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PRODUCT DESIGN FOR A CIRCULAR ECONOMY: FUNCTIONAL RECOVERY ON FOCUS

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Abstract

This paper explores existing design strategies, guidelines and product features that enable functional recovery operations like repair, refurbishing or remanufacturing. A circular economy demands for products to be kept as valuable as possible for as long as possible. Therefore, recovery operations should be easy to perform in an efficient manner, which is influenced by product design. As a result of the literature review conducted, this paper presents a categorization of functional recovery guidelines for product design and identifies the need to plan for recovery at early design stages.

Keywords: sustainability, design guidelines, end of use, recovery operations, early design phase

1. Introduction

Products are nowadays discarded and replaced due to irreparable failures, technological obsolescence, and fashion trends. These product replacement activities promote an increase in resource consumption that translates into negative environmental impact, for the most common action after the replacement desire is to "throw away" the old. By performing recovery operations on them like maintenance, upgrade, repair, refurbishment, remanufacturing or parts harvesting a product's functionality, as well as, its value would be preserved and the environmental burden reduced (Chiu and Chu, 2012; Bakker et al., 2014; Go et al., 2015; den Hollander et al., 2017; Favi et al., 2017; Harivardhini et al., 2017; Suhariyanto et al., 2017).

Over the past years, product design strategies have taken into consideration environmental damage by focusing efforts on redesigning individual qualities, individual products or a product's industrial process to reduce its environmental impact. This was carried out by minimising the consumption of natural resources and energy or(and) by putting a focus on recycling operations (Ceschin and Gaziulusoy, 2016). However, most of the in-use product design strategies focus on a single product's use cycle.

Designing products for one lifespan does not fit well with the demands of a circular economy. The reason for it being that, the circular economy's main goal is to close the loop of materials and avoid the generation of waste, as a natural ecosystem would do, while promoting economic growth. This implies, as (den Hollander et al., 2017) put it, that the resources that enter the economic system must remain accounted for before, during and after their lifetime as useful products. In order to do so, products need to be brought back to its original state or similar after they have been used so they can be reused. The circular economy principles establish a hierarchy of preferred recovery strategies. Reuse is the most preferred one. It preserves the product's integrity and requires relatively little resources to bring a product back into the economic system. Recycling is the least preferred one as only part of the materials is recovered, while product integrity and value are completely lost. The recycling process is destructive in nature which leads to a loss of material quality (Lacy and Rutqvist, 2015) and the recovery efficiency obtained is low when compared to functional recovery operations (Ng and Song, 2015). The most adequate recovery strategy depends on the type of product. However, the overall design strategy of a circular economy is clear, keep products functional and valuable for as long as possible except for products that consume high amounts of resources, like energy or water, during their use phase (Allwood et al., 2011). For resource consuming products, there might be an optimal lifespan based on the environmental load trade-off between the substituting solution and the product in use, depending on the technological progress on the reduction of consumption over time (Bakker et al., 2014). Thus, if optimal recovery becomes a design driver, as the circular economy prescribes, design strategies to create new products must be focused on contributing to efficient recovery operations, which allow for the material quality to be preserved.

In this context, the question that this paper addresses is **"How can product design ease the process of recovering functionality from products?"** As a result of a literature review, design strategies, guidelines and product features that enhance a product's potential to have multiple or/and long-life cycles are presented with a focus on the recovery operations to be performed on them and the expected quality output of each recovery strategy. The hypothesis that product design influences value recovery is well presented and found to be stated reiteratively in literature. This paper also reveals the lack of research on product design for circular economy at early design stages given the little amount of found papers; and the necessity to plan for the necessary recovery operations early in the design process so that the process becomes more efficient. The scope of the research has been limited by the assumption that the necessary business model for a successful value recovery process is in place (Bocken et al., 2016).

