Product lifetime extension through design
Encouraging consumers to repair electronic products in a circular economy

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PRODUCT LIFETIME EXTENSION THROUGH DESIGN

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Renske van den Berge

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TU Delft

European Commission

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Product lifetime extension through design:
Encouraging consumers to repair electronic products in a circular economy

Dissertation

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by

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Voor mama

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ENGLISH SUMMARY

It becomes increasingly clear that our production and consumption patterns of electrical and electronic products exceed the limits of what one planet can handle (Hummels and Argyrou, 2021). Prolonging product lifetimes decreases the value losses caused by the destruction of existing products and lowers the amount of waste within a circular economy. Therefore, product lifetime extension via repair is addressed as one of the most impactful strategies to tackle the issues associated with the production and consumption of electrical and electronic products (Ellen MacArthur, 2013; McCollough, 2009).

Regarding the potential of product repair, we face nowadays' challenge that most discarded products were never repaired during their lifetime (Magnier and Mugge, 2022). Literature proposed several design for repair strategies, predominantly from a technical (engineering) perspective. However, changing current consumption patterns depends upon people's willingness to take action, and a technically repairable design may not automatically result in repair behavior (Makov and Fitzpatrick, 2021). Consumers and their behavior thus play a key role in prolonging the lifetimes of our daily used products (Evans and Cooper, 2010; Sahakian and Wilhite, 2014).

The primary objective of this thesis is to explore the role of design in stimulating consumers to extending product lifetimes via repair. A consumer perspective is considered to investigate why consumers decide to prematurely replace products and their barriers towards repair. Furthermore, design and marketing strategies to stimulate lifetime extension via repair (e.g., support in failure diagnosis, modularity, and lifetime labels) are identified from literature. To demonstrate how design can encourage consumers to extend product lifetimes via repair, the effectiveness, boundaries and the required conditions of these strategies are tested in several empirical studies.

Main research question:
How can design prevent premature obsolescence by encouraging consumers to prolong the lifetimes of electronic products via repair?

Sub research questions (SRQ):

1. Why do consumers decide to replace products prematurely?
2. What barriers do consumers experience concerning product lifetime extension?
3. How can design and marketing interventions help consumers with repair and thereby extend their products' lifetimes?

This thesis consists of two parts. In the first part, the process of product replacement is considered from the consumer's perspective. The comprehensive understanding of the replacement process of Chapter 2 aims to answer SRQ1. It emphasizes that, during product replacement, trade-offs are made between the functional, emotional, social, epistemic and conditional values of the owned product with a potential new product. These trade-offs influence the decision to either retain a product or replace it with a new one. In addition, it shows that repeated usage/satiation, new developments and trends, marketing efforts and trade-in promotions can be barriers that negatively influence the replacement tendency (SRQ2). Furthermore, several strategies are discussed that can increase the owned product's values and stimulate retention via product attachment, sustaining aesthetic value, stimulating product care and maintenance, and enabling upgradeability.

To provide more detail in what barriers consumers face towards product lifetime extension (SRQ2), Chapter 3 provides in-depth insights into consumers' considerations about product lifetimes, barriers to extending lifetimes, and responses to a product lifetime label. Results of interviews with Dutch consumers suggested an overall positive view on long-lasting products. However, participants indicated that product value generally depreciated during time of ownership and considered themselves unable to estimate how long products should last. This can be detrimental for product lifetime extension as low expectations tend to negatively influence actual lifetimes. To extend product lifetimes, people often disregarded the option of repairing malfunctioning products. They have limited knowledge and ability, and believed repair provides poor value for money. Lifetime extension was also be hindered by market-related factors, such as convenient replacement services, new technological developments, and (attractive) deals. When introducing a label to better inform about the lifetime and possibilities to extend it, this label should contain relevant and reliable information. When information about repairability is included, it should be considered that people may have conflicting associations with repair (e.g., inconvenient, time-consuming, costly).

The results of Part I deliver a thorough and explanatory overview of the consumer perspective on extending product lifetimes, which serves as the foundation for the experimental research carried out in Part II of this thesis. Repair is identified as a promising solution to extend product lifetimes. However, the fact that a product can be physically repaired does not mean that consumers will act accordingly. To address the identified barrier of a low ability to repair, Chapter 4 suggests that design interventions may increase consumers' "can-do" repair mentality. In three experiments, we test the effect of a design intervention, namely the presence of a fault indication, on consumers' willingness to repair. Our results showed a significantly higher willingness to repair in the presence of a fault indication, which is explained by a higher level of perceived self-efficacy (i.e., a "can-do" attitude). However, this result only held true for products that are relatively less likely to be professionally repaired and require a relative low investment, such as coffee makers and (handstick cordless) vacuum cleaners.

To increase the ability to repair, modularity is also addressed as a promising design strategy to stimulate product lifetime extension. Past research demonstrated promising results of increased repair intentions with current modular smartphone consumers. However, the average consumer does not (yet) consider modular products the norm. Two experiments were set up in Chapter 5 to test the effect of modularity on consumers' likeliness to repair and to investigate which specific design cues can encourage consumers to execute DIY ('do-it-yourself') repair. Interestingly, the likeliness to use professional repair increased for modular smartphones, while the likeliness to DIY repair remained low. The second study showed that facilitating design cues on the inside of a modular smartphone (i.e., icons to explicate the different components) in addition to supportive information (i.e., pictures of the device opened) did succeed in increasing consumers' likeliness to consider DIY repair. These results suggest that a solely (technical) modular product design is not enough to encourage DIY repair and more support (e.g., facilitating cues and additional information) is required.

Chapter 6 attempts to move beyond design strategies and looks into product marketing to stimulate repair intentions of consumers. The results showed that providing information about the reliability and upgradeability of a product via a lifetime label can support consumers in extending lifetimes. Specifically, the experiments demonstrated that high reliability scores can increase the likelihood of repairing smartphones, whereas low reliability scores may actually negatively influence repair tendencies. Furthermore, the possibility of improving the functionality of the repaired component via an upgrade increased the likelihood of repairing smartphones as well. Providing such information is thus not only a beneficial marketing tool to increase purchase preference, as it can also enhance repair actions. To ensure lifetimes are considered when a product fails during their lifetime, we recommend the lifetime label to remains visible and accessible for consumers throughout their lifetime.

Finally, Chapter 7 discusses several pathways and guidance for both design practice and policymakers to stimulate product lifetime extension via repair. Reflections on the implications of product lifetime extension within a circular economy are made. First, it is important to realize that product lifetime extension requires a shift in current industry practice and the way businesses are organized nowadays. Furthermore, for a successful repair adoption, we should acknowledge consumers' desire for new products with the latest features. Also, potential unintended rebound effects of repair and lifetime labels should be explored, as well as social justice around product lifetime extension as products with high lifetime expectations often require a relatively higher financial investment. Furthermore, we emphasize that creating a repairing society is not solely a consumer's responsibility. A systemic approach and cooperation between all involved stakeholders are required for a successful transition to repair and product lifetime extension practices.

In sum, by adopting a consumer-centric approach, the content of this thesis offers contributions to design research on product lifetime extension and repair. Designers and policymakers can use our insights to stimulate much-needed consumer repair practices of (electronic) products within a circular economy.

NEDERLANDSE SAMENVATTING

Het wordt steeds duidelijker dat de huidige manier van produceren en consumeren van elektrische producten de grenzen overschrijdt van wat onze planeet aankan (Hummels en Argyrou, 2021). Binnen een circulaire economie zorgt het verlengen van de levensduur van producten ervoor dat de waarde van bestaande producten langer behouden blijft. Daardoor wordt het milieu minder belast met, onder andere, schadelijke uitstoot van broeikasgassen en afval. De verlenging van de levensduur van producten wordt dan ook beschouwd als een van de meest impactvolle strategieën binnen de circulaire economie. Eén manier om de levensduur van elektrische producten te verlengen is door ze te repareren (Ellen MacArthur, 2013; McCollough, 2009).

Reparatie kan een methode zijn om de levensduur van producten te verlengen. Echter, blijkt dat op dit moment de meeste afgedankte producten nooit zijn gerepareerd tijdens hun levensduur (Magnier en Mugge, 2022). In de literatuur worden verschillende 'Design voor Reparatiestrategieën' voorgesteld, waarbij de nadruk ligt op het technische perspectief. Het veranderen van de huidige consumptiepatronen hangt echter af van de bereidheid van mensen om zelf actie te ondernemen. Dat wil zeggen, een technisch repareer-baar ontwerp resulteert niet automatisch in reparatiegedrag (Makov en Fitzpatrick, 2021). Consumenten en hun gedrag spelen dus een sleutelrol bij het verlengen van de levensduur van onze producten (Evans en Cooper, 2010; Sahakian en Wilhite, 2014).

Het primaire doel van dit proefschrift is om te onderzoeken hoe design consumenten kan stimuleren om producten te repareren en zo de levensduur van deze producten te verlengen. Om dit te onderzoeken is er vanuit een consumentenperspectief onderzocht waarom mensen besluiten producten voortijdig te vervangen en wat hun belemmeringen zijn voor langer gebruik. Daarnaast zijn er vanuit de literatuur ontwerp- en marketingstrategieën geïdentificeerd die consumentenreparatie kunnen stimuleren, bijvoorbeeld door hulp bij de foutdiagnose, een modulair ontwerp, het upgraden van producten en de introductie van productlevensduur labels om de consument beter te informeren. Om aan te tonen of deze strategieën consumenten aanmoedigen tot reparatie, worden de effectiviteit, grenzen en vereiste voorwaarden van deze strategieën getest in verschillende empirische onderzoeken.

Hoofd onderzoeksvraag:
Hoe kan design consumenten stimuleren om elektrische producten te repareren om zo hun levensduur te verlengen en voortijdige afdanking te voorkomen?

Deelonderzoeksvragen:

1. Waarom besluiten consumenten om producten voortijdig te vervangen?
2. Welke belemmeringen ervaren consumenten om de levensduur van hun producten te verlengen?
3. Hoe kunnen ontwerp- en marketinginterventies consumenten stimuleren om reparatie uit te voeren en daarmee de levensduur van hun producten verlengen?

Dit proefschrift is opgedeeld in 2 delen. In het eerste deel wordt vanuit het perspectief van de consument het proces van productvervanging onderzocht in hoofdstukken 2 en 3. In hoofdstuk 2 is het proces van vervanging uitgebreid beschouwd (deelvraag 1). Het laat zien hoe het besluit om een product al dan niet te vervangen tot stand komt. Hierbij worden afwegingen gemaakt tussen de waarden van het eigen product en de waarden van een potentieel nieuw product. Deze afweging van functionele, emotionele, sociale, epistemische en conditionele waarden beïnvloedt de beslissing om een apparaat te behouden of te vervangen door een nieuw exemplaar. Daarnaast blijkt dat herhaaldelijk gebruik/productverzadiging, nieuwe ontwikkelingen en trends, marketing en trade-in (inruil) promoties voortijdige vervanging kunnen aanwakkeren. Verder worden verschillende strategieën besproken die de waarden van producten in eigendom kunnen verhogen en dus het behoud ervan kunnen stimuleren, te weten producthechting, het behouden van de esthetische waarde, het stimuleren van productreparatie en onderhoud, en het mogelijk maken om producten te upgraden.

Om deelvraag 2 te beantwoorden biedt hoofdstuk 3 diepgaande inzichten in de overwegingen van consumenten om de levensduur van producten te verlengen. Het hoofdstuk gaat specifiek in op overwegingen omtrent de levensduur van producten, barrières bij het verlengen van de levensduur, en potentiële reacties op een productlevensduurlabel. Uit de resultaten van interviews met Nederlandse consumenten blijkt dat er sprake is van een positieve kijk op producten die lang meegaan. Echter, over het algemeen daalt de waarde van de producten gedurende de levensduur, en achtten consumenten zichzelf niet in staat in te schatten hoe lang producten mee zouden moeten gaan. Dit heeft als nadelig effect dat lage verwachtingen de werkelijke levensduur negatief kunnen beïnvloeden. Daarnaast geven consumenten aan beperkte kennis en vaardigheden te hebben voor reparatie en zijn van mening dat het weinig waar biedt voor hun geld. Levensduurverlenging van producten kan ook worden belemmerd door markt-gerelateerde factoren, zoals handige vervangingsservices voor nieuwe producten (b.v., vandaag besteld, morgen in huis), nieuwe technologische ontwikkelingen en aantrekkelijke kortingen. Om consumenten beter te informeren over de verwachte levensduur en mogelijkheden om deze te verlengen, wordt productlevensduur label genoemd als mogelijke optie. Om zo'n label deel te maken van hun besluitvorming, moet het volgens consumenten relevante en betrouwbare informatie bevatten. Echter wanneer via dit label informatie over repareerbaarheid wordt gegeven, er rekening moet worden gehouden dat reparatie ook tegenstrijdige associaties kan oproepen, bijvoorbeeld dat het een gedoe is, tijdrovend en soms prijzig.

De resultaten van Deel I zorgen voor zowel een overzichtelijk als diepgaand inzicht in het consumentenperspectief op het verlengen van de levensduur van producten. Dit is gebruikt als basis voor het experimentele onderzoek dat in Deel II van dit proefschrift is uitgevoerd. Deel II start met het onderzoeken hoe design kan worden ingezet om het repareren van producten te stimuleren om zo de levensduur te verlengen. Als barrière voor consumentenreparatie is in Hoofdstuk 3 onder andere het lage vermogen tot het uitvoeren van reparaties geïdentificeerd. Om dit aan te pakken, suggereert Hoofdstuk 4 dat designinterventies in een product de 'can-do'-reparatiementaliteit van consumenten kan vergroten. In drie experimenten hebben we gekeken naar het effect van een designinterventie, de aanwezigheid van een foutindicatie, en deze getest op de reparatiebereidheid van consumenten. Onze resultaten laten een significant hogere reparatiebereidheid zien in de aanwezigheid van zo'n foutindicatie, wat wordt verklaard door een verhoogde beoordeling van zelf-effectiviteit (d.w.z. een 'can-do'-mentaliteit) om te repareren. Dit resultaat geldt echter alleen voor producten die relatief minder snel naar de professionele reparateur worden gebracht en een lagere investering zijn, zoals koffiezetapparaten en (draadloze) stofzuigers.

Om het vermogen van consumenten om te repareren te vergroten, is het ontwerpen van producten die modulair zijn tevens een veelbelovende strategie om de levensduurverlenging van producten te stimuleren. Echter, voor de gemiddelde consument is het gebruik en bezit van modulaire producten (nog) niet de norm. In hoofdstuk 5 wordt in twee experimenten onderzocht of een modulair productontwerp de reparatiebereidheid van consumenten kan verhogen. Ook wordt onderzocht of specifieke aanwijzingen en signalen in het design consumenten kunnen aanmoedigen om zelf reparaties uit te voeren. Interessant genoeg laten de resultaten van het eerste experiment zien dat de kans op professionele reparatie voor modulaire smartphones toeneemt, terwijl de kans op doe-het-zelf-reparatie laag blijft. Vervolgonderzoek in het tweede experiment laat zien dat een aanwijzing aan de binnenkant van een modulaire smartphone (d.m.v. een pictogram om de verschillende componenten uit te leggen) in combinatie met ondersteunende informatie (d.w.z. een afbeelding van het geopende apparaat) de intentie van consumenten om de smartphone zelf te repareren kan vergroten. Deze resultaten suggereren dat een modulair productontwerp niet persé voldoende is om de doe-het-zelf-reparatie aan te moedigen. Het impliceert dat de consument ondersteuning nodig heeft om zich de stappen van het repareren van een modulair product te kunnen inbeelden, en dus meer nodig heeft dan alleen aanwijzingen die aangeven hoe het kan worden geopend.

Hoofdstuk 6 gaat verder met het onderzoeken van ontwerpstrategieën, en exploreert hoe productmarketing de reparatie-intenties van consumenten kan stimuleren. De resultaten tonen aan dat het verstrekken van informatie over de betrouwbaarheid en upgradebaarheid van een product, via een levensduurlabel, consumenten kan ondersteunen bij het langer gebruiken van hun producten. Het toont aan dat hogere betrouwbaarheidsscores resulteren in een grotere intentie tot het repareren van een smartphone dan een lagere score. Bovendien laat het zien dat de mogelijkheid om de functionaliteit van het gerepareerde onderdeel via een upgrade te verbeteren de kans op reparatie van smartphones vergroot. Het verstrekken van informatie over de mogelijkheid tot upgraden is dus niet alleen een nuttig marketinginstrument bij verkoop, het kan ook de intentie om te repareren bevorderen. Om te zorgen dat er rekening wordt gehouden met de resterende levensduur wanneer een product kapotgaat, raden we aan om dergelijk levensduurlabel zichtbaar op het product te bevestigen en altijd toegankelijk te maken voor de consument.

Ten slotte bespreken we in Hoofdstuk 7 verschillende richtlijnen en suggesties voor zowel de ontwerppraktijk als beleidsmakers om levensduurverlenging door middel van reparatie te realiseren. Daarnaast wordt er gereflecteerd op de implicaties van productlevensduurverlenging binnen een circulaire economie. Ten eerste is het belangrijk om te beseffen dat het verlengen van de productlevensduur veranderingen vereist in de huidige manier waarop bedrijven zijn georganiseerd. Bovendien moet men voor een succesvolle acceptatie van repareerbaarheid, de eventuele wens van consumenten naar nieuwe producten met de nieuwste functies erkennen. Ook zullen potentiële onbedoelde neveneffecten van reparatie- en productlevensduur labels moeten worden verkend. Aangezien producten met hoge levensduurverwachtingen vaak een relatief hogere investering vergen, moet ook sociale rechtvaardigheid rond de verlenging van de levensduur van producten worden meegenomen. Ten slotte willen we benadrukken dat het creëren van een samenleving waarin reparatie de norm is, niet uitsluitend de verantwoordelijkheid is van de consument. Een systemische aanpak en samenwerking tussen alle betrokken belanghebbenden is vereist voor een succesvolle transitie naar reparatie- en productlevens-duurverlengingspraktijken.

De consumentgerichte benadering van dit proefschrift draagt bij aan onderzoek naar verlenging van de levensduur van producten en reparatie, door middel van design. Ontwerpers en beleidsmakers kunnen onze inzichten gebruiken om reparatiegedrag van consumenten bij (elektronische) producten te stimuleren wat hard nodig is voor de realisatie van een circulaire economie.

PROLOGUE

“Would you like to have a coffee?” It was a Sunday morning in March, and we had just finished our family breakfast. I was in the mood for a cappuccino, so I replied, “Yes, please! I would love one.” As we continued chatting in the kitchen, we heard my partner’s mother exclaim, “Oh dear, he’s doing that again…” Intrigued, I walked up to her and noticed two buttons flashing rapidly on the coffee machine, the same buttons used to brew coffee. The fast-blinking lights conveyed a sense of urgency, making us feel nervous. We were certain that something was wrong, but it was unclear what exactly. After trying to reset the machine multiple times, even unplugging, and plugging it back in, we had to accept that the issue was too severe to ignore. No coffee for me that morning…

> “Never mind, guys. Don’t waste your time on it. Last week he was doing this as well. I’ll take care of it… Besides, it’s been years since I bought it! I can’t even remember how long ago. Maybe it’s time for a new one.”

The above situation is one that many can relate to. You want to use a product, and suddenly it fails. The once-reliable device that performed an (essential) function in your daily life, like brewing your morning coffee or doing your laundry, gives up on you. Such a situation disrupts your daily routine. Often, you do not understand why the product failed or how to fix it. The unknown cause of the failure leads to feelings of nervousness and frustration. You start questioning the reliability of a device that had always been trustworthy, and you begin to notice signs of wear, like scratches and dirt, that previously went unnoticed. The thought of whether you need a new one crosses your mind. Repairing it seems like a hassle, especially when you don’t even know what’s wrong or how long it will work after the repairs before failing again. Not to mention the cost of repairs…

Fortunately, thanks to the knowledge I gained from my research, I was able to inform my partner’s mother that the most common cause of coffee machine failure is calcification. She promised to try decalcifying it and see if she could get the device working again. The next day, I received the following message:

> “The coffee machine is working again! Decalcifying it worked, using a descaling kit I found that was provided when I bought it. I also searched the internet for solutions to fix the blinking buttons. This just shows how relevant your research is; otherwise, I would have definitely thrown it away!”

With this relatively simple operation, the lifetime of the coffee machine had been extended and was saved from unnecessarily ending up in the waste pile.

OBSOLETE PRODUCTS - STREET IN DELFT THE NETHERLANDS

1

Introduction

1

1.1 THE MOTIVATION FOR WRITING THIS THESIS

The waste of electrical and electronic equipment (WEEE) is one of the fastest-growing waste streams in Europe and is expected to grow even more in the future (Forti et al., 2020). Today's production and consumption of electronic products have significant impacts on our environment and cause severe issues. For example, the materials needed for this production require the utilization of (scarce) resources. The extraction and processing of materials, such as metals, consumes large amounts of water, minerals, and electricity. If not managed well, this process can also release toxic chemicals, and pollute our air, water, and soil systems (Global Electronics Council, 2021).Firstly, the production processes of the sheer volumes of consumer electronics cause harmful CO_2 emissions polluting the environment (Allwood et al., 2011). Furthermore, many of the resources required for the production of these products are finite and the global stock of essential raw materials is becoming increasingly critical. Shortages of critical materials may therefore cause issues for industry and the environment, and as a result may put global politics on edge (European Commission, 2020). The recent report of the European Commission (2020) on this topic addressed these issues and pinpointed that the EU should reinforce its strategic approach towards more resilient raw material value.

Once electrical and electronic products reach the end of their life cycle, they are often discarded and end up in landfills. E-waste management has been prioritized in developed countries; however, a lot of e-waste is also sent to low- to middle-income countries. Transferring the e-waste problem to these countries, who often lack the appropriate infrastructure and legislation, is problematic (Thakur and Kumar, 2022). It poses severe social and health-related risks due to unsafe practices for humans and the contamination of the environment, as improper recycling processes contribute to the loss of valuable resources and the leaching of toxic materials into the environment (Global Electronics Council, 2021; Heacock et al., 2016). So far, future scenario studies indicate that if we continue the way we produce and consume electronics as we do nowadays, the amount of e-waste could increase from 58 million tons in 2021 to 75 million tons in 2030 and 112 million tons in 2050. This means e-waste will be doubled in 2050 unless serious action is undertaken to reverse this trend (Parajuly et al., 2019). Calculations of the 'Earth overshoot day' provide a more tangible picture to illustrate how much more we, humans, consume and discard compared to what our planet can handle. For example, Dutch consumers today need 3.6 times our Earth's capacity to cover the liquidating stock of ecological resources and accumulating waste resulting from their consumption pattern. This means each year in spring we are already crossing the limit of what our planet can handle for the entire year (https://www.overshootday.org/, July 2023).

During the four years that I spent on researching lifetimes of electrical and electronic products, such as washing machines, vacuum cleaners, smartphones and TVs, I have discussed my research with many friends, family, colleagues, and other acquaintances. When I asked if they could relate to the importance of product lifetime extension for the environment, many immediately started to share personal stories about their own experiences with early product failures or the lack of durability in modern products. Initially, people responded with genuine curiosity and interest, but many also seemed unaware of the environmental impact of short-lived products. For example, many were unaware about the impact of the lifetime of their smartphones on the environment, and the fact that using their smartphone for a longer period of time would lower their environmental footprint.

When I mentioned repair as a way to extend product lifetimes, I also noticed some doubt and hesitation. Repairing can be a hassle; identifying the issue can be time-consuming, finding available experts is not always easy, and it can be expensive (e.g., Güsser-Fachbach et al., 2023; Jaeger-Erben et al., 2021; Terzioğlu, 2021). Simultaneously, alternatives to replace a product with a new one were perceived as very attractive, such as one-day delivery and services that take care of the disposal of the old product. This often makes replacing the product with a new one a more convenient choice. Moreover, there are numerous alternatives on the market with the latest features, and sometimes the argument was posed that it is from an environmental perspective (e.g., improved energy efficiency) better to replace the product with a new one that is more efficient. Especially when this product is marketed as an attractive deal. While this can be true in principle, research showed that in practice most products are already replaced before they reach their environmental break-even point (i.e., the moment when a new more energy-efficient product is more desirable for the environment compared to using the old one) (Bakker et al., 2014). Therefore, products we have in our possession, which could potentially have served for a few more years, are often discarded prematurely. Apart from this misperception about the impact of our products on the environment, it has occurred to me that an underlying reason for our replacement behavior could be the desire for the excitement of purchasing a new product. Something fresh to break the monotony of daily life.

As my research progressed, I have delved deeper into my fascination with understanding why we constantly crave new things. We, including myself, have become accustomed to replacing products that still function when we feel "it's time for new ones." This led me to wonder: What are the (underlying) barriers consumers face toward extending product lifetimes? We perceive product failure as a signal to replace it, because often we do not know how and if it is even possible to repair the product. Can we change this perception so a product's design could actually stimulate repair behavior? And what information

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can support consumers to repair products when failure occurs? Supporting consumers to extend product lifetimes via repair can be part of the much-needed turning of the tide from a linear and disposal society to a circular and sustainable society.

1.2 KEEPING PRODUCTS' VALUE HIGH IN A CIRCULAR ECONOMY

In our society, a linear way of production and consumption is currently the norm. Traditional business models are based on a 'take-make-use-dispose' principle, in which the main aim of businesses is to generate profits from selling products and goods (Mugge, 2017). As a result of a linear focus, the industrial system became largely dependent on fossil fuels and accustomed to generating profit from a one-way flow of materials and products over time (Bocken et al., 2016).

The circular economy principle offers a potential solution to reduce the need for new product manufacturing and, consequently, decrease the consumption of fossil fuels and virgin (critical) raw materials. It proposes an economy that is inherently restorative and aims to maintain the highest utility and value of products, components, and materials at all times (Geissdoerfer et al., 2017; McCollough, 2009). In a circular economy, products and materials are continuously cycled. Products can be cycled through practices such as maintenance, repair, reuse, redistribution, refurbishment, remanufacturing, and recycling. The goal is to maximize the value derived from products and materials throughout these cycles and eliminate the concept of "waste" by mimicking a natural system of conserving and reusing resources (Chertow, 2008). This approach strives to achieve closed loops of material and product flows, ensuring that no value is lost, and everything is preserved for as long as possible. In the ideal scenario of the circular economy, waste thus ceases to exist as all products and materials are part of a continuous loop within the system (Ellen MacArthur, 2013).

The Value Hill (cf. Figure 1) illustrates the value of a product throughout its entire lifecycle in both a linear and a circular scenario. In this figure, the vertical axis represents the amount of value in a product, while the horizontal axis represents time. During the pre-use phase, the value of the product increases through various stages, including the extraction of raw materials, manufacturing, assembly, and eventually sale through a retailer. The use phase begins with the product reaching its maximum value. In the linear scenario of the "Value Hill", a product with a relatively short use phase is shown. In this scenario, no value preservation methods are applied during the post-use phase. As a result, the product quickly loses value after a brief period of use. In the circular scenario of the "Value Hill", the product is "looped back" multiple times during the post-use phase.

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During the use phase, the lifetime is extended through repair and maintenance activities. During the post-use phase, the product could be reused/redistributed, refurbished, or remanufactured allowing multiple lifecycles. Eventually, the product is recycled, and materials are looped back into the system avoiding complete value destruction. In this way, the product's value and its lifetime are preserved and extended to their maximum.

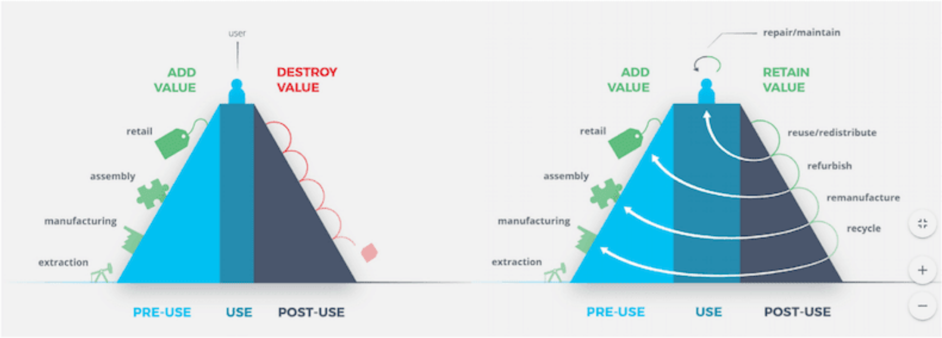

Figure 1. The circular economy value hill (Achterberg et al., 2016)

Extending the use phase of the first consumer slows resource loops (European Environment Agency (EEA), 2021) and thus allows for the preservation of the product's maximum initial value by preventing premature replacement. This can be achieved by keeping products in good working condition, for example, by maintaining them to ensure optimal functionality throughout their lifetime and by repairing malfunctions to restore these products' functionality (Ackermann et al., 2018). Preserving value at this stage means the product's initial value will remain. Compared to remanufacturing or recycling processes, during which components or the entire product may be lost, relatively limited additional resources or CO_2 emissions are needed to recover value during repair. Product lifetime extension is thus an impactful and preferred strategy for addressing the issues associated with the production and consumption of electrical and electronic products, as it minimizes the destruction of value and production of waste (Ellen MacArthur, 2013; McCollough, 2009). Therefore, it is important to stimulate consumers to extend product lifetimes in the use phase by encouraging them to maintain and repair their products.

1.3 THE ROLES OF DIFFERENT STAKEHOLDERS IN PRODUCT LIFETIME EXTENSION

Our current linear way of consuming is deeply rooted in our society. The transition towards a more circular consumption system is, therefore, challenging and a complex matter that requires the cooperation of various stakeholders (Ellen MacArthur, 2013; Ghisellini et al., 2016).

In the first place, the current linear revenue model poses a problem as it thrives on profits derived from selling new products (e.g., Bocken et al., 2016). Consequently, manufacturers and retailers play a significant role in promoting premature obsolescence (Satyro et al., 2018; Thornquist, 2017). For instance, manufacturers often focus on incremental innovations for existing products, leading consumers towards early product replacement triggered by marketing campaigns, a relatively effortless way to maximize profits (Mackenzie et al., 2011). Also, retailers also want to sell products to make a profit, for example, via advertisements promoting their speedy delivery services, or encouraging to replace a product when it is broken. The desire and curiosity for newness of consumers may drive manufacturers to invest in incremental or trend-sensitive product innovations, making it challenging for both sides to embrace change. To make a change, manufacturers and retailers could act by offering circular products via sustainable business models and redirect their focus toward developing more durable product innovations that integrate all aspects of the circular economy (Bocken et al., 2016; Chapman, 2009). For consumers, circular product offerings need to be attractive and financially competitive to adopt them. To increase consumer adoption, services and business models that support various loops, such as offering attractive repair services and re-selling existing products in a refurbished state, have received increased research attention (Lieder et al., 2017; Tunn et al., 2019).

Governmental bodies play a pivotal role in stimulating manufacturers to develop more sustainable products and business models through their policymaking (Dalhammar et al., 2022). For example, one way to encourage product lifetime extension is to introduce legislation to change the practices of manufacturers. For example, the introduction of Extended Producer Responsibility (EPR), which refers to legislation that enforces manufacturers to become responsible for the discarded goods they put on the market instead of the government (Bieser et al., 2022; Mansuy et al., 2020; Wilhelm, 2012). Another approach more specifically related to lifetime extension, is the development of laws that penalize industries for producing non-durable products (Valant, 2016). A success story resulting from the implementation of such policies is the case of the French consumer organization UFC, which successfully won a lawsuit in 2020 against Nintendo for “planned obsolescence” of the controllers of the Switch consoles. As a result, Nintento ensured all controllers were repaired for free. In addition, despite penalizing laws and regulations, governmental bodies should encourage manufacturers to adopt circular and value-preserving practices by stimulating specific practices via tax benefits. For instance, they could lower taxes on profits made from circular business models, such as repair services or the reselling of existing refurbished products (Ölander and Thøgersen, 2014).

Recently, a new proposal was made for Ecodesign regulations to further improve circularity, energy performance and other environmental sustainability aspects for specific product groups (European Parliament and European Union Council, 2022). Furthermore, the Right to Repair legislation in the EU was developed to stimulate repair practices. This legislation entails several regulations. Within the legal guarantee, sellers will be required to offer repair except when it is more expensive than replacement. Beyond the legal guarantee, a new set of rights and tools will be available to consumers. These are a right for consumers to claim repair from producers, a producers' obligation to inform consumers about the products that they are obliged to repair, an online matchmaking repair platform to connect consumers with repairers, a European Repair Information Form which consumers will be able to request from any repairer, and a European quality standard for repair services (European Commision, 2023). While this legislation is a step in the right direction, the current legislation mostly focuses on the direct role of manufacturers and retailers and less on how consumers can undertake repair action themselves. Additionally, the "French Repairability Index" was developed to inform consumers about products' repairability via a repairability score at the point of sale, and in Belgium such an index is currently under development.

For manufacturers and governments to change to a circular and repairing society, societal initiatives can have a large impact. One example is "The Right to Repair" movement, which has the objective to make repair affordable, accessible and mainstream. This initiative provided crucial input for developed Right to Repair legislation in the EU. Furthermore, initiatives from academia (e.g., the PROMPT project cf. Chapter 1.6) can contribute to facilitating the change to a more circular society. To stimulate societal and academic initiatives that encourage product lifetime extension, governments could consider encouraging initiatives that positively encourage the shift towards more circular consumption patterns. Financial instruments such as the Horizon Europe research and innovation programme offer opportunities for the funding of (academic) projects investigating potential solutions to the issues resulting from our consumption society. In addition, the offering of subsidies for repair cafés, waste management initiatives of companies, or platforms that support the reselling of repaired or refurbished products also (Jaeger-Erben et al., 2015; Kannengießer, 2020; van der Velden, 2021).

