Exploiting the Right to Repair towards a sustainable future: a systematic literature review

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Abstract

Although the circular economy is not a new concept, most companies still follow linear economy models. Repairing is a circular economy strategy that slows resource usage. However, the repair is relatively overlooked with respect to other strategies. The objective of this paper is to investigate how to design repairable products to be compliant with the "Right to Repair" paradigm. Through a systematic literature review, this study collects and classifies design practices relevant for quick and easy repairing, providing a definition and some application cases for them. It finally discusses the adoption of Digital Technologies to reinforce Design for Repair practices.

Keywords: Design, Repair, Sustainability

Introduction

Most manufacturing companies design their products and processes to minimise development and production costs while pursuing their value proposition and customers' satisfaction (Hernandez et al., 2020). By doing so, linear value chains are usually designed, and products are difficult (or impossible) to be re-inserted into other value creation processes (Svensson et al., 2018). On top of that, the supply of products in mature markets is greater than the consumers' demand, leading to a constantly growing waste flow (The global e-waste, 2019). Thus, products end up in landfills quite quickly, creating a negative footprint on our planet.

Due to technologisation (Grinvald and Tur-Sinai, 2019), almost every consumer product has some type of electronics embedded in it, and the electronic waste increase is inevitable. The problem is getting more severe due to technophile consumers who do not want to use a product for a long time but prefer to change it as soon as new technology is available (Sabbaghi and Behdad, 2017).

So, our planet makes an urgent call to reduce waste. The “Forum for the Future” report estimates the current pace of resource consumption is 50% faster than their renewal. Thus, countries must react immediately to prevent this trend; otherwise, the Earth’s natural resources will run out by 2050 (Forum for the future report, 2021).

Governments of leading countries, such as the USA, Australia, the UK, and the EU, reply to such emergencies by establishing regulatory policies. One of these is the Right to Repair directive that aims at guaranteeing consumers the right to choose “who, what, where, why, when, how, and for how much their equipment is to be repaired” (The repair association, 2022). This regulation also aims at stimulating manufacturers to design products that are easily, safely and cheaply repaired. Fostering repair would allow consumers to use products longer, and product life cycle extension would slow down the use of resources. Having established the infrastructure to make repair possible, the next step will be to convince consumers to use their right to repair. To promote a culture of repair, there are Repair Cafés spread all over Western Europe and North America, where people meet to repair their everyday objects (Kannengießer, 2020). Despite this regulation effort, most companies keep on following a linear economy strategy (Bakker et al., 2014). The academic community also replies to the call for more sustainable business through waste reduction: the number of studies on the circular economy, sustainability in general and waste management is constantly growing (Bressanelli et al., 2020). Actually, repair as a standalone concept has received comparatively little academic attention since it has been relatively overlooked in the circular economy literature, as it is barely considered in classic 3R/4R/6R schemes. Being one of the steps (after reuse) to recover a product value and minimise waste (King et al., 2006), it deserves focused investigation on why it is not widely applied and how to promote it further.

Therefore, the objective of this study is to investigate how to design easily repairable products to be compliant with the “Right to Repair” paradigm in a circular economy. For that end, a systematic literature review is carried out. The remainder of this paper is structured as follows. First, a research background based on the systematic literature review is employed to outline Repair with respect to the other value recovery strategies. Then, a classification of collected design for repair practices is presented. Lastly, the paper discusses the findings in light of the potential application of digital technologies.

Research Background

Repair as a sustainable value recovery strategy

Repair is a product value recovery strategy that aims at correcting specific faults of a product (King et al., 2006) and restoring it to good working conditions after its damage (Bocken et al., 2016). Thus, repair extends the life cycle of a product, letting consumers use the product longer.