2. Methodology

To answer the research question previously presented, a **systematic literature review** was carried out inspired by the method proposed in (Waddington et al., 2012). First, a comprehensive research covering scientific and non-scientific papers on the topic of circular economy was done. Second, a more systematic literature review was conducted. The electronic database Scopus was used to retrieve scientific papers. The search terms used to retrieve the documents from Scopus were divided in three categories: product design, end of life strategies and circular economy. The search terms used for each of the categories were:

1. Search terms related to product design: "concept* design"; "early stage" AND "product design"; "sustainable" AND "product design"; "circular" AND "product design"; "ecodesign"; "design for sustainability"; "design for environment"
2. Search terms related to end of life strategies: "life-cycle"; "end of life"; "end of use" "closed loop"; "resource effic*"; "reuse*"; "repair*"; "remanufacture*"; "recover"
3. Search terms related to circular economy: "circular economy"

The resulting search strings where a combination of three of these terms maximum within one category or as a combination with another category. One example of a generated search string would be: "early stage" AND "product design" AND "circular economy". The symbol "*" was used to retrieve words with the same root but different endings, i.e. concept and conceptual would be searched as "concept*". Only articles, reviews and conference papers where considered without any limitation regarding year or journal. Only documents in English where considered. The literature search was carried out in the first week of October of 2017.

The search engine was set to look for the aforementioned keywords in either the title, the abstract or the author's keywords. Given the large amount of papers retrieved, the collection of papers was narrowed down by looking only into the title and abstract to determine the relevancy of the paper to the research., which was determined by searching specifically for keywords like "product design" "early stage" and the main recovery operations that the authors where interested in "reuse" "repair" "refurbish" "remanufacture" "maintenance". This reduced the number of articles from thousands (the retrieved papers count for around 13000 in total) to 20. Finally, through snowballing –looking into referenced papers by the sampled papers - 7 more articles were added to count up to 27 papers in total for the second, systematic literature review.

3. Results and discussion

3.1. Scientific papers related to product design and circular economy

By looking at the chronological development of publications on Scopus over the past years, it is clear to see that there has been a growing number of papers being published since 2014 that relate the aforementioned category of search terms related to product design with (AND) the search term "circular economy". In total 93 articles, of which only 3 refer to early design stages or concept design, them being conference papers dating from the years 2016 and 2017. Figure 1 shows the chronological development of publications in Scopus.

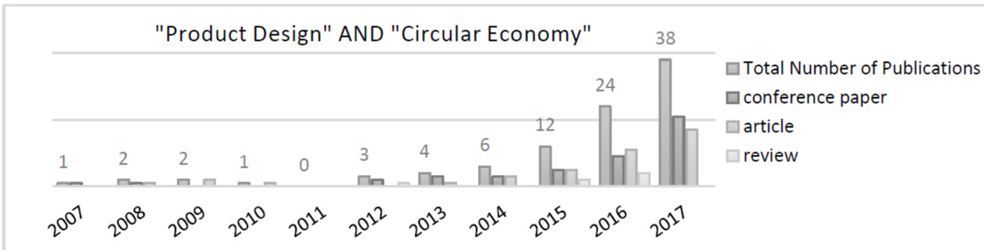

Figure 1. Distribution of number of publications for each year when using the search term circular economy and all the aforementioned terms in the category of product design

Despite the fact that a circular economy shifts, by its principles, the term of "end of life" to the term "end of use" at least for the recovery processes of repair, refurbishment and remanufacturing; there are not any results to be found with the keyword "end of use". This might be due to the fact that the term "end of life" has been used in literature to refer to the moment when a product is obsolete, in the eyes of the user, or cannot perform its functions any longer without distinction on whether it is the first use cycle or the last. However, it is not considered to be a gap of knowledge.

3.2. How can product design improve functional recovery from products?

In dealing with this research question, two perspectives have been taken. A retrospective one, going from finished products to design recommendations for an improved and more efficient end of life recovery process and a forward-looking perspective, going from design to product in which design strategies and guidelines are the starting point. Both approaches meet when considering value recovery operations, which are focused on functionality and appearance, as the main focus of the product design process.

3.2.1. Product design in retrospective: Finished products as a reflection of the design process

Product design features are defined as the characteristics of a product that describe its appearance, components and capabilities. They represent an adequate source of knowledge since they are the result of design decisions. Their detailed definition during the design process is of great relevance for after production activities, especially functional recovery activities, for they can ease or hinder the performance of operations and thus, the overall efficiency of the process.