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1.4 THE CONSUMER ROLE IN PRODUCT LIFETIME EXTENSION

The previous section demonstrates that achieving requires a complex interplay involving multiple stakeholders. However, one could question if the efforts from all the above-mentioned stakeholders involved to facilitate the transition to a more sustainable society are sufficient. For people, it is common to replace products even though they are functioning well (Cox et al., 2013). Research shows that 31% of washing machines, 66% of vacuum cleaners, 56% of TVs, and 69% of smartphones (Harmer et al., 2019; Hennies and Stamminger, 2016; Wieser and Tröger, 2018) are replaced for other reasons than being broken 'beyond' repair. Whether a consumer perceives a product as 'obsolete' (Antonides, 1991; Cooper, 2004) is influenced by factors, such as (social) norms, values, and personal needs or desires (Bayus, 1991; Echegaray, 2016). For instance, a smartphone may be perceived as obsolete due to a low-quality camera or a broken screen. From a technical and environmental standpoint, this might be premature as the product is still physically functioning or can be repaired. For example, for a smartphone the highest environmental impact is the PCB and thus repairing other components when they fail is beneficial for the environment (Clément et al., 2020). However, earlier research showed that even though a product is produced in a durable or repairable manner, it does not mean consumers will automatically use it longer (Makov and Fitzpatrick, 2021). The consumers' perception of a product being 'obsolete' significantly impacts the product lifetime. Consequently, consumers play a key role in the early replacement of products (Cooper, 2004). Their willingness to make changes in their current consumption patterns is crucial to create a society in which circular consumption becomes the norm. To facilitate the shift towards a circular consumption society, it is thus important to consider what goes on in consumers' minds when they choose between product lifetime extension and product replacements.

1.4.1. PRODUCT OBSOLESCENCE AND CONSUMERS' REASONS FOR REPLACEMENT

To address the consumer aspects of premature obsolescence, it is important to first understand product obsolescence and consumers' reasons for replacement. A product's lifetime ends when a product is deemed 'obsolete' by the consumer. The term 'planned obsolescence' was first introduced by Bernard London in 1932 as a solution to end the Great Depression and boost the economy by increasing sales. In 1960, Packard discussed 'Planned Obsolescence' in his book 'The Waste Makers,' wherein he criticized the industry for intentionally creating obsolescence by introducing products to the market that either break down earlier than necessary or are overly influenced by trends and fashion. He differentiated obsolescence based on function, quality, and desirability. Later, Granberg (1997) identified two primary types of obsolescence. He characterized absolute obsolescence resulting from physical wear and tear of the product and relative obsolescence arising from a comparison between the old and new products. Van Nes and Cramer (2005) outlined four general reasons for product replacement. Firstly, wear and tear can cause a product to break or cease. Secondly, an upgraded, new version of the product may possess enhanced utility, rendering the existing product insufficient due to new safety or usage demands. Enhanced expression refers to when a product falls short in terms of comfort, quality, or style. Finally, a product may be replaced due to a new desire, functioning well but lacking certain characteristics offered by newer products. In addition to the aforementioned main types of obsolescence and general replacement rationales, the literature has defined various specific subtypes of product obsolescence. I have compiled and summarized the most frequently occurring and overlapping terms as follows:

Quality obsolescence can occur when one or more critical product functionalities fail, such as a washing machine with a broken pump. It can also result from a perceived decrease in functional performance, such as a smartphone with reduced battery capacity or a vacuum cleaner with diminished suction power (Guiltinan, 2009; Mugge et al., 2005; Nicole Van Nes et al., 1999). **Technological obsolescence** can arise when new technological innovations hinder a product's proper functioning, such as mandatory software updates. It can also occur when a new innovation outperforms the older technology, for example, the availability of faster 5G networks that are only compatible with newer phone versions. A subtype is software obsolescence, which can arise when software quality degrades to the extent that the product no longer fulfills its (required) functions (Antonides, 1991; Cooper, 2004; Poppe et al., 2021). **Economic obsolescence** may come into play when a device in possession is in good working order but is less favorable from an economic point of view compared to a new device (Cooper, 2004; Khan et al., 2018). For instance, investing in a more energy-efficient washing machine that eventually offsets the energy bill savings. **Ecological obsolescence** can materialize when a product is replaced by an environmentally friendlier alternative (Nicole Van Nes et al., 1999; Wilson et al., 2017). For example, switching from a conventional tumble dryer to one with a heat pump to reduce energy consumption. **Aesthetic obsolescence** occurs when a new product gains appeal due to evolving market trends. A sleeker design of a phone's new version can render the previous version aesthetically outdated. However, a visibly used vacuum cleaner that still functions well may also become aesthetically obsolete (Burns, 2010; Mugge et al., 2005). **Psychological obsolescence** emerges when a product is replaced due to social influences, often tied to social status or symbolic value (Cooper, 2004; Echegaray, 2016). For instance, upgrading to the newest smartphone version to align with peers who own it. Lastly, **social obsolescence** can occur from changes in social norms. For example, owning a smartphone has become self-evident within the last decade. Using those products is becoming the norm and even essential parties (e.g., banks, health insurance) expect you to own one for their services.

These parties may have requirements for using their services (e.g., software that allows data protection to keep personal information safe). As a result, people may be forced to buy or replace products to meet social standard and stay included in society (Burns, 2010; Mugge et al., 2005; Wilson et al., 2017).

The aforementioned types of obsolescence underscore the challenges that need to be tackled to encourage consumers to consume more sustainably and extend product lifetimes. In this thesis, premature replacement is addressed, which denotes the phenomenon of discarding products earlier than necessary. When addressing this phenomenon, it must be noted that often absolute obsolescence may not be as definitive as it is defined to be in the literature. It may occur when a product is replaced unnecessarily because of a failure that could have been remedied with appropriate maintenance or repair actions. Also, it is important to note that in most instances, the perception of a product's obsolescence can be highly subjective, and typically, multiple reasons (a combination of various obsolescence types as defined above) contribute to the decision to replace a product (Cox et al., 2013). For instance, diminished suction power in a vacuum cleaner together with scratches caused by its usage may prompt quality obsolescence. Another example is the advancements of improved camera functionalities in smartphones that trigger technological obsolescence together with the fear of missing out on new features and the risk of being socially excluded due to psychological obsolescence. To mitigate premature product obsolescence, it is, therefore, crucial to investigate the phenomenon of premature replacement from a consumer's perspective and address the complex interplay of various obsolescence types, cf. Figure 2.

1.4.2. CONSUMERS' BARRIERS TOWARDS REPAIR

If a product fails during its lifetime, consumer studies showed that most discarded products were never repaired during their lives demonstrating a lack of repair behavior (Harmer et al., 2019; Hennies and Stamminger, 2016; Wieser and Tröger, 2018). Research has unveiled several barriers that hinder consumers from embracing repair. The foremost barrier is the cost of repair, encompassing labor charges and spare part prices. Moreover, there exists a lack of ability to repair in terms of skills and knowledge (Ackermann et al., 2021; Jaeger-Erben et al., 2021). To overcome the barriers towards repair, existing design research predominately adopted a perspective rooted in engineering, by focusing on how to make product repair technically feasible. For example via the usage of screws instead of glue as connectors to enable (dis)assembly practices needed for repair activities (Raihanian Mashhadi et al., 2016; Sabbaghi et al., 2016). However, the mere physical capability of repair does not guarantee consumer compliance (Makov and Fitzpatrick, 2021). Looking more closely at the repairing process of consumers, identifying issues, and formulating successful repair steps pose several challenges as well (Pozo Arcos et al., 2020). The availability of spare parts is limited and repair services often lack convenience, being either infrequently accessible or lacking a robust repair infrastructure (e.g., drop-off points or interim replacements) (Cordella et al., 2021; Sabbaghi et al., 2017). Reflecting on this, it becomes questionable if a purely physically repairable product is enough for the consumer to consider repair as worthwhile. Aside from financial constraints of repair, design-related impediments within the product and service sphere thus do not readily encourage repair and lifetime extension. Consequently, new products that are easily obtainable often prove a more convenient choice for consumers. Especially for products that have undergone rapid technological advancements over the years, this may be problematic (Cox et al., 2013), as the goal of repair remains limited to restoring the product's initial functionality, not to improve it.

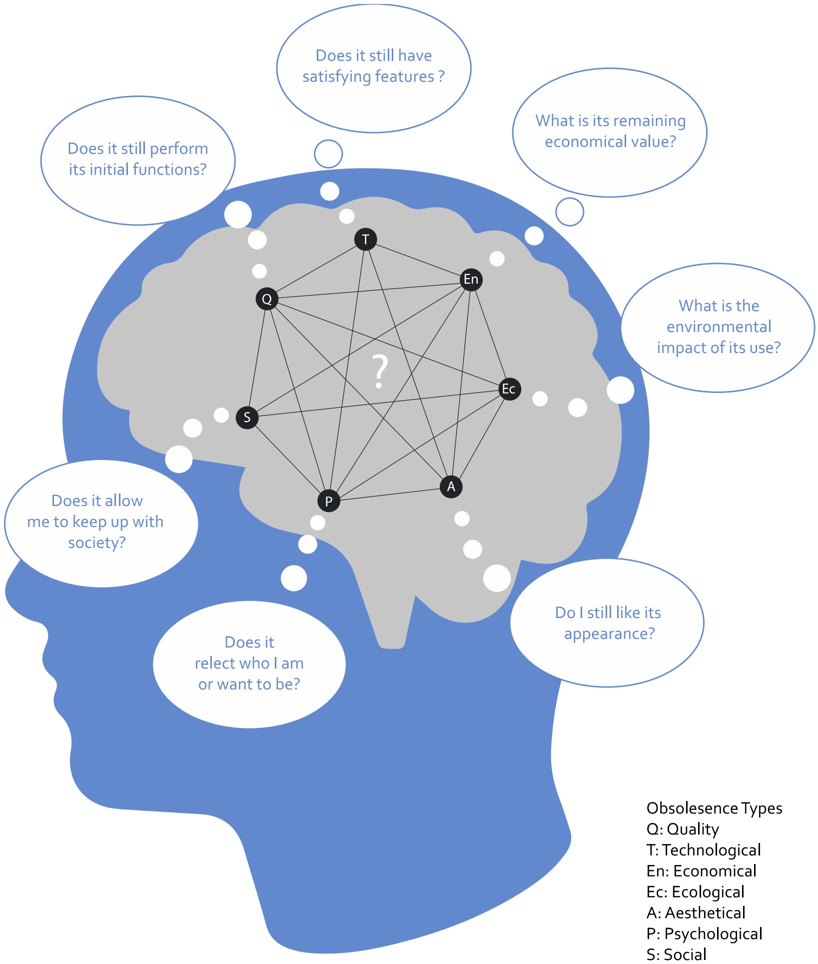

Figure 2. The complex interplay of various obsolescence types in the consideration to retain, repair or replace a product

1.5 MEASURING PREMATURE OBSOLESCENCE: THE PROMPT PROJECT

To tackle the issue of premature product replacement, The PROMPT (PRemature Obsolescence Multi-stakeholder Product Testing programme) project (https://prompt-project.eu) has been initiated. The PROMPT project was part of the European Commission H2020 Programme and enabled the research for this thesis. It aims to assess product lifetimes before products enter the market by developing a testing programme based on academic research. The testing programme covers major aspects of product longevity. The goal is to provide testing bodies, consumer organizations, market surveillance authorities, and other interested stakeholders tangible definitions and methodology to assess premature obsolescence. These assessments can provide inputs for a potential lifetime label to better inform consumers about the product lifetime at purchase. In a consortium with research institutes, consumer organizations, repair companies, and repair platforms, Figure 3, a multi-stakeholder approach was taken. This allowed independent authorities, manufacturers and consumer organizations to assess a range of products from the electrical and electronics sector.

Figure 3. The different project partners involved in the PROMPT project

The consortium focused on three core aspects of product longevity of electronic products. The first one was product reliability, aimed to define the various aspects and influencing factors of product durability, for example, failure test such as drop tests for smartphones, and cyclization tests for washing machines to check what failures can occur after multiple use cycles. The second one was product repairability, which was focused on an evaluation of product design on repair from an engineering perspective. For example, by developing a testing procedure to assess the disassembly time and steps required for repair. However, despite a reliable and repairable product design, the consumer ultimately decides to replace a product even though it is working well or could have been technically repaired. Therefore, the third core aspect focused on consumer behavior and the role of the market in premature obsolescence. For example, a person may be less likely to repair a product when it is difficult to identify what is wrong with it when it fails or when a repair service offered by the manufacturer is inconvenient (e.g., time-consuming, costly). Therefore, we needed to explore what design/service aspects would influence whether or not to replace or repair a product. The testing program of the PROMPT project focused on smartphones, televisions, washing machines and vacuum cleaners. These products were chosen because all have a significant market penetration, environmental impact, use frequency and importance to consumers. Furthermore, the products have a variety in functionality and technological advancement (i.e., high for smartphones and TVs and medium for vacuum cleaners, and low for washing machines). Fitting these criteria, these product categories were found to be a relevant for the research of electrical and electronic products in this thesis, which we expanded with a study on coffee machines (cf. Chapter 4).

Within the PROMPT project, our focus was this third core aspect influencing premature obsolescence. The research outcomes led to design guidelines to prevent premature obsolescence from a consumer and market perspective. These guidelines fed eventually into testing criteria, which were developed via iterative workshops organized throughout the project. The developed testing criteria to assess the consumer behavior and market aspects that may lead to premature obsolescence of products were included into a general testing program, together with the previously mentioned reliability and repairability aspects. The testing criteria were piloted in several labs across Europe, and iteratively improved afterwards. The advisory board of PROMPT included manufacturers, and repairer experts, which provided feedback on a yearly basis. The finding of the PROMPT project were shared with policymakers and manufacturers (via a press conference in Brussels and via reports) and disseminate among consumers (via reports and newsletters). The academic research which was conducted to uncover the consumer behavior and market-related aspects were used as content for this thesis.

1.6 RESEARCH OBJECTIVE AND CONTRIBUTION

The primary objective of this thesis is to explore the role of design in extending product lifetimes by stimulating consumer repair behavior. Previous research has indicated

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that consumers' barriers to repair significantly influence decisions to retain or replace (electronic) items (Magnier and Mugge, 2022; Terzioğlu, 2021). To encourage the extension of product lifetimes, it is crucial to investigate consumers' considerations during replacement decision-making and uncover the influential factors of premature product replacement (e.g., Cooper, 2004). Therefore, this thesis adopts a consumers' perspective. It aims to provide a consumer's perspective on product lifetimes, reasoning for replacement decisions and product lifetime extension via repair. This approach reveals the complex interplay between the barriers to repair and identifies suitable design strategies that have the potential to inspire consumers to transition toward a society in which product lifetime extension and repair becomes the default consumer behavioral choice.

By translating insights from consumers and (sustainable) behavioral theories into practical implications for product design, this thesis attempts to combine the fields of sustainable consumer research and design research. This is an emerging and relatively unexplored area in the realm of product lifetime extension, however, it is urgently required for the transition to a circular economy because circular product designs can only be successful if consumers act accordingly (Camacho-Otero et al., 2018). For example, products that are physically designed to be repaired do not automatically trigger repair behavior (Makov and Fitzpatrick, 2021). Therefore, the consumer perspective on repair should be incorporated in the research agendas of both academia and policymakers striving to contribute to the transition to a circular economy. Secondly, while design and marketing strategies to stimulate lifetime extension via repair (e.g., modularity, upgradeability, lifetime labels) have been discussed in the literature (Bonvoisin et al., 2016; Dalhammar and Richter, 2017; Khan et al., 2018; Wieser and Tröger, 2018), their empirical effectiveness and the conditions under which these work effectively often remains insufficiently investigated. In addition, the influence of lifetime labels and upgradeability on repair intentions remains underexplored. Yet, evidence of the effects of these strategies on consumer behavior is vital to determine their efficacy (Blundell, 1988).

This thesis encompasses several empirical studies testing how design and marketing strategies effectively can encourage consumers to extend product lifetimes by stimulating repair behavior. Furthemore, it investigated the boundaries and under what conditions these strategies would work. The content of this thesis offers contributions to design research, practitioners, and policymakers engaged in the circular economy field. It provides practical implications to incentivize consumers to repair and, consequently, prolong product lifetimes through design.

1.7 RESEARCH QUESTIONS

The addressed research gap resulted in the formulation of the main research question of this thesis:

How can design prevent premature obsolescence by encouraging consumers to prolong the lifetimes of electronic products via repair?

To answer the main research question, the thesis is divided into two parts addressing three sub-research question (SRQs). In the first part '*Preventing premature obsolescence from a consumer's perspective*' the process of product replacement is thoroughly investigated and aims to reveal the consumer barriers to extending the lifetimes of their products. Two SRQs are formulated accordingly:

SRQ1: Why do consumers decide to replace products prematurely?
SRQ2: What barriers do consumers experience concerning product lifetime extension?

In the second part, *'The impact of design and marketing strategies on consumers' intentions to extend product lifetimes via repair'* the effects of several design strategies on consumers' repair intentions are empirically tested in an experimental setup. The third SRQ is formulated accordingly:

SRQ 3: *How can design and marketing interventions help consumers with repair and thereby extend their products' lifetimes?*

1.8 THESIS OUTLINE

In Part I of this thesis, the primary goal is to investigate the process of product replacement from the consumer's perspective. To address SRQ1, Chapter 2 first introduces a theoretical framework explaining the processes behind consumers' replacement behavior. Based on a literature review, Chapter 2 explains consumers' processes behind product replacement behavior. Furthermore, we show the influencing factors that can either decrease or sustain product value throughout the product lifetime based on insights from existing literature.

Chapter 3 provides in-depth insights into consumers' perspectives regarding product lifetimes and their barriers to extending them, addressing SRQ2. Interviews with Dutch consumers (n=22) illuminate the underlying rationales and thought processes guiding consumers' choices between replacement and repair and provide more detail on elaborating how people evaluate product lifetimes. Also, it demonstrates what prevents people from extending the lifetimes of their products and encompasses opinions about a label informing consumers about products' lifetime.

Part II of this thesis addresses SRQ3 and investigates the empirical effectiveness, conditions and boundaries of various design and marketing strategies identified in Part I. Several experiments are conducted in Chapters 4,5 and 6 to demonstrate their potential to stimulate consumers to extend product lifetimes via repair.

To extend product lifetime, consumers generally have limited (perceived) ability to repair their electronic products. The studies presented in Chapter 4 specifically investigate if support in diagnosing the failure can incentivize consumer repair intentions. In three experiments, we test if a fault indication can boost consumers' perceived self-efficacy (i.e., a "can-do" attitude), leading to a greater inclination to repair. Furthermore, we investigate its boundaries and conditions by looking at the impact of a fault indication on both low- and high-investment products, which are less or more commonly subject to professional repair.

In Chapter 5, modularity is investigated as a promising design intervention for extending product lifetimes. A modular product consists of independent 'building blocks' and is designed in such a way the modules can be easily replaced or repaired when malfunctioning (Bonvoisin et al., 2016). Two experiments are set up to evaluate and explain the influence of modularity on consumers' likelihood to repair. Furthermore, it explores the conditions (i.e., via the support of different types of cues) that are required for consumers to act and repair modular products themselves.

Chapter 6 explores the potential of providing information about product lifetimes via a lifetime label on product lifetime extension. Specifically, it investigates the effect of reliability and upgradeability information on repair intentions. With an experimental setup, we investigate if a higher reliability score and the possibility of upgrading the defective component during a repair can stimulate smartphone repair behavior.

The thesis ends with a discussion in Chapter 7, in which all findings are reviewed, and the research questions are answered. Potential avenues are provided for researchers and practitioners who aim to stimulate product lifetime extensions via design. Furthermore, a reflection is made on what is needed to successfully encourage consumers towards a society in which product repair becomes the norm.

A visual of the outline of the thesis and in which chapters the research questions are addressed can be found in Figure 4.

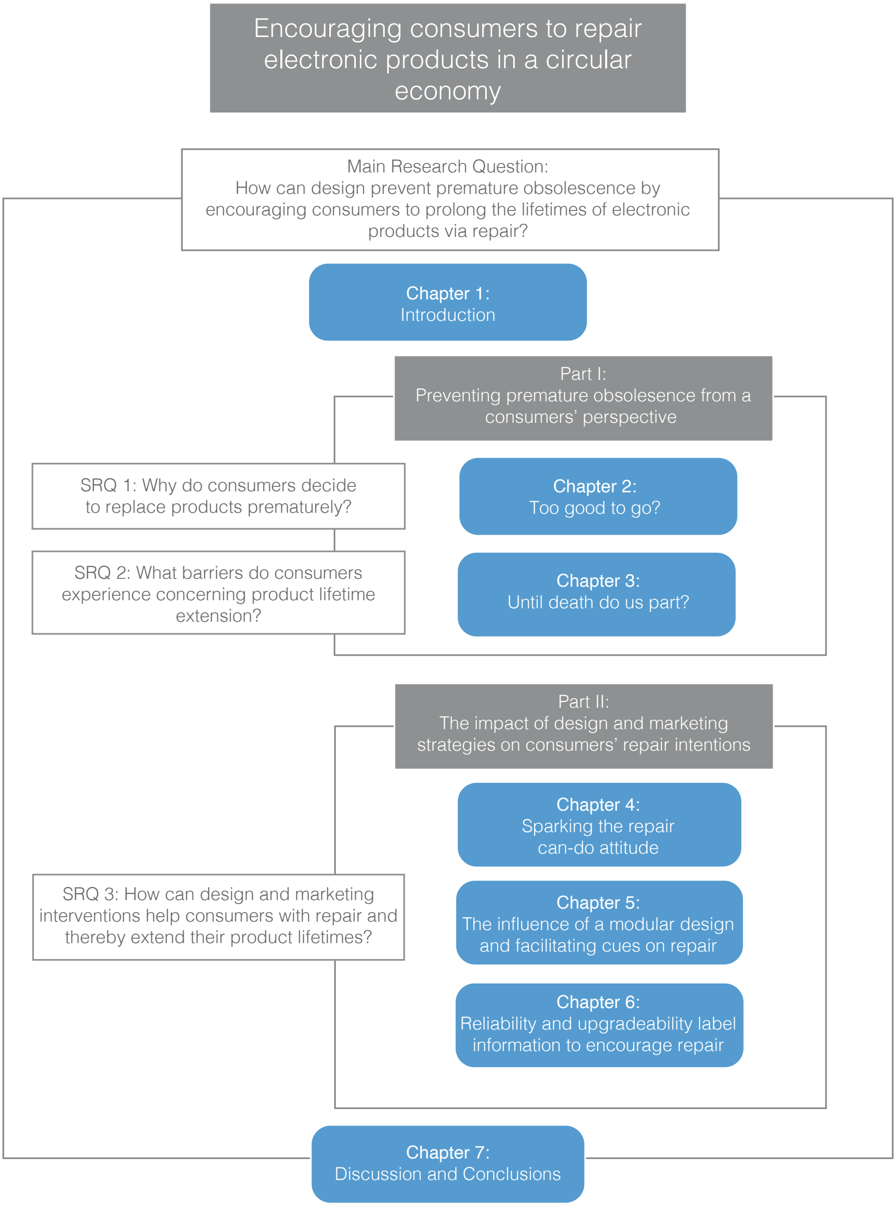

Figure 4. The outline of the thesis

PART I |

PREVENTING PREMATURE OBSOLESCENCE FROM A CONSUMERS' PERSPECTIVE

JUNGLE STYLED WATERKETTLE - LOCAL SUPERMARKET ROTTERDAM

2

Too good to go? Consumers' replacement behavior and potential strategies for stimulating product retention

This chapter was previously published:
Van den Berge, R., Magnier, L., & Mugge, R. (2021). Too good to go? Consumers' replacement behaviour and potential strategies for stimulating product retention. Current Opinion in Psychology, 39, 66–71. .org/10.1016/j.copsyc.2020.07.014

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Chapter 1 showed that many products are disposed of before they have reached the end of their functional life. From an environmental perspective, such early replacement is undesirable. Consumers generally have a preference to use products for a long time, but do not seem to behave accordingly, which stresses the importance of the consumers' role in premature product replacement (Cooper, 2004).

This chapter addresses the consumers' role within product lifetime extension and aims to answer why consumers decide to replace products prematurely (SRQ1). By providing a state-of-the-art overview of the current knowledge on consumers' replacement behavior, it provides insights on the psychological process of product replacement. Subsequently, it identifies several influencing factors for replacement decision-making based on existing literature. Among those, several barriers are revealed that consumers experience to extend product lifetimes (SRQ2). Furthermore, based on the literature different strategies to promote product retention by supporting the inherent values of owned products are identified. The chapter concludes with summarized findings and prospects for future research.

2.1 INTRODUCTION

It is common for people to replace products even though they are functioning well (Cox et al., 2013). Research shows that 31% of washing machines, 66% of vacuum cleaners, 56% of TVs and 69% of smartphones (Harmer et al., 2019; Hennies and Stamminger, 2016; Wieser and Tröger, 2018) are replaced for other reasons than being broken 'beyond' repair. Also in the fashion industry, many clothes are worn for a shorter amount of time than they actually could (Zamani et al., 2017). Furthermore, when a product is malfunctioning, many consumers do not consider repair as a valuable option (Pérez-Belis et al., 2017).

Early product replacement results in increased waste, use of scarce resources and CO2 emissions, which have strong negative impacts on the environment (Bakker et al., 2014). So far, there has been an increased interest in recycling of products, but more can actually be gained by prolonging the product's first life (Mugge, 2017). Consumers have a strong intention to purchase reliable and long-lasting products but do not seem to behave accordingly (Whalen, 2019). While industry creates a demand for new products by introducing these on the market regularly, it is eventually the consumer determining whether or not to replace his/her product (Antonides, 1991). This stresses the importance of the consumers' role in early product replacement (Cooper, 2004).

This paper provides scholars, industry, and policy, a state- of-the-art overview of the current knowledge on con- sumers' replacement behaviour. We first explain the psychological process of product replacement. On the basis of this process, we then present different strategies to stimulate product retention. We conclude with possible avenues for future research.

2.2 PSYCHOLOGICAL PROCESS OF PRODUCT REPLACEMENT

Product replacement is often not only based on rational decision-making, in which consumers compare the costs of the replacement and the relative utility of the old versus the new product (Guiltinan, 2010). New technological developments of products and evolutions in fashion and designs have demonstrated accelerating effects on replacement intervals (Grewal et al., 2004). Besides utilitarian motives, fashionable designs, changing customer needs and new technologies significantly influence product replacement (Fels et al., 2016). Furthermore, firms' strategies to frequently introduce next-generation products tend to shorten replacement intervals (Boone et al., 2001).

When considering consumers' relationships with products, different values come into play. Sheth, Newman and Gross (Sheth et al., 1991) defined five different types of values influencing consumer choice. These values are important to understand consumers' decision to retain or to replace a product. The first is functional value, referring to the product's functional, utilitarian and physical product performance. Emotional value relates to the extent to which the product arouses feelings and affective states. Epistemic value refers to the product arousing curiosity, providing novelty or the need for a change of pace. Social value refers to associations and belonging to a group. Finally, conditional value relates to how specific situations or circumstances influence consumer decisions (Sheth et al., 1991).

During the replacement decision, trade-offs are made between the values of the currently owned product and of a potential new product (Echegaray, 2016; Nicole Van Nes and Cramer, 2005). On the one hand, the owned product offers specific values to the owner, such as functional value due to its performance and features. The product may also provide emotional value, for example, because it was a gift from a loved one. On the other hand, new products can provide improved performance (i.e. functional value) and arouse curiosity with new features (i.e. epistemic value), but require a financial investment. Marketing strategies (e.g., advertisements) can heighten the new products' values. During these trade-offs, some values are more salient than others, depending on the type of product, context, and specific consumer needs and desires (Bayus, 1991; Echegaray, 2016). While making the trade-offs, the consumer can either decide that the relative value of the new product in comparison to the owned product is worth the financial investment, resulting in replacement, or (s)he can decide that the relative value of the owned product is still high enough, resulting in retention (Guiltinan, 2010).

Product values are not static and can change over time. The functional value of the owned product can decrease if the product (partly) malfunctions (Hou et al., 2020). Traces of usage (i.e. wear and tear) can decrease the product's aesthetics and thus its emotional value (Baxter et al., 2017). Furthermore, repeated product usage triggers feelings of satiation (Hou et al., 2020), which lowers the perceived value of the owned product. This negatively affects the 'mental book value' of the owned product, even without actual performance or aesthetics losses (Miller et al., 2019; Okada, 2001). Products and their values are mentally written off by the consumer during ownership, and based on the initial purchase price, consumers have expectations about how long a product should last. They incorporate this in their trade-offs, resulting in a greater tendency to replace 'older' products as they have made their money worth. Consumers may also adjust their product value preferences over time, as a result of the introduction of new product features. The greater the dissimilarity of the features and appearance of the owned product compared to the new product, the more likely consumers will replace it (Okada, 2006; Sohn et al., 2019). Finally, trade-in promotions have an effect on the likeliness to replace a still-functioning product (Fels et al., 2016), and therefore can provide the final push in the decision to replace.

While consumers often replace products before the end of their functional life, research also shows that consumers paradoxically have an aversion to waste products and to not make full use of their utility (Bolton and Alba, 2012). Unnecessary wasting of products can even negatively affect brand attitudes (van Herpen and de Hooge, 2019). Replacing a product that still functions can be accompanied with a feeling of guilt because consumers generally feel the need to justify their replacement Behavior (Wieser and Tröger, 2018). To justify a possible replacement, consumers may even show careless Behavior towards the owned product, such as product neglect and risky Behaviors. By acting carelessly, the value of the owned product is likely to decrease (Bellezza et al., 2017).

2.3 STRATEGIES TO STIMULATE RETENTION BY SUPPORTING THE OWNED PRODUCT'S VALUES

Research has distinguished several strategies to stimulate product retention. These strategies trigger the different values (Sheth et al., 1991) that impact product replacement, and strive to keep the values of the owned product as high as possible. The different strategies can address different values concomitantly. In this section, the strategies are ordered based on the value they contribute to most.

2.3.1. SUPPORTING EMOTIONAL VALUE

Supporting product attachment

The first strategy to stimulate product retention is by supporting the emotional value of the owned product via product attachment. Product attachment can be defined as "the strength of the emotional bond a consumer experiences with a product" (Mugge et al., 2010; Schifferstein and Zwartkruis-Pelgrim, 2008). Literature has underlined the role of strengthening the person-product relationship to prevent premature replacement of products (Chapman, 2009, 2015). Individuals become attached to products that have a special meaning to them, which gives these products an extra emotional value (Mugge et al., 2005). When individuals are attached to their products, they tend to maintain them and to have a higher willingness to repair them, resulting in longer lifetimes (Page, 2014; Nicole Van Nes and Cramer, 2006).

Several determinants of product attachment exist, such as memories, self-expression, group affiliation and pleasure (Mugge et al., 2008; Schifferstein and Zwartkruis-Pelgrim, 2008). Memories and self-expression are recognized as most influential for product retention because these may bring about irreplaceable possessions [37], which suggests that the special meaning is not present in other products (Grayson and Shulman, 2000; Mugge et al., 2005; Schifferstein and Zwartkruis-Pelgrim, 2008).

Memories suggest that products can serve as a reminder of a person or past event. The narratives that such products provide can trigger deep emotional bonds, and products can even obtain an heirloom status (Chapman, 2015; Jung et al., 2011). Consequently, individuals tend to keep products that are associated with memories for a longer period of time (Niinimäki and Hassi, 2011; Schifferstein and Zwartkruis-Pelgrim, 2008). Even though memories often develop automatically, products can also actively invite individuals to form associations by offering a context or activity to reflect, thereby stimulating emotional value (Casais et al., 2018). Furthermore, research demonstrated that it is possible to bring emotional value to products by using life stories for embodying significant aspects of a person's identity in the design (Orth et al., 2018).

People can also develop irreplaceable attachments to products that express their identity. Such self-expression can be triggered via product personalisation (Mugge et al., 2009). By personalising products via DIY-activities or mass customisation, individuals attach self-expressive value to the product, which in turn strengthens their emotional bond (Armstrong et al., 2016; Jung et al., 2011; Mugge et al., 2009; Niinimäki and Koskinen, 2011).

Recent literature pinpointed specific cases where emotional attachment to products can negatively influence the environment. People may choose to keep an object of attachment in ownership although it has been functionally replaced by another (Haws et al., 2012). Such product hibernation (Bakker et al., 2014) can have negative environmental consequences because it prevents usable goods to have a useful second life or be recycled. Additionally, unemotional design has recently been advocated as a strategy to remove the emotional aspects linked to conspicuous consumption (Thornquist, 2017). By doing so, consumers would acquire emotional detachment to products and in turn more sustainable consumption patterns.

Sustaining aesthetic value

Products can also offer emotional value via their aesthetics (Sheth et al., 1991). Everyday aesthetic experiences play an important role in consumption (Patrick, 2016). Over time, signs of usage or changes in fashion may decrease the owned product's aesthetic value, which can lead to premature replacement. There is a need for products' aesthetics to be resilient towards both wear and emerging trends (Haug, 2018).

Several strategies have been proposed to sustain the aesthetic value and thereby encourage product retention. The first is implementing a design that is less susceptible to fashion changes, such as a classic or timeless design (Flood Heaton and McDonagh, 2017; Lobos, 2014; Nieuwenhuis, 2008). Classic or timeless designs are visually simplistic, ordered and harmonious. Because this design style adheres to people's evolutionary desire for symmetric and simple appearances, it is generally preferred across social groups and endures throughout time (Snelders et al., 2014; Veryzer and Hutchinson, 1998). Aesthetic value can also be sustained via the use of specific materials in the design. In most situations, signs of wear and tear decrease aesthetic value because people perceive scratches and usage signs as unattractive and less desirable (Mugge et al., 2008; Van Weelden et al., 2016). Past research has explored possibilities to prevent this decrease in aesthetic value, for example, by embodying products in materials that tend to wear gracefully over time, such as leather or wood (Bridgens et al., 2019; Lilley et al., 2019; Mugge et al., 2005).

