THE RIGHT-TO-REPAIR MOVEMENT AND SUSTAINABLE DESIGN IMPLICATIONS: A FOCUS ON THREE INDUSTRIAL SECTORS

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ABSTRACT

While products get more challenging to repair, the right-to-repair movement aims to empower consumers in their ability to "use, modify, and repair" a device "whenever, wherever, and however" they want. Here, the best design practices and remaining challenges of three industrial sectors – namely, consumer electronics, biomedical devices, and clothing industry – are investigated in light of the right-to-repair movement. Based on literature reviews and industrial surveys, a SWOT analysis is provided for each sector, and sustainable implications for product repair readiness are drawn. Concretely, recommendations to design, develop and sell products with right-to-repair in mind are given by sector. Future directions for a more quantitative assessment and implementation of design for product repair are discussed to ensure the augmentation of the circularity and sustainability performance of products.

Keywords: Design for X (DfX), Sustainability, Circular economy, Right-to-repair, Product design

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1 INTRODUCTION

1.1 Context and objectives

Products are getting more difficult to repair by consumers for a handful of reasons: physical restrictions; unavailability of parts, repair manuals, or diagnostic software and tools; designs that make independent repairs less safe, time-consuming, and costly; application of patent rights and enforcement of trademarks; disparagement of non-original manufacturer equipment (OEM) parts and independent repair; or even, software locks (Jaeger-Erben et al., 2021; Federal Trade Commission, 2021). At the same time, while a significant pool of sustainable design methods and tools (such as design for Re-X, i.e., reuse, repair, remanufacture and/or recycle) has been developed since the 1990s (Pigosso et al., 2010; Rousseaux et al., 2017), their adoption by product makers is still too low (Rossi et al., 2016; Faludi et al., 2020).

More recently, both circular economy (CE) related laws and consumer ecological awareness, e.g., through the right-to-repair movement (Hernandez et al., 2020; Stead and Coulton, 2022), push OEMs to make products more repairable, i.e., to facilitate the process of extending the life of a product during its (first) use by retaining or restoring its functionalities with (minor) repairs that can be done by users, manufacturers, or professional service providers. In fact, in both the European Union (EU) and the United States of America (US), policymakers are attempting to increase the number of repairs made, e.g., through (i) the introduction of recent changes in the EU Ecodesign Directive (including right-to-repair obligations), (ii) the mandatory implementation and display of the Repairability Index on products for specific categories of electronic equipment sold in France, or (iii) the proposed US Right-to-repair legislation (Svensson-Hoglund et al., 2021).

With this background, the two research questions guiding this research work are: (i) what are the best practices and remaining challenges to designing for repair in diverse industrial sectors, and (ii) what recommendations can be given to foster sustainable repair activities? In the present study, three industrial sectors of interest (their respective relevance being illustrated hereafter) for the right-to-repair movement are investigated, namely: (i) consumer electronics; (ii) biomedical devices; and (iii), apparel/textile products. Following a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) through the prism of the right-to-repair movement in each of these industries, product design implications and business/policy model orientations are drawn to advance the actual repairability of the future generations of products.

1.2 Motivations of the right-to-repair movement in three industries

1.2.1 Stakes in the consumer electronics industry

The repairability of consumer electronics has been a topic of special interest for numerous scholars in the sustainable design community over the last couple of years, e.g., on laptops (Woidasky and Cetinkaya, 2021), washing machines (Bracquene et al., 2021), or smartphones (as further detailed in Section 3). Of the electric appliances investigated by Laitala et al. (2021), from consumers' return experiences, mobile phones were most frequently broken (28%), followed by dishwashers and washing machines (12%), and finally refrigerators, freezers, and stoves (less than 10%). According to the authors, several key factors, such as better accessibility to original spare parts, tools, and product manuals, in addition to increased knowledge of repair rights and warranties, are essential to more successful repairs and, thus, longer service lifespans.