The literature, majorly concerning EOL decision making and management, suggests which products' features have the highest influence on the recovery process and also, which product features affect the choice of the end of life (use) strategy. The criterion to categorize the features found in literature was determined by the authors based on whether the product features are determined by design, e.g. height, weight; or "imposed" by a product's context, e.g. technology around a product, consumer's acceptance, trends, business model, etc. This article will refer to product design features and leave product context features aside. Although product context features influence the potential economic success of a reused product they are considered to be beyond the scope of this research.

Product design features are classified by whether they refer to the **product's architecture or to the product's usage features**. They both influence the ease of recovery of a product. Product architecture features are primarily related to the nature, geometry, and number of components and the way in which these are assembled. Product usage features refer to characteristics of the product that deteriorate, thus becoming relevant for the performance of the product while in use or for future uses. As a result of looking into papers that fall under the category of **end-of-life decision making**, product features that determine which end of life strategy will be the most adequate for each product have been mapped. The collected data advises on the influence of product features into recovery strategies. However, it was found difficult to determine specifically which particular features influenced, directly or indirectly, which particular operations from the recovery process, i.e. cleaning, diagnosing, disassembling, reassembling, etc. The majority of the papers refer explicitly and generally to recovery strategies but implicitly to the recovery operations that need to be performed to recover the product. In addition, by looking into papers focused on **specific recovery strategies**, product characteristics that hinder the expected recovery strategies like maintenance, remanufacturing, or broadly speaking the reusability of a product, have also been mapped. It was found again that most of the stated product features refer to recovery strategies and not particular operations. Both results have been presented in Table 1, which aims to map the influence that product features have on different recovery strategies.

Table 1. Influential product features with respect to different end of life processes

Field of Study	Authors	Product architecture features	Product usage features	Recovery strategies/operations referred
End-of-life decision making	Rose and Ishii, 1999	Number of parts*, number of materials*, number of modules, functional complexity (relationship between modules and functions they perform), hazardous materials, size (*) critical characteristics to predict EOL strategy	Wear out life, level of cleanliness of product* – after its use.	Reuse, service, remanufacture, recycle or disposal
	Ramani et al., 2010	Product structure, disassembly level and sequence	Material properties, functional performance, reliability	Reuse, refurbishing, remanufacturing and material recovery
	Ma and Kremer, 2016	Product structure, joining and geometrical relationship among components, disassembly sequence, direction and force	-	Reuse, recycling and remanufacturing
	Chiu and Chu, 2012	Product architecture, disassembly sequence	Number and type of materials,	Reuse, remanufacture and recycling
Maintenance –only for mechanical products	Coulibaly et al., 2008	Complexity of the structure, i.e. geometry of parts and assembly links (fasteners)	Survivability (ability of the product to continue to work after the failure of a considered component)	Failure detection, diagnostic, reparation and test
Re-manufacturing	Hatcher et al., 2011	Product structure or geometry and joining or fastening methods	Value of materials, durability of parts	Disassembly, cleaning, differ from one product to another
	Sundin and Bras, 2005	Product and part geometries, fasteners and joining methods,	Process resistance of parts	Remanufacturing, refurbishment
Reparability	Pamminger et al., 2017	Product structure, joining elements, assembly of components (sequence, number of parts, directions)	Ageing resistance materials, robustness	Repair, reuse and remanufacture. Disassembly, reassembly and diagnosis

3.2.2. Planning for the recovery process through product design

Efficient product recovery would be achieved if the end of life strategy was **planned for early in the design process** (Ng and Song, 2015). This idea, also suggested in literature related to EOL management, is thought to facilitate efficient and effective take-back and recovery (Ramani et al., 2010). Planning means expecting the product to go through a certain recovery process, after a certain period of time – use phase of the whole lifecycle- and adapting its features to the process. It can only happen when a recovery strategy has already been decided for the product, which dictates the design strategy to be adopted. It is logical and necessary to make the product suitable to go through the recovery operations before the product has been released to production, when changes cannot be made. Therefore, planning for a product´s recovery would be done during the design process and not after production. (Shin et al., 2011) support the idea of planning at the beginning of product conceptual design so that end of life requirements will be considered together with customer requirements.