2.3.2. SUPPORTING FUNCTIONAL VALUE

Stimulating product care and maintenance

To prevent a potential loss in the functional value of the owned product, it is important that the consumer takes good care of the product. Product care is defined as all activities initiated by the consumer that lead to the extension of a product's lifetime (Ackermann et al., 2018). Product care thus includes maintenance and repair activities. Whereas maintenance can prevent the product's functional value to drop, repair can solve a defect and thereby return the reduced functional value to the original performance state.

People only take care of products when they are motivated, have the ability to take care (in terms of time, expertise, and money) and experience a trigger to do so (Ackermann et al., 2018; Mugge, 2017; Sabbaghi et al., 2017). Unfortunately, this is not the case for many products, often resulting in a premature loss of functional value. Several strategies have been proposed to encourage people to take better care of their products, for example, by making care activities more enjoyable (enhancing motivation), easy and timesaving (enhancing ability), and by reminding consumers of required care activities at the right moment in time (providing a trigger) (Ackermann et al., 2018; Den Hollander et al., 2017). Furthemore, extended product warranties can stimulate repair activities (Brusselaers et al., 2019; Gullstrand Edbring et al., 2016).

Enabling upgradeability

Upgradeable products involve physical products that provide options to improve them in the future (Michaud et al., 2017). Upgradeability is also referred to as evolvability (Haines-Gadd et al., 2018) and entails designing products that can have different phases of use and adjust to developing needs and/or technology with more advanced parts and additional functionalities. By doing so, upgradeability enables to sustain the product's functional value and can persuade consumers to retain the owned product. While

2

past research proposed upgradeability as a valuable strategy and consumers express positive attitudes to upgradeable products (Brusselaers et al., 2019; Sabbaghi et al., 2017), product upgradeability remains rather underdeveloped in the market. Product-Service Systems and modular design (i.e. products consisting of various interchangeable modules) could provide possibilities to facilitate upgradeability (Khan et al., 2018; Ülkü et al., 2012).

2.3.3. SUPPORTING MULTIPLE VALUES SIMULTANEOUSLY

While the aforementioned strategies aim to support the emotional or functional values of products, these strategies can also contribute to other values of the owned product. Values can be intertwined and together encourage the retention of this product over its replacement. For example, self-expression and group affiliation, both social values, may stimulate the emotional bond consumers have towards a product (Kumar and Noble, 2016; Mugge, 2017; Schifferstein and Zwartkruis-Pelgrim, 2008), thereby providing emotional value as well.

In supporting the functional value of a product, upgradeability can address desires of novelty and increase the epistemic value by breathing new life in the owned product. It may also enhance social value by enabling the consumer to keep up with a group, or have conditional value by enabling him/her to adapt the product to specific circumstances.

Product care activities may initially focus on sustaining the functional value of a product. However, these activities may also result in product attachment because of the executed conscious and meaningful person-product interactions (Michaud et al., 2017; Veryzer and Hutchinson, 1998), and therefore can be deeply intertwined with the emotional value individuals attach to a product. This may be especially true for specific care activities and materials (e.g. oil for wood and polish for leather) (Lilley et al., 2016). While cherished products are more likely to be well taken care of (Niinimäki and Koskinen, 2011), executing repair activities may also enhance emotional value that resides in this product (Ackermann et al., 2018) if these repair activities evoke positive emotions (Desmet, 2012).

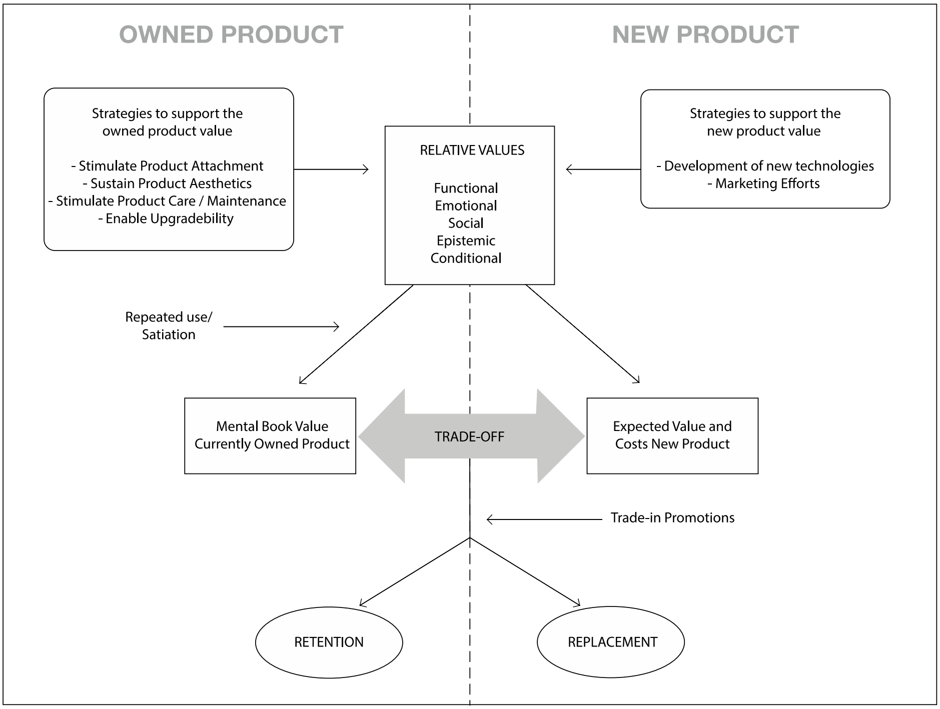

Figure 5. Psychological process of product replacement

2.4 CONCLUSION AND AVENUES FOR FUTURE RESEARCH

This paper summarizes the current literature on replacement behavior, and highlights the value trade-offs consumers make in the decision to replace. Figure 5 presents an overview of this process and potential strategies that can support the values of the owned product. An important remark is that the replacement decision involves different values, depending on the product, consumer, and context.

An important limitation of the literature on strategies is that most are only theoretically discussed and empirical research (e.g. longitudinal studies, surveys, experimental and/or scenario studies) is lacking. This is needed to test their effectiveness on consumers' replacement intentions and behaviors, and their potential for lowering the environmental impact of products. Besides, further research is needed to uncover how each strategy should be implemented (e.g., types of upgrades) to reach the best effect for a specific product and context.

Furthermore, research has distinguished strategies that mostly focus on sustaining functional and emotional values. Less attention has been paid on sustaining social, epistemic and conditional values. Focusing on the social value of products could be effective as social norms can have a powerful and persuasive influence on sustainable consumer behavior and decision making (Trudel, 2018). Regarding epistemic value, novelty and new features arousing curiosity of the consumer are features often found in new products. However, knowledge on the value of upgradeability for enhancing epistemic value is lacking. Regarding conditional value, research could focus on what conditions could stimulate the consumer to retain products. Furthemore to product/service design interventions, policy may play a role in establishing such conditions. For example, it would be interesting to investigate if product lifetime labels informing consumers about the expected lifetime of the product can increase the lifetime expectation, and consequently, result in a slower decrease of a product's mental book value.

Concluding, studying strategies that make it preferable for consumers to postpone product replacement, and under what conditions this is most likely to happen, represent interesting avenues for future research. The necessity to reduce the environmental impact of consumption has become irrefutable. Studying ways to encourage consumers to move away from a throw-away society is therefore of great relevance.

2

REPLACED BUT STILL FUNCTIONING VACUUM CLEANER OF ONE OF THE INTERVIEW PARTICIPANTS

3

Until death do us part? In-depth insights into consumers' considerations about product lifetimes and lifetime extension

This chapter was previously published:
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Based on Chapter 2, we know why people replace products and what barriers they encounter to extend their lifetimes. However, we also noticed that literature on replacement behavior did not yet provide an in-depth reasoning on consumers' considerations of product lifetimes. To further explore why consumers experience certain barriers towards product lifetime extension (SRQ2), we wanted to thoroughly understand consumers' considerations of lifetimes and lifetime extension in the replacement process. Furthermore, to stimulate product lifetime extension, consumers can be informed via a lifetime label about expected product longevity (Braithwaite et al., 2015; Gnanapragasam et al., 2018). Earlier studies have yielded promising results (Bovea, Ibáñez-Forés, Pérez-Belis, Juan, et al., 2018; Jacobs and Hörisch, 2021). However, the effectiveness of such a lifetime label for changing consumers' purchase decisions is likely to depend on how it is implemented, which remains under-explored.

This chapter further expands the findings of Chapter 2 by providing in-depth insights into consumers' considerations about product lifetimes during the replacement process. By doing so, it aims to explore the consumers' perspective on product lifetimes in a profound manner. It starts with a discussion of the theoretical background. Subsequently, it presents the methodology and results of qualitative interviews exploring consumers' considerations about product lifetimes, their barriers toward lifetime extension, and responses to potential lifetime labels. Finally, directions for future research are proposed.

3.1 INTRODUCTION

Today's production and consumption of electronic products are damaging the environment. Production processes require the extraction of (critical) raw materials and produce CO2 emissions (Allwood et al., 2011). Furthermore, the handling of waste from discarded products causes social and health-related issues in low-income countries (Heacock et al., 2016). Future global scenarios indicate that waste from electronic products will grow from 58 million tons in 2021 to 75 million tons in 2030 and 112 million in 2050 (Parajuly et al., 2019), and thus reductions are essential.

The field of industrial ecology focuses on the stages of the production processes of goods and services from a nature perspective, seeking to mimic a natural system by conserving and reusing resources (Chertow, 2008). One way to achieve this is via a circular economy, which strives to maximize the value of products and materials during all cycles, while aiming to eliminate "waste" (Ellen MacArthur, 2013). To date, much attention has been given to the outer loops (i.e., recycling) of the circular economy (e.g., Kirchherr et al., 2017). However, value is lost during recycling, because recycling consumes energy and some materials cannot be fully recovered (McCollough, 2009). It would therefore be more beneficial to focus on the inner loops (i.e., prolonging). Product longevity enables value retention by preventing early replacement. As this conserves resources longer, it provides a promising solution for issues resulting from producing and consuming electronic products. However, many products are discarded prematurely. Studies showed that 31% of washing machines, 66% of vacuum cleaners, 56% of TVs, and 69% of smartphones were disposed while still (partly) functional (Harmer et al., 2019; Hennies and Stamminger, 2016; Wieser and Tröger, 2018). It should be noted that a functioning product is replaced for different reasons than a nonfunctioning product. Consumers may replace functioning products because they do not satisfy new desires (T. Cooper, 2005; Magnier and Mugge, 2022), such as an improved smartphone camera. In such cases, replacement stems from the perception that the product is obsolete (i.e., no longer useful).

Consumers' perceptions thus play an important role in either shortening or extending the lifetimes of electronic products. Research has demonstrated that consumers generally prefer long-lasting and durable products (Gnanapragasam et al., 2018). Nonetheless, there is a widespread belief that products are not made to last (Wieser et al., 2015), and consumers' expectations about the lifetime of electronic products have significantly shortened (Kumar et al., 2017). Consumers seem to acknowledge producers' role in shortening product lifetimes, but neither condemn this nor consider product durability (Echegaray, 2016; Sun et al., 2021). They have come to expect rapid product updates and fast-moving trends, thereby accelerating replacement speeds (Cox et al., 2013; Grewal et al., 2004). However, in-depth insights into consumers' considerations concerning product lifetimes remain limited.

Several opportunities for extending product lifetimes have been formulated in the literature (Van den Berge et al., 2021; Nicole Van Nes and Cramer, 2005). Repair is frequently mentioned, as it restores (parts of) the product's functionality (Bocken et al., 2016). However, consumers often face barriers to repair (Jaeger-Erben et al., 2021). Also, technological developments and trends encourage consumers to replace well-functioning products (Grewal et al., 2004). Noteworthy most studies on replacement behavior are quantitative (e.g., Hou et al., 2020; Jaeger-Erben et al., 2021; Sabbaghi et al., 2017), and do not explore the underlying reasons among consumers. Another opportunity to extend product lifetimes is a lifetime label (Braithwaite et al., 2015; Gnanapragasam et al., 2018), which informs consumers about expected product longevity and has yielded promising results (Bovea, Ibáñez-Forés, Pérez-Belis, Juan, et al., 2018; Jacobs and Hörisch, 2021). However, the effectiveness of such a label for changing consumers' purchase decisions is likely to depend on how it is implemented. Our research provides insights into the specific conditions (e.g., related to label design, policy) that will influence lifetime labels' effectiveness.

We contribute to the literature with in-depth insights into consumers' thought processes regarding product lifetimes. We aim to go beyond the quantitative results of prior studies and explore the reasoning underlying consumers' responses. Hereby, we provide a comprehensive understanding of early product replacement, which is useful for industry and policymakers aiming to extend product lifetimes. This paper starts by presenting the theoretical background. Subsequently, we present the results of in-depth interviews exploring consumers' considerations about product lifetimes, their barriers toward lifetimes extension, and responses to potential lifetime labels. Finally, we propose directions for future research.

3.2 THEORETICAL BACKGROUND

3.2.1. DEFINITIONS OF PRODUCT LIFETIMES AND REASONS FOR PRODUCT REPLACEMENT

In this chapter, the "actual lifetime" of a product is defined as the period between its purchase and the moment it is disposed of or replaced by another product (Den Hollander et al., 2017; Nicole Van Nes and Cramer, 2006). This definition focuses on products' first lives. We realize that products can have useful second lives (e.g., second-hand, refurbished) but discarded products frequently end up in the storage (Poppelaars et al., 2020; Wilson et al., 2017), and thus extending the first life is most beneficial. "Expected lifetime" is defined as the time the consumer expects the product to last and “desired lifetime” as the time the consumer would like the product to last. Both expected and desired lifetime are estimated by the consumers themselves.

Literature defines several types of “product obsolescence” as reasons for replacement. Quality obsolescence refers to a decrease in product performance resulting from wear and tear or malfunctioning parts; for instance, broken pumps in washing machines (Guiltinan, 2009; Mugge et al., 2005; Nicole Van Nes and Cramer, 2005). Technological obsolescence refers to new developments offering improved functionality; for instance, new smartphones that can access faster internet networks (Grewal et al., 2004; Jensen et al., 2021). Economic obsolescence refers to products being replaced by cheaper-to-run models; for instance, more eco-efficient washing machines (Cooper, 2004; Khan et al., 2018). Aesthetic obsolescence refers to changes in product appearance caused by wear and tear or emerging trends, for instance scratches on smartphones or changes in color preferences (Burns, 2010; Mugge et al., 2005). Psychological obsolescence refers to the symbolic value of products; for instance, a new product that allows one to keep up-to-date with peers (Cooper, 2004; Nicole Van Nes and Cramer, 2005). Frequently, products are replaced because of a combination of multiple previously defined types of obsolescence (Magnier and Mugge, 2022).

3.2.2. PRODUCT REPLACEMENT PROCESS

We can consider the product replacement process as a subtype of the general EKB model. This model shows that decision-making involves extensive thought processes that consider many factors (Engel et al., 1968). The replacement decision-making process is different from the general process of buying because consumers already own a similar product. Specifically, the decision to replace or retain a product involves a trade-off. Consumers compare the costs and values of a new product to those of their owned product (Van den Berge et al., 2021). The previously defined types of obsolescence (cf. Chapter 1) revealed that product replacement decisions are often not solely rational (Guiltinan, 2010). The weighted product values can be functional (e.g., providing good functionality), emotional (e.g., evoking memories), social (e.g., providing social status), epistemic (e.g., providing novelty) and conditional (e.g. fitting a certain life stage) (Sheth et al., 1991). Replacement results from a relative change in one or more of these values (c.f Chapter 2). Differences in value importance can be found between product categories. For example, emotional value is generally more important for hedonic than for utilitarian products (Korhonen et al., 2018).

To extend a product’s lifetime, it is important to keep its value high. During ownership, consumers mentally write off products (Okada, 2001). The depreciated value of an owned product compared to the potential value of a new product influences the replacement process. Past research recommended that products should be both physically durable (sustaining functional value) and resilient toward future developments (sustaining epistemic value) (Haug, 2018) to ensure long-term value. Early product replacement may also evoke feelings of dissatisfaction and guilt because it is wasteful (Wilhelm et al., 2011). Conversely, marketing efforts and trade-in promotions can trigger the replacement tendency (Van den Berge et al., 2021). The replacement tendency greatly depends on how long the consumer has owned the product and to what extent it "has made its money's worth." During ownership, repeated use and satiation contribute to product value depreciation (Hou et al., 2020; Magnier and Mugge, 2022).

3.2.3. CONSUMERS' CONSIDERATIONS ABOUT PRODUCT LIFETIME EXTENSION

Product failure decreases its functional value and can trigger a replacement (Wilhelm, 2012). Repair has been proposed as a critical strategy to extend product lifetimes (e.g., Bocken et al., 2016; Kirchherr et al., 2017). It recovers products' functional value and may increase emotional value because successful repairs can evoke positive feelings, such as pride (Ackermann et al., 2018). Nevertheless, prior research also revealed multiple barriers that hinder consumers from executing repair activities, such as high costs (Bovea et al., 2017; Laitala et al., 2021; Tecchio et al., 2019). Although tax incentives for repairs appear to be an interesting avenue to stimulate repair, recent research suggested that it remains unclear whether the resulting cost reduction would be sufficient to lower the barrier (Svensson-Hoglund et al., 2021). It is also interesting to note that consumers often overestimate repair costs, which may prevent them from considering repair as an option (Brusselaers et al., 2019). Extended warranties may make repair a more worthwhile option (Bocken et al., 2014; Ertz et al., 2019). However, compared to other product features their influence on purchase decisions is low because extended warranty rights are often poorly understood and confused with legal guarantees (Maronick, 2007; Svensson-Hoglund et al., 2021). Other barriers to repair are lack of skills (Rogers et al., 2021), mat Manufacturers may also be uninclined to increase repairability because it could limit sales of new devices (Sabbaghi and Behdad, 2018). To encourage manufacturers to increase repairability, various initiatives have emerged, such as the "The Right to Repair" movement. Additionally, the "French Repairability Index" requires manufacturers to inform consumers about products' repairability. Nonetheless, consumers do not seem to look for repairability in products (Bovea, Ibáñez-Forés, Pérez-Belis, Juan, et al., 2018; Sabbaghi et al., 2016). For lifetime extension, it is therefore important to obtain a comprehensive understanding of the reasons underlying consumers' hesitance toward repairability.

3.2.4. POTENTIAL OF A PRODUCT LIFETIME LABEL TO EXTEND LIFETIMES

Consumers have highly varied lifetime expectations (Jaeger-Erben and Hipp, 2018) and are generally unable to judge the environmental aspects of products. They often rely on labels for related information (Atkinson and Rosenthal, 2014). Therefore, lifetime labels have been identified as a promising tool to support consumers in considering product lifetimes at purchase (Gnanapragasam et al., 2018). Previous studies demonstrated that a product's lifetime label (expressing lifetime in years) may even be perceived as more important than the brand or energy consumption of washing machines (Jacobs and Hörisch, 2021). Lifetime labels can include information about the reliability of materials and components and/or products' repairability. A high score on a lifetime label may cause consumers to mentally write off their product's value more slowly, resulting in a higher likelihood to keep using and repairing it. In eco-design regulations, a label presenting the minimum lifetime is currently considered for some products (Marcus, 2020). However, there are some concerns. Misinterpretation of labels can cause unintentional rebound effects; for example, the energy-efficiency label can trigger the belief that buying more electronic products is unproblematic as long as these are energy efficient (Waechter et al., 2015). Second, consumers indicate their own behavior (i.e., use intensity) also impacts lifetime, and thus prefer labels displaying useful lifetimes in use cycles over displaying lifetimes in years (Dalhammar and Richter, 2017; European Economic and Social Committee (EESC), 2016). Finally, research suggested low awareness regarding the impact of short product lifetimes on the environment (Islam et al., 2021). However, more research is required to determine whether raising environmental awareness via lifetime labels can influence consumers to choose longer-lasting products.

3.3 METHOD

3.3.1. SEMI-STRUCTURED INTERVIEWS

To uncover people's feelings, thoughts, and experiences, in-depth face-to-face interviews are an effective method (Patton, 2002). The interviews were semi-structured, leaving room for new topics to emerge and enabling building further on established findings (Gioia et al., 2013). Open-ended questions allowed participants to describe experiences in their own words. "Why" questions stimulated the further elaboration of the discussed topics.

3.3.2. PRODUCT CATEGORIES

The product categories researched in this study met several criteria. They all have significant market penetration, environmental impact, importance to consumers, and use frequency. We additionally ensured variety in technological advancement and functionality. Accordingly, we selected washing machines, vacuum cleaners, TVs, and smartphones. Technological advancement was considered high for smartphones and TVs, medium for vacuum cleaners, and low for washing machines. We chose smartphones because of their centrality in daily life and susceptibility to (portable) usage damage (e.g., replacement due to broken screen or battery failure), and TVs because of their susceptibility to trends (e.g., replacement with a higher-resolution model).

3.3.3. SAMPLE

Participants were recruited via a university-based consumer panel. Our sample reflects a Dutch perspective, with relatively wealthy consumers, widely available products, and fast delivery. This context is especially interesting, as Dutch consumers are more prone to replace their products prematurely (Islam et al., 2021). Replacement behavior in the Netherlands is comparable to other Western European countries, such as France, Belgium, Germany, and Spain (Magnier and Mugge, 2022). Our insights are therefore expected to be useful for countries with similar consumption patterns. Finally, interviewing Dutch consumers allowed us to conduct interviews at participants' homes, and thereby use the newly bought products to stimulate discussion about replacement. An online selection form was sent to 940 panel members. To ensure reliable responses, panel members could only participate if they had replaced one or two of the selected products within the six-month period preceding the interview. Participants should have bought the product either new or second-hand for personal use (excluding gifts). From the 232 responses, 59 panel members had replaced one or two of the selected products during the preceding six months. We selected 22 participants varying in age (29-73 years; mean: 52 years), gender (41% male, 59% female), and monthly net household income (cf. Table 1), covering each product category with insights from eight participants. All participants were rewarded a ten-euro voucher.

3.3.4. PROCEDURE

The developed interview guide (cf. AppendixA) was refined after two pilot interviews. All interviews took place at participants' homes (November 2019) to ensure they would feel comfortable sharing personal experiences and to observe their new and (if still owned) replaced products (cf. Figure 6). Interviews lasted 30-60 minutes, depending on whether one or two products were discussed. All participants gave permission to audiotape the interview and signed an informed consent form. Participants described their reasons for replacing the product, satisfaction with the lifetime of the replaced product, and the lifetime expectations of the new product. We discussed the repair activities executed and/or considered for both the replaced and new product, and asked if participants took lifetime expectations into account when acquiring the new product. Also, we asked about the extent to which lifetime labels could influence their purchase decision. All questions were probed with a "why" question. We focused on repair and lifetime labels as these can strongly impact lifetime extension. Prior literature demonstrated that 70% of partly malfunctioning products were not considered for repair before being replaced (Magnier and Mugge, 2022). This illustrates that encouraging repair practices is still much needed. Additionally, labels have been proven to be influential in choices of products in other domains (e.g., energy-efficiency labels) and have been suggested as a means to extend lifetimes (e.g., Bovea et al., 2018; Dalhammar and Richter, 2017; Gnanapragasam et al., 2018; Jacobs and Hörisch, 2021). While the label concerns the purchase phase, the repair aspects cover the use and disposal phases of consumption. This focus thus enabled us to cover multiple consumption phases, where consumers' choices can impact lifetime extension. The question about participants' knowledge of the environmental impacts of products was posed at the end to prevent socially desirable answers.

Table 1. Details of the interview sample

Participant	*Gender*	*Age*	*Income (€)*	*WM*	*VC*	*TV*	*SP*
P1	Female	67	unknown	x	x		
P2	Female	56	3750 – 4500		x		x
P3	Male	61	3750 – 4500			x	x
P4	Female	50	unknown		x		x
P5	Male	68	3750 – 4500			x	x
P6	Male	63	2250 – 3000	x	x		
P7	Male	50	unknown			x	x
P8	Female	41	unknown		x	x	
P9	Male	52	3750 – 4500		x		x
P10	Male	59	4500 or more			x	
P11	Female	29	750 – 1500		x		x
P12	Female	56	3750 – 4500			x	
P13	Female	30	2250 – 3000				x
P14	Female	73	2250 – 3000			x	
P15	Female	51	unknown	x			
P16	Female	55	unknown		x		
P17	Male	34	750 – 1500	x			
P18	Female	56	3750 – 4500	x			
P19	Female	57	3750 – 4500	x			
P20	Male	66	4500 or more	x			
P21	Male	48	4500 or more			x	
P22	Female	31	3750 – 4500	x			

Figure 6. Illustrated example: Pictures of the new (left) versus replaced (right) TVs and smartphones of participant 3

3.3.5. DATA ANALYSIS

All interviews were fully transcribed. We used inductive data processing to describe the insights that emerged in a detailed manner, while staying close to the raw data (Saldaña, 2013). First, the transcripts were coded using Atlas.ti software. We discussed the initial codes in the research team by clustering overlapping codes. Looking for patterns and themes, we eliminated irrelevant codes during several iterative sessions. This resulted in a total of 101 subcodes. Subsequently, these were grouped in 42 codes. The codes were clustered in thirteen categories and three themes. Figure 7 displays the steps.

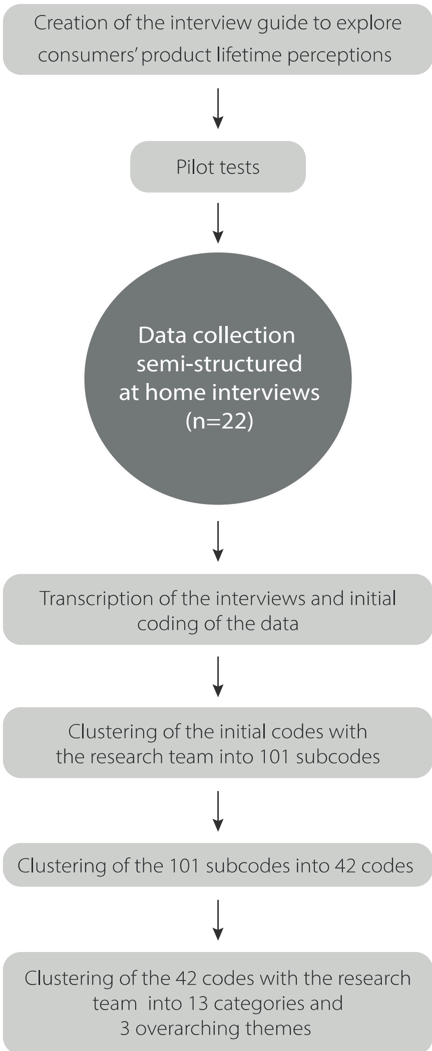


Figure 7. The steps of the data analysis

3.4 RESULTS

Figure 8 displays the themes and categories showing our main findings. Appendix B presents an overview of the coding scheme per theme.

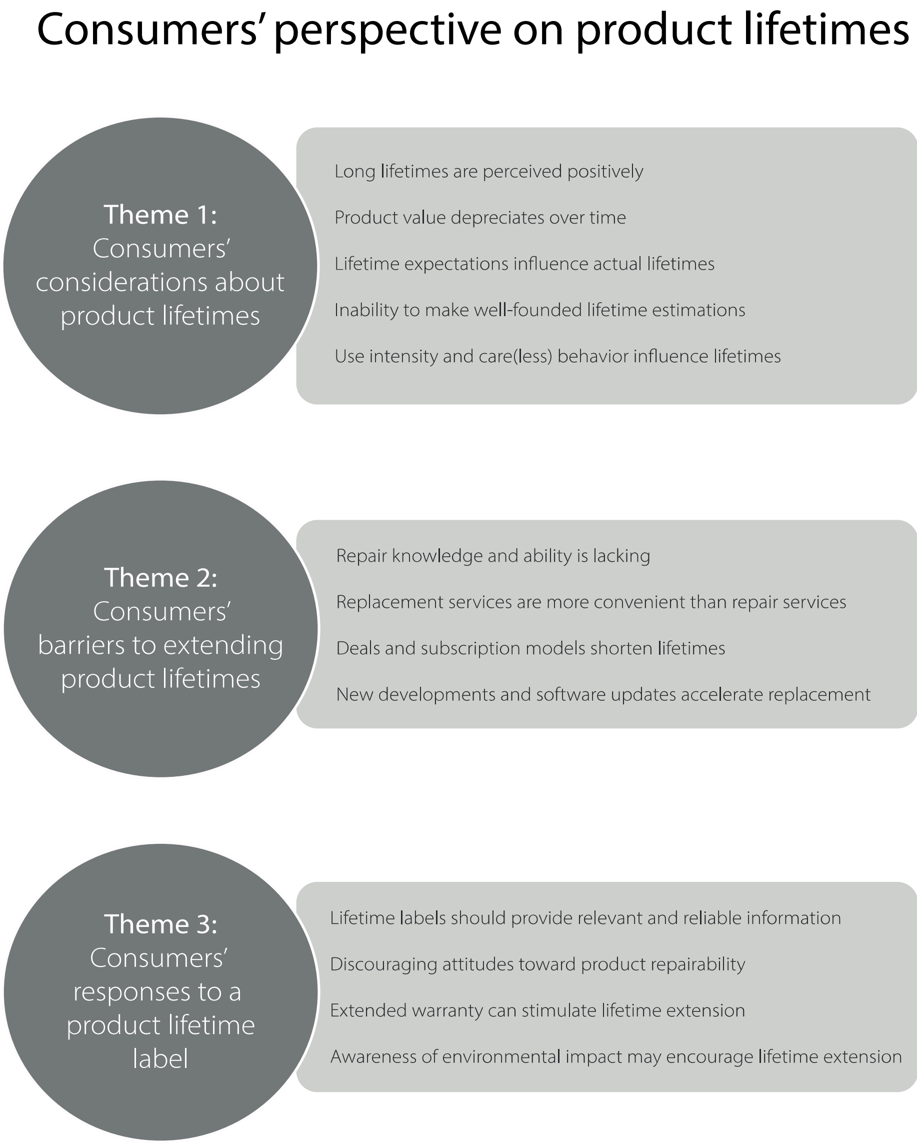


Figure 8. The themes and categories of the interview data

3.4.1. CONSUMERS' CONSIDERATIONS ABOUT PRODUCT LIFETIMES

Long lifetimes are perceived positively

Participants indicated relatively high satisfaction when the replaced product exceeded lifetime expectations, especially for utilitarian products, such as washing machines and vacuum cleaners. In contrast, satisfaction was relatively low when the actual lifetime underperformed expectations. This occasionally provoked feelings of irritation and anger (cf. Table 2, P15) and was perceived as a waste of money and resources. Regarding desired lifetimes, most participants wanted to use products as long as possible, only replacing them when deemed necessary. Investing time and effort in selecting new products was considered bothersome, especially for utilitarian products.

Product value depreciates over time

Although most participants wanted to use products as long as possible, their products' value also depreciated over time. Decreasing emotional, social, and epistemic value was especially true for trend-sensitive products, such as smartphones and TVs, and played an important role in value depreciation. For example, participant 11 (cf. Table 2) explained that the need to capture life events (emotional value) and the fear of missing out on the latest features adopted by peers (social value) resulted in the early replacement of a smartphone.

Lifetime expectations influence actual lifetimes

Next to desired lifetimes, we asked participants about expected lifetimes. For all product categories, we found that when a defect arose, participants considered the product's expected lifetime to evaluate if the time was right for replacement. Also, we found that expected lifetimes can influence actual lifetimes. When consumers felt that the product had fulfilled its duty, they were more comfortable with replacing it. To illustrate, participant 20 (cf. Table 2) stated that after the product met lifetime expectations, the fear of near-future product failure – i.e., lack of trust in its reliability – triggered its replacement.

Inability to make well-founded lifetime estimations

Most participants were unable to make well-founded judgments about their products' expected lifetimes. Their responses varied greatly from 2-4 years for smartphones, 4-10 years for TVs, 5-15 years for vacuum cleaners and 5-30 years for washing machines. Their expectations were guesses, based on their "gut feeling." Therefore, they did not actively consider lifetimes of products at purchase. Participants relied on brand, price, reviews, and previous experiences in making lifetime estimations (cf. Table 2, P16). Some doubted the reliability of reviews posted on producers' and resellers' websites because they believed these mainly serve marketing purposes. They preferred reviews from independent parties (e.g., consumer associations), but also noted that these reviews often only share experiences from the early product lifetime with no information on longevity.

Table 2. The categories and example quotes of the theme "Consumers' considerations about product lifetimes"

Category	**Example quote**
Long product lifetimes are perceived positively	"I wanted it to last longer because a washing machine that lasts only five years … I didn't like that. Not only for my own wallet, but also the idea that every five years you take a product to the scrapyard…" *P15*
Product value depreciates over time	"I was in doubt because it was not really broken yet. Uhm, and costs. It's just really expensive to get a new one […] In theory the old smartphone still works, but then I saw other people taking beautiful photos. I started to realize that my photos are always a bit blurry. Then you start to miss that feature." *P11*
Lifetime expectations influence actual lifetimes	"I think we owned the old one for 15 years. It probably would have washed for a while longer, but at some point, it started to make noise and move around. Then, you start thinking, when is it going to fail? […] Fifteen years is a good age for a washing machine." *P20*
Inability to make a well-founded lifetime estimation	"I don't know actually … You can kind of get that from reviews now and then … And yes, also from hearsay, from the experiences of people around you." *P16*
Use intensity and care(less) behavior influence lifetimes	"I think the new washing machine will last at least 10 years… However, you can't express this in years … For a washing machine you have to look at the number of washes. I now have only one child at home, so we will just wash a lot less than we used to." *P18*

Use intensity and care(less) behavior influence lifetimes

All participants indicated the importance of use intensity and their own behavior on the actual lifetime (cf. Table 2, P18). Several participants engaged in care activities, such as using a smartphone flip cover and running a washing machine empty at a high temperature, while others were unfamiliar with measures to ensure long lifetimes. Our results revealed large differences in care behavior among participants. Some indicated that they handle their possessions with care, whereas others said that their neglect caused a product breakdown.