1.2.2 Stakes in the biomedical industry

According to a 2018 survey of four Mayo Clinic campuses, plastic accounts for "at least 20% of medical waste, which is often disposed in landfills rather than recycled." Further exacerbating this problem is that 56.7% of survey participants "reported being unclear which OR [operating room] items are recyclable" (Azouz et al., 2019). With concerns surrounding patient safety and preserving the cleanliness of medical equipment, sustainable, reusable items are often traded for single-use items that generate large amounts of waste. Though the initial cost of creating more sustainable medical equipment can be intimidating, current research focuses on the utilization of eco-friendly materials, such as the silk of the *Bombyx mori* silkworm, to create implantable devices that are not only more sustainable, but less likely to be rejected

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by the body (Ahmed et al, 2022). In addition, the focus has begun to shift to materials that are more easily reused and sterilized, such as stainless steel or glass, alongside improving the processes used to manufacture medical equipment so that it is more efficient and utilizes exact amounts of materials (Battelle Insider, 2021). While many current sustainable solutions focus on the production of devices, the right-to-repair has the potential to make already existing devices more sustainable. By allowing consumers to "use, modify, and repair" a device "whenever, wherever, and however" they want, expensive maintenance or the disposal of repairable equipment can be avoided (The Repair Association, 2022). Current legislation, such as the Critical Medical Infrastructure Right-to-Repair Act of 2020, aims to promote the reasonable release of materials to aid in the quick and easy repair of essential medical devices. This would ultimately allow consumers to repair equipment with cost-effective parts and services from third-party manufacturers. Future research has the potential to continue to develop devices from sustainable materials, along with expanding the right-to-repair devices to those used at home by patients rather than in just a hospital setting.

1.2.3 Stakes in the clothing industry

In 2021 alone, the fashion and textile industry generated a revenue of 1.5 trillion dollars (Smith, 2022). While the industry is projected to grow exponentially in the coming years, several problems have arisen regarding the sustainability and repairability of fashion. The environmental impact of the fashion industry is detrimental, as it is the main contributor to microplastic pollution and accounts for 10% of the global carbon dioxide output (Dottle and Gu, 2022). In addition, more than 60% of fabrics from clothing are synthetics derived from fossil fuels (Schlossberg, 2019). In recent years, solutions have arisen to combat damage from the fashion industry, with one being the rise of the second-hand fashion market. Over the years, the second-hand fashion market has increased in popularity due to the increased use of selling platforms such as Depop and ThredUP. Second-hand market sales are projected to reach 75 billion dollars in 2025, compared to 36 billion dollars in 2021 (Anderson, 2022). Additionally, the EU has taken action toward fashion sustainability through a set of proposals aligned with the European Green Deal, the 2020 Circular Economy Action Plan, and the 2021 EU Industrial Strategy. By 2030, the EU hopes that textile products will be produced wholefully and sustainably, with repairability and reusability replacing disposability. The proposals outline specific requirements for textiles to advance in recyclability, reusability, durability, and mandatory recycled fiber content (Webb, 2022). A study performed by the Global Fast Fashion Market highlights problems concerning the future of the fashion industry. While steps towards sustainability, reusability, and reparability are being made primarily in North America and Europe, the fast fashion economy is expected to double in size, posing further questions on whether the steps toward ethical fashion are enough to overturn the rapidly expanding unsustainable fashion industry (Kumar, 2022).

2 MATERIALS AND METHODS

2.1 Research approach

The flowchart depicted in Figure 1 illustrates the overall research approach. For each of the three industrial sectors investigated, a literature review combined with a complementary industrial survey is conducted to construct a complete SWOT analysis of the specific industry in light of the right-to-repair movement, integrating the perspectives of the users, industrialists, designers, and researchers. On that basis, directions to support design for repair are advanced and discussed.

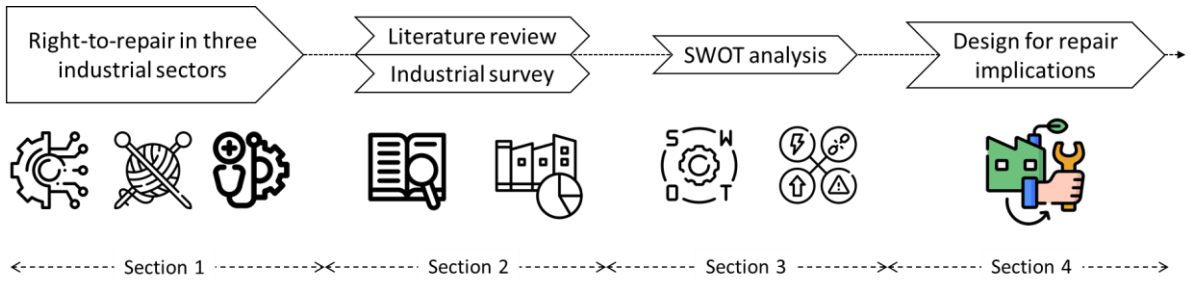

Figure 1. Research approach and synopsis of this paper

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2.2 Literature review and industrial survey