In the circular economy literature, repairing strategy has been relatively overlooked, as it is barely considered in classic 3R/4R/6R schemes. Repair is one of the R-strategies of extended circular economy models, such as 9-R or 10-R (Carlsson et al., 2021). However, literature to date mainly focused on other recovering strategies such as recycling, remanufacturing and refurbishing existing linear supply chains. Nevertheless, compared to other recovery activities, the repair is a more environmentally friendly option since it does not require complex reverse logistics and reverse manufacturing processes and infrastructures (Huang et al., 2016). Being the first step in product recovery management, the repair is simpler and cheaper to implement, as it requires lesser investments of resources, time, and energy to bring the product back into the system (Hernandez et al., 2020). Repair is an economically convenient option, especially if the user himself can perform it. For this purpose, there is an international global community of Repair Cafes that encourages society to repair their products when needed by approaching local experts instead of throwing them away. Several repair institutions (such as Repair Association, Service Industry Association, Electronic Frontier Foundation, iFixit.org) advocate for repair-friendly policies, regulations, statutes, and standards on the state and local levels. This way, they promote a repairing culture so that the product utility is maximised, and the waste from the product's disposal is minimised.

However, the repair is not a convenient strategy in 100% of cases. In the era of continuous technological development, products' environmental performances constantly evolve, and recently developed products could be designed to consume less energy or contain lower material density that makes them leave a lighter environmental footprint, not to mention users' safety or other performances. A study by Bakker et al. (2014) compares replacement scenarios of a 20-years old refrigerator with a recently bought one to define an optimal life cycle (Bakker et al., 2014), considering an environmental impact score. This study demonstrates the importance of a trade-off between value recovery strategies, such as repair, and the energy efficiency of technological novelties.

Design for Repair as a Lever of Circular Economy

Given that repair is an essential lever of a circular economy, indeed, the early stages of product development are crucial to enable circular and sustainable practices (Bressanelli et al., 2020; Bocken et al., 2016): in fact, the closer we move to the manufacturing stage, the fewer the degrees of freedom; so, it is difficult to incorporate any changes since resources, infrastructures and activities are already set for a specific product design. According to (Gauthier, 2017), up to 80% of a product's environmental costs are generated during its design phase. Therefore, development engineers must consider the sustainability perspective from the very beginning.

The literature on the "Design for X" concept presents different practices about designing a product to optimise subsequent performances, including environmental footprint. Research by Bocken et al. (2016) suggests classifying Design for X strategies in those that close, narrow, or slow the loop of resource usage. Considering repair as an activity that extends a product life cycle, the "Design for Repair" strategy belongs to the "slowing the loop" category (Bocken et al., 2016).

Research methodology

Scientific contributions selection was based on the two groups of keywords: (i) related to "repair", "right to repair", and "design for repair", and (ii) related to sustainability, such as "circular economy", "green", "eco". Scopus was the selected database, as it is a quite renowned source for engineering studies; articles, books, conference papers and editorials were included, and three subject areas were selected: "Engineering", "Business Management and Accounting", and "Econometrics and Finance" as they appear to be the most related to the field of study. The language of contributions was set for English only.

The combined use of keywords brought to the total number of 370 papers that were then filtered by relevance, based on journals, titles and abstracts. Due to the space constraints, not all selected papers are discussed in this study. A detailed process chart for the systematic literature review is presented in Figure 1 (Moher et al., 2009). This paper contains a content-based analysis of the selected articles.