3.4.2. CONSUMERS' BARRIERS TO EXTENDING PRODUCT LIFETIMES

Repair knowledge and ability is lacking

Most participants considered themselves unable to execute repair activities. Only one participant self-repaired a washing machine (broken door) and three participants repaired their phones (replacing screen/battery). None repaired a vacuum cleaner or TV. Participants often did not know what was wrong with the product (cf. Table 3, P17). The only participant who self-repaired a washing machine consulted an expert beforehand,

and professional technicians repaired all broken smartphones. Also, participants did not consider repair a valuable option (cf. Table 3, P5), deeming it expensive mainly because they included labor costs in their calculations. Participants also indicated that current products are not designed to be repaired. For example, the absence of screws in a TV made them wonder whether the product was repairable at all.

Replacement services are more convenient than repair services

Replacement services, such as next-day product deliveries, are a convenient choice. Participants mentioned that the service aspect of replacement was a determining factor in the decision to choose replacement over repair. They suggested that improvement of repair services may encourage repairs – for example, increasing repair service convenience by eliminating physical barriers (e.g., at-home repair) (cf. Table 3, P2), improving service provider findability (e.g., repair platforms on the internet), or providing faster service (e.g., next-day repairs).

Deals and subscription models stimulate replacement

Good deals could easily persuade participants to replace well-functioning products. For instance, offering new smartphones with contract renewal (cf. Table 3, P9) accelerated the value depreciation of the owned product and triggered its replacement with a newer higher-performance model. Additionally, some participants justified their replacement because the lifetime expectations of their product were met, and an attractive deal was the final trigger.

New developments and software updates shorten lifetimes

Our results showed that washing machines were mostly replaced because of a defect, while only three TVs were replaced because of defects. Three other TVs still functioned flawlessly, and new functionalities were the main reason for replacement (e.g., bigger screens with higher-quality images) (cf. Table 3, P3). The remaining two were incompatible with the service provider. Especially for TVs, newer models with improved performance accelerated the value depreciation of the owned product. Additionally, software obsolescence caused early replacement. For example, participant 13 replaced his smartphone because he could no longer download (essential) applications (cf. Table 3).

Table 3. The categories and example quotes of the theme "Consumers' barriers to extending product lifetimes"

Category	Example quotes
Repair knowledge and ability is lacking	"A washing machine is a product too technical for me personally to make a seriously good estimate about repairability. So, if it does not work, yes, then I just cannot estimate whether only the light does not work, or if the whole function is gone." *P17*
	"Indeed, if a defect occurs, you can go back to the store and ask what it will cost to have the TV fixed again. And when they say it will cost 50 percent of the purchase price to have it repaired… then you start thinking is this worth the money?" *P5*
Replacement services are more convenient than repair services	"I shouldn't have to go all the way into town with a vacuum cleaner, because then I would not do it. But it would be useful if there is such a repair support, that it is a bit close or something. That will encourage, I think." *P2*
Deals and subscription models shorten lifetimes	"I think there's some sort of idea: every two years I must have a new phone, whether or not it is: because my subscription has expired, and I'm allowed a new subscription, so I want a new phone." *P9*
New developments and software updates accelerate replacement	"Yes well, I was thinking … I'm sitting here watching a nice television. But are the colors the best? Does it work seamlessly? Then it could always be a little better. So, we [decided to replace] and now have this very luxurious product." *P3*
	"I couldn't download apps anymore, for example [banking smartphone application]. I found that annoying. That was most decisive in the replacement." *P13*

3

3.4.3. CONSUMERS' RESPONSES TO A PRODUCT LIFETIME LABEL

Lifetime labels should provide relevant and reliable information

We asked participants whether labels with lifetime information would be useful to them. Responses were diverse; participants tended to respond positively to being better informed about product reliability and expected lifetime. However, they also had doubts. First, labels should be objectively monitored by independent parties to be reliable. Second, participants mentioned the difficulty of predicting lifetime in years, because it strongly depends on use intensity and behavior (e.g., misuse or carelessness) (cf. Table 4, P4). They indicated that one or more use scenarios (e.g., weekly use frequency of washing machines) could help.

Discouraging attitudes toward product repairability

Overall, participants were unlikely to take the product's repairability into account during purchase. Some were even surprised or confused by this question. They believed manufacturers would not benefit from improving repairability. Many manufacturers do not communicate information about repairability, and therefore participants could not have considered repairability. Some participants even suggested that promoting repairability could trigger worries about possible breakdowns when acquiring a product (cf. Table 4, P11). Considering that repair information is not generally available in the

Netherlands, receiving such information for one specific product at purchase would trigger associations with repair that consumers would otherwise not have. Participants inferred that breakdowns should be expected, and this repair information was provided because the product would need more repairs than other products. If repair information is only given for a specific product in a category, participants may thus question its quality and durability.

Extended warranty can stimulate lifetime extension

While asking about repair considerations, many participants spontaneously answered that they would use their warranty rights if their new product broke down during the warranty period (cf. Table 4, P6). Beyond the warranty period, the product's age, repair costs and the price of a new device become more prominent in the repair-versus-replacement decision. Participants also indicated doubts about manufacturers' intentions in offering extended warranties, because they think manufacturers have little interest in repairing broken products and would rather sell new ones.

Awareness of environmental impact may encourage lifetime extension

Finally, we asked participants about their awareness of the environmental impact of products. Participants primarily mentioned that the energy efficiency and recycling of products contribute to a better environment. However, they rarely spontaneously mentioned the negative environmental impact of short product lifetimes. When we introduced them to this topic, many participants said they were not fully aware about the consequences of early replacement (cf. Table 4, P22) and currently lacked information to judge products on their environmental impact in relation to the expected lifetime.

Table 4. The categories and exemplary quotes of the theme "Consumers' responses toward a product lifetime label"

Category	***Example quote***
Lifetime labels should provide relevant and reliable information	"Uhm yes, I think that [a lifetime label] is very difficult with smartphones because it depends so much also on your individual use, and whether you put a case on it and so on. I think that's even more important." *P4*
Discouraging attitudes toward product repairability	"No, I did not consider the repairability of this vacuum cleaner [...] Repairable parts make you wonder, oh, will that be necessary? Will it break down?" *P11*
Extended warranty can stimulate lifetime extension	"No, I would not repair this device. If it is within the warranty period, then of course I would. Then you're just throwing money out of the window if you do not make use of that. However, if I'm past that .... The new things are usually a lot cheaper." *P6*
Environmental impact awareness may encourage lifetime extension	"Well, I don't know how harmful it is that I bought a new washing machine [...] I can't say what that really does for the environment, the future emissions [...]. Maybe you could be more aware of that. If you know what the consequences are [of replacement]." *P22*

3.5 GENERAL DISCUSSION

This research contributes to the literature by providing in-depth insights into consumers' perspectives on product lifetimes. We found that consumers have positive attitudes toward product longevity, and confirm that early product replacement can lead to dissatisfaction and feelings of guilt (Wilhelm et al., 2011). This provides promising opportunities for reducing the environmental impact of consumption via the inner loops in a circular economy. Consumers prefer products, particularly utilitarian ones, to be long-lasting mostly because this is convenient. Convenience appears to be key in the decision to either retain or replace a product, which extends earlier research on consumers' need for convenience in services (Berry et al., 2002). However, our results also confirm that consumers mentally write off the value of products as these age (Okada, 2001; Van den Berge et al., 2021). Attention should be paid to decreasing the pace of value depreciation, especially for trend-sensitive products (Korhonen et al., 2018). Additionally, our participants confirm the disbelief that products are designed to last (Echegaray, 2016; Wieser et al., 2015). Our results confirm there is great variety in lifetime expectations within the categories (e.g., EEB, 2019; Jaeger-Erben and Hipp, 2018). We show that many consumers are clueless about their lifetime estimations, which can explain this variation. Furthermore, the fact that consumers' lifetime expectations may influence actual lifetimes is problematic, especially because lifetime expectations are generally decreasing (Kumar et al., 2017). To lengthen actual lifetimes, it is important to increase expectations and support consumers to consistently include expected lifetimes in their purchase decision.

As barriers to extending lifetimes, we confirm a lack of repair knowledge (e.g., Jaeger-Erben et al., 2021) and high (estimated) costs (Brusselaers et al., 2019; Sabbaghi and Behdad, 2018; Tecchio et al., 2019). Consumers may be quite willing to extend product lifetimes. However, our results imply that to compete with relatively cheap and swiftly delivered replacement alternatives, product lifetime extension possibilities (e.g., repair services) should be designed to be more convenient for consumers. Additionally, our results validate that deals and subscription models can trigger the replacement of still-functioning products (Van den Berge et al., 2021). We show that their influence becomes increasingly prevalent when lifetime expectations are met, which highlights the importance of extending expectations. Also, our results confirm that new developments influence the replacement tendency (Jensen et al., 2021), especially for hedonic products, where feelings of satiation have a strong influence (Hou et al., 2020; Magnier and Mugge, 2022).

Regarding the potential of lifetime labels to better inform consumers about the expected lifetime (Braithwaite et al., 2015; Gnanapragasam et al., 2018; Jacobs and Hörisch, 2021), our findings contribute by demonstrating that such labels can only support consumers if they provide relevant and reliable information. Although improved product repairability has been proposed as a solution to extend product lifetimes (Bovea, Ibáñez-Forés, Pérez-Belis, Juan, et al., 2018; Den Hollander, 2018), our findings suggest that incorporating repairability into lifetime labels could cause worries among consumers regarding products' durability. However, consumers might become more willing to consider repairability if a repairability index provided by a reliable institution is displayed on all products. Such an index would normalize repair and give a more accurate representation of devices in terms of life cycle costing or expectations about product care at purchase.

Also, lowering the threshold of repair costs to the price of new products by providing extended warranties may help (Brusselaers et al., 2019). However, the confirmed lack of understanding of the differences between manufacturers' extended warranties and legal guarantees (Maronick, 2007; Svensson-Hoglund et al., 2021) may cause issues. Finally, our results confirm the low consumers' awareness of the environmental impact of short lifetimes of electronic products (Islam et al., 2021). Making this relation more obvious can potentially trigger consumers to retain their products longer.

3.5.1. PRACTICAL IMPLICATIONS

Taking the consumers' perspective on product lifetimes into account is crucial for practitioners who aim to lengthen lifetimes and reduce the negative environmental impact of electronic products. We found that long lifetimes are perceived positively, which yields an interesting opportunity for manufacturers to enhance consumers' image of the brand. To lengthen product lifetimes, industry should focus on preventing value depreciation by sustaining product value. For example, functional and emotional value can be preserved by using scratch- and damage-resistant materials and epistemic value can be preserved by making products more resistant or adaptable to future developments. Finally, to help consumers make well-founded lifetime estimations, independent organizations (e.g., consumer associations) may consider assessing expected lifetimes in their product reviews. Then, consumers may prioritize products' longevity in their purchase decisions.

To alleviate barriers to extending product lifetimes, manufacturers should consider not only long-term software support but also adjust current designs. For instance, product developers could incorporate "cues for repair" (e.g., fault indications). These cues can increase consumers' ability to repair by supporting them in the different repair steps. Manufacturers could also focus on making lifetime extension more economically viable by reconsidering business models (Bocken et al., 2016). For example, manufacturers can offer repair services for a monthly fee or lease agreements where the manufacturer retains ownership of the product and is therefore intrinsically motivated to develop products that last.

For lifetime labels to be successful, practitioners should consider potential rebound effects. For instance, displaying a minimum number of years (Marcus, 2020) may unintentionally give consumers “permission” to replace well-functioning products when these years have passed. Therefore, specific criteria underlying lifetimes, such as reliability of critical parts or repairability (e.g., ease of battery/screen replacement) may be preferred. To improve consumers’ attitudes toward repairability, raising awareness about the potential benefits of repair (e.g., saving costs, reduced environmental impacts) should be explored. Also, independent organizations (e.g., consumer associations) could launch awareness campaigns to enhance repair adoption. Furthermore, offering extended warranties may increase consumers’ trust that the product is designed to last, enhancing the company’s brand image. However, the warranty terms and conditions should be clear regarding coverage, how to sign up for it and whom to contact when a failure occurs. Finally, information about products’ environmental impact provided on lifetime labels may encourage consumers to consider additional environmental consequences (next to energy efficiency) at purchase.

Finally, policymakers could consider legislation for industry to communicate information about the lifetime via labels. This may make the expected lifetime a more common choice criterion for consumers and incentivize manufacturers to design long-lasting products to score high on this label. Furthermore, stimulating repair activities via legislation could make repair a more worthwhile option for consumers; however, lower repair taxes may not be sufficient (Svensson-Hoglund et al., 2021). A focus on implementing policies that require manufacturers to design consumer-repairable products (e.g., accessibility of critical parts, standardization of spare parts), increasing the proximity and number of approved repairers, and providing repair support (e.g., repair cafes) are therefore also necessary. Finally, the extension of legal warranties may stimulate consumers’ repair activities, and in turn, trigger manufacturers to design long-lasting products.

3.5.2. LIMITATIONS AND AVENUES FOR FUTURE RESEARCH

Research on ecolabels demonstrated that consumer responses may vary across countries (Peschel et al., 2016). Our results represent a developed country’s perspective on lifetimes and understanding the Dutch context may be relevant to other comparable countries (e.g., France, Belgium, Germany, Spain). Notably, within Western European countries, Dutch consumers are fairly environmentally conscious, but less willing to bear personal costs compared to French and German consumers (Golob and Kronegger, 2019). Therefore, our sample may have been critical toward lifetime extension strategies, such as repair investments. Verifying these insights in different countries is recommended to generalize our results.

Our research focused on investigating four different electronic products regarding lifetime extension. Consumers' replacement behavior differs between product categories (Cox et al., 2013) and different products may thus need different lifetime extension strategies. Also, some existing design strategies (e.g., modularity or upgradeability) were not mentioned by our participants. We recommend future research to focus on investigating other lifetime extension opportunities to extend our findings and identify the optimal strategy for specific product categories. Also, future studies could investigate the factors that influence the market success of repair services (e.g., repair at home, temporary loan device) and if these can improve repairability perceptions.

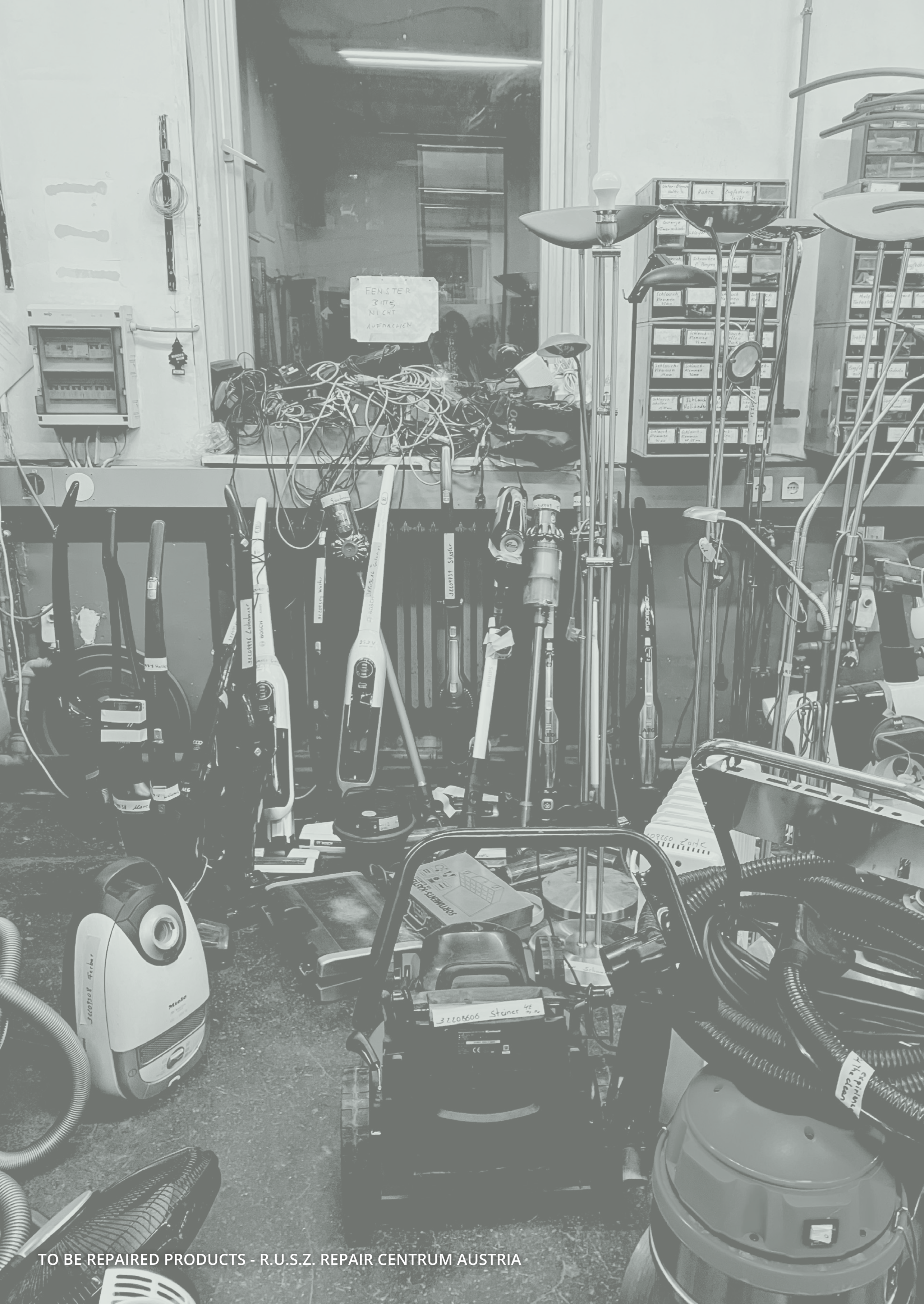
Regarding lifetime labels, more research is needed to understand how lifetime-related information should be presented to be relevant and reliable for consumers (e.g., by showing numbers, percentages, ratings of environmental impacts) and influence choice most effectively. Additionally, future studies could investigate how lifetime labels can better inform warranty rights. Finally, communicating information about the expected lifetime of products would enable consumers to have a fairer idea of their relative price over the full lifetime – which may make them more inclined to choose a product that is more expensive but lasts longer. Future research could therefore focus on measuring the effect of communicating the expected lifetime compared to other factors, such as price and brand, in purchase decision-making.

3.6 CONCLUSION

Lengthening product lifetimes is necessary to reduce human ecological impact, and studying this topic is therefore of great relevance for the field of industrial ecology. Our findings show the potential of extending product lifetimes as consumers desire long-lasting products, and well-designed lifetime labels can guide them in their decision-making. Extending product lifetimes can thus play an important role in realizing a circular economy and making more efficient use of our scarce resources. We want to stress that a systemic approach is required to catalyze a change in our current way of production and consumption. To extend product lifetimes, governmental bodies play a key role both top-down (in developing legislation) and bottom-up (in creating consumers' awareness). However, to avoid resistance to change, it is essential to profoundly understand both consumers' and manufacturers' perspectives. Taking their perspectives into account may accelerate a change in mindset and adoption of legislation, thereby smoothening the transition toward a circular economy. Ultimately, this shift will only succeed if all parties (government, consumers, industry) are enabled to contribute toward a more sustainable society.

PART II |

THE IMPACT OF DESIGN AND MARKETING STRATEGIES ON CONSUMERS' REPAIR INTENTIONS



TO BE REPAIRED PRODUCTS - R.U.S.Z. REPAIR CENTRUM AUSTRIA

4

Sparking the repair "can-do" attitude: Enhancing users' willingness to repair through design support in fault diagnostics

This chapter was previously published:
van den Berge, R., Magnier, L., & Mugge, R. (2023). Sparking the Repair "Can-Do" Attitude: Enhancing Users' Willingness to Repair through Design Support in Fault Diagnostics. *International Journal of Design*, 17(3), 25-39 https://doi.org/10.57698/v17i3.02

Chapter 2 presented different strategies that can contribute to changing consumption patterns of consumer electronics, such as design for repair. Yet, Chapter 1 revealed that many products nowadays are not designed to be repaired (Proske et al., 2017; Rosborou, 2020; Wieser et al., 2015). Consumers often do not consider repairing electronic products (Jaeger-Erben et al., 2021; Magnier and Mugge, 2022) and are more likely to replace them instead (Harmer et al., 2019; Hennies and Stamminger, 2016; Wieser and Tröger, 2018). In the investigation of the barriers towards product lifetime extension, Chapter 3 showed that consumers generally have a low ability to repair consumer electronics. However, it also highlighted a general preference for long-lasting products and suggested that increasing consumers' ability to repair via cues in the design (e.g., a fault indication) may encourage them to repair their products.

This chapter addresses SRQ3 by exploring how design can support consumers with repair and thereby extend their products' lifetimes. By doing so, it empirically expands the literature on lifetime extension strategies, in which this strategy was thus far only discussed theoretically (cf. Chapter 2). Specifically, Chapter 4 aims to study if consumers' willingness to repair electronic products can be increased via an intervention in the product design. It presents three experiments in which we use a fault indication as a design intervention to increase consumers' self-efficacy to repair, and consequently, their repair intentions.

4.1 INTRODUCTION

The current approach to production and consumption has negative consequences for our environment. The growing production of electronic products severely impacts our environment due to CO_2 climate emissions, leading to an increase in temperature and a rise in sea level (Allwood et al., 2011; Bakker et al., 2014). Additionally, such production requires the extraction of scarce (metal) materials. The sourcing, processing, and disposal of these materials are problematic, as they result in water and land pollution, thereby negatively impacting the global environment and health. Growth in the production of electronic products can also lead to material scarcity. Our dependence on critical materials used for (modern) technologies poses a potential societal risk (Heacock et al., 2016; Köhler, 2012). Despite these problems, prior studies have shown that the lifetimes of electronic products are becoming ever-shorter (M. Park, 2010). This results in a growing stream of e-waste, which is expected to continue to rise in future scenario studies (Parajuly et al., 2019).

Designers could possibly reverse these negative consequences of consumption via product, service, and system designs. The principles of the circular economy (CE) provide promising solutions to change the way we produce and consume products (Ellen MacArthur, 2013). Even though interest in CE is growing (Geissdoerfer et al., 2017), attention is still largely focused on product recycling (e.g., Kirchherr et al., 2017). Recycling is a less preferred option in a CE because the product integrity (i.e., initial value) is lost (Den Hollander et al., 2017). Retaining products' initial value through prolonged usage should be favored instead, as this slows down the material and energy flows of production and consumption and reduces the impact on the environment (Bakker and Schuit, 2017; Konietzko et al., 2020; McCollough, 2009). However, in order to move from the traditional "take, make and dispose" mindset into a CE, users need to change how they interact with electronic products.

Prior research has indicated the potential of repair of (partially) malfunctioning products to prolong product lifetimes (Bocken et al., 2014; Author, 2022). Yet, many products nowadays are not designed to be repaired (Proske et al., 2017; Rosborou, 2020; Wieser et al., 2015). Past research has proposed several ways to facilitate repair by design (Raihanian Mashhadi et al., 2016; Sabbaghi et al., 2016). These repair strategies generally take a design engineering perspective and address technical aspects of the product design (e.g., ease of disassembly). However, even if a product is technically repairable, it does not mean that users will act accordingly (Makov and Fitzpatrick, 2021). At present, users often do not consider repairing electronic products (Jaeger-Erben et al., 2021; Author, 2022), and are more likely to replace them instead (Harmer et al., 2019; Hennies and Stamminger, 2016; Wieser and Tröger, 2018).

The decision to repair is affected by many factors. Low ability to repair is among the major hindrances preventing users from fixing their electronic products (Author, 2018). Users often lack the knowledge and skills to execute repairs themselves and even if they do, the repair task can be time demanding. Furthermore, it may be difficult to find spare parts and their delivery conditions (e.g., price, delivery time) may be deficient (Jaeger-Erben et al., 2021; Rogers et al., 2021; Terzioğlu, 2021). When employing professional repair, the inconvenience of repair services is discouraging (e.g., availability, time-consuming) (Poppe et al., 2021). While some studies suggested that environmental concerns can be a motivator for repair (Laitala et al., 2021; Sonego et al., 2022; Terzioğlu, 2021), the high costs of repair can make it perceived as a non-rational decision. Repair is often perceived as economically unattractive because the low prices of new products make replacement a more obvious choice (Brusselaers et al., 2019; Author, 2023). However, research has shown that for both washing machines and vacuum cleaners, repair can be considered a more economically favorable option than replacement during most of their lifetime (Brusselaers et al., 2019; Svensson et al., 2022). Unfortunately, many users are not aware of this flawed assessment of the low perceived value of repair. One could argue that an increased ability to repair (i.e., competence) could also facilitate making better cost-benefit estimations, thereby overcoming repair cost barriers.

Despite the value of design as an important catalyst for encouraging users' repair behavior (Sonego et al., 2022), past research has demonstrated a limited focus on the integration of the user perspective in the design (process) of circular offerings (Camacho-Otero et al., 2018). A potential barrier for repair that design should address is that users are often not aware of the causes of their electronic product failures (Pérez-Belis et al., 2017; Pozo Arcos et al., 2021). Not being able to diagnose the failure may negatively influence users' estimated ability to repair because it reduces their level of perceived self-efficacy toward repair. Perceived self-efficacy is explained as a person's "can-do" mentality: the belief in a personal capacity, or ability, to perform specific tasks (Fuchs et al., 2010). For designers, it is important to understand how design can increase users' level of self-efficacy toward repair in order to positively affect their willingness to repair electronic products.

This chapter aims to study if users' willingness to repair electronic products can be increased via an intervention in product design. Specifically, we present three experiments in which we used a fault indication as a design intervention to increase users' self-efficacy to repair. We tested whether this design intervention influenced the willingness to repair a malfunctioning product. We used an experimental set-up because this allowed us to empirically test the effect of including a fault indication on users' willingness to repair while controlling for other influencing effects. After presenting our findings, we provide theoretical implications for future research. Also, we discuss practical implications for designers of electronic products that aim to stimulate repair via their (circular) product designs.

4.2 WILLINGNESS TO REPAIR AND PERCEIVED SELF-EFFICACY

When aiming to stimulate consumers' repair behavior via product design, it is important to consider consumer perspectives during the process of repairing. Repairing involves several steps: diagnosing the failure, disassembling the product, repairing the defective component, reassembling the product, and functional testing. The first step of failure diagnosis is crucial in the repair process (Pozo Arcos et al., 2020; Sabbaghi et al., 2017). In some cases, it may be perfectly clear what the failure is, such as when a smartphone's screen is broken; the consumer can more easily determine whether the product can be repaired. A cost assessment can be made and as a result, the consumer can make a value trade-off on whether a repair would be worthwhile (Van den Berge et al., 2021). On the other hand, if a consumer is unable to accurately assess whether and how repair can restore the product value, this can be detrimental when determining whether it would be worthwhile to either replace or repair a malfunctioning product. A study by Pozo Arcos et al. (2021) showed that electronic product designs generally fail to provide fault diagnosis guidance to consumers. We propose that a fault indication can provide such guidance and will therefore encourage consumers to repair instead of replacing their products.

4.2.1. THE EFFECT OF A FAULT INDICATION ON THE WILLINGNESS TO REPAIR

A fault indication is a signal (e.g., a code on a display, or a colored/blinking light) appearing on the product when a failure occurs. The consumer can look up the meaning of the code or light in the product manual or online to learn the cause of the failure. Tecchio et al. (2016) suggested that in the case of washing machines and dishwashers, fault indications provide useful information that supports consumers in diagnosing a product failure. However, there is no empirical evidence as to whether such fault indications help to stimulate people's willingness to repair. One could argue about whether providing knowledge about the product fault is always enough to stimulate repairs. Specifically, there are many situations in which the failure is obvious (e.g., a broken smartphone screen), but people are still unwilling to repair because of a variety of reasons (e.g., the hassle of collecting the right spare part, the time it takes to figure out the repair options, or the expected costs). Despite these barriers to conducting repair, we propose that a failure indication on the product itself will help consumers to overcome the first hurdle – diagnosis. This will make them feel more knowledgeable, increasing their willingness to repair. Accordingly, we hypothesize:

> H1 – Consumers will be more willing to repair electronic products when a fault indication is present, compared to when a fault indication is absent.

4.2.2. THE MEDIATING EFFECT OF PERCEIVED SELF-EFFICACY

To successfully incorporate repair-stimulating interventions in product designs, it is important for designers to understand the underlying mechanism of how a fault indication increases the willingness to repair. According to the Theory of Planned Behavior, attitude, subjective norms, and perceived behavioral control influence the intention (i.e., willingness), and consequently, the specific targeted behavior of consumers (Azjen, 1991). The attitude and subjective norms refer to the individual's personal beliefs and the normative beliefs of society toward performing a certain behavior. Perceived behavioral control refers to a person's perception of the ease or difficulty of performing a specific targeted behavior. In the literature, perceived behavioral control is conceptually related to the perceived level of self-efficacy (i.e., personal capability) (Fuchs et al., 2010). The assessment of perceived self-efficacy or a person's can-do mentality is based on a reflection of previous experiences and expected obstacles. The reported lack of repair skills (Jaeger-Erben et al., 2021; Rogers et al., 2021; Terzioğlu, 2021) demonstrates the low perceived self-efficacy that consumers usually have toward repair, which negatively influences their tendency to repair electronic products. Increasing consumers' perceived self-efficacy to repair may therefore encourage individuals' repair intentions.

Displaying a fault indication informs the consumer about the cause of the failure – this gives the consumer more knowledge and thus control over the situation. The repair steps can be more easily identified than when no such indication is displayed. We, therefore, expect that the consumers' self-efficacy (and the related perceived behavioral control) toward the targeted repair behavior would increase. Subsequently, an increased level of self-efficacy would positively increase their willingness to repair, leading to the following hypothesis:

> H2 – The perceived level of self-efficacy will mediate the effect of a fault indication (absent or present) on the willingness to repair electronic products.

4.3 GENERAL METHODOLOGY

To empirically test if consumers' willingness to repair electronic products can be increased via an intervention in product design, three studies using a scenario-based experimental approach were conducted. The experimental setup allowed us to isolate and test the specific effects of a chosen intervention (i.e., fault indication). Moreover, it enabled us to uncover mainstream effects (rather than unique, individual cases) of the intervention (Field and Hole, 2002).

Study Design and Stimuli

We tested the effect of the absence/presence of a fault indication on participants' intentions to repair a broken product in four product categories. Specifically, in each study, we randomly presented the participants with a scenario of a broken product, which was either presenting no fault indication or a fault indication to the consumer. The scenarios consisted of a short text and a visual depiction of the product. To limit the influence of potential aesthetic preferences, all products had a prototypical appearance and color. The brand name and logo were removed to prevent personal preferences and prior associations from influencing the results. The text provided information about the model, performance (state), time of ownership, and the fact that the product failed. Specifically, the product was textually presented as a mid-range model that, before breaking down, had performed normally compared to similar products. Information about the performance was added to reduce the possibility that uncertainty about the satisfaction level of the initial state of the product would influence the results. Furthermore, the age of products can play an important role in the decision to repair, as product value tends to depreciate during its lifetime (Makov and Fitzpatrick, 2021; Van den Berge et al., 2021). To make sure a repair would still be considered a valuable option for the participant, we determined the time of ownership between the legal two-year warranty period (i.e., during which the manufacturer covers repair costs) and the average actual lifetime of the chosen product. We used product-specific common failures in our scenarios. All failures across the studies match in such a way that they prevented the products from performing their primary function. In this way, we ensured that the participants would not think that the device could still be used despite the failure, which may influence their repair decision. If the fault indication was present, the indication was visually added to the picture of the product together with an informative text about the specific failure. The scenarios can be found in Appendix C.

Procedure and Measures

Participants were asked to empathize with the scenario and answer a series of questions as if this situation had occurred in their everyday lives. To collect the data, we used Qualtrics software to design an online survey. This survey included several measurements on multi-item scales. We measured participants' willingness to repair the product using the following three items: "How likely/inclined/willing are you to have this product repaired?" (1="not at all"; 7="very much") (adapted from White et al., 2011). Participants' level of self-efficacy was measured using the following three items: "I feel competent enough to select the best repair actions needed for this product," "I feel that I have the relevant knowledge and expertise to make sound evaluations about the repair actions needed for this product" and "I had difficulties evaluating the repair actions needed for this product" (reversed item; 1="strongly disagree"; 7=" strongly agree") (adapted from Fuchs et al., 2010). Lastly, to check if our manipulation of the fault indication was successful, we asked participants about their understanding of the cause of the failure using the following three items: “The fault was clear to me,” “I would be able to identify the type of failure,” and “I have had enough information to know the type of failure” (1=“strongly disagree”; 7=“strongly agree”).

Data Collection and Analysis

Data was collected via Prolific, which is an online platform to recruit participants (www.prolific.co). To make sure participants could empathize with the possible repair need, the minimum age of the participants was set to 25 years. This minimum age would increase the likelihood that participants have personally owned the product for several years and could therefore imagine what they would do if it broke down. The collected data was analyzed using SPSS. In the analyses, we compared the means of the different conditions to test the effects of the fault indication on the willingness to repair and the mediation of the perceived self-efficacy. Unless suggested otherwise, the assumptions of normality and homogeneity were met in our analyses.

4.4 STUDY 1A

The purpose of this first study was to investigate whether the presence of a fault indication increases the willingness to repair consumer electronics (H1). We additionally investigated whether this can be explained by an increased level of self-efficacy (H2).

4.4.1. METHOD

Study Design and Stimuli

Study 1a consisted of a between-subject experimental design with two conditions (fault indication: absent vs. present). We chose to utilize a coffee maker as a target product for this study for several reasons. Coffee makers are widespread in households – drip filter machines are particularly common, with a relatively high use intensity (three times a week on average) and high ranking among appliances that most recently broke down (Pérez-Belis et al., 2017; Stanek et al., 2021). Also, the majority of these coffee makers are not considered for repair and many consumers find them not worth mending when they can get a new one for a similar price (Jaeger-Erben and Hipp, 2018; Pérez-Belis et al., 2017). Lastly, studies have shown that repairing coffee makers is more beneficial for the environment than replacing it (Bovea et al., 2020), and therefore we considered them as an appropriate product category for our study. As the average lifetime of a coffee maker is around six years (Pérez-Belis et al., 2017)) we included a time of ownership of three years in the scenarios.