In order to provide a diverse perspective on a complex and multifaceted issue, a combination of academic material and "grey literature" (reports, policy, news articles, etc.) was used. For analyzing the implications of the right-to-repair in the consumer electronics industry, research combined data from academic literature using the Google Scholar database, with insights from official press releases from OEMs (e.g., Samsung and Apple, as the two leaders of the smartphone market), as well as complementary online information from consumer electronics association (e.g., iFixit, one of the most acknowledged online repair communities and parts retailer offering open-source repair manuals and product teardowns) and policy reports (e.g., from the Federal Trade Commission). The combination of keywords used to identify these sources was the following: {"right-to-repair" OR "repairability" OR "design for repair"} AND {"consumer electronics" OR "electronic products" OR "smartphones"}.

For the information pertaining to biomedical devices and their sustainability implications, academic articles and grey literature were used. To find journal articles, Google Scholar and Scopus were the main databases used. Journals included The New England Journal of Medicine, The American Journal of Surgery, and Mechanical Engineering. Information found through journal articles was most relevant to the subtopics of creating sustainable biomedical devices, addressing topics such as the recycling of supplies and the use of plant-based materials. Alongside journal articles, the material was sourced from grey literature, including press articles, governmental documents, and opinion pieces. Grey literature was used to better understand the perspective of the consumer, and as such, most of the information found was pertinent to the right-to-repair movement and how it applies to biomedical devices. When looking for relevant material across all platforms, common search terms such as “the right-to-repair biomedical devices” and “biomedical devices sustainability” were used. These phrases and their variations allowed for sufficiently narrow search fields to properly produce specific results.

Regarding the application of the right-to-repair and social sustainability in the textile/fashion industry, analysis was facilitated through journal articles and books found in the Wiley Online Library, Google Scholar, and the University of Illinois Library database. References were collected and analyzed with consideration of the main research points: sustainability in the clothing industry, the second-hand fashion market, and the environmental impact of current fashion practices. Resources found in databases provided key information on the repairability of fashion and waste prevention in relation to clothing. Much of the grey literature was sourced from The New York Times, Forbes, and Bloomberg, found through Google. This was used to find further information on the second-hand market and the environmental damage caused by the fashion industry, pertaining to topics of fashion and the right-to-repair movement. Keywords including “sustainability,” “fast fashion,” “second-hand market,” “repairability,” and “reusability” were utilized to conduct research.

3 RESULTS

3.1 Consumer electronics

Svensson-Hoglund et al. (2021) provided an extensive analysis of fundamental obstacles to both supply and demand of repair of consumer electronics, as well as the current and proposed design and policy solutions to address barriers and increase repair activities. For instance, regarding consumer perception, the two main barriers are (i) the lack of consumer awareness of repair rights under warranty and guarantee, and (ii) the lack of understanding of reparability at the time of purchasing a device. One concrete solution is the deployment of the durability and repairability index (including information about the timeframe for spare parts availability). Barriers related to product design in regard to the conducting of sound repair include: (i) device and parts that cannot be disassembled without destruction (e.g., glued parts), (ii) OEM-specific design choices (e.g., proprietary screws), (iii) the lack of compatibility for spares (function and design, i.e., non-generic parts), (iv) premature obsolescence (e.g., lack of updates on embedded software), as summarized in Figure 2. Current proposals and solutions are, for example, (i) the WA Fair Repair bill (ban on design preventing reasonable diagnostic or repair functions) in the US, (ii) the Ecodesign Directive (e.g., dismantling with standard or common tools) and associated requirements (e.g., availability of firmware updates) in the EU.