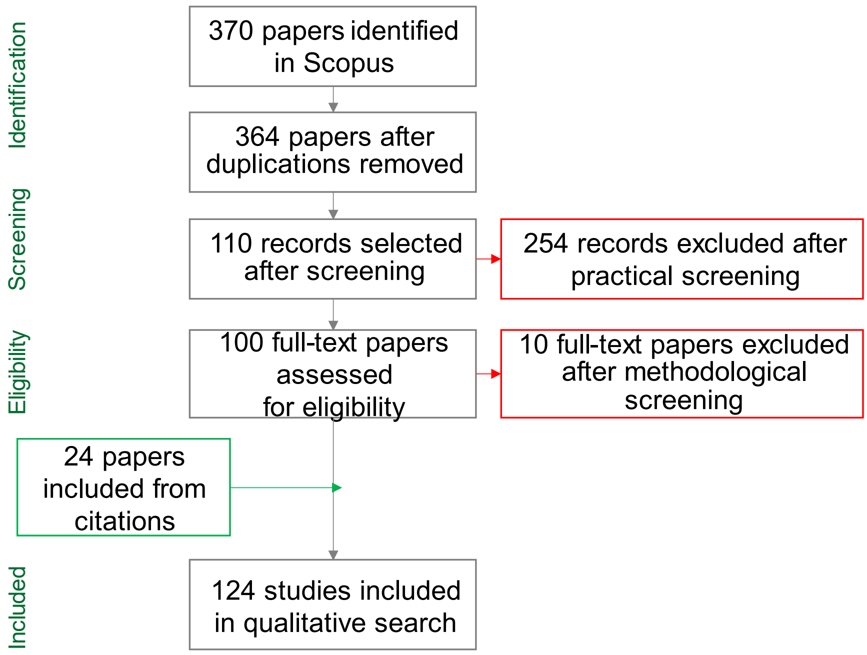

Figure 1. Process chart for the systematic literature review (Moher et al., 2009)

There were two main exclusion criteria for practical screening. The first one is related to the research area: the papers on civil engineering, sociology, history, political sciences, materials and energy management, design creativity, linguistics and education were excluded. The second one is related to the focus of the study: papers focused on recycling, materials selection, and the assessment of the environmental impact of such activities were excluded.

During the methodological screening phase, the following criteria were applied: exclusion of technical documents that contain a detailed description of repair services which are hardly generalisable; exclusion of papers in which repair is just mentioned, but it is not a focus of study. After the keywords-based search, a backward approach was adopted to include the relevant studies cited in the found contributions: this led to additional 24 papers being included in the review.

All papers have been analysed to identify a list of design for "slowing the loop" strategies and to collect the design practices that are relevant for easily repairable products. Thus, the findings section contains a classification of "design for slowing the loop" practices that could be applied to conceptualise Design for Repair and provides a definition for each of those practices.

Findings: Conceptualisation of Design for Repair

A review of design practices that aim at slowing the loop has shown that most of them are related to the product design phase and few others to the product use phase. The first category mainly covers the rules of product architecture, while the second one is focused on methods to develop a product in a way to be liked by users so that they are willing to use it as long as possible. The first category could be further split into two: practices for physical durability and practices for technological durability. The following sections will summarise these "Design for Repair" practices within each category.

Functional features for physical durability to extend product functional cycle

The physical durability of products is the central pillar of long-life product design (Bocken et al., 2016) and is influenced by product architecture, materials choices, etc. As the complexity of repairing activities depends heavily on the product architecture, the repair is directly tied up with the physical durability. Products that are designed for longevity make possible and easier repairing activities. (Svensson et al., 2018). Table 1 summarises all collected features related to the physical durability of products that are particularly relevant for making repair easier and quicker. Table 1 also provides a definition formulated by the authors and a collection of detailed practices for each feature.