For coffee makers, one of the most common failures is the calcification of the components (Postma and Kesteren, n.d.), which mostly affects components subjected to (hot) water flows. For example, a rubber seal inside a coffee maker is susceptible to calcification. In the scenario without a fault indication (i.e., absent), a description of the failure with no indication of its cause was presented. The product failed and was not able to brew coffee anymore. In the scenario with a fault indication (i.e., present), an error code ("fault 2") was displayed on the coffee maker; this code was explained in the (online) manual as meaning that the rubber seal of the water basin was damaged and needed to be replaced, cf. Appendix C

Measures and Sample

Participants evaluated the scenarios on multi-item scales measuring their willingness to repair (α=.95) and level of perceived self-efficacy. We excluded the third item of the self-efficacy scale as this negatively affected reliability (α<0.70). A reason for the low Cronbach's alpha could be that the third item had a reverse phrasing. As only two items were left, we checked the Pearson correlation coefficient to evaluate the reliability of the self-efficacy scale. This showed a strong positive correlation (r=.87). Lastly, the participants completed the manipulation check (α=.91). In total, 104 participants completed the survey, of whom 33 indicated that they do not use a coffee maker that runs on electricity (i.e., that needs a power plug to function) at home. We assumed they would have found it more difficult to relate to the described situation and thus were excluded from the dataset. Also, two participants who failed the attention check were excluded. This resulted in a total of 69 participants (Age: M=35.87, SD=10.86; Gender: Male=44.9%, Female=55.1%, Other=0%).

4.4.2. RESULTS

Manipulation Check

We first performed an independent sample t-test to check if our manipulation was successful. We used the fault indication as the independent variable (IV) and the participant's understanding of the cause of the failure as the dependent variable (DV). The results showed a significant difference in participants' understanding of the failure when the fault indication was present (M_{absent}=3.24 vs. $M_{present}$=5.29; t(67)=-5.12; p<.001). Participants thus better understood the cause of the failure when the fault indication was shown, and our manipulation was successful.

The Effect of a Fault Indication on the Willingness to Repair

We conducted bootstrapped (5,000 samples) parametric tests because the willingness to repair data deviated from the normal distribution. These tests are fairly robust against violations of the normal distribution assumption (e.g., Barber and Thompson, 2000; Blanca et al., 2017). We performed an independent sample t-test with fault indication (IV) and willingness to repair (DV). Our results showed that when the fault indication was present, the willingness to repair the coffee maker was significantly higher compared to when the fault indication was absent (Mabsent=4.06 vs. Mpresent=5.49; t(67)=-3.60; p<.001, 95%CI[-2.29,-.68]), see Figure 9. These findings confirm H1.

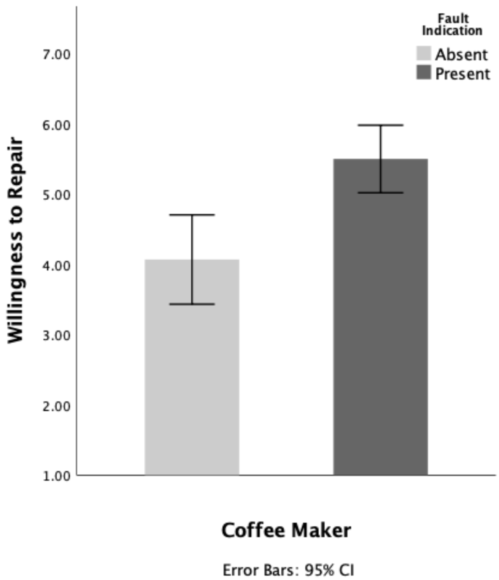


Figure 9. The willingness to repair a CM with or without fault indication

4

The Mediating Effect of Self-Efficacy

To test if the positive effect of a fault indication on the willingness to repair a coffee maker could be explained by a higher level of perceived level of self-efficacy, we conducted a mediation analysis. First, we performed an independent sample t-test to analyze the effect of the presence of a fault indication (IV) on the level of self-efficacy (DV). The results showed that participants in the present condition had a significantly higher level of perceived self-efficacy (Mabsent=3.50 vs. Mpresent=4.61; t(67)=-2.88, p<.01, 95%CI:[-1.84,-.34]), cf. Table 5.

To uncover whether the increased level of self-efficacy could explain the increased willingness to repair, we performed a mediation analysis using model 4 of the PROCESS macro for SPSS (Hayes, 2013). The indirect effect of the fault indication on the willingness to repair for the level of self-efficacy was tested using non-parametric bootstrapping and showed significant results (b=0.53; BootSE=.24; 95%CI:[.13,1.07]). The direct effects revealed that the fault indication positively influenced the level of self-efficacy (b=1.01; SE=.38; 95%CI:[.34,1.87] p<.01)) while self-efficacy, in turn, positively influenced the willingness to repair (b=.48; SE=.11; 95%CI:[.25,.70]; p<.001). As both direct and indirect effects are significant, these results show a partial mediation confirming H2.

4.5 STUDY 1B

The purpose of Study 1b is to generalize the findings of Study 1a by checking whether the positive effect of the fault indication on the willingness to repair remains stable for different types of products. Additionally, considering that the failure selected in Study 1a is a specific error in coffee makers, it may be useful to validate our outcomes with other types of defects. Reflecting on the stimuli used in Study 1a, repairing the rubber seal of the water reservoir of a coffee maker could have been perceived as a task with relatively low estimated repair costs. It is thus worthwhile to replicate the study with a repair need scenario that involves spare parts requiring a higher investment and check if the results remain stable. Therefore, we empirically tested H1 and H2 for the scenario of a broken handstick cordless vacuum cleaner.

4.5.1. METHOD

Study Design and Stimuli

The study consists of a between-subject experimental design with two conditions (fault indication: absent vs. present). We chose to utilize a handstick cordless vacuum cleaner, because vacuum cleaners in general are commonly owned household devices, but often for this specific type battery fails early in the product's lifetime (Thysen and Berwald, 2021). Additionally, the replacement of a failing battery is expected to be perceived as a higher investment than the replacement of the damaged coffee maker rubber seal used in Study 1a. In line with Study 1a, the product was introduced as being a "mid-range model" with "normal performance." The time of ownership was estimated to be three years. In the scenario without the fault indication, it was textually indicated that the product "failed" and "did not function anymore." In the condition with the fault indication present, a red light on the battery was added and the scenario text referred to the (online) manual indicating that this meant that the battery was damaged and needed to be replaced, cf. Appendix C.

Measures and Sample

Similar as Study 1a, the participants evaluated the scenarios on multi-item scales measuring their willingness to repair (α=.96) and level of perceived self-efficacy (using only the first two items; r=.77) and completed the manipulation check (α=.96). Five participants who failed the attention check were excluded from the dataset. Of all participants, 55.6% indicated owning a handstick cordless vacuum cleaner. However, most of the households in the EU own a vacuum cleaner (penetration rate of 1.3

per household), but handstick cordless vacuum cleaners are less commonly owned than cylindric vacuum cleaners (Rames et al., 2019). As both are similar in terms of functionality, we decided to also include the participants who indicated they do not own an HCVC. The final sample consisted of 72 respondents (Age: Mean=38.11, SD=8.69; Gender: Male=47.2%, Female=52.8%, Other=0%).

4.5.2. RESULTS

Manipulation Check

We first performed an independent sample t-test to check if our manipulation was successful. The results showed a significantly higher understanding of the cause of the fault when the fault indication was present (M_{absent}=2.80 vs. $M_{present}$=5.70; t(70)=-7.57; p<.001, 95%CI:[-3.67,-2.14]), indicating that our manipulation was successful.

4

The Effect of a Fault Indication on the Willingness to Repair

We performed an independent sample t-test using bootstrapping with fault indication (IV) and the willingness to repair (DV). Our analysis showed a marginally significant effect of fault indication. Even though only marginally significant, the means are in the expected direction, suggesting that participants were more willing to repair the product when the fault indication was present (M_{absent}=4.38 vs. $M_{present}$=5.19; t(70)=-1.77; p<.10, 95% CI:[-1.71,-.11]), which provides further support for H1, Figure 10.

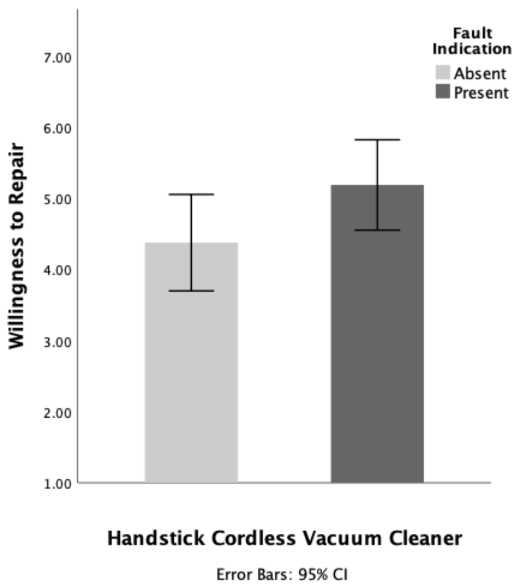


Figure 10. The willingness to repair an HCVC with or without fault indication

The Mediating Effect of Self-Efficacy

An independent sample t-test with the fault indication (IV) and self-efficacy (DV) showed that a fault indication significantly increased participants' self-efficacy (Mabsent=3.68 vs. Mpresent=4.70; t(70)=-2,28, p<.05, 95% CI:[-1.90,.15]), cf. Table 5. Next, a mediation analysis (using PROCESS macro for SPSS model 4 (Hayes, 2013)) revealed a significant indirect effect of self-efficacy mediating the relationship between the fault indication and the willingness to repair (b=0.57; SE=0.28; 95%CI:[.07,1.18]). The fault indication positively influenced the level of self-efficacy (b=1.02; SE=.45; 95%CI:[.13,1.92]); p<0.05), and self-efficacy positively influenced the willingness to repair (b=.56; SE=.10; CI:[0.35,.76]; p<.001), providing support for H2.

4.5.3. DISCUSSION OF STUDY 1A AND 1B

The results of Study 1a and 1b show that understanding the cause of a product failure by implementing a fault indication in the design of electronic products may trigger consumers to proceed to repair. Both studies demonstrated that a fault indication positively influenced the willingness to repair, which was explained by an increased level of self-efficacy. When provided with a fault indication, participants perceived an increased level of self-efficacy and thus felt more competent and knowledgeable to make sound evaluations about repair actions when a fault indication was provided. This enabled participants to better estimate the time and costs of the repair, for example. The marginally significant results of Study 1b of the fault indication on the willingness to repair could be due to the relatively small sample size.

Reflecting on the used stimuli in our Studies 1a and 1b, it is worthwhile to investigate whether an increased level of self-efficacy is also helpful for electronic products that consumers are more likely to have professionally repaired. For example, for (high investment) products with higher technological complexity, consumers are used to contacting professional repair technicians to fix possible defects. For these types of products, a fault indication and the subsequent increase in self-efficacy may thus have a limited effect because consumers do not need to feel competent, as the repair is performed by a professional.

4.6 THE MODERATING EFFECT OF LIKELIHOOD OF PROFESSIONAL REPAIR

The effect of a fault indication on people's willingness to repair may depend on differences in the likelihood of professional repair, which is dependent on the type of product. Especially for low-investment products, buying a new one can be perceived as a low-risk and convenient choice compared to finding out what is wrong with the product and consequently pursuing repair. For example, products that are relatively low in investment or less technologically complex, such as CM and HCVC, are less likely to be considered for professional repair compared to a more technologically complex (high-investment) product such as a washing machine (Rogers et al., 2021). That said, a fault indication can lower the repair barrier, because the consumer is informed about the cause of the failure and can make a better judgment about whether repair, for example, would turn out to be easy to perform or a more economically attractive option. However, more technical products representing a higher investment, such as a dishwasher or washing machine, may be more likely to be repaired by a professional (Sabbaghi et al., 2016). Specifically, the investment price of the product is high enough to consider a repair worthwhile or its technological complexity goes beyond consumers' repair knowledge. For these products, we expect that a fault indication is less likely to influence consumers' willingness to repair because there is less need for the consumer to know the cause of the failure as a professional is consulted in any case. We, therefore, hypothesize the following:

> H3 – The fact that a product is likely to be repaired professionally moderates the effect of a fault indication on the willingness to repair electronic products. Specifically, the presence of a fault indication positively affects the willingness to repair if the product is unlikely to be professionally repaired. If the product is likely to be professionally repaired, the effect of a fault indication is not significant.

4.7 STUDY 2

The purpose of Study 2 is to generalize the findings of Studies 1a and 1b and uncover if the likelihood of performing professional repair will serve as a moderator for the effect of the fault indication on consumers' willingness to repair products (H3).

4.7.1. METHOD

Study Design and Stimuli

The study consisted of a 2 (fault indication: absent vs. present) x 2 (product category: high vs. low likelihood of professional repair) between-subject experimental design. We chose a cylindric vacuum cleaner as a product category with a relatively low likelihood of being professionally repaired. A cylindric vacuum cleaner is similar in terms of functionality to the handstick cordless vacuum cleaner of Study 1b, as well as comparable in terms of the complexity of its technological operation. Also, for the majority of the failure scenarios for a vacuum cleaner, repair and reuse are most beneficial for the environment (Bovea et al., 2020). The penetration rate of 1.3 vacuum cleaners per household in the EU (Rames et al., 2019) shows their wide dissemination. However, a study in the UK showed that only 18% of the participants have had their currently-in-use vacuum cleaner repaired (Harmer et al., 2019). We chose a washing machine for a product category with a higher likelihood of being professionally repaired. Washing machines are also common household products but represent a relatively expensive investment and can be considered technologically more complex than vacuum cleaners. Also, earlier studies have shown that consumers consider themselves to have low repair competence for washing machines (Jaeger-Erben et al., 2021), and are likely to consider turning to a professional to repair them (Magnier and Mugge, 2022).

Each participant was presented with one of the four conditions. The average lifetime of a cylindric vacuum cleaner is estimated at around 6.0 years and a washing machine is around 8.3 years (Wieser et al., 2015). Therefore, we determined the time of ownership of four years for a cylindric vacuum cleaner and six years for a washing machine as a moment in which the consumer would still consider repair to be a worthwhile option but may also be likely to consider replacing their product. We chose a damaged filter as a failure of the cylindric vacuum cleaner, as earlier studies showed that a common symptom of failure is not having suction. Many consumers do not maintain their filters, which results in failures, as preventing a blocked filter is essential for keeping a vacuum cleaner in good working condition (Harmer et al., 2019; Pozo Arcos et al., 2020). In the case of washing machines, we chose damaged drum bearings because this failure type is one of the most common breakdowns reported by both consumers and professional repairers (Tecchio et al., 2019; Thysen and Berwald, 2021). In the scenarios where a fault indication was absent, the cylindric vacuum cleaner lost its suction power and the washing machine was not able to activate the wash programs anymore. In the scenarios in which the fault indication was present, a red light lit up next to a filter icon on the cylindric vacuum cleaner, and an error code ("fault 5") was shown on the washing machine's display. Both fault indications referred to the (online) manual, which provided details about the failure and indicated which component needed to be replaced, cf. Appendix C.

Measures and Sample

Following the procedure of Studies 1a and b, we measured participants' willingness to repair the product (α=0.95), their level of perceived self-efficacy (using only the first two items, r=0.76), and completed the manipulation check (α=0.88). Additionally, we asked participants to rate the following item: "How likely are you to have this product repaired by a professional repairer?" (1= "not at all"; 7= "very much"). Participants who did not own the product (WM: n=4; CVC: n=3) and who failed the attention check (n=2) were excluded from the dataset. This resulted in a total of 139 participants (Age:M=41.10, SD=10.61; Gender: Male=54.0%, Female=46.0%, Other=0%)

4.7.2. RESULTS

Manipulation Check

To check our manipulation of the fault indication, we performed two independent sample t-tests for the CVC and WM separately. Results showed that there were significant effects of the presence of a fault indication on the understanding of the cause of the failure for the cylindric vacuum cleaner ($M_{CVC\ absent}=4.02$ vs. $M_{CVC\ present}=5.86$; $t(68)=-5.63$; $p<.001$, 95%CI:[-2.48,-1.19]) and the WM ($M_{WM\ absent}=3.39$ vs. $M_{WM\ present}=5.42$; $t(67)=-6.05$; $p<.001$, 95%CI:[-2.67,-1.37]). Additionally, we performed an independent samples t-test with the product category as the independent variable and the likelihood of professional repair as the dependent variable to check if our manipulation on the likelihood of being professionally repaired was successful. The results revealed that cylindric vacuum cleaners were significantly less likely to be professionally repaired compared to washing machines ($M_{CVC}=3.86$ vs. $M_{WM}=5.72$, $t(137)=5.53$; $p<.001$, 95%CI:[1.20,2.50]). All manipulations were thus successful.

4

The Effect of a Fault Indication on the Willingness to Repair

We performed a two-way bootstrapped ANOVA using the fault indication and product category as independent variables and willingness to repair as the dependent variable. Participants were significantly more willing to repair a product when a fault indication was present ($M_{absent}=4.68$ vs. $M_{present}=5.31$; $F(1,135)=5.09$; $p<.05$, 95%CI:[-1.19,-.08]), which supports H1. There was no significant main effect of the product category on willingness to repair. As hypothesized, there was a marginally significant interaction effect of the fault indication and product category on the willingness to repair ($F(1,135)=3.72$; $p=.056$), cf. Figure 11.

Next, we analyzed the effects per product category. Our bootstrapped independent sample t-tests results showed that for the cylindric vacuum cleaner, the willingness to repair was significantly higher when the fault indication was present ($M_{CVC\ absent}=4.25$ vs. $M_{CVC\ present}=5.42$, $t(68)=-3.03$; $p<.01$, 95%CI:[-1.94,-.40]), providing further support for H1. However, for the washing machine, no significant difference between the two conditions was found ($M_{WM\ absent}=5.12$ vs. $M_{WM\ present}=5.21$, $t(67)=.05$; $p>.50$, 95% CI:[-.89,.69]).

The Moderated Mediation Effect of Self-Efficacy

We first performed a bootstrapped two-way ANOVA using the fault indication and product category as the independent variables, and the level of self-efficacy as the dependent variable. The results showed a significantly higher level of self-efficacy when the fault indication was present ($M_{absent}= 3.61$ vs. $M_{present}= 4.44$; $F(1,135)=8.35$, $p<.01$). Also, a marginally significant effect was found for product category, suggesting that participants had lower perceived self-efficacy for the WM compared to the cylindric vacuum cleaner (MWM= 3.75 vs. MCVC= 4.29; F(1,135)=3.43, p<.10). There was no significant interaction effect.

For the moderated mediation analysis, we used model 8 of the PROCESS macro for SPSS including bootstrapping (Hayes, 2013), cf. Figure 12. We included the fault indication as the independent variable, willingness to repair as the dependent, self-efficacy as the mediator, and the likelihood of professional repair as a moderator. The indirect effect of the fault indication on the willingness to repair showed a statistically significant index of moderated mediation (b=-.10; BootSE=.05; 95%CI:[-.20,-.01]). This means that the indirect effect of fault indication on the willingness to repair through self-efficacy was stronger for the participants who were less likely to professionally repair. These results confirm H3.

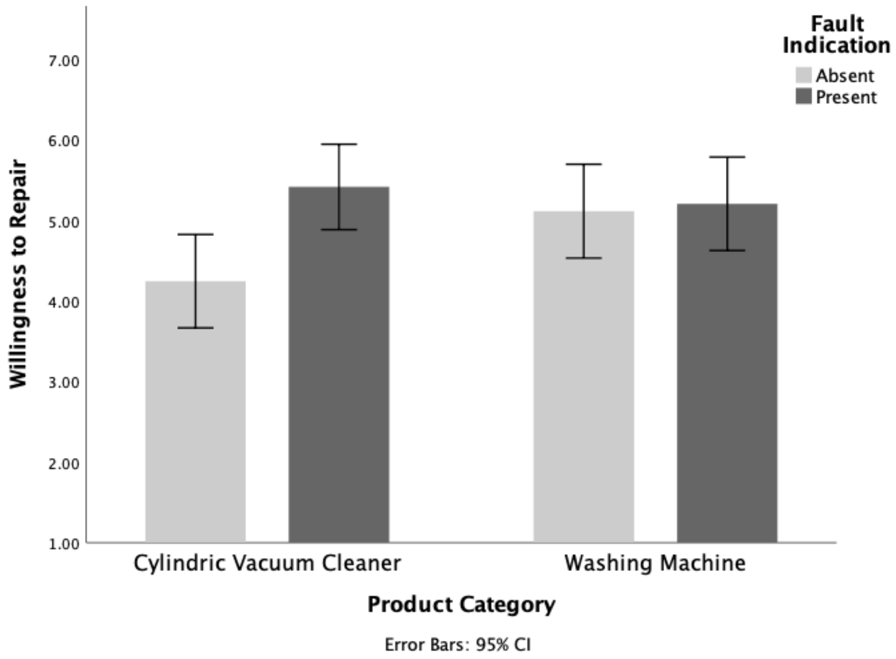


Figure 11. The willingness to repair a CVC and WM with or without fault indication

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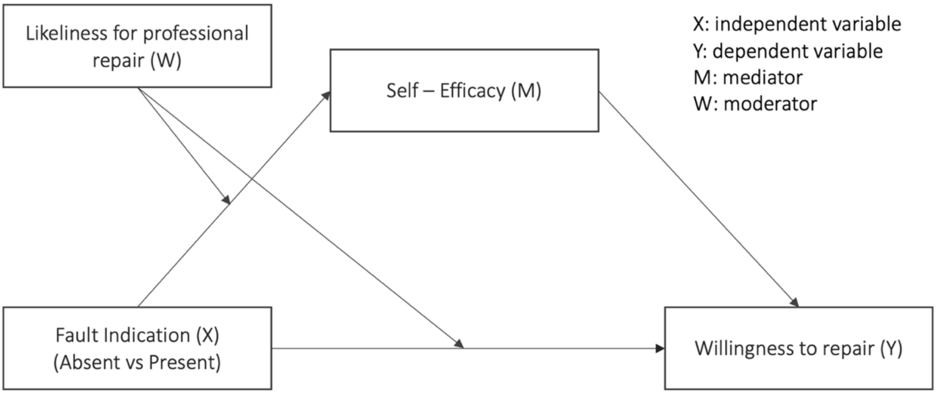

Figure 12. Moderated Mediation based on Hayes (2013) Model 8

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Table 5. The means and standard deviations (SD) of the variables for the study conditions

Variables		**Study 1a**		**Study 1b**		**Study 2**			
Product Category		*CM*		*HCVC*		*CVC*		*WM*	
Fault Indication		*Absent (n=36)*	*Present (n=33)*	*Absent (n=37)*	*Present (n=35)*	*Absent (n=35)*	*Present (n=35)*	*Absent (n=34)*	*Present (n=35)*
Manipulation Check Fault Indication	Mean	3.24	5.29	2.80	5.70	4.01	5.86	3.39	5.42
	SD	1.76	1.55	1.58	1.67	1.69	0.94	1.59	1.16
Willingness to Repair	Mean	4.06	5.50	4.38	5.19	4.25	5.42	5.12	5.21
	SD	1.88	1.35	2.04	1.85	1.69	1.55	1.67	1.69
Perceived Self-Efficacy	Mean	3.50	4.60	3.68	4.70	3.71	4.87	3.50	4.01
	SD	1.78	1.36	1.90	1.90	1.95	1.55	1.66	1.65

4.8 GENERAL DISCUSSION

Our society faces environmental challenges that call for the urgent development of more circular and sustainable products. We provided empirical evidence that design for repair can be a fruitful avenue to further pursue sustainability-focused design research. Across three studies we showed that a fault indication positively influences the willingness to repair electronic products. This effect was explained by an increased level of self-efficacy and was visible for a variety of failure types. Simply knowing what is wrong when products fail can thus empower consumers to take action and replace broken components. We must note that the willingness to repair electronic products that are likely to be professionally repaired (e.g., because they are complex or expensive to replace) was already high without providing a failure indication. For this reason, the lack of a significant effect of the fault indication on consumers' willingness to repair these products is not considered an issue because these products are repaired relatively often anyway. In sum, we can conclude that a fault indication is generally an effective method to increase consumers' willingness to repair failures for many consumer electronics.

The potential role of product design in facilitating consumers' repair behavior has been highlighted in the past (Bocken et al., 2014; Magnier and Mugge, 2022). However, empirical research merely addressed the technical (design engineering) aspects of repairable designs (Raihanian Mashhadi et al., 2016; Sabbaghi et al., 2016; Sonego et al., 2022) while making objects physically repairable does not guarantee that the consumer will carry out repair actions (Jaeger-Erben et al., 2021; Makov and Fitzpatrick, 2021). By taking a consumer perspective, we go beyond the technical aspects of repairable designs and show that an increased perceived self-efficacy raises the likelihood that consumers will actually pursue repair actions. Even though our results may seem somewhat intuitive, the fact is that in today's market, fault indications to aid consumers with repair are not often included in many electronic products. Furthermore, scientific research on the effects of fault indications has been lacking. Our results contribute to the literature on design for repair by demonstrating that fault indications can be of great relevance to stimulate repair, especially for low-investment products. Design practitioners can use our findings to explain the value of fault indications to other stakeholders in the design process, and thereby verify the need of potential additional investments. This is of great relevance for design practitioners aiming to extend product lifetimes via repair.

In the decision to replace or repair, consumers are often unable to accurately estimate whether or not a repair would be worthwhile (Van den Berge et al., 2023a), which may result in a negative attitude toward repair. Following the principles of the Theory of Planned Behavior, we showed that providing consumers with a fault indication increased their level of perceived behavioral control (or self-efficacy) and consequently their repair intentions. Furthermore, next to the effect on repair intent, perceived behavioral control may also positively affect the existing (individual) attitude toward repair (Azjen, 1991). In other words, consumers may develop a repair "can-do" attitude that will affect their individual beliefs about repair, which can consequently lead to a shift in subjective norms and beliefs. To ultimtely change the subjective norms of society, a critical mass of people willing to repair electronic household products is needed (Sunstein, 2019). Ultimately, increasing consumers' "can-do attitude" can thus potentially be a useful step in a collective behavioral change toward a more sustainable society.

4.8.1. PRACTICAL IMPLICATIONS

Understanding how consumers' repair behavior can be stimulated via product design is important for design practitioners who aim to contribute to a more circular society. Specifically, next to designing products that are physically repairable, designers should provide consumers with support in diagnosing the reasons for product failure. At present, fault (i.e., error) indications are available for specific household devices, such as washing machines and dishwashers (Tecchio et al., 2016). However, our results indicate that fault indications on coffee makers and vacuum cleaners, for which these are less often provided, would have the largest impact. Therefore, we suggest that designers should also consider incorporating fault indications in lower-investment and less complex products.

To manage the costs associated with implementing fault indications in the design, designers could focus on providing these only for the most commonly occurring failure(s). For most products, it is well-known what the most commonly occurring failures are. We suggest designers can implement appropriate sensors and fault indications accordingly. To avoid unnecessary failures, the fault indication should not complicate the functionality of the product. Also, it should be clearly noticeable on the product, to ensure the consumer would not overlook it. Furthermore, the fault indication should be designed in a way that it feels approachable and helpful to consumers, thereby reducing the perceived complexity and anxiety of the repair task. For example, a coffee maker could signal a calcification (Postma and Kesteren, n.d.), or a vacuum cleaner could signal the necessity of a filter replacement (Harmer et al., 2019) via the appearance of a (coloured) indicatory icon on the product's display. Blinking lights may also be used as these attract much attention. However, with the design of such lights, designers should consider the speed of blinking, as a high tempo may induce anxiety, rather than prevent it. In addition, the fault indication should be easily traceable via an online manual or on the company website. Step-by-step guidance and/or movies explaining repair procedures could also be provided to further support the consumer's ability to repair the product. Also, the aesthetic qualities of fault indicators should be considered because more attractive fault indications may be perceived as high-quality ('what is beautiful is good' principle; Dion et al., 1972), as well as more pleasurable (Desmet, 2012), thereby increasing the chances that consumers will take action. Fault indications can be made more attractive by implementing well-known design principles, such as harmony or unity and by integrating these indications seamlessly in the product design. The fact that the willingness to repair a washing machine was quite high without a fault indication is promising because it means that consumers were already more prone to repair these products. For these products, it is important to design professional repair services that will not demotivate consumers in their steps towards professional repair. Fortunately, legislation that aims to make repair services more accessible and feasible (e.g., the Right to Repair) is currently under development. The consumer products market will need to adapt to comply with these regulations. In this respect, we suggest two potential directions to further increase the willingness to repair products via professional repair. For consumers who prefer a prompt solution for a malfunctioning product, a well-designed repair service that is market competitive with existing replacement services in terms of speed would be an interesting direction. For consumers who would like to save costs by repairing these products themselves, designers could consider exploring whether providing support beyond a fault indication would make consumers inclined to repair these more expensive and complex products. For example, support throughout the different repair steps via cues or an extended online repair support service, with (video) tutorials.

When designing for repair, we would also like to highlight the importance of the general physical interaction with the product to its perceived repairability. For example, a material that is easily scratched or damaged during repair, or sharp edges on product components that can hurt you could refrain consumers to pursuing repair actions. Also, too heavy or solid devices could be potentially intimidating for repair (Mugge et al., 2018). Furthermore, when implementing design interventions to increase consumers' level of self-efficacy, designers should also consider the total environmental impact of the intervention. It is for example undesirable that the addition of a fault diagnosis will increase the complexity of the design, leading to earlier product failures, or will require many additional scarce resources that increase the overall footprint of the product. Designers should thus consider possible rebound effects of their interventions by performing life cycle analyses (LCA).

Past research has proposed product attachment as a different design strategy to extend product lifetimes (Mugge et al., 2005; Schifferstein and Zwartkruis-Pelgrim, 2008). If a person feels attached to an object, they are more likely to repair it when it breaks down because replacing it, would mean that the special meaning is lost. For these objects, fault indications are probably less needed as people will do their utmost best to try and repair such favorite objects. However, most electronic products are not likely to be objects of attachment, as coffee makers or vacuum cleaners are usually not emotionally laden objects and do not provide an irreplaceable special meaning (Mugge et al., 2008). Lastly, encouraging repair behavior may be challenging because it is not in line with current linear business models. Designers may face challenges in making such products financially attractive for companies. Nonetheless, it is important to note that in a company's contribution to a circular economy, the repair of products can have many positive impacts and is, therefore, worthwhile to consider. For example, well-designed repair services may create company revenue. This can be done directly by designing profitable repair services, and indirectly by creating brand loyalty. Using design for repair strategies may thus be helpful to create a competitive advantage in the highly competitive market of consumer electronics.

4.8.2. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Several limitations that provide interesting avenues for future research should be highlighted. First, our findings are limited to the effect of fault indications on consumers' willingness to repair. The effect of fault indications on the service performance of repair professionals remains unexplored. Already knowing the cause of the failure makes the diagnosis step superfluous, thereby potentially decreasing time and costs involved in failure diagnostics. For example, a fault indication allows the repairer to order the appropriate spare parts beforehand and have them ready at the moment of repair. This may lead to a more efficient and less costly repair process, which will positively influence consumers' repair decision-making. To substantiate this potential, we suggest future research to further investigate the effect of fault indications on the service performance of repair professionals.

Although our research focused on the failure diagnostics stage, we acknowledge that interventions at other stages in the repair process could also boost consumers' level of repair self-efficacy. For example, design interventions that support the dis- or reassembly stages (e.g., screws or a notch indicating where a device can be opened, or icons on components indicating their function) may have a similar effect on self-efficacy but at other stages of the repair process. We recommend designing products in such a way that the "can-do" attitude is supported throughout the entire repair process. Furthermore, there may be more design interventions that could increase consumers' repair 'can-do' mentality. Therefore, studying other design interventions may also be helpful for product lifetime extension. Studies on how modular designs could increase the likeliness for do-it-yourself (DIY) repair have already shown promising results (Van den Berge et al., 2023b). To further expand on how design can stimulate repair intentions, we encourage design researchers to investigate the effects of such alternative design interventions on willingness to repair.

Providing a fault indication merely addresses the barrier of a problematic failure diagnosis. Whether a fault indication would also support overcoming other ability-related barriers such as high estimated repair costs or spare part availability (Laitala et al., 2021; Van den Berge et al., 2021) remains unclear. We believe that providing fault indications could also be an opportunity to connect consumers to more specific repair information about spare parts, repair steps, and repair services (e.g., by referring to an (online) repair manual for support). This may consequently reduce the time and effort needed to collect information about the repair but may also remove incorrect assumptions about the repair (e.g., high costs for spare parts), thereby increasing willingness to repair. Therefore, it seems worthwhile to further explore the potential opportunities of implementing fault indications beyond the fact that they support failure diagnostics, taking away other repair barriers as well. In addition, while our focus was on how fault indications can improve repair self-efficacy, it is important to mention that the decision to repair is a complex process influenced by many more factors, such as the time needed for repair, cost-effectiveness, and understanding of the environmental benefits. We suggest future research should investigate how specific (design) interventions can influence these factors.

It is important to mention that the results reflect the intended behavior of our participants. The study was conducted in an experimental and controlled setting, due to which we measured participants' intentions to repair their product in a scenario rather than their actual repair behaviors. Even though it is promising to see that people's repair intentions increased as a result of the fault indication, we also realize that in a real-life setting, other factors may intervene due to which these intentions to repair may not necessarily result in actual repair behavior (a.k.a intention-behavior gap; Sheeran and Webb, 2016). Therefore, we would encourage future research to study the effects of a fault indication in a real-life setting.

Finally, self-efficacy may have a similar desirable effect on people's willingness to repair other types of products, such as furniture or clothing, as many people do not execute repair because they lack the ability (Laitala et al., 2021). Fault indications such as error codes or blinking lights may not be appropriate for these types of products. Nevertheless, to contribute to a more circular society, we encourage designers and design researchers to explore possibilities to further increase consumers' repair "can-do mentality" in the various repair stages and for different consumer products.