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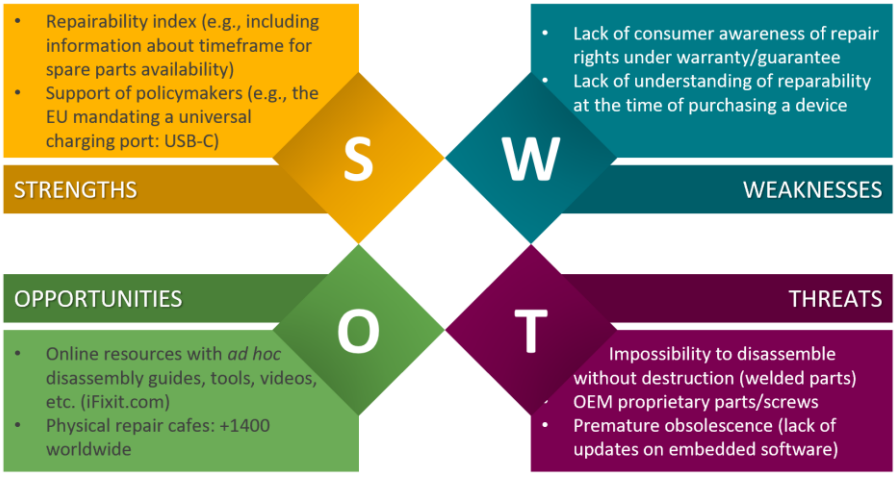

Figure 2. SWOT analysis of the right-to-repair movement for consumer electronics

In fact, the EU recently mandated a universal charging port (USB-C) for phones, cameras, and tablets sold after 2024. As a direct design consequence, companies like Apple, which have leveraged proprietary charging technology in lieu of a universal port, will need to redesign their products for the European market (Okie, 2022). In addition, repairability indexes indicating how easily a device can be repaired for electronics have been mandatory in France since 2021 (Reparability Index, 2022). Importantly, an instruction manual and an Excel-based tool are provided for the calculation of the repairability index of electrical and electronic equipment, based on five criteria, as illustrated in Table 1: (i) documentation, (ii) disassembly, accessibility, tools, fasteners, (iii) availability of spare parts, (iv) price of spare parts, and (v) criterion specific to the category of equipment concerned.

In a 2021 executive order signed by the US President, complementary opportunity or enabling design for repair pushes the Federal Trade Commission to make third-party product repair easier. It aims "to limit powerful equipment manufacturers from restricting people's ability to use independent repair shops or do DIY repairs". In this line, 27 states introduced more than 40 right-to-repair bills. For instance, the New York's Digital Fair Repair Act requires electronics manufacturers to make tools, parts, and instructions for repair available across the state.

Furthermore, Apple recently committed itself to developing and expanding a self-service repair program, offering replacement parts and service manuals to DIYers and repair shops alike (Apple, 2022; iFixit, 2022). Interestingly, as a financial incentive for certain repairs, customers can receive store credit when returning a replaced part for recycling. As such, Apple aims to increase the repairability index of its products (e.g., the iPhone 12, having a repairability index of 6 out of 10, as showcased in Table 1), to offer an alternative to one of the best available options on the market regarding product modularity and repairability potential (i.e., the Fairphone, with a repairability index of 9.2 out of 10) (Reparability Index, 2022).

Table 1. Comparison of repairability indices of two smartphones (Reparability Index, 2022)

Criteria and sub-criteria	Fairphone 4 5G (6GB, 128GB)	Apple iPhone 12 Pro Max (128GB)
1. Availability of the technical documentation related to the maintenance and repair instructions	20 / 20	12.3 / 20
2.1. Ease of disassembly	10 / 10	2.5 / 10
2.2. Necessary tools for disassembly	5 / 5	0.9 / 5
2.3. Fastener characteristics	4 / 5	2.5 / 5
3.1. Availability of spare parts	10 / 15	7.2 /15
3.2. Delivery time of spare parts	4.1 / 5	2.2 / 5
4. Ratio between the price of parts to the price of the product	19 / 20	12 / 20
5.1. Information about the type of updates	10 / 10	10 / 10
5.2. Free remote assistance	5 / 5	5 / 5
5.3. Possibility to reset software	5 / 5	5 / 5
Total	92.1 / 100	59.6 / 100

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Similar initiatives have been launched at Samsung, the largest smartphone manufacturer in the world. Samsung announced it would make screens, back glass, and charging parts available to customers so that they can repair their own devices. To design and develop self-repair programs, they are notably collaborating with iFixit, a growing online repair community and parts retailer, offering open-source repair manuals and product teardowns. The growth of repair cafes worldwide is another essential element to empower customers to find tools, materials, and the help of volunteers to repair a variety of products: the site Repaircafe.org offers a list of more than 1400 repair cafes worldwide (Van der Velden, 2021). To a large extent, customers who have a successful experience repairing a specific electronic device are more likely to recommend repair cafes, as "successful repair experiences can improve the perceived reliability level of the product" (Mashhadi et al., 2016).