Table 1. Functional features of easily repairable products

Design Feature	Definition	Practices
Easy and quick disassembly and reassembly	Possibility to perform straight-forward intuitive disassembly process and uncomplicated reassembly process	• Use assembly methods that allow disassembly without damage to (reusable) components (van den Berg and Bakker, 2015) • Apply loose fits for internal components, avoid many (5+) screws on different surfaces for a single component, avoid unnecessary components (van den Berg and Bakker, 2015; Mulder et al., 2014) • Avoid welding, glueing and adhesive between sub-assemblies (van den Berg and Bakker, 2015) • Do not use coated, painted or plated components; prevent discolouring (Mulder et al., 2014) • Ensure that fasteners' material is similar or compatible with that of the base material, thus limiting the opportunity of damage to parts during disassembly (van den Berg and Bakker, 2015) • Give priority to a non-destructive disassembly for maintenance and repair (instead, destructive disassembly is more appropriate for recycling) (van den Berg and Bakker, 2015) • Keying: utilising matching geometric features, e.g., matching sizes and shapes like holes and pins, ensuring correct positioning of connectors, components and parts (den Hollander, 2018) • Minimise the number of fasteners used in an assembly and standardise them to simplify and reduce the number of manufacturing operations; • Standardise assembly/ disassembly procedures to simplify maintenance tasks (Benabdellah et al., 2019) • Standardise the size, shape, and interface locations of "building blocks" (e.g., locations for mating attachment or mounting points and input/output line connectors), keep the visible relationship between components and coloured wires (Pozo Arcos et al., 2021) • Use nonexclusive / non-proprietary disassembly and repair tools (Sabbaghi, M. and Behdad, S., 2017)
Openability	Ability to open a product and be able to access its architecture with	• Assemble products with standard screws (Huang et al., 2016) • Avoid hidden fixings and snaps, deeply recessed fasteners, unnecessarily long cables (Pozo Arcos et al., 2021)

	standard tools and equipment.	• Use non-isolated electrical measuring points (valid for testing) (Pozo Arcos et al., 2021)
Modularity	Product feature that ensures its construction using individually distinct functional units instead of a solid monolithic structure	• Clear separation between the physical components, developing products architectures as a joint union of physically detachable modules (Bressanelli et al., 2020; Pozo Arcos et al., 2021) • Place together components with similar failure rates or life cycles, avoid combining components with different physical life or maintenance intervals to prevent the obsolescence of the entire product (van den Berg and Bakker, 2015; Huang et al., 2016)
Commonality of components	Use of common parts across product lines	• Use of components that are feasible to back up from one product line to another within the industry (sector agreements) (Chaouni Benabdellah et al., 2019)
Standardisation of components	Use of non-custom components, made using equipment and process available on the market at various suppliers	• Apply the standard design to make replacements feasible and economically viable (Huang et al., 2016) • Use of easily replaceable standard components and materials (Mulder et al., 2014; Pozo Arcos et al., 2021)
Spare parts and tools availability	Existence of spare parts and repair tools on the market	• Allow easy access and identification of the spare parts (van den Berg and Bakker, 2015) • Establish proper supply chain partners and collaborative measures to provide the spare parts • Engage a network of repairing servicing working by agreement with relative manufacturers and involve eCommerce platforms for selling the spare parts (Svensson et al., 2018)
Guidelines	Providing manuals and documentation containing information on how to service product	• Provide understandable repair instructions, including guidelines for disassembly and assembly sequences (Huang et al., 2016) • Store and provide any information on performed inspections, faults, history repairs, replacements, etc. (Pozo Arcos et al., 2021) • Provide easily understandable and reliable information about how to use and service product, advice on product care, describe signals of product malfunctioning (Pozo Arcos et al., 2021)
User Feedback & Information	Including intuitive interaction signals about the functioning and failure of a product	• Design signals in the form of text, light, sound or movement provided by the product in response to an interaction with the user (ex. light when powered; click sound during attachment/ detachment; error signal in the form of blinking lights) (Pozo Arcos et al., 2021) • Providing evident indications about product malfunctioning (den Hollander, 2018)

Technological durability to comply with last technological developments

In the era of technological revolution, prolonging the product life cycle through repairing is not always the best choice if more technologically advanced solutions come to the market. Besides, nowadays, consumers desire to use technologically updated devices

(Sabbaghi, M. and Behdad, S., 2017). Thus, to prevent customers from simply abandoning their old products and buying more technologically advanced substitutions, product developers must consider technological durability features. Table 2 summarises the collected technological features to incentivise product repair and provides a definition and detailed practices for each of them.