4.9 CONCLUSION

To stimulate people's intentions to repair their consumer electronics, designers should consider increasing consumers' repair 'can-do' attitude. This can be achieved by providing design indications (e.g., a fault indication) that increase consumers' perceived self-efficacy to repair. Especially for lower-investment electronic products, the results are relevant because many consumers do not consider it to be worthwhile to take these products for professional repair. Simply understanding a product's failure can thus support consumer's repair intentions, which is valuable knowledge for designers and design researchers that aim to extend the lifetimes of electronic products via repair.

A SMARTPHONE WITH A BROKEN SCREEN

5

The influence of a modular design and facilitating cues on consumers' likeliness to repair electronic products

This chapter is based on the article:
Van den Berge, R. B. R., Magnier, L. B. M., & Mugge, R. (2022). The influence of a modular design and facilitating cues on consumers' likeliness to repair electronic products. In *5th PLATE (Product Lifetimes and the Environment) Conference Espoo, Finland, 31 May – 2 June* (pp. 1115-1121). Aalto University

To further explore how design interventions can help consumers with repair and thereby extend products' lifetimes (SRQ3), Chapter 5 builds on Chapter 4's findings concerning the effect of support in failure diagnostics. It does so by addressing another barrier in the repair process, which is the low ability to perform the repair task because the product design does not allow for repair. In this way, it aims to address the empirical literature gap of mostly theoretically discussed lifetime extension strategies (cf. Chapter 2).

For repair practices, DIY ('do-it-yourself') repair is often cheaper and faster but also demands a change in current behaviors (cf. Chapter 1). To increase consumers' ability to repair products, Chapter 2 highlighted modularity as a promising design strategy for product lifetime extension because a modular design would make it easier for consumers to repair products themselves. Chapter 5 aims to investigate if modularity as a design intervention can indeed encourage consumers to repair and under which conditions this is more likely. Two experiments are set up to test the effect of modularity on consumers' likeliness to repair and to investigate what specific design cues can encourage consumers to execute DIY repair.

5.1 INTRODUCTION

The growing amount of electronic product waste (e-waste) is becoming increasingly problematic worldwide (Parajuly et al., 2019). Repair has been addressed as a promising strategy to counter the environmental issues resulting from our current consumption and production patterns (Bocken et al., 2016). However, repairing electronic products when they are malfunctioning or broken is not yet common (Magnier and Mugge, 2022). Consumers encounter many barriers to repair, such as high costs, lack of spare parts, and limited knowledge and ability (Ackermann et al., 2021; Jaeger-Erben et al., 2021; Rogers et al., 2021; Svensson et al., 2022; Terzioğlu, 2021). Prior research implied that consumers' limited ability to repair may be caused by the way products are designed (Raihanian Mashhadi et al., 2016). For instance, smartphone casings are often glued, which takes more time and effort to disassemble.

Modularity has been addressed as a design strategy to enhance the physical reparability of products (Mestre and Cooper, 2017; Mugge et al., 2005; Schischke et al., 2019). A modular product consists of independent 'building blocks' (modules) and is designed in such a way the modules can be easily replaced or repaired when malfunctioning (Bonvoisin et al., 2016). In addition to enhancing repair, modularity potentially allows consumers to keep their products up to date with new technologies via upgrades, thereby increasing lifetime expectations (Den Hollander, 2018; Ülkü et al., 2012). Therefore, modularity can be beneficial for slowing down resource loops (Bocken et al., 2016). Yet, the fact that products are physically designed to be repaired, does not mean consumers will act accordingly (Makov and Fitzpatrick, 2021).

A study on current users of modular smartphones demonstrated a strengthened perceived ability for DIY ('do-it-yourself') repair (Amend et al., 2022). However, these users may not reflect the average consumer because modular products are not (yet) the norm. Many consumers are accustomed to involving professionals to repair electronic products, such as smartphones and washing machines (Magnier and Mugge, 2022). A modular design would make it easier for consumers to repair products themselves, which is often cheaper and faster, but also demands a change in their current behavior. We contribute to the literature by investigating the impact of a modular design on consumers' likeliness to get the product repaired as well as to conduct DIY repair.

5.2 THE LIKELINESS AND PERCEIVED DIFFICULTY TO REPAIR MODULAR PRODUCTS

At present, consumers generally do not believe products are designed to be repaired (Van den Berge et al., 2023a; Wieser et al., 2015), and their likeliness to consider repairing a malfunctioning product is low (Magnier and Mugge, 2022). This low likelihood to repair is partly due to the associated difficulty of the repair task (Pozo Arcos et al., 2021; Svensson et al., 2022). Research showed that a high perceived difficulty reduces the attractiveness of a task because it may seem unfamiliar to the consumer (Pocheptsova et al., 2010). A modular design is intended to counter this negative perception of repairing consumer electronics. The fact that the modules can be easily disassembled may result in a more attractive repair task because it would be less effortful and time-consuming. Therefore, we expect that modularity will decrease the perceived difficulty of the repair task, which will positively influence consumers' likeliness to repair. Accordingly, we hypothesize:

> *H1: Consumers are more likely to repair an electronic product with a modular design than one with a conventional design*
> *H2: The perceived difficulty of the repair task mediates the effect of modularity on the likeliness to repair*

5.3 STUDY 1: MODULARITY TO ENCOURAGE WASHING MACHINE AND SMARTPHONE REPAIR

5.3.1. METHOD

The experiment had a 2 (product category: washing machine vs. smartphone) x 2 (product design: conventional vs. modular) between-subject design. Washing machines and smartphones are commonly owned and the environmental impact decreases when their current average lifetime is prolonged (Bakker and Schuit, 2017). Furthermore, the perceived ability to repair these products is low (Jaeger-Erben et al., 2021). We decided to include a 'workhorse' product (i.e., valued for its functional utility) and an 'up-to-date' product (i.e., susceptible to changes in appearance or technology) to consider differences in repair attitudes among product categories (Cox et al., 2013; Pérez-Belis et al., 2017).

We created four scenarios using commonly occurring failures. For the washing machine, the drum bearings were worn out, and for the smartphone, the battery was not working properly (Thysen and Berwald, 2021). We deliberately chose a defect that resulted in a reduced product performance rather than a complete breakdown. The latter may urge immediate action because daily routines are disrupted. Since we aimed to investigate the effect of modularity, we wanted to limit the influence of urge in the repair consideration of the participants. To ensure repair would still be considered a valuable option (Van den Berge et al., 2021), the moment the defect occurred was defined between the mandatory warranty period and average use time (Wieser et al., 2015) (washing machine: 6 years; smartphone: 2 years and 2 months). We used the same brandless product pictures for the conventional and modular scenarios, cf. figure 13. The products were introduced as mid-range models with normal performance. For the modular conditions, the scenario textually explained the product consisted of several independent smaller parts (modules), which can be easily replaced or repaired when malfunctioning.

Figure 13. Pictorial stimuli of Study 1

Participants were recruited online via Prolific. All participants (n=155) were from the UK, above 25 years old (Mage=38.79, SD=11.22, Male=49.7%, Female=48.4%, Other=1.9%), and indicated to own a washing machine/ smartphone. All passed the attention check. They evaluated the scenarios on their general likeliness to repair ('How likely/inclined/ willing are you to have this product repaired?'; 1=strongly disagree; 7=strongly agree; α=.97 adapted from White et al., 2011) and perceived difficulty of the repair task ('Repairing the product described in the situation above ...is easy/hard; ...is easy/hard to complete; ...will take little/much time; α=.88; adapted from (Pocheptsova et al., 2010) on 7-point scales. We additionally included two single items to measure the likeliness for DIY and professional repair, 'How likely are you to repair this product yourself/have this product repaired by a professional repairer?' (1='not at all'; 7='very much'). Finally, the participants completed a manipulation check on the degree of modularity ('This product is made of modules that are easily replaceable', 'It is easy to replace malfunctioning parts in this product', 'through its design, this product supports the replacement or repair of malfunctioning parts' (1 = strongly disagree; 7 = strongly agree; α=.91).

5.3.2. RESULTS

We conducted bootstrapped (5000 samples) parametric tests as these are fairly robust when the assumption of normality is violated (e.g., Blanca et al., 2017). An independent sample t-test with product design as the independent variable and the degree of modularity as the dependent variable showed our manipulation was successful ($M_{conventional}$=3.88 vs. $M_{modular}$=6.36, t(153)=-12.58,p<.001).

We performed three two-way ANOVAs with product design and product category as independent variables and the three types of repair likeliness as dependent variables. For the general likeliness to repair participants were significantly more likely to repair the modular than the conventional product ($M_{conventional}$=4.15 vs. $M_{modular}$=5.35; F(1,151)= 17.86;p<.001), confirming H1. Furthermore, a marginally significant main effect suggested a higher general likeliness to repair washing machines than smartphones ($M_{washingmachine}$=5.02 vs. $M_{smartphone}$=4.48; F(1,151)=3.68;p=.06). No significant interaction effect was found.

Interestingly, the modular design did not significantly increase the likeliness for DIY repair. Instead, participants were more likely to professionally repair a modular product compared to a conventional one ($M_{conventional}$=4.54 vs. $M_{modular}$=5.59; F(1,151)=11.20; p<.001). More specifically, the marginally significant interaction effect between the product design and product category on likeliness to professional repair (F(1,151)=3.05; p=.08) suggests that a modular design is more influential in enhancing professional repair for smartphones. Even though the general likeliness to repair significantly increased for modular washing machines, the effect of modularity on professional repair likeliness was not significant. Nevertheless, the means are in the expected direction, cf. table 6.

Table 6. The means and standard deviations (SD) of the four conditions of Study 2

	Washing machine		**Smartphone**	
	Conventional (n=39)	*Modular (n=40)*	*Conventional (n=40)*	*Modular (n=36)*
Degree of modularity	3.90 (1.45)	6.37 (.84)	3.88 (1.42)	6.36 (1.12)
General likeliness to repair	4.52 (1.84)	5.53 (1.59)	3.78 (2.03)	5.18 (1.51)
Difficulty of the task	4.76 (.96)	3.63 (1.39)	4.00 (1.56)	2.90 (1.54)
DIY repair likeliness	1.95 (1.75)	2.28 (1.84)	2.40 (2.16)	2.81 (2.23)
Professional repair likeliness	4.97 (2.08)	5.48 (1.88)	4.10 (2.19)	5.69 (1.53)

Finally, we performed a mediation analysis to check whether the perceived difficulty of the task explains the effect of the modular design on the likeliness to repair. Using PROCESS model 4 (Hayes, 2013), the indirect effect showed significant results ($b=.28$; $BootSE=.11$; 95%CI:[.08,.05]). Specifically, modularity negatively influenced the perceived difficulty of the task ($b=-1.09$; $SE=.23$; 95%CI:[-1.54;-.64] $p<.001$), which in turn had a positive effect on the likeliness to repair ($b=-.26$; $SE=.10$; 95%CI:[-.45;-.06]; $p<.05$). Our results thus indicate a partial mediation, confirming H2.

5.3.3. DISCUSSION STUDY 1

The findings of study 1 showed that modularity increased the general likeliness to repair, which was explained by a decreased perceived difficulty of the repair task. However, a modular design only influenced the likeliness to consider professional repair. This is surprising as we often implicitly assume that modular designs would encourage DIY repair, as the replaceable modules would make repair easier to conduct and could also save expensive labor costs. Therefore, exploring what would increase the likeliness to DIY repair modular smartphones is interesting to explore further.

5.4 DESIGN CUES AND THE LIKELINESS TO DIY REPAIR MODULAR PRODUCTS

Even though modular products encourage repair, consumers do not feel sufficiently able to do such repairs themselves. Instead of consulting a professional repairer, designers may further support them to increase their perceived ability to conduct DIY repair. Research suggested that design interventions (i.e., affordances) can be useful to prompt consumers to adopt sustainable behavior (Bhamra et al., 2011; Ohnmacht et al., 2018). Affordances are defined as “action possibilities in the environment in relation to the action capabilities of the consumer” (Gibson, 1977). It prompts a specific use or interaction with the consumer, for example, a handle on a door invites you to open it.
Repair affordances thus represent the repair action possibilities in the relation between the consumer and a malfunctioning object. For example, for repair consumers generally need to open the product, diagnose the problem, relate this to the correct component, and replace this component with a new one. All are repair affordances, and if modular products do not sufficiently support consumers in these actions, DIY repair is unlikely to happen. To increase the ability for DIY repair, signifiers, which are physically perceivable cues, are needed to support the specific repair steps and can make them more easily processed (Norman, 2008).

Different types of cues can be designed to bring about repair affordances. For example, a cue on the outside that indicates where to open the product could make it easier to start the repair task, or a cue inside the product could make the to-be-repaired component easier to identify. Therefore, we hypothesized the following:

> *H3: Consumers are more likely to DIY repair a modular product when the design includes explicit repair cues*

5.5 STUDY 2: DESIGN CUES TO SUPPORT SMARTPHONE DIY REPAIR

5.5.1. METHOD

The experiment used a 2 (outside cue: present vs. absent) x 2 (inside cue: present vs. absent) between-subject design. We focused on smartphones because these are often replaced even with minor defects, and DIY repairs can cut repair costs. Additionally, some examples of modular/ repairable smartphones are available on the market (e.g., Fairphone, Nokia) making our insights relevant to practitioners.

5

In line with study 1, the smartphone was introduced as a mid-range model with normal performance. The time of ownership was 2 years and 2 months, and brand names were removed, cf. Figure 14. In all scenarios, the smartphone had a modular design with a failing battery. We included two types of cues. One was a notch (i.e., inlet) on the smartphone's exterior, which can be used to open the device. One was an icon on the inside indicating the smartphone's components (e.g., battery), which was shown on the website/(online) manual. Participants were recruited similarly to study 1. All owned a smartphone (n=158, M_{age}=41.37, SD=13.56, Male = 50%, Female = 50%, Other = 0%), and passed an attention check.

Similar to study 1, we measured the general likeliness to repair (α=.94) and the perceived difficulty of the repair task (α=.90). We measured the likeliness for DIY and professional repair on 3-item scales ('How likely/inclined/willing are you to repair this product yourself' α=.97/to have this product repaired by a professional repairer?'; 1='not at all'; 7='very much' α=.96). We checked our manipulations on 3-item scales (1=strongly disagree; 7=strongly agree) for the outside cue ('It is immediately evident/clearly indicated where this smartphone can be opened', 'I do not expect to have difficulties to open this smartphone'; α=.88) and the inside cue ('It is immediately evident/clear how different components could be identified inside this smartphone', 'I do not expect to have difficulties to identify different components'; α=.92).

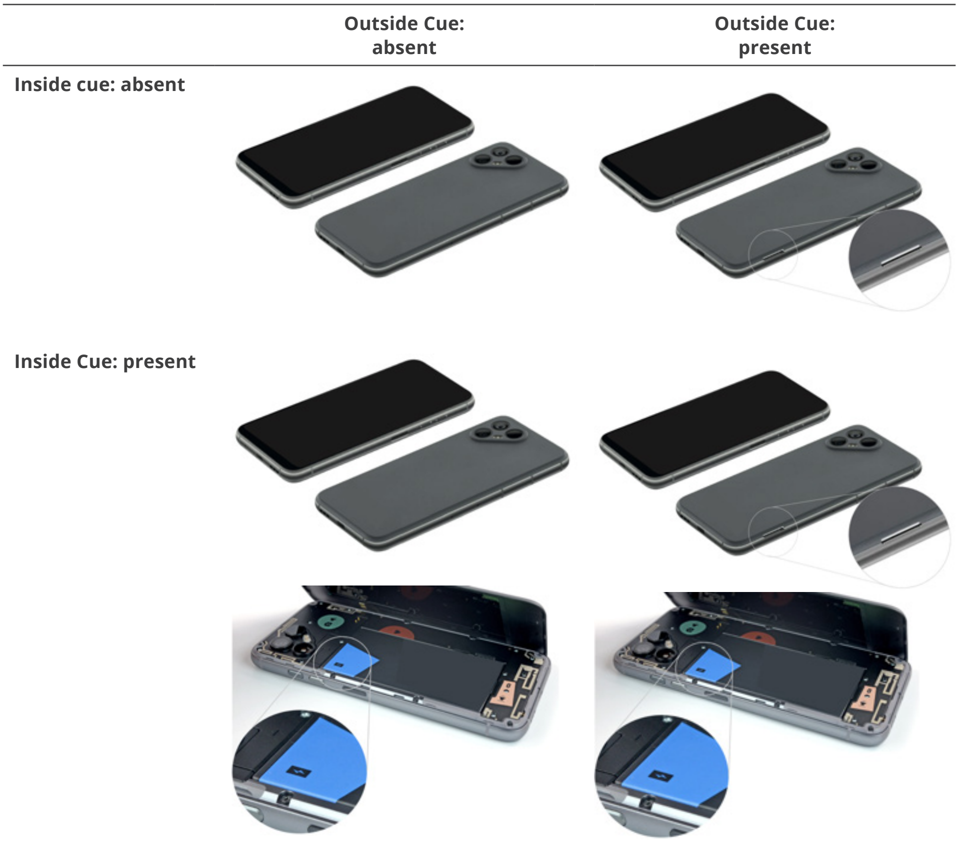

Figure 14. Pictorial stimuli of Study 2

5.5.2. RESULTS

We performed two bootstrapped independent t-tests with the cues as the independent variables and the accompanying manipulation check as the dependent variable. The results showed that both manipulations were successful (M_{no_OutCue}=4.31 vs. M_{OutCue}=6.21, t(156)=-9.17, p<.001; M_{No_InCue} =4.06 vs. M_{InCue}=5.50, t(156)=-6.34, p<.001).

We performed three two-way ANOVAs with the cues as independent variables and the three types of repair likeliness as dependent variables. In general, participants were more likely to repair the modular smartphone in the presence of an inside cue compared to when such a cue was absent (M_{No_InCue}=5.40 vs. M_{InCue} =5.99; F(1,154)=6.61; p<.05), which was not the case for the outside cue. The interaction was insignificant. The ANOVA with the likeliness for DIY repair as a dependent variable showed similar results and participants were thus more likely to perform DIY repair when an inside cue was provided (M_{No_InCue}=4.19 vs. M_{InCue}=5.13; F(1,154)=7.46; p<.01), which was not the case for the outside cue. The interaction was insignificant. The likeliness for professional repair did not significantly change by both cues, cf. table 7.

Table 7. The means and standard deviations (SD) of the four conditions of Study 2

	Outside cue: absent		Outside cue: present	
	Inside cue: absent (n=40)	*Inside cue: present (n=41)*	*Inside cue: absent (n=37)*	*Inside cue: present (n=40)*
Manipulation outside cue	3.61 (1.54)	4.99 (1.34)	6.20 (.85)	6.22 (.95)
Manipulation inside cue	3.72 (1.63)	5.64 (1.04)	4.42 (1.64)	5.35 (1.46)
General likeliness to repair	5.29 (1.70)	5.90 (1.20)	5.50 (1.58)	6.08 (1.29)
Difficulty of the task	2.59 (1.26)	2.46 (1.31)	2.38 (1.09)	2.38 (1.30)
Likeliness DIY repair	4.06 (2.23)	4.84 (2.18)	4.32 (2.28)	5.42 (1.91)
Likeliness Professional Repair	4.05 (1.83)	3.85 (1.99)	4.35 (2.03)	3.57 (1.86)

5.6 GENERAL DISCUSSION

Across two studies we confirmed the general potential of modular design to stimulate the repair (Mugge et al., 2005; Schischke et al., 2019) and demonstrated that a decreased perceived difficulty of the repair task explained the increased repair intentions of consumers. As high perceived difficulty of repair reduces it attractiveness (Pozo Arcos et al., 2021; Svensson et al., 2022), our results contribute to the literature by showing a modular design may overcome this repair barrier. This is positive for product lifetime extension as modular designs facilitate repairs, thereby increasing the lifetime expectations (Bocken et al., 2016; Den Hollander, 2018; Ülkü et al., 2012). However, in line with research showing that technically repairable products do not automatically lead to repair behavior (Makov and Fitzpatrick, 2021), our results revealed a purely modular design may not be enough to pursue DIY repair activities of smartphones.

In our exploration of the conditions in which consumers would consider DIY repair for modular design, we investigated if a design intervention (i.e., affordance) could prompt consumers to adopt such DIY repair behavior. Our results revealed that a design intervention in the shape of a cue on the outside of the product indicating where to open up the device (i.e., a signifier) did not succeed. For consumers to consider DIY repair, consumers need a modular design in combination with a repair cue on the inside of the smartphone that provides (pictorial) information to explicate the different components. Therefore, we could argue that to stimulate DIY repair, signifiers, which are physical perceivable cues (Norman, 2008) are not sufficient, and support during the execution of the repair task is needed. In sum, we can conclude that a modular design is, in general, an effective design strategy to stimulate the repair of smartphones. For stimulating DIY repair, cues inside the product design that facilitate the repair task should be considered.

5.6.1. PRACTICAL IMPLICATIONS

Understanding how consumers' repair behavior can be stimulated via modular product designs is important for design practitioners who aim to contribute to a more circular society. First, we highlight that even though modular designs are in principle physically repairable, designers should realize that for stimulating DIY repair, consumers need more support in the execution of the repair task. When aiming to provide support for DIY repair activities through design, a signifying cue on the outside of the device (e.g., an inlet) indicating how to open up the device may not be enough. Designers should consider implementing cues in the design that support beyond the first steps of the repair process, and facilitate during the repair process (i.e., via icons on the inside product components). When designing facilitating cues that support the consumers during the repair process, additional supportive information (e.g., pictures) may further stimulate repair actions. We therefore recommend designing a supportive service (e.g., an online page on the company's website) for the consumer to consult. This step can help in visualizing what is to be done during the execution of the repair, and make them realize they can do it. To do so, we recommend making an easily approachable troubleshoot page on companies' websites, in which the repair process is explained step-by-step and preferably pictures (or movies) of the different repair steps are included. In sum, when designing for repair, designers should be aware that consumers are quite motivated to adopt repair behavior. However, they do need support to behave accordingly as they lack the now-how. A simple intervention in the product design (e.g., an icon) may be just enough to prompt DIY repair behavior among consumers. To do so, it is important for designers to focus on decreasing the perceived difficulty of the repair process, as this explains a higher likeliness to repair modular products themselves. Consequently, this relatively simple intervention in the product design can prompt repair when encountering a broken smartphone. This is beneficial for the transition to a circular society in which repair is the default consumer choice.

5.6.2. LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

Several limitations that provide interesting avenues for future research should be highlighted. Firstly, although our study provides interesting insights into how to successfully implement modularity, our results do not exactly explain why the inside cue was more effective than the outside cue. Reflecting on our stimuli, participants could have experienced more support via the icon (i.e., inside cue), as it facilitated the repair act itself, compared to facilitating where to start the repair via the signifying notch (i.e., outside cue). Therefore, for a modular product, the opening may not be considered a big constraint, and the focus should be on cues that support the consumer during the repair act. Considering the inside cue, we must note that the visual information (i.e., a picture of the inside of the smartphone) provided with the inside cue in our study scenarios could also impacted our participants repair intentions. Reflecting on processing fluency theory, we could argue that this pictorial information provided with the inside cue scenarios may have supported in understanding the steps to be taken for completing the repair task (Schwarz et al., 2021). This may have helped to envision the repair steps and to reassure them that performing a repair is within their capabilities. To stimulate DIY repair of modular products, we, therefore, recommend future research to investigate if the increased repair intention was caused by the inside cue only (i.e., the icon) or was enhanced by/the result of the provided picture of the inside of the smartphone in the scenario.

A modular design supports the consumer during the process of repair task, however, there are more steps to be considered in the repair process in which the consumer may need more support, such as in the failure diagnostics stage. Results of Chapter 4 suggested that providing support in failure diagnostics could also be effective to encourage consumers to adopt repair behavior. Therefore, we recommend future research to also consider investigating support in the failure diagnosis stage of modular products when these fail. This can be done by implementing fault indications for frequently occurring failures of the specific product category and investigate their impact on consumer repair intentions and behaviors.

The controlled experimental scenario-based study setting allowed to isolate the effects of modularity and different cues that may afford repair intentions. However, we should mention that our results reflect the intended behavior of the participants because we did not measure actual behaviors in a real-life setting. While experiments are a proven method and a good predictor of actual behaviors, we recommend future research to replicate our findings in a real-life setting, thereby addressing potential intention-behavior gaps (Sheeran and Webb, 2016).

A modular design allows for easy repairs; however, it may also support the upgrading of certain product components. This is an interesting and relevant asset of modular product designs that can help to extend product lifetimes, especially for electronic products that are likely to become obsolete because they are sensitive to new developments and trends (e.g., smartphones, TVs). The possibility of upgrading a product during repair may make the repair act more interesting to consider because the functionality would not only be restored during repair but also improved. As this asset remains underexplored in this study, we recommend future research to further investigate if the possibility of upgrading a modular product during repair could further encourage consumers to pursue repair intentions.

Finally, the focus on smartphone repairs should not imply that our findings are limited to this specific product category. The repair of other electrical and electronic products may also benefit from modular designs. Therefore, we recommend future research to investigate if a modular design with facilitating cues can increase DIY repair of other product categories. For example, it would be interesting to investigate the impact of facilitating cues on a modular washing machine or TV on consumers' DIY repair intentions. By doing so, we recommend to also include facilitating cues that make sure the different steps of the repair process are clear to the consumer.

5.7 CONCLUSION

To stimulate people's intentions to repair their smartphones, designers should consider designing modular products. Design for modularity decreases the perceived difficulty of the repair task, which in turn increased consumers' general intention to repair. Also, while for conventional designs many consumers do not consider repairing their smartphones, DIY repair of modular products can make repair more attractive in terms of costs. When aiming to stimulate DIY repair, having the right support in repairing a failure of a modular product can support consumer's DIY repair intentions. By investigating different types of cues, our results are valuable knowledge for designers interested in applying modularity in their designs with the intention to stimulate (DIY) repair behavior.

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Encouraging smartphone repairs through reliability and upgradeability information

Beyond fault indications and modular designs, other interventions, such as marketing interventions, can encourage consumers to conduct repair and thereby extend their products' lifetimes. For example, by informing about the product lifetime, the consumer can be enabled to make better lifetime estimations and obtain more knowledge about, for example, repair possibilities (cf. Chapter 3).

To better inform consumers about the product lifetime, a product lifetime label can be used. Chapter 3 explored the potential response towards lifetime labels, and implied that consumers would consider lifetime labels if these contain relevant information. While design interventions mostly focus on increasing functional value, investigating a lifetime label could serve as an intervention to preserve the remaining mental book value and thereby stimulate product lifetime extension (cf. Chapter 2). Specifically, Chapter 6 focuses on whether a high reliability score and the possibility of upgrading defective components can enhance consumers' intention to repair. To do so, two experimental studies are setup to investigate the impact of the reliability score and the possibility of upgrading on the likelihood to repair a smartphone.

6.1 COMMUNICATING PRODUCT LIFETIME-RELATED INFORMATION

Designing long-lasting products, that are reliable, repairable, and upgradeable, contributes to product lifetime extension (Mestre and Cooper, 2017). However, transitioning from current linear consumption patterns to more circular behaviors, and consequently, lifetime extension presents challenges. Research shows consumers are unable to make a well-founded lifetime estimation because they lack the accurate information to do so. As a result, they do not actively consider product lifetimes (Van den Berge et al., 2023a). To prevent that consumers prematurely replace their products, the importance of product lifetime extension needs to become more prominent in replacement and repair decision-making. To do so, consumers need to be supported in making better judgments about the product's lifetime.

To communicate environmental product information, studies on (eco)labels showed a positive effect on environmentally conscious behavior and willingness to pay (Atkinson and Rosenthal, 2014; Boyer et al., 2020; Rahbar and Wahid, 2011). Recently, lifetime labels have been introduced as a potential policy instrument to influence product lifetimes. While studies showed that lifetime labels can positively influence purchase decision-making, there is not yet a universally agreed standard for assessing product lifetimes (European Economic and Social Committee (EESC), 2016; Milios and Dalhammar, 2023). Studies did show that displaying the number of years of expected lifetime can have a positive influence on purchase intentions and make the brand and energy consumption less influential (Jacobs and Hörisch, 2021). However, displaying a specific number of years may also lead to higher replacement tendencies when these years are exceeded, even though the product is still functioning well (Van den Berge et al., 2023a). To avoid this potential rebound effect, including information beyond the product's expected lifetime in years, for example, by informing them about repairability, reliability, and upgradeability (e.g., via a score or rating) may be a solution (Dalhammar and Richter, 2017).

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Assessing the repairability of products plays a vital role in conveying information about product lifetimes (Tecchio et al., 2016). A product designed for easy repairability allows for straightforward part replacement, includes fault indicators for diagnosis, and ensures the availability of spare parts (e.g., Wilhelm, 2012). Various initiatives, like iFixit (www.ifixit.com), have devised scoring systems to assess the repairability of products on the market. Furthermore, France has introduced repairability labels to support consumers at purchase with information on repair options for several product categories, such as smartphones, and Belgium is planning to introduce it soon too (Dalhammar et al., 2022). This approach aims to enhance consumer awareness of the product repairability during their consumption choices. However, studies have shown that merely providing repairability information does not necessarily translate into increased consumer interest in repair (Makov and Fitzpatrick, 2021). Promoting repairability to consumers may even raise their concerns regarding potential breakdowns and frequent repairs, which are linked to costs and inconvenience (Van den Berge et al., 2023a). Consequently, delivering solely information about repairability on a lifetime label may not be enough to convince consumers to have these products repaired.

Research also pointed to the importance of addressing reliability when informing about product lifetimes (Bovea, Ibáñez-Forés, Pérez-Belis, and Juan, 2018; Cordella et al., 2019; Milios and Dalhammar, 2023; Tecchio et al., 2016), as reliability is related to products' perceived quality and expected performance (Sweeney and Souter, 2001). To assess the product reliability, the product should be rated on its quality and robustness (G. J. Park et al., 2006; Nicole van Nes and Cramer, 2003). For electronic products, the reliability can be tested through lifecycle tests conducted in testing laboratories (Tucci et al., 2014), such as accelerated battery testing, or drop tests for smartphones. Research showed that high expectations about the product lifetime are positively related to expected reliability, which may result in longer actual product lifetimes (cf., Chapter 3) This implies that high reliability expectations may result in product lifetime extension. Lifetime labels can provide more certainty about product reliability to the consumer (Bovea, Ibáñez-Forés, Pérez-Belis, and Juan, 2018; Gnanapragasam et al., 2018; Milios and Dalhammar, 2023). When the reliability of a product is high, the mental book value will be sustained for a longer period of time. As a result, the consideration of repair as a viable option may also persist for an extended period of time. However, while the influence of lifetime expectations on initial purchase decisions has been studied (European Economic and Social Committee (EESC), 2016; Jacobs and Hörisch, 2021), it remains unclear whether high perceived reliability could affect repair intentions during a product's lifetime.

Besides the importance of displaying information about future reliability on lifetime labels, the urge for the latest and newest technology also plays a crucial role in determining the desirability of a repair action, especially for products such as smartphones (Jaeger-Erben et al., 2021; Svensson et al., 2022). To ensure that products fit consumers evolving needs over time, research indicated the importance of future-proof products, that allow for upgrades (Van Nes and Cramer, 2005). Upgradeable products are designed to evolve and allow to stay up to date with new developments (Haines-Gadd et al., 2018). An example is the brand Fairphone that provides camera upgrades for their existing smartphones. Incorporating information about the product upgradeability has a positive impact on product expected lifetime and willingness to pay (Cordella et al., 2019; Dalhammar and Richter, 2017; Michaud et al., 2017). However, whether information about upgradeability on lifetime labels could also influence repair decision-making remains unclear.

This chapter seeks to examine whether a high reliability score and the possibility of upgrading defective components can enhance consumers' intention to repair. Specifically, we conducted two experimental studies to investigate the impact of the reliability score and the possibility of upgrading on the likelihood to repair a smartphone. By exploring repair intentions, we aim to contribute to the literature on lifetime labels by demonstrating a positive influence of reliability scoring and upgradeability information on product lifetime extension, beyond increased preferences at purchase.

6.2 RELIABILITY INFORMATION

To inform consumers about reliability-related information of electronic products via a lifetime label, a scoring system can be used. Currently, the European Commission is working on scoring systems, for example through pass/fail criteria that products must fulfill (Cordella et al., 2019). A higher reliability score would imply well-evaluated robustness and quality compared to similar types of products, which are generally preferred by consumers during purchase decision-making (Cox et al., 2013). However, a decision to repair a broken product typically occurs later in its life, possibly after several years. At this moment in time, it is likely the product's mental book value depreciated (Van den Berge et al., 2021). Earlier studies showed that when the performance and quality of a product are perceived as high, its value will remain for a longer amount of time (e.g., Sarigöllü et al., 2021). For example, a reliable product is typically designed for long-lasting lifetimes, and therefore, product quality is important for consumers' product satisfaction (Agustin and Singh, 2005; Van Nes, 2010). High perceived value resulting from high perceived quality is thus expected to be beneficial for consumers' value trade-off during the repair decision-making because it provides better competition to a replacement alternative (Van den Berge et al., 2021). Therefore, a higher reliability score may lead to an increased likeliness to repair the product in comparison to when a product has a lower reliability score. We expect that when reliability scores increase, the likeliness to repair will increase in a linear way across the scores. Accordingly, we hypothesize:

H1: Increasing reliability scores on a lifetime label will result in a linear increase in the likeliness to repair consumer electronics

6.3 STUDY 1: THE EFFECT OF A RELIABILITY SCORE ON SMARTPHONE REPAIR INTENTIONS

6.3.1. METHOD

Study design and stimuli

To investigate H1, study 1 compared 5 reliability scores (1/5 vs. 2/5 vs. 3/5 vs. 4/5 vs. 5/5) and a control condition in a scenario-based between-subject experimental study design. The scenario included a smartphone in need of repair. We chose a smartphone as a stimulus because this is a commonly owned electronic product that has become an essential object in people's daily lives. Also, the impact of the production of smartphones is relatively high compared to the resources that are needed for the usage phase (e.g., energy consumption) (Clément et al., 2020). Nevertheless, 57% of smartphones were replaced when partially malfunctioning, of which 70% did not consider a repair (Magnier and Mugge, 2022). Therefore, extending smartphones lifetime via repair can significantly reduce the demand for resources and materials required for the production of new ones, making it relevant for further investigation.