3.2 Biomedical devices

Due to an increase in the amount of hard-to-recycle plastics and waste generated by biomedical devices, sustainability has become an important issue, especially with regard to the manufacturing and maintenance of medical equipment. As outlined in Figure 3, the primary strength of improving the sustainability of biomedical devices is the ability to increase eco-friendliness in a hospital setting. While sustainable devices may be more expensive to design and manufacture, the ability to reuse and repair devices offers a cost-effective, long-term solution. According to Stephen Grimes, the DaVinci surgical robot costs around $1.5 million, with annual maintenance costing $200,000 (Shah, 2018). If the DaVinci surgical robot were redesigned so that repairs could be done at a hospital, maintenance would come at a fraction of the current cost without high servicing fees. While eco-friendliness and cost-effectiveness are incentives to create sustainable biomedical devices, major hurdles include high up-front costs and the necessary redesigning process, often resulting in devices that are difficult to sterilize (Arena, 2020). In addition, if devices like this surgical robot were made so that hospitals had the right-to-repair the device, it would become increasingly difficult to protect intellectual property and regulate quality. Third parties manufacturing device parts are not regulated by organizations such as the US Food & Drug Administration (FDA), which presents challenges in preventing the use of low-quality products being used by consumers (Pipes, 2021).

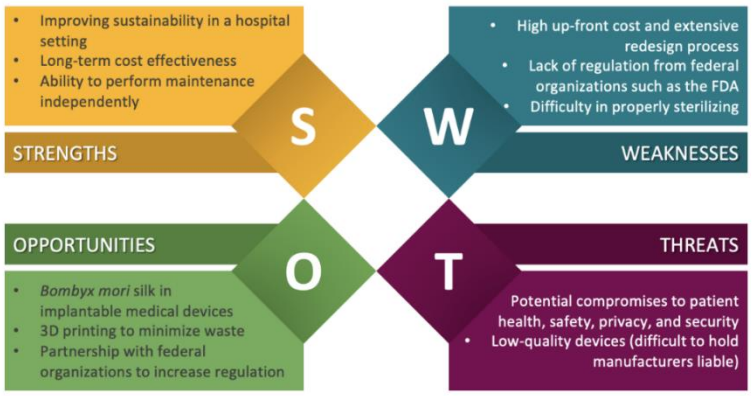

Figure 3. SWOT analysis of the right-to-repair movement in the biomedical industry

The main opportunities for sustainable medical devices are mainly found within biomaterials, especially in the realm of implantable medical devices. In particular, the silk of the *Bombyx mori* silkworm is being investigated as a material to make implantable medical devices more sustainable and less likely to be rejected by the body (Ahmed et al., 2022). 3D printing is additionally being explored as a method for reducing waste, as it utilizes exact amounts of materials without leaving excess that is thrown away (Kent, 2022). Furthermore, the utilization of organizations such as the FDA can ensure that manufacturing done by third parties is regulated in a manner that makes device repair more accessible and cost-effective without the possibility of compromising quality (Shah, 2018).

The main concerns surrounding the creation and repair of sustainable medical devices are centered around safety and liability. For example, in 2015, the Centers for Disease Control and Prevention (CDC) aided the Los Angeles County Health Department as it investigated an outbreak of carbapenem-resistant Enterobacterales (CRE) cases at the University of California, Los Angeles Medical Center (Center for Disease Control and Prevention, 2021). Eventually, it was discovered that

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the CRE cases were linked to the improper cleaning of reusable duodenoscopes, a device that is inserted down the throat to perform medical procedures. Despite the use of medical devices that were considered reusable and therefore more eco-friendly, patient health was compromised because of not following proper disinfection protocol. As such, compromises in quality due to third-party manufacturers may lead to undue patient harm and death. If this were to occur, it would be complicated to hold third parties accountable, and instead, liability will be directed to the original manufacturer (Shah, 2018). In regard to private patient health information, medical devices containing sensitive data have the potential to be compromised if detailed information regarding their manufacturing is released.

While sustainable medical devices are becoming an important topic of research due to the amount of waste generated in a hospital setting, current flaws prevent sustainable medical devices from being implemented in medical facilities. With the right-to-repair only being implemented in specific emergency cases, such as ventilators during the COVID-19 pandemic, hospitals are often opting to use devices that are either not sustainable, or require costly, frequent maintenance. In addition, concerns surrounding patient safety, privacy, and liability prevent the full use of sustainable medical devices, as they can have detrimental consequences. Though these concerns currently prevent the implementation of fully sustainable medical devices, research is being done to examine different areas of potential progress, including plant-based biomaterials and 3D printing.