Planning for recovery operations can avoid the high labour costs of remanufacturing, mentioned by (Prendeville and Bocken, 2017) as an inhibitor for their case study, by reducing operation times and therefore, labour costs. It can also help in reducing storage costs associated to remanufacturing, if they are planned for it during the product layout. (Schöggl et al., 2017) also remark that planning would help in reducing repair costs because the potential to improve performance decreases the further the product is closer to production. Additionally, planning influences the environmental impact of a product. (Walker, 2012) emphasizes the importance of considering all the operations around the product, including the value recovery ones, and how energy intensive they are. He demonstrates how maintenance operations can be relevant in determining a product's environmental impact. (Sanyé-Mengual et al., 2014) have also shown how different maintenance operations can result in highly different environmental impact figures. They study two different products, demonstrating that if maintenance tasks are planned for and well communicated to consumers, the environmental impact due to maintenance tasks, which is not frequently considered, could be reduced. Finally, since recovery operations are reliant on the infrastructure in place, where the operations will be performed, through planning the task can be optimized and eased.

3.2.3. Product design to make products more circular

As it has been previously shown through the aforementioned retrospective and has been stated by (Go et al., 2015), product design decisions will inevitably affect recovery efficiency. Therefore, **product design strategies** have to focus on recovering and/or preserving a product's integrity if circular economy instructions become a driver for design. This paper presents design strategies that put product value recovery on the focal point following the typology of key concepts for a circular economy by (den Hollander et al., 2017) with some exceptions. Design for recycling, emotional durability and recontextualization strategies have not been included in the paper for the reasons that: recycling does not preserve the functionality of the product, design for emotional durability is of a strong subjective nature and it is not recovery focused and finally, design for recontextualization has also been omitted for there is not specific product outcome or operation to be performed.

The preferred design strategies for product value recovery are presented along the corresponding necessary recovery operations and also, the expected quality output that should result from recovery process. This approach has been taken so that it is clear in general terms what the procedures for recovery are for each plan of action. This is presented in Table 2. There are two clear categories within the design strategies, design strategies targeting product use extension and design strategies aiming at product reuse. However, they are not exclusive from each other. This is to say that life extension strategies can be combined with product reuse strategies with the aim to develop a product whose value will be easy to recover and maintain, for instance.

Design strategies focused on **preventive maintenance** aim to design a product where the removal of agents not specified in the product's original requirements as well as product specific operations will be easy to perform. Maintaining a product requires of product specific operations like refilling of fluid agents or worn out parts replacement. It is evident that maintaining the sharp edge of a knife –a sharp edge is considered to be OR- differs greatly from maintaining a vehicle to OR, although both they both aim at maintenance. It is important to notice that product maintenance requires of periodical monitoring and diagnosis (Iung and Levrat, 2014). **Hardware upgrading** strategies are mainly focused on the successful replacement of modules to gain more functionalities relative to the original functions. **Repairing** strategies are similar to those of corrective maintenance and breakdown maintenance. The strategy aims to ease repairing operations on products so that they can be easily recovered to a functional state and then, reused. **Refurbishing** or reconditioning strategies –synonyms in terms of (den Hollander et al., 2017)- are similar, in terms of the necessary operations to perform to recover the product, to those of **remanufacturing** taken from (Go et al., 2015) and (Sundin and Bras, 2005) and to those of **part harvesting**. The difference lies in the output quality reached after the process.

Table 2. Design strategies for functional value recovery and the recovery operations that allow for the desired quality output

