the business model it is embedded in. This may, for instance, determine to what extent a manufacturer chooses to limit or allow access to the workings and innards of its products. It follows that *design for product integrity* needs to be applied in conjunction with business models that allow the (repeated) capture of economic value over time. For example, in order to make a product that was *designed for remanufacturing* really work, obsolete products need to be consistently returned to the OEM to be remanufactured. This requires arrangements for reverse logistics and a transactional model that allows the (re)manufacturers to retain economic control of their product over time.

Role of Design

A business built around long-life products and recovered resources cannot operate without products that support that strategy, preferably by intention and design. For product designers, changes in business model could result in product design briefs that contrast starkly to those for the linear economy *throw-away* products. Although this might seem a daunting prospect at first, it also increases the importance of the product designer's role.

To conclude, in a CE, with waste no longer an option, recovery of (p)resources is bound to become more important. Future research could focus on how to improve the quality of the decisions how to manage and recover (p)resources over time. We expect that this will become a discriminating factor for the success of business strategies and thus product design strategies. The new typology provides a basis for comparison and communication that can help product designers make design decisions that will facilitate the transition from a linear to a CE system. With this article, we hope to stimulate the debate and take a first step toward a wider adoption of the concept of a CE.

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