Table 2. Technological features to incentivise product repair

Design Feature	Definition	Practices
Adaptability	Ensuring the possibility to make updates and upgrades to the product	• Develop a long/term plan of possible future developments of the product (van den Berg and Bakker, 2015) • Allow product flexibility to perform updates of different functions (Bocken et al., 2016)
Anticipate legislation	Considering upcoming regulations to meet potential restrictions	• Being compliant with the upcoming legislation: the one that is still under discussion (van den Berg and Bakker, 2015) • Pro-active influence on the formation of new legislation to avoid taking costly last-minute actions (Thierry et al., 1995)
Energy efficiency	Product design that complied with the energy efficiency stands (state of the art)	• Assume several energy sources to charge the product (Hernandez et al., 2020) • Consider batteries' lifetime to be aligned with the product lifecycle (Bakker et al., 2014)
Updateability	Keeping product performance as it was originally designed	• Constantly releasing updates to maintain the competition and ensure the product's effectiveness in changing environment (Svensson et al., 2018)
Upgradability	Ability of a product to continue being useful under changing conditions by improving the quality, value, and effectiveness or performance	• Communicate available upgrades to consumers and provide them with the right to decide whether accept or decline new upgrades (Tamò-Larrieux, 2021) • Design product architecture (software and hardware) to facilitate the enhancement of product functionalities (Schneider et al., 2018) • Enhance products' original design specifications, functional capabilities and/or cosmetic condition (Yamada et al., 2016) • Exchange of additional product components (den Hollander, 2018) • Use materials and assembly methods that do not prevent the upgrade and rebuilding of the product (Xing, K. and Belusko, M., 2008)

Emotional durability to enhance product care by the consumers

The third and the last category of design features presented in this paper is related to the phase of product use. Haung et al. (2016) and Carlsson et al. (2021) highlight the importance of considering the user's perspective when designing products for a specific lifecycle because, in the end, the decision to continue the product use depends only on the user's preferences. Therefore, it is essential to develop products to strengthen consumers' emotional attachment so that they will prefer to repair them when needed and continue to use them for longer. Table 3 summarises the product features related to emotional durability.

Table 3. Emotive features to incentivise product repair

Design Feature	Definition	Practices
Trustable design	Ensuring safety, high quality, reliability and durability of a product	• Prevent “planned obsolescence” (Bakker et al., 2014) • Apply functional features to ensure the physical durability of the product: “not breaking down unexpectedly and keeping on functioning in a reliable manner” (den Hollander, 2018) • The main driver of detachment and dissatisfaction is a failure in utility. Ensure the product performs well and can maintain itself, the product is safe to use, e.g. avoid toxic materials, unprotected sharp elements (Haines-Gadd et al., 2018)
Attachment, emotional and social value	Product design to recall in consumers a feeling of connection to the product and stimulate product care	• Allowing customisable product architecture so that the users may personalise their products in a way it matches their personality (see Personalisation below) • Communicate the potential value of a product to its users, underline the meaning it bears (Nazlı, 2021) • Design inspired by unique handcrafted objects • Produce a group affiliation and promote connection to the community by communicating how the product may involve others and unite people • Provide after-sales services to enhance the experience of the product use (Hernandez et al., 2020)
Detachment	Neutrality of product design	• Develop a neutral design for those products that do not usually contain a particular value for consumers and focus on functionality (Haines-Gadd, M.; Chapman, J.; Lloyd, P; Mason, J.; Aliakseyeu D, 2018) (Haines-Gadd et al., 2018)

Ergonomics in use and servicing	Product design to ensure suitable and intuitive functioning	• Related to product architecture (see User feedback above for more details) (Haines-Gadd et al., 2018):
		  ○ Clear communication of failures or needs for servicing, such as lights blinking, red lights (vs green for normal functioning), sounds, etc.
		  ○ Visible buttons to enable safe opening/closing
		  ○ Use of magnets to place back a withdrawn part
		• Related to after-sales services: the presence of the authorised and qualified network of services