3.3 Clothing industry

Different solutions have been proposed and considered regarding the fast fashion industry, the repairability of fashion, and the second-hand market. Certain companies in recent years have taken measures to increase the repairability of their products to combat the rising impact of fast fashion. For example, the footwear company Trickers provides a free lifetime supply of repairs for all the shoes purchased from their company. This new option is ground-breaking in terms of increasing sustainability. Repairing pieces can expand the wearability of clothing tenfold, and garments can become as good as new, if not better, with a continuous supply of repairs. However, not many companies are currently implementing practices like those of Trickers, inevitably leading to a lack of wide-scale change regarding the repairability of fashion (Leitch, 2021).

Thrifting through the second-hand market has also seen an increase in popularity. Thrifting can provide a sustainable and cost-effective option while increasing the longevity of a piece of clothing. This new practice has also provided growth for many second-hand selling platforms, creating business opportunities for people within the platform selling their clothing. Despite the benefits, it is important to note that thrifting was initially created as a solution for lower-income community members. Therefore, the rise in demand has created reduced options for people who need second-hand clothing, thus making thrifting an optimal option but with certain limitations (Nair, 2019), as shown in Figure 4.

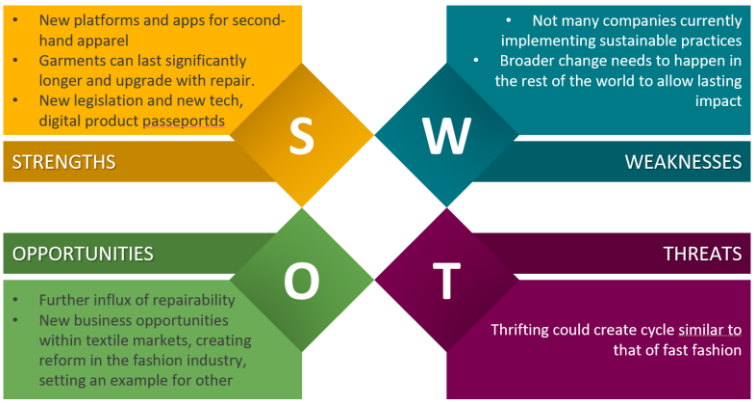

Figure 4. SWOT analysis of the right-to-repair movement in the clothing industry

The EU has designed a set of proposals with the intention of more sustainable and wholesome production of textiles, and increased reusability and repairability. They have developed new technology, including digital product passports, which entail "mandatory requirements on circularity and environmental sustainability" (Webb, 2022). Additionally, the EU hopes to tackle problems regarding microplastics, hazardous substances, and textile waste. The steps the EU are taking can set

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an example for others to follow; movement beyond just the EU needs to occur for large-scale change. Recent steps with a focus on the repairability and renewability of clothing have taken strides toward creating a more sustainable fashion industry. With new repairing practices, the wearability and longevity of a piece of clothing is increased tenfold. Yet, with not many companies implementing these practices given that it is time-consuming and unrealistic for larger corporations, wide-scale change will likely not occur (Leitch, 2021).

4 DISCUSSION AND CONCLUSION

Based on the SWOT analyses, concrete design and business recommendations are drawn for these sectors, and implications are discussed to design products with "right-to-repair" in mind more broadly.

4.1 Implications for designing and selling electronics with "right-to-repair" in mind

For product architects and engineers, understanding the criteria behind the repairability index (see Table 1), and taking them into account when designing new products, is critical to ensure their sound repairability. As the inconvenience of dissembling electronic devices and spare parts shortage are the main barriers toward consumer repair (Mashhadi et al., 2016), integrating (i) design for ease of disassembly, with (ii) design for modularity guidelines, coupled with (iii) a circular and local network of spare parts providers, is essential to enable product repair by consumers. In practice, most consumer electronics are already arranged in modules (e.g., display, back cover, battery), but this is only one piece of the puzzle to allow product repair effectively (Fazio et al., 2021). As long as these modules (and associated sub-components) are highly connected through a combination of screws, clips, cables, connectors, solders and/or adhesives hardly accessible, replacing and/or repairing the broken module or part would be a challenging task for the user. Solutions include (i) improving the accessibility of the core/critical parts of a given product (i.e., the parts having a regular need for repair or replacement due to failure rate, component life cycle, maintenance/upgrade), (ii) standardized fasteners and tools, (iii) easy-to-access and easy-to-understand documentation for product disassembly and maintenance, (iv) increasing the awareness consumers and the accessibility to community repair cafes. Pragmatically speaking, when designing, developing, and putting a product on the market, one can imagine a simple tag embedded or attached to the product with, e.g., essential disassembly instructions, or a QR code to access all the resources needed in order to properly maintain/repair/upgrade the product when needed.