Product Design for:	Strategy's Goal	Recovery Operations	Source for Operations	Operation's Goal	Output Quality
Preventive Maintenance	Enable use extension	Cleaning, diagnosis, product specific overhauling activities to rise quality levels up to OR and test	Kimura, 1999; Coulibaly et al., 2008	To retain a product's functional capabilities and/or cosmetic condition.	Similar or lower than OR
Upgrading (Hardware)		Cleaning, diagnosis, disassembly, modules replacement, reassembly, testing	Go et al., 2015	Enhancing, relative to the original design specifications, a product´s functional capabilities and or cosmetic condition	Higher than original requirements for the upgraded modules
Repairing - Corrective Maintenance and Breakdown Maintenance	Product reuse	Core collection*, diagnosis, cleaning, disassembly, specific component remediation, reassembly, testing (*) product specific	Pamminger et al., 2017	Correction of specific faults to bring a product back to working or cosmetic conditions	Similar or lower than OR
Refurbishing or Reconditioning		Core collection, diagnosis, cleaning, disassembly, storage, product repair/remediation, reassembly, testing	Deduced from remanufacturing process	Bring back to working or cosmetic condition	Similar or lower than OR
Part harvesting	Part reuse	Part collection, diagnosis, cleaning, disassembly, storage, repair/remediation, reassembly, testing	Deduction from remanufacturing process	Collection of working product's parts for new products.	OR or higher(1)
Remanufacturing	Product reuse	Core collection, diagnosis, cleaning, disassembly, storage, product repair/remediation, reassembly, testing	Sundin and Bras, 2005; RIC, 2016	Bring product back to original performance specifications	OR or higher[(1)]

The output quality of different strategies is directly related to the recovery process and can be a driver for design choices. For instance, if what is expected from a product is to have lower than OR requirements for certain features, design choices might change. It is also interesting to notice that remanufacturing processes can result higher than OR standards. This is common for mechanical products whose failures commonly occur when at the beginning of their use life. Remanufacturing companies, by offering reused and therefore, tested products, have the capability to offer higher than out-of-the-conveyor standards. It is common practice for engines, they are less prone to fail when they are given a second (or other) life through remanufacturing.

By looking into which recovery operations each design strategy leads to, design guidelines for specific recovery tasks have been mapped. The rationale behind this classification is that, as it is represented in Table 3, most operations are common among the different design strategies, however, the difference lies in the level of "deepness" in which they are performed in a product. For instance, cleaning for maintenance might refer to surface cleaning whereas cleaning for remanufacturing involves cleaning every component of an assembly to the core (including the core, if necessary). Some recovery operations are not needed in all the strategies. Another example to illustrate this idea, core collection, in the case of repair, is a product specific operation that depends on the business model. Products aimed to be repaired might undergo similar operations than those that want to be refurbished however, the level at which operations for recovery are performed varies. As an example, cleaning a product that is only aimed to be repaired might involve only superficial cleaning and around the repaired element, while a product that is aimed to be refurbished will require deeper cleaning of the overall product. However, as it is noticeable, the cleaning task on both products should be easy to perform.

Table 3. Recovery operations for each design strategy

Recovery Strategy	Operation level	Cleaning	Diagnosis/ Testing	Dis-assembly	Re-assembly	Storage	Disassembly stopping point
Maintenance	Superficial	x	x	x	x		Superficial
Upgrading	Only to upgradable modules	x	x	x	x		Upgradable module
Repair	Only on failing parts	x	x	x	x		Up to damaged component
Refurbishment	Failing parts + overall product but not in depth, just enough to make it marketable	x	x	x	x	x	Up to core
Part Harvesting	Like remanufacturing but only for specified parts	x	x	x	x	x	Up to desired part, might include the desired part
Remanufacture	All operations performed on the entire product – core + the rest	x	x	x	x	x	Up to core, might include the core

Operation focused guidelines are not exclusive, but rather they are to be used in conjunction. Since they are defined per operation, various design guidelines are to be used for the same product if it has to undergo multiple recovery operations. However, from the results found it is unclear which guidelines should have preference over other guidelines in the situation of a trade-off between product requirements. Additionally, it has not been found at which stage of the design process shall they be used.

Common operations in all design strategies are cleaning, diagnosis or testing and disassembly and reassembly. In fact, the **degree of cleanliness** in a product after its use is mentioned in (Rose and Ishii, 1999) as a critical feature to decide for the most adequate end of life strategy. **Inspection or diagnosis** tasks become especially relevant for maintenance operations (Coulibaly et al., 2008). Diagnosing a product or inspecting it will give information of its condition and functionality therefore it is also a critical operation. Finally, **non-destructive disassembly and reassembly** operations are necessary in order to have access to the subassemblies of a product. It is a critical task because it determines the accessibility and reparability, to some extent, of a product. For instance, if a product cannot be disassembled in a non-destructive manner because it has been glued, it will take more time and work labour to recover and thus, can make the process less economically interesting.