Personalisation	Allowing a user to personalise its products and enhance a feeling of uniqueness	• Create opportunities so the user can re-design and reconfigure the product during its use: users desire to differentiate themselves from others and express their identity, as this gives a sense of uniqueness (Kannengießer, 2020)
Timeless design	Applying classic and “never old” design techniques	• Prevent “fashion obsolescence” in design: products with strong temporal identities can become obsolete very quickly not because of the failure of their functional side but because of the design and the emotions they produce in people (Hernandez et al., 2020) • Use Time & Eco-Appropriate Materials: consider the various time and ecological dimensions of the materials that exist within the product lifetime (Haines-Gadd et al., 2018)

Green marketing concept	Communication of benefits of repairing as a strategy to keep up sustainability	• Clear and visible communication of green design and repairing benefits, replying to environmental concerns of customers (Nazli, 2021), for example: ○ the percentage of recycled materials used to produce and repair an item ○ the sustainable sources of materials

Figure 2 presents the complete classification of design practices that aim at facilitating and/or incentive product repair and therefore ensure better circularity and sustainability.

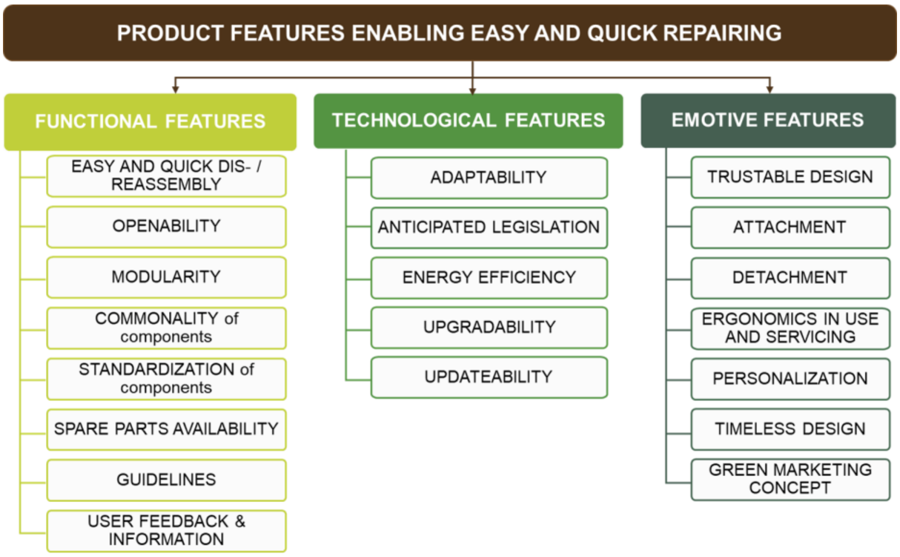

Figure 2. Product features that enable quick and easy product repairing

Discussion and Conclusion: going beyond traditional Design for Repair practices through Digital Technologies

This paper presents introductory research that aims at exploring the Design for Repair practices. With this paper, the authors also aim to raise awareness of existing issues in resource usage for product development and customers' attitude to product consumption. The performed literature review demonstrates that the "Design for repair" strategy is relatively overlooked and that a holistic vision of its practices is missing. Through this literature review, we found that practices related to physical durability are widely discussed, probably as they are more connected with traditional manufacturing excellence practices, while others are less investigated.

One of the main issues in integrating sustainability in product design is collecting data to evaluate the effect of design features on the environmental, economic and social dimensions. These data are possible to retrieve using digital technologies. In general, we found that the digital technologies application in design and repairing play a key role because they are potential enablers of sustainable design and seem to be a promising way to overcome practical challenges of Design for Repair. For example, an IoT-enabled business model can minimise product planned obsolescence since it enables digital product upgrades. Secondly, the role of emotive features in product design is currently underestimated, and the Right to Repair movement could trigger greater attention to the topic. Future research directions contain a better frame of collected features and analysis of enabling factors (such as digital technologies application) and related barriers, and then integration of all aspects to conceptualise better Design for Repair.

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