Each scenario consisted of a picture of an existing smartphone with a prototypical appearance. The brand name and logo were removed to diminish the influence of personal preferences and associations. A short explanatory text described that the smartphone was from a well-known brand with a normal performance compared to similar smartphones and had an initial purchase price of 500 euros. This price estimation was based on the average of mid to high-end smartphones in Europe (Cordella et al., 2020). As consumers' willingness to pay for repairs decreases over time, the time of ownership plays an important role when considering a repair (Makov and Fitzpatrick, 2021; Van den Berge et al., 2021). To make sure repair could still be considered valuable, we selected a time of ownership of 2 years and 2 months, which is within the range of the actual lives of smartphones (i.e., 1.8 – 3.6 years (Frick et al., 2021; Jaeger-Erben et al., 2021; Magnier and Mugge, 2022; Nasiri and Shokouhyar, 2021; Wieser et al., 2015; Wilson et al., 2017). For the failure type, we chose a cracked touch screen, as this is one of the most commonly occurring smartphone failures (Raihanian Mashhadi et al., 2016; Wieser and Tröger, 2018)

For the reliability score, we chose to use a numeric scoring ranging from 1 (lowest) to 5 (highest), because an alphabetic scoring (i.e., A-G may) may cause confusion with Energy Efficiency Label (European Economic and Social Committee (EESC), 2016). Color codes tend to improve salience on labels (Talati et al., 2019) and are therefore added to our visuals. A text explained the reliability score informed about the robustness of the product, and the ability to retain its original quality over time compared to other smartphones. To avoid the risk of being perceived as unreliable, the score was indicated to be determined by an independent and trustworthy institution (Van den Berge et al., 2023a). We included an offer of a professional repair service in the scenario. Professional repairs are often considered for smartphone repair, and the outcomes are relatively successful compared to self-repairs (Laitala et al., 2021). Also, desk research showed that screen repairs are commonly offered by professional (independent) repair services.

6.3.2. PRE-TEST

To discover what would be an acceptable repair service offer for the participants, we conducted a pretest. To describe a realistic repair service for the participants, we first performed online desk research to compare and select several commonly attributes people take into consideration when choosing repair:

- The speed; the time it takes to have the product repaired
- The distance; the time it takes to travel to the repairer.
- The costs; the price the consumer pays to have the product repaired
- The warranty; the period in which the repairer guarantees that an occurring defect of the repaired part will be resolved.

We included multiple attribute levels ranging from the lower end (e.g., no warranty provided after a repair) to the higher end (e.g., 12 months warranty offered after a repair) in the pretest. We presented 84 Western-European participants (Gender: Male=41, Female=39, Oher=3, Prefer not to say=1; Age:18-72 years, M=38.32, SD=12.62) the scenario of a smartphone with a broken screen, and evaluated the acceptability of the defined attribute levels using a 4-point scale (1=preferred; 2=acceptable; 3=undesirable; 4=unacceptable). The results showed that a repair within 24 hours, reachable within 20 minutes of traveling time, and a warranty of 6 months would be acceptable for consumers. For the repair costs, the means of the acceptability of the price of 50 (M=1.15) euros and 100 euros (M=2.30) were quite far apart. To make sure not to offer a price that is either perceived as very attractive or undesirable, we decided to use 75 euros as a repair price (cf. Appendix D for the attribute levels and pre-test outcomes).

Procedure and Measures

In study 1, participants were asked to imagine the scenario of a broken smartphone using the acceptable attribute levels for repair services of the pre-test, cf. Appendix D. We first measured participants' likeliness to repair the smartphone with the presented repair service (adapted from White et al., 2011) using 3 items. To check if the manipulation of the reliability label score increased consumers' perceptions of the smartphone's value and reliability, we used the four Quality items of the PERVAL scale (adapted from Sweeney and Souter, 2001). Lastly, we measured participants' environmental concern on six items to control for their influence on the likeliness to repair (Kilbourne and Pickett, 2008). All items were measured on 7-point scales, cf. Appendix E.
The participants were recruited via Prolific, which is an online platform to recruit

participants (www.prolific.co). In total, 264 Western European participants (Age: $M=32.65$, $SD= 9.89$; Gender: Male=48.8%, Female=48.8%, Other=2.8%) completed the online survey created using Qualtrics software (www.qualtrics.com). A timer ensured the participants should take at least 30 seconds to read the scenario. Fourteen participants were excluded from the sample, because they failed the attention check, did not finish the survey, or completed the questionnaire below the threshold of three minutes. This resulted in a final sample of 250 participants.

6.3.3. RESULTS

Manipulation Check

We first performed a one-way ANOVA to check if our manipulation was successful. We including the control condition also showed a significant main effect ($F(5,244)=23.89$; $p<.001$). Tukey's post hoc test showed for the control condition, the perceived quality was significantly higher compared to the lowest scores (1/5 and 2/5) ($p<0.001$), but not for the other scores ($p>0.5$). This implies that only low reliability scores affect the perceived quality, and no significant differences were found between higher scores and not showing a score. In addition, to check the effect if a reliability would be enforced on all products, we performed a one-way ANOVA in which we used the 5 reliability score conditions as the independent variable (IV), the mean value of the PERVAL's Quality items as the dependent variable (DV). We included a Polynomial Contrast analysis to check for a linear effect. The results showed that for the reliability scores participants' perception of the product's perceived quality was significantly linearly ($p<0.001$) increasing between the scores ($F(4,204)=27.87$; $p<.001$), cf. table 8 for the means, and thus the manipulation was successful.

The linear effect of the reliability score on the likeliness to repair

A one-way ANOVA including the control condition showed a significant main effect ($F(5,244)=2.41$; $p<.05$), cf. table 8, Tukey's post hoc test showed for the control condition, the likeliness to repair was significantly higher compared to the lowest scores (1/5; $p<0.001$). Also, the likeliness to repair a smartphone with the lowest scores (1/5) was significantly lower compared to the higher scores (4/5; $p<0.01$ and 5/5;$p<0.01$), but not compared to the 2/5 and 3/5 scores. In addition, a one-way ANCOVA was performed with the 5 reliability scores (IV), likeliness to repair with the repair service (DV). We included a Polynomial Contrast analysis to check for a linear effect. The covariate environmental concern was marginally significant ($F(1,203)=3.54$, $p=.06$). The results demonstrated that with increasing reliability scores, the likeliness to repair the smartphone also significantly increased ($F(4,203)=2.46$; $p<.05$). The contrast analysis showed that across the conditions the increased effect was linear ($p<.005$), supporting H1. Finally, we should note the participants of the control group were relatively likely to repair the smartphone ($M=5.45$), cf. Figure 15.

Table 8. The means and standard deviations (SD) of the six conditions of study 1; significant Posthoc test results in superscript

Conditions	Reliability score					
	No score (n=41)	*1/5 (n=40)*	*2/5 (n=42)*	*3/5 (n=42)*	*4/5 (n=44)*	*5/5 (n=41)*
Variables						
Perceived quality (α=.91)	4.84[a]	3.19[b]	3.42[b]	4.65	5.24[a]	5.07[a]
	(1.12)	(1.38)	(1.37)	(0.96)	(0.89)	(1.17)
Likeliness to repair (α=.95)	5.45[a]	4.49[b]	4.83	5.12	5.36[a]	5.40[a]
	(1.55)	(1.90)	(1.37)	(1.27)	(1.51)	(1.74)
Environmental concern (α=.91)	5.76	5.56	5.82	5.77	5.58	5.63
	(1.05)	(1.18)	(1.11)	(.96)	(1.17)	(1.30)

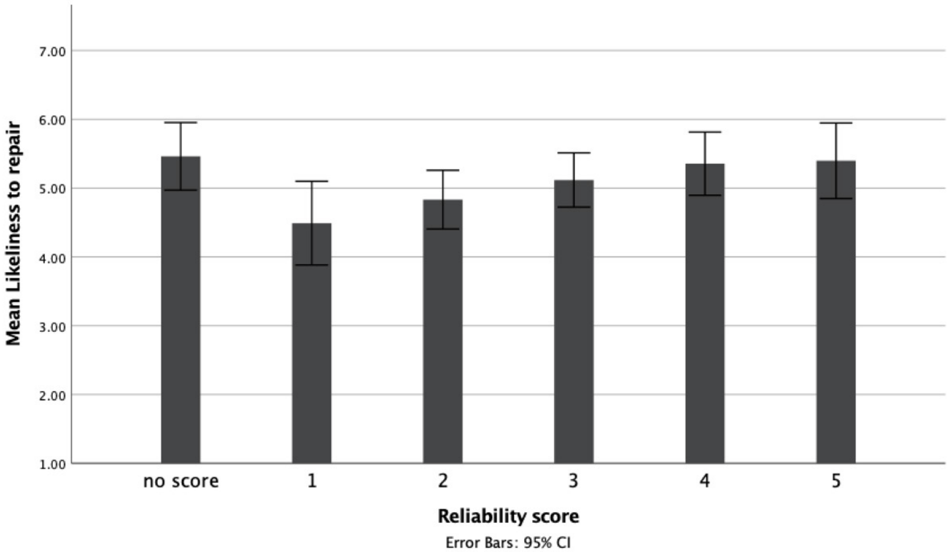

Figure 15. The linear increase of likeliness to repair for the different reliability scores and control condition

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6.3.4. DISCUSSION STUDY 1

Our results show a positive, linear effect of increasing reliability scores on repair intentions. Through considering repair intentions, these results go beyond earlier findings of the effects of lifetime labels during purchase (Jacobs and Hörisch, 2021). Nevertheless, we must note that when no score was provided, the likeliness to repair a smartphone was relatively high, which a high score did not significantly further increased. The results imply that low scores may, in fact, reduce repair intentions, as our participants were significantly less likely to repair smartphones without or with a high-reliability score. To explain this, we reflected on our used repair costs in the scenario, as repair costs have a large impact on consumers' decision-making (e.g., Sabbaghi and Behdad, 2018). The relatively high purchase price (500 euros) in comparison to the repair price (75 euros) may have been considered as not worthwhile for the lowest score, but in fact may have prevailed in deciding whether or not to repair when no score was provided. Reflecting on our scenario, the high likeliness to repair in the control condition could have been the result of a relatively well-evaluated trade-off made between the purchase price and the repair price. Therefore, it is worthwhile to further explore the boundaries of repair pricing.

6.4 UPGRADEABILITY INFORMATION

Study 1 showed that when the reliability score of a product is high, a repair is more likely to be considered. However, the choice to repair or replace a product comprises rationalities about the product's utility, but also what people desire (Höijer et al., 2006; Van den Berge et al., 2021; Van Lange et al., 2013). With the repair, the smartphone's screen, and thus initial functionality would be restored. However, smartphones are sensitive to trends and new developments (Cox et al., 2013; Van den Berge et al., 2021) and the desire for new features is a common reason to replace (and not repair) a smartphone (Magnier and Mugge, 2022).

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To stimulate repair, perceived novelty of the repair outcome might also determine the desirability of the repair act (Jaeger-Erben et al., 2021; Svensson et al., 2022). Therefore, while the perceived quality of the reliability score sustained the mental book value of the smartphone, it may still decrease after ownership of several years or months through feelings of satiation and repeated usage (Van den Berge et al., 2021). A consumer may be more likely to repair a highly reliable product, however, such a repair does not address the need for new or improved product features they may have developed over the time of ownership. The fact that this need can be fulfilled by replacing it with a new product, may be a barrier for consumers to repair it (Magnier and Mugge, 2022). For example, the products functionality was perceived as fine before the failure, but in the meantime, technology has evolved and desires for improved functionalities may have arisen accordingly. A high reliability score may thus increase repair intentions; however, repairing such a product does not necessarily fulfil needs for improved product features, which may still result in decision to replace it with a new product.

Research suggested to include upgradeability-related information on a lifetime label and showed a positive effect on purchase decisions (Cordella et al., 2021; Haines-Gadd et al., 2018; Michaud et al., 2017). An upgradeable design allows to stay up to date with new trends and developments and allows to extend its useful lifetime (Khan et al., 2018). When a product fails, an upgradeable product provides an opportunity to replace the broken component with one that providing new features (Michaud et al., 2017). Upgradeability thus proposes an attractive benefit for the repair if the initial performance of the replaced product component will be improved. Therefore, it is likely that upgradeability information provided on a label will also increase repair intentions, as the expected improved performance provided may restore the mental book value of products that have been in possession for a while. Following this reasoning, it is worthwhile to explore if the possibility of upgrading the product during a repair (i.e., through a component with improved performance) could further increase the repair likeliness. We therefore hypothesized the following:

> *H2: The possibility of upgrading a product component will result in a higher likeliness to repair consumer electronics*

6.5 STUDY 2: THE IMPACT OF UPGRADEABILITY ON SMARTPHONE REPAIR

6.5.1. METHOD

Study design and materials

The set-up consisted of a 3 (reliability score: absent vs. low vs. high) x 2 (smartphone: conventional vs. upgradeable) scenarios-based between-subject experimental design, cf. Appendix E. To compare the effects of low and high-reliability score information, we chose to only use the 2/5 and 5/5 conditions. To explore the effects of upgradeability information, we presented the smartphone as either conventional or upgradeable. Visual and textual representation of the six scenarios were in line with study 1. For the upgradeable smartphone, a visual was added and a text explained that the faulty component could be upgraded with one of improved quality during the repair. We selected a broken camera as a failure because like a broken screen, poor camera quality is a common reason to replace smartphones (Proske and Jaeger-Erben, 2019). Therefore, upgrading a broken camera during repair can address the need for new and improved features. Also, desk research confirmed camera repairs are commonly offered by professional (independent) repair services. To investigate the impact of a higher repair price, we used a repair price of 125 euros.

Procedure and Measures

Following the same procedure as study 1, we measured participants' likeliness to repair and participants' environmental concern. To check the manipulations, again the PERVAL scale and two items addressing the upgradeability were included, cf. table 9. In total, 258 Western-European participants were recruited via Prolific and completed the online Qualtrics survey (Age: M=33.66, SD=9.60; Gender: Male=49.6%, Female=47.6%, Other=2.4%, Prefer not to say=.4%). Eight participants who completed the questionnaire below the threshold or failed the attention check were excluded from the sample, resulting in a total sample of 250 participants.

6.5.2. RESULTS

Manipulation check

We first performed a one-way ANOVA with the reliability score (IV) and the perceived quality (DV). The results and Tukey post hoc test showed significant differences in participants' perception of the product's quality between the three conditions ($M_{noscore}$=4.78; $M_{2/5}$=3.47; $M_{5/5}$=5.57; F(2,244)=81.60; p<.001). Second, we performed an independent sample t-test with the product design (IV) and perceived upgradeability (DV). The results showed a significant difference in participants' perception of the products' upgradeability between the conventional and upgradeable product design ($M_{conventional}$=3.24; $M_{upgradeable}$=6.35 t(248)=-17.55; p<.001). Both our manipulations were thus successful.

Likeliness to repair

Next, we performed a two-way ANCOVA including the reliability score, upgradeability (IVs), and likeliness to repair (DV). The covariate environmental concern was significant (F(1,243)=15.22, p<.001). The results showed a significant main effect for the reliability score ($M_{noscore}$=4.62; $M_{2/5}$=4.29; $M_{5/5}$=5.24; F(2,243)=9.41; p<.001). The pairwise comparison revealed only significant differences between the conditions with no or a low score (2/5) compared to the high score (5/5). There was no significant difference between no score and a low score (2/5). This means that when a reliability score is high, a repair is more likely to be considered compared to products without a score or with a low reliability score. Furthermore, an upgradeable design was more likely to be repaired compared to a conventional design ($M_{conventional}$=4.50; $M_{upgradeable}$=4.93; F(1,243)=5.69; p<.02). There was no significant interaction effect. These findings confirm H1 and H2, cf. Table 9 and Figure 16.

6.5.3. DISCUSSION STUDY 2

While information about product reliability can enhance repair intentions, the desire for new features may still refrain consumers from repairing the product (Jaeger-Erben et al., 2021; Svensson et al., 2022). Our study confirms the findings of study 1 showing that high-reliability scores can increase consumers' likeliness to repair. In addition, in study 2 we showed that for higher repair prices, not showing a score resulted in a significant lower likeliness to repair compared to a high-reliability score. Furthermore, we showed that during repair decision-making consumers were more also likely to repair smartphones when upgradeability information was provided. Therefore, we argue that next to adding reliability scores to lifetime labels, upgradeability information can further encourage consumers to extend the lifetime of their electronic products.

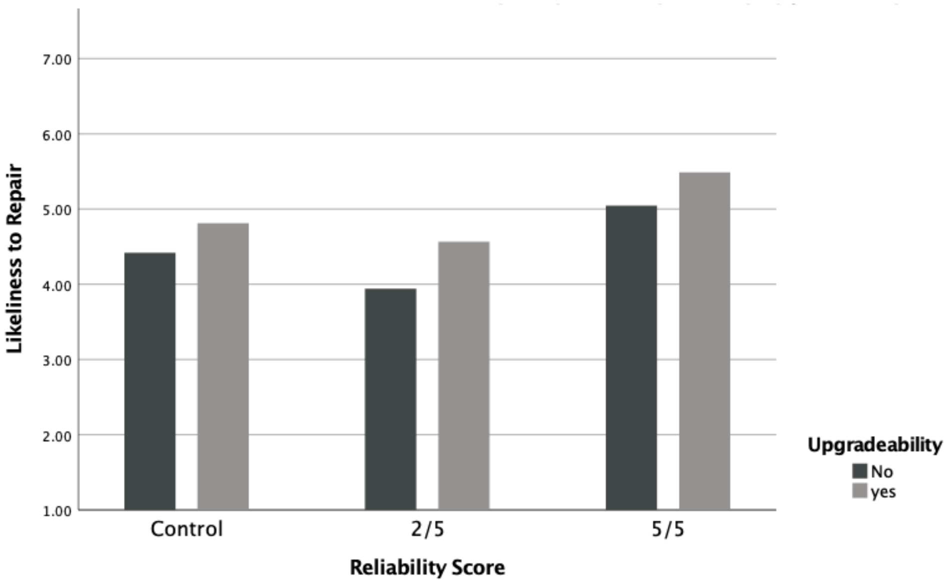

Figure 16. The likeliness to repair a smartphone for different reliability scores and upgradeability of the designs

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Table 9. The means and standard deviations (SD) of the six conditions of study 2

	Conventional			**Upgradeable**		
Conditions	*No score (n=42)*	*2/5 (n=41)*	*5/5 (n=43)*	*No score (n=41)*	*2/5 (n=40)*	*5/5 (n=43)*
Variables						
Perceived quality (α=.90)	4.77	3.44	5.37	4.79	3.51	5.77
	(0.90)	(1.13)	(1.16)	(0.98)	(1.25)	(0.96)
Upgradeability (r=.91)	3.19	2.96	3.55	6.21	6.14	6.67
	(1.56)	(1.39)	(1.94)	(1.16)	(1.33)	(0.54)
Likeliness to Repair (α=.96)	4.42	3.94	5.05	4.81	4.57	5.49
	(1.49)	(1.52)	(1.47)	(1.53)	(1.45)	(1.37)
Environmental concern (α=.91)	5.71	5.39	5.33	5.42	5.52	5.98
	(.97)	(.98)	(1.33)	(1.26)	(1.15)	(.78)

6.6 GENERAL DISCUSSION

To extend product lifetimes, earlier studies indicated the potential of including reliability and upgradeability information in a lifetime label (Bovea, Ibáñez-Forés, Pérez-Belis, Juan, et al., 2018; Cordella et al., 2019; Dalhammar and Richter, 2017). However, their impact on repair intentions remains unclear. The fact that consumers are quite willing to repair, but often not consider repair as a (default) option, is promising. Our findings go beyond research investigating the positive impact of lifetime label information during purchase decision-making (Jacobs and Hörisch, 2021; Michaud et al., 2017) by showing that such labels can also stimulate repair at later lifetime stages. We provided empirical evidence that lifetime-related information can encourage consumers to repair and, consequently, extend the lifetime of their products. In sum, our research expands the previous literature on lifetime labels by showing the potential to include reliability and upgradeability information on these labels beyond purchase decision-making. This implies that a label can act as a reminder of the reliability of the product, as well as the notion it is upgradeable. Bringing the products' expected reliability and upgradeability on top of mind may appeal consumers' existing repair motivations. It can make the option to repair a more attractive possibility to consider when a product breaks down, especially when this happens early in its lifetime. This enables consumers to consider repair as a serious solution for their broken product, which is beneficial for a circular society in which repair is the norm.

6.7.1. PRACTICAL IMPLICATIONS

Understanding how products' reliability and upgradeability information can stimulate and encourage repair is of interest to both policymakers and practice. Firstly, our findings provide further support for the introduction of a lifetime label aside or within the Energy Labelling Framework Regulation of the EU (Milios and Dalhammar, 2023). The EU H2020 PROMPT project already made a first start by investigating criteria for assessment of the product lifetime that include reliability and upgradeability aspects (www.promptproject.eu). Our findings support the importance of including these aspects on lifetime labels by showing its positive impact on repair intentions. Therefore, we recommend policymakers to implement reliability and upgradeability scoring systems, as an extension to existing repairability indexes, for the assessments needed for a product lifetime label.

Introducing such a label can stimulate manufacturers to focus on developing reliable and upgradeable products to ensure a high rank on the label, as well as encourage consumers to consider the product's lifetime in their repair decisions. As a result, we recommend policymakers to make a lifetime label mandatory on all products within a certain category. In this way, consumers can make a fair comparison between products at purchase. Furthermore, when this lifetime information is conveyed via a label, it is important to consider that most failures will happen in the future, perhaps even several years after purchase. Therefore, it is crucial that this information remains visible, noticeable, and traceable for electronic products, for example via a label that is incorporated in the design, or that is directly attached to the product (e.g. using a (subtle) sticker). This label should directly represent or enable the consumer to access more details about the lifetime information (e.g., via QR code). Next to that, to get broad support for repairs and create a competitive repair market, it is important that independent repairers are enabled to upgrade products during repairs. Therefore, we encourage legislation to focus on ensuring access to the appropriate knowledge about upgradeability practices, as well as the availability of (upgraded) components.

Considering the reliability and upgradeability aspects become increasingly important for product design, as the introduction of lifetime labels is currently under development, (Milios and Dalhammar, 2023). Our insights are encouraging for manufacturers and product/service designers who already focus on designing reliable and upgradeable products. For those manufacturers that are not yet advanced in incorporating reliability and upgradeability, we emphasize that designs that encourage lifetime extension becomes increasingly important and acknowledged among society (e.g., Right to Repair movement). This means, that offering highly reliable and upgradeable products is not only beneficial for our environment but may also be necessary to combat the competitive market of consumer electronics. To achieve this, manufacturers should concentrate their focus on designing reliable (e.g., by using durable materials, allowing for easy maintenance) and future proof products (e.g., allowing for and the offering of successive replacement components)

6.7.2. LIMITATIONS AND FUTURE RESEARCH IMPLICATIONS

Several limitations of our study may offer opportunities for future research. First our results showed that for a higher repair price, the impact of a high score on a reliability label was more significant compared to showing no score in the control condition. A possible explanation for this result may be that a higher repair price influenced the repair decision. However, we also must note that the investment of the smartphone in both studies is relatively high. The purchase price of the high-end smartphone may thus also influence the decision to repair because it is easier to be considered worthwhile (Brusselaers et al., 2019). Therefore, we encourage future researchers investigating the impact of reliability and upgradeability information to also consider more low-investment products in their studies.

Second, as we aimed to focus on reliability and upgradeability information to address the research gap on its effect on repair intentions, we decided not to include repairability information in the label. However, we do not believe information about the repairability should be excluded from a lifetime label, as the requirement to provide this information already encourage manufacturers to make their products more repairable (i.e., French repair index)(Dalhammar et al., 2022). Therefore, we encourage future research to also include this information in the future studies related to lifetime label information and its impact on repair intentions.

Furthermore, we must address that for the upgradeability information we decided to not provide a score, because unlike reliability it is more of a matter of fact whether it is possible or not. However, we do realize that design for upgradeability there can be different indicators of how easy this is to do. As our results show promising results regarding upgradeability, we recommend future studies to also study the impact of upgradeability scores on repair intentions. Future research should also consider how to communicate this information, at purchase, but also later in the product lifetime as this is a more likely scenario a failure will occur. We encourage to look further into Digital Product Passports (DPP), which is a unique product identifier linked to a database with information related to the products, ownership and access rights (Dalhammar et al., 2022). A DDP enables to share product related information essential for sustainability and circularity and can support consumer in making sustainable choices, and therefore may be interesting to link or combine with product lifetime labels.

Additionally, we chose to investigate frequently occurring failure types. By investigating an alternative failure, study 2 could generalize the findings of study 1. However, a product can also fail for other reasons than due to a drop on the floor and may not always be directly caused by the consumer. Other frequently occurring failures, such as a failing microphone or battery, may lower the perception of reliability when these fail. Therefore, to further generalize findings, future research could consider investigating whether other (frequently occurring) failures, not directly caused by the consumer itself, would display similar results.

Lastly, it is important to mention that our results reflect the intended behavior of the participants. While our results on repair intentions are promising, we should highlight that we did not measure actual behavior. Our study was conducted in an controlled setting and participants were asked to imagine the situation rather than being in an actual real-life setting, so we have to consider a potential intention-behavior gap (Sheeran and Webb, 2016) . Nevertheless, our results on repair intentions are promising, and we suggest that future studies could focus on studying repair activities of reliable and upgradeable electronic products in real-life settings.

6.7 CONCLUSION

To stimulate repair, designers should also consider the product's general reliability and upgradeability. High-reliability scores may result in sustained mental book value and thus make a repair a more valuable option to consider. Furthermore, the possibility to upgrade a product offers an additional benefit for product repairs because in the repair outcome, its functionality is not only recovered but improved. Providing reliability and upgradeability information encourages consumer repair behaviors, which is valuable knowledge for industries and policymakers that aim to extend lifetimes of electronic products.

EXHIBITING MY WORK AT DUTCH DESIGN WEEK 2022 (RE)VALUED - COLLABORATION WITH ACCENTURE

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Discussion and Conclusions

This thesis explored how design can encourage consumers to prolong the lifetimes of electronic products via repair. We started in Chapter 1 by addressing the research rationale and providing insight into the topic based on prior research from the literature. The remainder of the thesis was divided into two parts, addressing the sub-research questions formulated in Chapter 1. In the first part, Chapters 2 and 3 explore the process of product replacement from a consumer perspective. This resulted in a framework explaining consumers' replacement process and provided in-depth insight into consumers' considerations about product lifetimes and barriers to lifetime extension. In addition, we highlighted several design and marketing strategies from the literature that may stimulate product lifetime extension. In the second part, the focus was on testing design and marketing interventions that could reduce the barriers that consumers experience concerning repair. Through empirical studies, their effects on consumers' intentions to extend product lifetimes via repair were explored. Specifically, in Chapters 4 and 5 we investigated design interventions (i.e., fault indications and modular design) that may stimulate consumers to repair their products. In Chapter 6, we investigated whether lifetime label information related to reliability and upgradeability can encourage repair intentions.

This chapter presents the main findings and theoretical contributions of this thesis. Furthermore, it discusses implications for design and policymakers and several limitations that provide potential future research directions. It ends with a general reflection on product lifetime extension within a circular economy.

7.1 MAIN FINDINGS AND RESEARCH CONTRIBUTIONS

The way we, human society, produce and consume electronic products exceeds the limits of what our planet can handle. To create a society in which circular consumption becomes the norm, changes in current consumers' consumption patterns with electronic products are required (Cooper, 2004; Makov and Fitzpatrick, 2021). In this thesis, product lifetime extension is addressed, as preserving the value of electrical and electronic products can significantly reduce the environmental impact of our consumption (Ellen MacArthur, 2013; Geissdoerfer et al., 2017; Kirchherr et al., 2017). Specifically, this thesis explores how design can encourage consumers to pursue product lifetime extension by adopting repair activities in their behaviors.

The main findings of the different chapters all contribute to the literature on product lifetime extension and repair in specific ways. The sub-research questions, formulated in Chapter 1, provide answers to the main research question: "*How can design encourage consumers to prolong the lifetimes of electronic products via repair?*". The following section discusses the main findings and literature contributions and answers the three sub-research questions (cf. Chapter 1).

7.2 WHY DO CONSUMERS DECIDE TO REPLACE PRODUCTS PREMATURELY?

To investigate why consumers decide to replace their products prematurely, it is important to start by understanding what happens in consumers' minds when replacing products. Chapter 2 identifies and develops a literature-based framework of the influencing factors of product lifetime extension. This framework contributes to the replacement literature (e.g., Guiltinan, 2009; Okada, 2001) by showing the factors and strategies that can influence lifetime extensions either negatively, through the enhanced attraction of new products, or positively, through the enhanced value of owned products. Furthermore, chapter 3 contributes by providing in-depth insights into to understand consumers' underlying thought processes of the considerations of product lifetimes during the replacement process.

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7.2.1 THE VALUE TRADE-OFFS FOR PRODUCT REPLACEMENT

The literature-based framework developed in Chapter 2 shows that the replacement decision process involves a trade-off in which values are compared. On the one hand, the owned product offers specific values to the consumer. This could be for example functional value due to the utility it provides, or emotional value if the product was gifted by a loved one. On the other hand, new products can offer an improved functional value due to developments in their performance, as well as epistemic value when new features are added that arouse curiosity. Depending on the type of product, context, and specific consumer needs and desires some values are more salient than others. When a product breaks down, or the replacement of a still-functioning product is considered, the consumer compares the relative value of the new product to the mental book value of the owned product. When making this trade-off, the required financial investment of a new product and the potential repair costs for the owned product are included in making a decision.

7.2.2. FACTORS INFLUENCING PRODUCT VALUE DEPRECIATION

Our research contributes by exploring what can cause product value depreciation. The functional value of the owned product can decrease if the product (partly) malfunctions, or through the development of new technologies provided in new products. Furthermore, repeated product usage may cause a decrease in product aesthetics via signs of wear and tear (e.g., scratches) which lower emotional value (Baxter et al., 2017). Also, it may triggers feelings of satiation (Hou et al., 2020), which may lower the perceived epistemic value of the owned product. This negatively affects the mental book value of the owned product, even without actual performance or aesthetic losses (Miller et al., 2019; Okada, 2001). In addition, marketing strategies (e.g., advertisement campaigns) promoting new products can heighten the new products' perceived functional and epistemic value (e.g., by offering new features) or social value (e.g., by focusing on keeping up to date with peers), examples are shown in Figure 17. Also, certain circumstances, or life events, such as moving or family expansion, may depreciate the conditional value of the owned product. Finally, trade-in promotions can offer an attractive deal to replace owned products prematurely.

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Figure 17. Advertisements focused on new products providing increased functional, conditional, epistemic and social value

7.2.3. PRODUCT VALUE DEPRECIATION CAN LEAD TO PREMATURE REPLACEMENT

Chapter 3 confirmed consumers generally prefer long-lasting products (Wilhelm et al., 2011), which is promising for the consumer adoption of circular practices required for product lifetime extension. However, our interviews also confirmed that consumers mentally write off the value of products as these age (Okada, 2001; Van den Berge et al., 2021), by showing that participants' product perceived value depreciated over time. This value depreciation is an unconscious process that challenges people's aspiration for long lifetimes. New developments and trends accelerated this value depreciation, which in turn negatively influenced the replacement tendency. Especially for hedonic products, such as smartphones and televisions, feelings of satiation, development of new technologies and marketing efforts influence replacement (Hou et al., 2020; Korhonen et al., 2018; Magnier and Mugge, 2022). When making a decision an attractive deal often provided a final push toward the actual replacement.

7.2.4. STRATEGIES TO SUSTAIN PRODUCT VALUE

In Chapter 2, several strategies that can support the value of the owned product to extend product lifetimes were derived from literature insights. The first one is stimulating product attachment, because when individuals are attached to their products, they may have a higher willingness to repair them because they have an emotional bound with this product (Mugge et al., 2008; Page, 2014). This may result in longer lifetimes. Also, signs of usage or changes in fashion may decrease the owned product's value, which can lead to premature replacement. Therefore, sustaining aesthetic value may address the need for resilient product aesthetics towards both wear and trends (Patrick, 2016; Thornquist, 2017). For malfunctioning products, stimulating care and maintenance offers interesting opportunities for product lifetime extension, because repair aims to recover products' functional value. To stimulate repair, it is important that consumers have the ability to repair their products (Ackermann et al., 2018; Sabbaghi et al., 2017). Lastly, enabling upgradeability allows product functional value to evolve via their design over time, to adhere to consumers' future needs.

7.3 WHAT BARRIERS DO CONSUMERS EXPERIENCE CONCERNING PRODUCT LIFETIME EXTENSION?

To investigate consumers' barriers toward product lifetime extension, the literature-based framework of Chapter 2 highlights several consumer barriers. In addition, chapter 3 provides in-depth insights in the barriers consumers experience to extend product lifetimes. In the next section, we address four core barriers consumers have toward product lifetime extension that derived from our research documented in Part I.