Found design guidelines to ease cleaning tasks, depicted in Table 4, address a products geometry and its surface. It must be said, that cleaning refers to a general, standard cleaning process, not to a cleaning method in particular. Design guidelines that refer to product diagnosis, Table 5, address a product's structure and the needed equipment for testing. Guidelines on disassembly and reassembly, Table 6, address four main product features: a product's assembly configuration, its sequence, reversibility and the number of tool changes; a product's fixtures, referring to the different types, their quantity, their wear resistance, the placement and its variety; a product's geometry and the tools required to perform the task like disassembly guides. Finally, storage operations become relevant for operations like refurbishing, part harvesting and remanufacturing. Storage operations are referred, in remanufacturing literature, as an operation that has to be performed when the product as a whole is irreparable but some parts are useful. When this is the case, it becomes beneficial to store the spare functional parts to potentially be used in other products (Sundin and Bras, 2005). Presented in Table 7, they are associated to geometric and aesthetical properties of products.

Table 4. Product guidelines to ease the operation of cleaning

Ease of cleaning refers to the removal of external, undesired agents from a product		
Geometry	Minimize geometric features that trap contaminants Reduce the number of cavities that are capable of collecting residue Avoid sharp edges and thresholds	Allwood et al., 2011; Go et al., 2015
Surface	Protection against corrosion and dirt Protect against contamination caused by wear	

Table 5. Product guidelines to ease product diagnosis operations

Ease of Diagnosis Refers to physical inspection, to quickly check the condition of the components and functionality testing of electronic or mechanical components		
Product Structure	Make wear of parts detectable and visible. Predefined wear facings to prevent attached components to be affected, signals and sign to point out wearing Provide easy access to test points Aim to concentrate wear damage in small detachable parts (inserts and sleeves)	Allwood et al., 2011; Tischner and Hora, 2012; Go et al., 2015
Tools	Reduce the number of different testing and inspection equipment pieces needed and the level of sophistication required Provide good testing documentation and specifications	

Table 6. Product design guidelines to ease disassembly and reassembly

Disassembly and reassembly guidelines Deconstructing the product in a non-destructive manner to perform repairing and cleaning.			
Assembly configuration	Sequence	Set centre-elements on a base part Aim at self-locating interfaces Mark parts which must be removed first Avoid multiple directions and complex movements for disassembly Avoid the need for specialized disassembly procedures Avoid long disassembly sequences: consider part order, part disassembly directions and number of reorientations. Locate parts with the highest value in easily accessible positions Find an optimized disassembly plan Find an optimized disassembly stopping point Create modular subassemblies which do not require further disassembly operations	Hui et al., 2008; Allwood et al., 2011; Tischner and Hora, 2012; Go et al.,2015; Favi et al., 2017; Harivardhini et al., 2017
	Reversibility	Plan for a reversible assembly process Avoid permanent fasteners that require destructive removal. Allow for non-destructive disassembly using snap-fit types of connections, active disassembly using smart material and heat-reversible.	
	Tools	Consider number of tool changes	
Fixtures	Type	If destructive removal is necessary, ensure that damage to the core does not happen Reduce the number of fasteners prone to damage and breakage during removal Use fasteners rather than adhesives Use fasteners that are easy to remove or destroy Use reversible joints or connectors with fracture points Easy detachable connections Avoid welding and jamming of parts Ensure screw threads are sufficiently robust	Billatos and Basaly, 1997; Ramani et al., 2010; Tischner and Hora, 2012; Go et al., 2015; Favi et al., 2017
	Quantity	Reduce the total number of fasteners in the unit Reduce the number of press-fits Minimize the number of joints and connections	
	Wear	Increase corrosion resistance of fasteners	
	Placement	Reduce the number of fasteners not in direct line of sight Make joints visible and accessible, avoid hidden joints Provide easy access to disjoining, fracture or cutting points	
	Variety	Standardize fasteners by reducing the number of different types of fasteners and the number of different sized fasteners Use the same fasteners for many parts	
Product Geometry		Create geometry and shape with the purpose of facilitating handling operations Modularize valuable modules. Increase product accessibility by eliminating visual and physical obstructions Merge components, whenever possible, with the aim to minimise the number of components and to reduce the number of assembly and disassembly operations Develop standard interface for the connection of different modules	Allwood et al., 2011; Favi et al., 2017
Tools		Provide good documentation of specifications and clear installation manuals. Avoid need for specific tools	Go et al., 2015