4.2 Implications for designing biomedical devices with "right-to-repair" in mind

To fully utilize the benefits of sustainable medical devices, advancements and improvements must be made to current systems and technology. Addressing the issue of quality regulation is critical to the success of increasing sustainability and utilizing the right-to-repair. However, no standards have currently been set by federal organizations, allowing faulty devices and unreliable parts to enter the market, ultimately putting patient health and safety at risk. To mitigate this issue, local and state centers can be given the ability to regulate the quality of medical devices in a surrounding area. This would allow for the prevention of compromises to patient health and safety, as devices and device parts would be closely monitored to ensure proper function. While this is likely a long-term solution that is important for the success of sustainable medical devices, on a short-term scale, careful research on the use of 3D printing and its applications is necessary to implement the right-to-repair medical devices. It is unlikely that entire medical devices will be efficiently 3D printed, therefore, certain parts must be identified as ones that can be feasibly reproduced using sustainable methods. Creating “hybrid” devices made from both original and 3D printed parts would result in devices that are more sustainable as a whole. In addition, due to the increasing accessibility of technologies such as 3D printing, medical facilities will easily be able to print replacement parts as needed, saving time and money. By beginning with smaller, sustainable practices such as developing methods to create 3D printed parts for medical devices, steps can be made to create sustainable medical devices, allowing for the possibility of further applications, such as quality regulation on the local and state level.

4.3 Implications for designing and selling apparel with "right-to-repair" in mind

While the problem of sustainability and repairability in the fashion industry poses complications worldwide, solutions can be implemented to further curb these issues. Similar to one of the goals of the EU, implementing tags on clothing that supply information on the sustainable factors of that piece,

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such as how to dispose of it properly, how to repair it, or how to send it to the second-hand market would provide new steps towards bringing awareness to the right-to-repair movement in regard to clothing. The establishment of this practice by companies would ensure that the companies themselves are making efforts to think about repairability and renewability, and that consumers can be well-informed on how to treat their clothing pieces sustainably. While tags on clothing are an easy and effective solution, companies overall being more informed of the right-to-repair practices through online mediums would increase consumer knowledge of sustainable practices and generate change in the industry. Implementing sustainable and wholly sourced materials for companies would also initiate further steps in sustaining a better environment.

4.4 Perspectives for future works

While the present study focuses on specific best design practices and tools (e.g., the repairability index spreadsheet) to design for product repair, it can be worth investigating how they could be combined and/or integrated with other design for Re-X methods and tools such as matrix-based tools for quantitative analysis of disassembly (De Fazio et al., 2021) or circularity indicators for the evaluation of alternative concepts during early product design and development (Kamp Albæk et al., 2020). Importantly, as one might argue that design for product repair has to be done in consideration of financial, ecological, and intellectual property (IP) aspects (Kim et al., 2021), an update of the objective function of the green profit optimization model (Saidani et al., 2019) could be to: enable easy repair (i.e., minimize disassembly and repair times vs. complex and time-consuming remanufacturing process) while ensuring OEM profit, protecting product IP on critical parts, and reducing environmental footprint. In practice, repairability has to compete with the value addition post-repair as well as the reduced cost of repair than replacement of products (i.e., the potential cannibalization effect from a growing market share of repaired products has to be further studied). Last but not least, following the experimental work of Terzioğlu and Wever (2021) on 52 repair projects with master students, we encourage fostering circular design or design for Re-X (reuse, repair, recycling) into design education to make students aware of the residual value/potential of their broken devices, as well as to teach them the competencies (including both theoretical knowledge and technical skills) and to give them the appropriate tools to perform repair activities and to able to quantify the potential environmental and economic savings associated to an increased circularity (Saidani et al., 2022).

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