Table 7. Product design guidelines to ease storage

Ease of Storage Refers to the operations to keep valuable parts safe for future usage		
Geometry	Use identical or grossly dissimilar parts Avoid protrusions outside regular volume	Allwood et al., 2011
Aesthetics	Colour coding	

4. Conclusions

Product design plays a key role in achieving profitable end-of-life operations (Ramani et al., 2010). Therefore, product design should prepare products to have multiple life cycles, when circular economy is a driver for design. If products are designed for an efficient and affordable recovery, they can be valuable for a longer time. The most stated product features from EOL decision making and EOL management are: a product's geometry, the linkages between its components and how they are arranged as a whole. They influence a product's potential to be recovered after it has been used. It follows then, that if these features are settled adequately to match the recovery operation that they will undergo, the process of recovery will turn out to be more efficient, which can be quantified in terms of costs and required time per operation, as well as, the product's quality after going through the process. The efficiency of the recovery process relies greatly on whether it has been planned for in the product or not. Planning for the recovery operations, as the design strategies prescribe, is also useful to overcome challenges like high labour costs or storage costs associated to remanufacturing and refurbishing. Through planning the environmental impact of a product can be reduced by considering, for example, how resource intensive are the maintenance operations required for a product. It also helps in avoiding unwanted recovery results, like not being able to access a part or requiring for a specific unavailable tool.

From the design strategies that focus on multiple lifecycles, it has been found that they unclearly state the necessary operations required for each recovery strategy and the expected output quality. Hence, translating into bad guidance for designers given the broad sense of the terms and the inaccuracy in defining the process that products would undergo. This article has been able to put together those three relevant elements for the recovery process and has been able to conclude that different design strategies that aim for a product to have multiple lifecycles, do have recovery operations in common although these operations will differ from each other in the degree of effort required to perform the recovery, which depends on the product condition before recovery and the expected quality output of the company and the market. Following this idea, this research has been able to point out common critical operations for functional recovery. Those being: cleaning, diagnosis, disassembly and reassembly.

Shown that these guidelines have not been tested for implementation at early design stages, since they are the result of post-production objects analysis. The guidelines implementation needs to be tested. There is little information on how to use these guidelines or which guidelines should be prioritized over the others in case of a trade-off between them. Is it more important to prioritize reassembly or diagnosis, for instance? Also, at which point of the design process should these guidelines be implemented? The results of the paper are limited in the sense that they have not been implemented during the process with real cases. Scientific papers following up on the implementation of these design guidelines at early design stages have not been found. Instead, most of the papers refer to these guidelines as prescriptions or suggestions to be taken into account for future products. It is the aim of the researchers to investigate in the future design practice for functional value recovery. Also, a question that remains unanswered is "how to plan for the recovery operations through product design?" It is the intention of the researchers to continue with further investigations on the design practice to find out.

5. Limitations

Design strategies influencing the choice of material and manufacturing process and product structure alone cannot warranty the success of the recovery operation. It is clear that the necessary business model to allow for an economically successful process has to be put into place, and set in parallel with the design strategies to define distribution, logistics and management of the second life products, for instance. This has been an assumption used during the research process. The presented design strategies do not consider business capabilities, which are highly relevant when trying to market recovered products. The circular economy requires a more complex infrastructure than the one required in a linear one in terms of supply chain, logistics, marketing, recovery facilities and labour. The scope has been narrowed down to product-level requirements that make a product adequate to go through recovery processes successfully, it has not looked into a system level.

Another assumption made during this research is that there is an existing market that would demand for reused and long-life products without which these strategies would not make sense. The economy markets are driven by customer demands and this research assumes that this demand for reused products exits.

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