7.3.1. CONSUMERS' INABILITY TO MAKE WELL-FOUNDED LIFETIME ESTIMATIONS

When asking about the product lifetime, our interview findings revealed that many consumers are unable to make a well-founded estimation, illustrated by the great variety of lifetime expectations provided by participants within the different product categories. The results imply that consumers are unable to estimate how long products should last because they lack accurate information to do so. Low expectations about the product lifetime, can be detrimental as these tend to negatively influence actual lifetimes (Nishijima and Oguchi, 2022; Van den Berge et al., 2023a). Literature suggests that providing information about the product's lifetime can support consumers to extend product lifetimes (Sharma, 2021). Therefore, we have explored consumers' perspectives towards a potential lifetime label (Braithwaite et al., 2015; Gnanapragasam et al., 2018; Jacobs and Hörisch, 2021). Our findings suggest a positive response under the condition that they provide relevant and reliable information (e.g., through trustworthy institutions). Furthermore, receiving information about the repairability of a product in some cases triggered worries about possible breakdowns when acquiring a product, and thus should be considered when developing a lifetime label.

7.3.2. PERCEIVED INCONVENIENCE IN PRODUCT LIFETIME EXTENSION

The in-depth insights of Chapter 3 provided some nuance to the consumer's preference for long-lasting products. The insights uncovered that consumers prefer those products, particularly utilitarian ones, mostly because using a product for a long time, without having the fear that it will break and disrupt daily activities, is convenient. Therefore, the general consumers' preference for convenience (Berry et al., 2002) may explains why people replace well-functioning products and thus influenced the decision to either retain or replace a product. However, the consumers' need for convenience is challenged when a product fails, because, in comparison to convenient replacement services (e.g., next day delivery), the inconvenience of professional repair services is regarded as discouraging (e.g., time-consuming) (Jaeger-Erben et al., 2021; Rogers et al., 2021; Terzioğlu, 2021). As a result, it may thus steer consumers towards replacement instead of repair.

7.3.3. CONSUMERS' LACK OF REPAIR SKILLS AND ABILITY

While repair poses a promising solution to extend product lifetimes, consumers are facing many barriers to adopting repair practices. The findings of Chapter 3 confirm various barriers, such as a lack of knowledge (e.g., Jaeger-Erben et al., 2021) and high (estimated) costs (Brusselaers et al., 2019; Sabbaghi and Behdad, 2018; Tecchio et al., 2019). The low ability to repair is confirmed to be one of the major hindrances preventing consumers from fixing their electronic products (Ackermann et al., 2018), as we can confirm a lack of repair knowledge and skills to execute repairs themselves (Jaeger-Erben et al., 2021) among our participants. We contribute to the literature by showing that a lack of perceived repair ability can result from not knowing what caused the failure, discouraging them from proceeding to repair. In addition, we confirm the currently existing belief that products are not designed to last or be repaired (Echegaray, 2016; Wieser et al., 2015), and show this can evaporate any remaining faith consumers may have in their ability to fix something.

7.3.4. REPAIR AS THE NON-VALUABLE OPTION

Especially for trend-sensitive products, value depreciation provides an increasing barrier over time to extending the lifetime of electronic products. The interviews of Chapter 3 further underline that lifetime extension can be hindered by market-related factors causing value depreciation. These can be new technological developments which are incompatible with existing products (e.g., new software or changing (charging) connectors for smartphones), or make a new product more attractive (e.g., improved camera of a smartphone). This may depreciate the mental book value of the owned product making repair relatively a less attractive option to consider. Next to that, our insights reveal that repair is not considered a valuable option, because consumers usually include repair labor in their cost estimation, which influences the value trade-off in their replacement decision-making negatively. Consequently, consumers often do not consider the option of repairing malfunctioning products worthwhile, which is reflected in the few repair attempts of the interviewed consumers.

7.4 HOW CAN DESIGN AND MARKETING INTERVENTIONS HELP CONSUMERS WITH REPAIR AND THEREBY EXTEND THEIR PRODUCT LIFETIMES?

To answer this question, we have focused on testing design and marketing interventions to counter the barriers to repair identified in Part I. Based on our theoretical and qualitative findings from Chapters 2 and 3, we have conducted quantitative studies to test the effectiveness of the identified strategies. In these studies, we empirically investigate how design interventions (Chapters 4 and 5) and lifetime label information (Chapter 6) can increase consumers' intention to repair their electronic products. In both Chapters 4 and 5, we add empirical evidence to support the proposition that purely physically repairable product designs do not automatically lead to repair behavior (Makov and Fitzpatrick, 2021). With the results of Chapter 6, we build further on research suggesting the potential of including reliability and upgradeability information in a lifetime label to increase repair intentions in case of product failure (Cordella et al., 2019; Dalhammar and Richter, 2017; Michaud et al., 2017). With these results, we contribute to existing research suggesting that consumer-centric design for repair can be a fruitful avenue to further pursue sustainability-focused design research.

7.4.1. THE EFFECT OF FAULT INDICATIONS ON CONSUMERS' REPAIR SELF-EFFICACY AND INTENTIONS

In three experiments in Chapter 4, we test if increasing the ability to repair by providing a fault indication (e.g., an icon on a display or a (blinking) light) can increase consumers' willingness to repair electronic products. Our results show that participants had a significantly higher willingness to repair when presented with a fault indication, which was explained by a higher level of perceived self-efficacy (i.e., a "can-do" attitude). Simply knowing what is wrong when products fail can thus empower consumers to repair their products. However, for some more complex and high-investment products, such as washing machines, a professional repair is more likely to be considered compared to less complex and lower-investment products, such as coffee makers and (handstick cordless) vacuum cleaners. By including the likeliness for professional repair as a moderator, we show our results indeed only held true for products that were relatively low in complexity and required low financial investments for a variety of failure types. Therefore, our findings contribute to the literature on design for repair by showing that a fault indication is generally an effective way to increase consumers' willingness to repair failures for many consumer electronics. Secondly, we add empirical evidence of the potential role of product design in facilitating consumers' repair behavior (Bocken et al., 2014; Magnier and Mugge, 2022). By taking a consumer perspective, we go beyond the merely addressed technical aspects of repairable designs (Raihanian Mashhadi et al., 2016; Sabbaghi et al., 2016; Sonego et al., 2022) and show that increased perceived self-efficacy raises the likelihood to pursue repair actions.

7.4.2. THE EFFECT OF A MODULAR DESIGN WITH FACILITATING CUES ON CONSUMERS' DIY REPAIR INTENTIONS

In Chapter 5, we investigate the effect of a modular design as a design intervention to increase consumers' willingness to repair smartphones. The findings of our experimental research show that a modular design decreased the perceived difficulty of the repair task. However, the results show no significant effect for an increased DIY repair, which was surprising as we often implicitly assume that modular designs would encourage DIY repair (Amend et al., 2022; Proske and Jaeger-Erben, 2019). The findings of Chapter 5 imply that consumers need support when considering DIY repair, which is coherent with Chapter 4. A second study investigated differenct types of cues (i.e., an inlet and icon on the to be repaired component). Only the conditions that provide an icon together with a picture of the inside of a modular smartphone succeeded in increasing participants' likeliness to consider DIY repair. To explain this result, processing fluency theory suggests that the provision of this pictorial information may have supported in easing the task (Schwarz et al., 2021), because showing the inside of the smartphone may have supported envisioning the repair steps. However, we must acknowledge that based on our results we cannot confirm that the processing fluency actually ensured the higher likeliness to DIY repair. Therefore, to stimulate DIY repair of modular products, we recommend future research to further investigate the potential positive impact of processing fluency on increased repair intentions. When doing so, we recommend considering that the cue is easy noticeable for the consumer on the product, or during the repair act. Furthermore, the additional information should clearly show the required steps and reassures consumers that performing a repair is within their capabilities, for example by using pictures or movies that are easy accessible on the internet.

7.4.3. THE EFFECT OF LIFETIME LABEL INFORMATION ON CONSUMERS' REPAIR INTENTIONS

Chapter 3 suggests a positive consumers' response towards a product lifetime label. Such lifetime label can convey different types of information related to the product lifetime. Expanding on prior research on displaying repairability information (Bovea et al., 2018; Den Hollander, 2018), Chapter 6 investigates the effect of reliability and upgradeability information on product lifetime extension. In the experimental set-up, we attempt to overcome the barrier of inconvenient repair infrastructures (Jaeger-Erben et al., 2021; Sabbaghi et al., 2017), by offering an attractive speed and distance of repair services in our scenarios. In two experimental studies, we demonstrate that a higher reliability score increases the likelihood of repairing smartphones. Furthermore, we showed that the possibility of upgrading increased the likelihood of repairing smartphones. In sum, our results demonstrate that lifetime-related information about products' reliability and upgradeability is effective for lifetime extension via repair, as our findings show a positive effect of providing lifetime label information beyond purchase decision-making. Of course, under the condition these will remain visible and accessible for the consumer during the product lifetime. These findings are especially useful for the agenda of policymakers focusing on lifetime label development.

7.5 IMPLICATIONS FOR DESIGN

To ensure long product lifetimes, our research findings of Part I suggest designers should focus on designing products for which the value remains high during their lifetime. This implies that products' utility needs to stay reliable over time, as well as that repair should be doable and worthwhile, and products should be resistant to future developments and trends. The results of Part I also revealed consumers in fact are already willing to repair and may even feel guilty that they currently do not behave accordingly. It showed that they often do not know how to do it or are not prompted to think about it as a solution for their broken product. The insights of the empirical studies of Part II provide practical implications for practitioners with an interest in designing electronic products that enable repair. While the positive effect of fault indications and cues may appear to be a logical result on consumers' repair actions, the fact is that these are rarely implemented in product designs. Therefore, their impact should therefore not be taken lightly. A simple warning, cue or label may just be enough to prompt the possibility to repair a broken product in the mind of the consumer as a serious option to consider. Therefore, the results of our empirical studies showed that a (small) interventions in product design can have a relatively great impact. Furthermore, by focusing on the repair process (i.e., self-efficacy and perceived difficulty) to explain our results in part II, our results provide clear implications for design on how to implement design interventions that are effective to stimulate repair. Several implications and guidelines to implement these interventions are listed below.

First, we recommend designing reliable products with a long-expected product lifetime, as these in theory can be considered more worthwhile to repair when a failure occurs. In addition, offering high-quality, long-lasting products with convenient repair services when a failure occurs, can create value for the consumer (Bocken et al., 2016) which provides an advantage in the highly competitive consumer electronic market. In general, to stimulate repair, products need to be able to be repaired and the design should allow for it (e.g., through ease of access to (critical) components by decreasing and facilitating disassembly steps). Next to that, designing repair infrastructures (e.g., repair services or support) that are market-competitive with speedy and convenient replacement services is deemed necessary to stimulate repairs.

While most design researchers have focused on the products' physical repairability during these different stages (Raihanian Mashhadi et al., 2016; Sabbaghi et al., 2017), we have adopted a consumer-centric lens. Our findings showed that to make repair the default choice to consider when a failure occurs, consumers should be equipped with a repair 'can-do' mentality. The product design can be supportive for repair behavior (i.e. via design interventions such as fault indications or modularity). This is important for consumers adoption as the product's physical design will not automatically result in repair behavior (Makov and Fitzpatrick, 2021). For designers that aim to stimulate DIY repair of electronic products specifically, we recommend enhancing consumers' 'can-do' mentality during the different steps of the repair process. The typical steps of this process to be considered are diagnosing the failure, disassembling the product, repairing the defective component, reassembling the product, and functional testing.

Reflecting on this process, failure diagnostics is the essential first step for consumers to undertake product repair (Pozo Arcos et al., 2020). We suggest that implementing fault indications can support the failure diagnostics stage (e.g., through blinking lights) and increase consumers' can-do mentality, especially for the design of (low investment) electronic products for frequently occurring failures. We suggest designers implement appropriate sensors and fault indications, considering these should not complicate the functionality of the product. Also, it should be noticeable on the product, to ensure the consumer would not overlook it. For example, a coffee maker could signal a calcification (Postma and Kesteren, n.d.) via an appearing icon on its display, or a vacuum cleaner could signal the necessity of a filter replacement (Harmer et al., 2019) via the appearance of a (blinking) light. The fault indication should be easily traceable via an online manual or on the company website, where step-by-step guidance and/or movies explaining repair procedures could be provided to further support the consumer's ability to repair the product. For consumer adoption, fault indications can be made more attractive by implementing well-known design principles, such as harmony or unity, and by integrating these indications seamlessly into the product design.

To stimulate repairs, we recommend the design of modular products. A modular product structure can support the steps that involve the dis- and reassembly required for the repair of defective components. To do so, we recommend that designers provide explicit repair cues to stimulate DIY repair of modular products. These could be cues (i.e., icons) on the different product components on the inside of the product. However, we emphasize that to enhance consumers' repair intentions, additional supportive information (i.e., pictures, videos, text) should be provided, to ease the perception of the difficulty of the repair task. This supportive information is needed to help the consumer to envision the different repair steps that are required for the repair process (e.g., by showing a picture of the inside of a product on the website) and should go beyond to for example only providing an inlet on how to open the device (cf. Chapter 5). We suggest this information should be easily accessible when a failure occurs. For example via a QR code that is attached to the product and allows a link to repair manuals or videos to explain the different repair steps.

Finally, we encourage designers to develop future-proof upgradeable products. These can allow the implementation of improved technologies in existing products, such as an improved camera in a smartphone. Modular designs are based on the principle that components are easily replaceable, therefore providing an interesting opportunity to design for upgradeability. When designing modular and upgradeable products, however, it is important to consider the size of the modules and what this entails for repair. For example, too large modules can still be significantly wasteful, or too small modules may still be difficult to replace during the repair process due to their size. Also, to enhance the convenience of the DIY repair of modular products, we recommend that the location where the replacement module can be purchased (e.g., in a (web)store) should be easily traceable for the consumer. Also, while marketing a product as reliable and upgradeable encourages repair, it is beneficial for consumers' purchase preference as well. Therefore, it provides competitive market advantage.

7.6 IMPLICATIONS FOR POLICYMAKERS

Policy and legislation are important drivers for industry and can support systems to make the shift toward more circular consumer behavior. Therefore, governmental bodies play an important role in creating a society in which repair is the norm. Compliance with repair-related regulations is expected to be effective in stimulating the consumer products market to develop repairable products. The findings of this thesis provide several implications for policymakers to consider in legislation.

Legislation that aims to make repair (services) more accessible and feasible, such as Ecodesign and the Right to Repair, is currently under development. For both Ecodesign and the Right to Repair, the current proposals and legislation entail several repair service regulations for manufacturers (cf. Chapter 1). While this is a step in the right direction, there are still many restrictions for consumers and independent repairers to adopt repair. Our results imply that implementing policies that require manufacturers to design products that allow consumers to repair products themselves is essential to overcome the repair ability-related barriers. Enabling consumers to repair themselves, may make consumers more eager to give repair a try if they are supported well. Simultaneously, repairing products themselves may overcome the cost barrier consumers may have toward repair services. For example, low spare part availability limits consumers to repair (Tecchio et al., 2016). To enable consumers and independent repairers to pursue repair it is thus important to have (essential) spare parts affordable and mainstream available. Current Right to Repair legislation does not address this. Therefore, we suggest that spare parts should be offered in an accessible way and for an affordable price after they have been introduced on the market.

Additionally, policymakers could consider developing legislation about the standardization of spare parts that demand accessibility of critical components in product designs. While developing standardizations for spare parts, we do recommend considering conflicting criteria related to reliable and long-lasting design. For example, products with standard components that allow ease of disassembly should not suffer from less resistance to water damage. Furthermore, executing repairs must be safe for the consumer and professional repairer. For example, sharp edges of product components or the risk of electric shock during disassembly should be avoided in the design. Finally, while many innovations may be unnecessary, some can also result in more environmentally friendly designs which policymakers should not thwart either (e.g. more energy-efficient next-generation electrical and electronic products, or optimized product designs that need fewer materials). Therefore, we suggest that policymakers should consider room for product innovation that aim to create more sustainable and circular products in their legislation.

Legislations around VAT on repair labor costs are often mentioned as an effective way to stimulate more repair behavior. However, research revealed these may not be sufficient to overcome currently existing barriers and persuade consumers toward repair (Svensson-Hoglund et al., 2021). To overcome other repair barriers, we recommend policymakers could additionally focus on providing subsidies that encourage approved repairers to develop their businesses. This may improve current weak repair infrastructures as it will increase the number and proximity of possibilities for consumers to have their products repaired. Also, providing subsidies for repair support through social initiatives (e.g., repair cafes) can provide additional support for consumers aiming to have their products repaired. Additionally, the extension of legal warranties should be considered because covered repair costs are a great incentive for consumers to repair a product. In turn, it may trigger manufacturers to design long-lasting products to avoid the burden of repairing failing products within this extended legal warranty period. As consumers often experience confusion with warranties (Maronick, 2007; Svensson-Hoglund et al., 2021) terms and conditions should be clear regarding coverage. Also, policies could be required to make it clear for the consumer how to sign up for (extended) warrantees, and whom to contact when a failure occurs.

Finally, to make a fair comparison in terms of the product lifetime, it is recommended to develop legislation making it compulsory for manufacturers to display lifetime information on all products within specific targeted product categories. In doing so, it is important to consider the significant impact of consumer behavior on premature replacement. The investigation of the consumer and market-related factors in the PROMPT project allowed us to go beyond the technical aspects of reliability and repairability of product designs that could result in premature product replacement. Therefore, we recommend policymakers further proceed with the PROMPT findings and implement the testing program to assess the lifetime of products before they go to market. Via a lifetime label, the assessed lifetime of electronic products can be communicated to consumers and make the product lifetime a more commonly considered choice criterion for consumers. Furthermore, it can incentivize manufacturers to design long-lasting products to score high on this label (Milios and Dalhammar, 2023). We encourage implementing a lifetime label to provide a more accurate representation of devices in terms of life cycle costs. As high perceived reliability and upgradeability can also enhance repair intentions, policymakers should consider adding this information as a compulsory aspect of the assessment of a lifetime label. In doing so, they should ensure that this information remains visible and accessible throughout the product lifetimes.

7.7 LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

The findings of this thesis have several limitations that provide interesting future research directions.

7.7.1 INVESTIGATING THE IMPACT OF PRODUCT ATTACHMENT AND SUSTAINING AESTHETICS ON REPAIR INTENTIONS

Reflecting on the strategies to support the owned product value (Chapter 2), the primary focus was on the strategies of stimulating product care and maintenance and enabling upgradeability. Consequently, other strategies remained out of scope that provide interesting opportunities for future research. For example, research shows that executing DIY repair activities can be meaningful and conscious interactions between consumers and, when successful, can provoke positive emotions (Ackermann et al., 2018; Desmet, 2012; Mugge et al., 2005). Consequently, DIY repairs may also stimulate product attachment which increases the emotional value of products. Therefore, we encourage further research to investigate the effect of product attachment on consumers' repair intentions.

For the research of this thesis, the effects of sustaining the aesthetic value of the owned product were out of our scope. Signs of wear and tear may not be directly related to repair, however, it may decrease owned products' aesthetic value because people perceive scratches and usage signs as unattractive and less desirable (Harmer et al., 2019; Van Weelden et al., 2016). This may negatively influence the decision to repair when the product malfunctions. We therefore encourage future research to study how to sustain product's aesthetical value, for example by embodying products in materials that tend to wear gracefully over time, such as leather or wood (Bridgens et al., 2019; Lilley et al., 2019).

Also, sustaining the aesthetic value through timeless design styles was considered out of scope, because of the tension between timelessness and the need for differentiation and innovation. For example, the rapid technological advancement of many electronic products, such as smartphones, makes it difficult to adhere to a timeless design. Nevertheless, consumers may be more likely to consider repairing products with characteristics of timeless designs (Lobos, 2014), and research on refurbished products suggested that timeless designs are considered aesthetically pleasing for consumers (Wallner, 2023), which may be beneficial for value retention. Therefore, we encourage design researchers and practitioners to carefully consider the positive and negative consequences of timeless design styles when designing long-lasting electronic products.

7.7.2. EXPLORING WAYS TO ENHANCE PRODUCTS' MENTAL BOOK VALUE

In Part II we explored through empirical studies how to encourage repair behavior through design. All in all, several possibilities to lower the barriers to repair are addressed in this thesis. Repair aims to restore the initial utility of a product and thus initially recovers functional value. However, a focus on enhancing products' mental book value could also be useful. In Chapter 6 we showed that supporting products' mental book value by providing lifetime information via a label enhanced repair intention. Our focus on providing upgradeability information implies a potential effect of increased epistemic product value on repair intentions but should be further studied. Additionally, there are many other possibilities to stimulate product lifetime extension. A focus could go beyond enhancing emotional value (e.g., through meaningful repair interactions), such as on supporting social value (e.g., through repair festivals or café) as these also have a powerful and persuasive influence on sustainable consumer behavior and decision-making (Trudel, 2018). We would therefore encourage future research to keep exploring alternative routes to enhance mental product value in future research.

7.7.3. THE CHALLENGES OF INCLUDING CONSUMER AND MARKET ASPECTS IN PRODUCT LIFETIME ASSESSMENT

To facilitate the shift towards a society in which long product usage and repair is the norm, the PROMPT project aimed to develop a testing program to assess product lifetimes before they go to market. The output of the PROMPT project provides useful input for a potential scoring system that can be used to develop a lifetime label. Using this label, the consumer can consider the product's lifetime during purchase. The consumer/market-related criteria for the assessment of product lifetimes were developed in parallel with the research conducted for this thesis. These criteria were related to supporting the consumer in repairing, maintaining, and upgrading the product, aging and wear tests, and information about extended warrantees. However, several proposed criteria were not integrated into the final testing program developed for PROMPT, such as the assessment of a timeless design, as these posed several issues regarding the repeatability which was caused by the subjective influence of the lab experts conducting the test. Since we believe a timeless design is important for long-lasting product designs, we encourage future research to focus on developing a method for objective assessment.

7.7.4. KEEPING THE REPAIR INTENTION-BEHAVIOR GAP IN MIND

Our experimental approach allowed us to explore the general effects of different design and marketing strategies to stimulate product lifetime extension via repair. Using this methodology, we could isolate the effects of our identified design and marketing strategies in their potential to stimulate product lifetime extension. Therefore, our approach offers high internal validity because of the control of other effects, making our results credible and trustworthy. However, a limitation is that our results reflect the intended behavior of our participants and did not measure actual behavior in a real-life setting (i.e., ecological validity). By considering the time of ownership in the scenarios of our experiment, we have attempted to simulate a real-life setting. Furthermore, studying the effect of behavioral intentions often a good predictor for actual behavior (Azjen, 1991). Nevertheless, we advise future research testing fault indications, modular design, and information about reliability and upgradeability via lifetime labels to control for possible intention-behavior gaps (Sheeran and Webb, 2016). We suggest this should be done through longitudinal field studies. In doing so, several challenges of these types of studies should considered, such as the recruitment and dedication of participants to participate in a study involvement of multiple years, and the risks of participants dropping out of the study over time.

7.7.5. CONSIDERING OTHER PRODUCT CATEGORIES SUCH AS FURNITURE OR CLOTHING

This thesis investigates household products such as coffee machines, vacuum cleaners, and washing machines, and consumer electronics, such as TVs and smartphones. However, the insights may not be limited to electronic products. For example, many consumers do not consider repairing furniture or clothing for similar reasons, such as the lack of ability to repair (Laitala et al., 2021). While fault indications, such as error codes or blinking lights, may not be appropriate for these types of products, several other ways to increase consumers' ability to repair as explored in this thesis might be useful. For example, a modular design may also allow easy repair for furniture or clothing, as it allows for the replacement of broken components or damaged fabric. Also, upgradeability could be useful to renew the value of products. For example, for furniture, it could allow to adapt to further (unforeseen) needs of the consumer which may occur when moving or experiencing life events (e.g., such as expanding family or children leaving home). Therefore, we encourage research to explore possibilities to upgrade different types consumer products through its product design and accompanying services. Next to that, we would like to highlight the importance of lifetime-related information, such as information about the reliability of the used materials. As the perceived quality is valued in clothing (Aakko and Niinimäki, 2022), we recommend informing the consumer about the quality of the fabric because this be useful in making more sustainable choices via a lifetime label making this an interesting route to further pursue. Also, for other product categories, we recommend providing information about upgradeability possibilities to adapt to future needs, especially for trend sensitive products.

7.7.6. EXPLORE THE IMPACT OF ALTERNATIVE MODES OF CONSUMPTION ON PRODUCT LIFETIME EXTENSION

Lastly, the focus of this research has been on products sold via a traditional linear ownership model and repair services. As most business models rely on the exchange of product ownership (i.e., asset sales) and repair services for money, this represents a common way of consuming electronic products (Ertz et al., 2019). As a result, alternative modes of consumption such as reselling of second-hand goods, access-based consumption (e.g., renting and leasing), and collaborative consumption (e.g., sharing platforms) were out of our study scope. However, alternative modes of consumption can offer interesting opportunities for sustainable business models (Bocken et al., 2014; Tunn et al., 2019). For example, when manufacturers keep ownership through leasing models, they are incentivized to produce high-quality long-lasting products. For consumers, renting products such as white goods or kitchen appliances may be attractive. They can provide flexibility as maintenance and repair are outsourced and reduce concerns about potential breakdowns and products becoming outdated (Gullstrand Edbring et al., 2016). Therefore, we encourage future research to focus on consumer behavior around leasing and renting models in relation to product lifetime extension. Next to that, as we studied consumer behavior, we have to emphasize our results are mostly useful for the business-to-consumer market (B2C). The business-to-business (B2B) market, however, may offer interesting opportunities for alternative modes of consumption. For example, offering leasing services for companies that provide smartphones and laptops to their employees. These constructs could offer repair services when products break, making sure their lifetime is extended, and allowing repaired products to circulate within companies. Therefore, we recommend future research to focus on the opportunities of B2B product offerings on product lifetime extension.

7.8 REFLECTIONS ON PRODUCT LIFETIME EXTENSION WITHIN A CIRCULAR ECONOMY

After a thorough investigation of product lifetime extension from a consumer perspective while writing this thesis, it is time to reflect on the implications of design to encourage consumers to prolong the lifetimes of electronic products via repair in our transition to a circular economy. For example, what does it mean for companies to operate in a circular economy where long product lifetimes and repair are the norm? What is needed for a successful repair adoption of consumer behavior? How can lifetime labels support product lifetime extension? And is a consumer focus enough to create the shift towards a more sustainable society? To answer these questions, a holistic perspective on a repair society concerning the research output of this thesis is considered.

7.8.1. PRODUCT LIFETIME EXTENSION REQUIRES A SHIFT IN CURRENT INDUSTRY PRACTICES

In a repair society, we assume all products are repaired when broken down, and ideally could last for eternity. In the case every broken product is repaired, we should be prepared for what this would imply for society, companies, and consumers. First and foremost, the amount of e-waste will be significantly reduced because waste remains limited to the replacement of defective parts of broken devices. As a result, CO_2 emissions from the production and waste handling of electronic products will drop, as well as the amount of required (raw) materials, which is highly beneficial for the environment. However, companies will be up for a challenge. At the end of the day, product longevity implies that companies will grow less in terms of sales. Linear ownership models are currently the norm, and longer product usage may be beneficial for the environment, but not necessarily for current business revenues as it implies that less products are sold. This prospect may cause resistance towards the necessary change towards a more circular society, and it is expected that legislations are required to stimulate change among businesses. However, companies should consider that they can still make profit from repair and selling separate product component instead of complete devices. Furthermore, visions of green growth are emerging, which suggest that economic growth and development can be fostered while ensuring that natural assets continue to provide the resources required for our well-being (OECD, 2011). However, green growth is also questioned as being not more than a misguided objective because it lacks empirical evidence (Hickel and Kallis, 2020).

Green growth or not, based on the research reported in this thesis, to operate in an economy in which repair is the norm, businesses can only remain a competitive advantage if they focus on designing products that are made to be repaired, and reorganize their business (models) to such extend ttheze do not (only) rely on selling more products. The results of Part II of this thesis offer pathways of how design can be supportive for consumers to prolong the lifetimes of products via repair. Therefore, developing convenient repair services and attractive sustainable business models (e.g., renting, leasing) is required to provide alternative means to create monetary revenues for business in a circular economy.

7.8.2. CONSIDER THE DESIRE OF NEWNESS TO ENSURE CONSUMER'S REPAIR ADOPTION

Companies face challenges to operate in a society in which repair is the norm, however, consumers are challenged as well. For example, it is important to acknowledge and accept the fact that we are humans, and thus curious by nature. Some are more than others, but by nature, we are programmed to improve the state-of-the-art and have a curiosity for new things (Sheth et al., 1991). Also, innovations are not always a bad thing, as they may be beneficial for reducing the energy consumption of our products (e.g., energy-efficient washing machines), and repairing is not always the most environmentally friendly option if the replacement component has significantly large environmental impacts (e.g., the replacement of PCB (i.e., printed circuit board) (Parchomenko et al., 2023)).

One way to tackle our need for new stuff would be for designers to question whether providing epistemic value can go hand in hand with a repair. For example, providing an upgrade during repair can provide this feeling of newness and therefore make lifetime extension via repair more attractive. However, during the PROMPT project we noticed that designing a modular and upgradeable product may be difficult as you cannot foresee what future innovations will require. Next to that, we must face the realization that we are on a finite planet. While realizing this, we can ask ourselves the question of how fulfilling our urge for new products actually is. The satisfaction of buying something new is often short-lived because its usage makes it quickly become part of our daily routines again. What if we could regard repairing as a satisfactory endeavor, and as an opportunity to provide us control of our behavior and its impact on the environment? In this way, we could consider lengthening product lifetime as an enriching experience and contribute to the well-being of people.

To do so, our mindset should be shifted from replacing a product when it fails, toward the aim to use products as long as possible, and regard repair as the default option. To create this shift in mindset, a critical mass of people is needed to create social norms that adhere to the principles of a circular economy (Sunstein, 2019). Consumers who repair nowadays may be categorized as frugal people, or likely from an older generation when repair was a more common endeavor. However, there is also an upcoming group of repair enthusiasts who nowadays may be a pro-environmental minority but should not be underestimated in their capacity to generate change. If their repair activities continue to spread among society until a moment a 'critical mass' is researched, a tipping point could pave the way toward change and generate new social norms (Bolderdijk and Jans, 2021). Currently, pro-environmental actions on an individual level often involve conflicts between normative goals (e.g., repairing products to lower the impact on the environment) and hedonic (e.g., it may be more convenient to buy a new product) and gain reasons (e.g., repair is relatively costly) (Steg et al., 2014). To create new social norms from a consumer perspective, pro-environmental normative goals should be strengthened (Azjen, 1991; Steg et al., 2014). The empirical results of this thesis provide useful contributions to strengthen those (in becoming) willing to undertake repair actions. The design and marketing interventions make it more likely to execute repair behaviors to reach the critical mass required for change. This is beneficial for changing current mindsets toward a society in which lifetime extension via repair becomes the norm.

7.8.3. REBOUND EFFECTS OF PRODUCT LIFETIME ASSESSMENTS AND SOCIAL JUSTICE

When focusing on product lifetime assessment, several rebound effects should be explored to make sure that designing long-lasting products indeed has the intended positive effect on our environment. For example, research on energy labels showed labels can distort consumers' perceptions of consuming environmentally friendly (Waechter et al., 2015). Therefore, in the development of a lifetime label, it is important to avoid unintended consequences of such a label. For example, one aspect to consider is that a lifetime label may result in a moral licensing (Barkemeyer et al., 2023); a person buying products with a long lifetime, justifying other environmentally unfriendly behavior. For example, that buying many products is fine as long as they are expected to have a long lifetime or using the purchase of long-lasting products as an excuse to justify the booking of a long-distance flight for a holiday. To keep these unintended effects within limits, we recommend pursuing a broader policy than just long-lasting products for a circular society and recommend weighing specific lifetime extension-related policy instruments together with those of other sustainable behavior and circular-related policy in general.

The design of long-lasting products implies people should be willing to accept to pay more for long-lasting products. When developing a lifetime label, it should be considered that the willingness to consume environmentally friendly products is positively related to higher individual carbon, water, and material footprint, and as a result, lifetime labels are expected to thrive in more affluent markets (Barkemeyer et al., 2023). This has implications for social justice, as lower-income households may not be able to afford products with high lifetime expectations. People with lower incomes, and consequently a lower environmental footprint, should not have to suffer from the fact long-lasting products required a higher initial investment. Therefore, considering justice in sustainable transitions is important to make sure circular behavior is adopted across the entire society and different countries fairly. We suggest policy could consider social justice and equality among different social groups is weighted and considered in circular transitions and practices such as product lifetime extension.

7.8.4. A SYSTEMIC APPROACH IS REQUIRED FOR PRODUCT LIFETIME EXTENSION

Lastly, as said, the focus of this thesis has been on changing the behavior of the individual's perspective, focusing on people's attitudes, behaviors, and choices when considering lifetime extension via repair. While having this focus, we want to emphasize that this is not the only aspect that will change our society towards a circular economy. We fully recognize that a system-focused approach is needed to be effective in bringing about change and tackling the issues resulting from climate change in the long run (Shove, 2010). We want to emphasize that it is a chicken and egg story with a lot of chicken and eggs, let's say a full hen house with all different sorts of chicken. So no, I do not believe all responsibility can be pinned on the consumer. Manufacturers have the responsibility to sustainably produce products as well as enable sustainable behavior, such as repair, through their product designs. Policymakers should develop legislation that moves the industry toward a more sustainable way of producing and create a critical mass of consumers to change towards new norms in which circular behaviors prevail. The specific practical and policy implications in each chapter further underscore full recognition of a required system approach to bring about change. Our focus on enabling the consumer to take responsibility for more sustainable behavior can thus be considered as the fact that one simply must start somewhere to create the ripple effect required for the necessary transition to a circular consumption society.

EPILOGUE

It was a sunny day in September. We walked along the gravel path into my partner's mother's house through the back door. As always, we were welcomed cheerfully, and she asked if we wanted something to drink. I said a cup of tea, Niels asked for a coffee. We walked to the kitchen, but before we got there, she walked over to me and looked at me almost guiltily. She said:

> "Renske, I have something to confess to you. I think it's really stupid, but I bought a new coffee machine. After we fixed it last time it worked again for a while, but later it started to malfunction again with the crazy blinking lights. I had no choice but to replace it with a new one…".

I found it touching that she was so guilt-ridden towards me, and I have to say I tried to hide my disappointment as best I could. I said it wasn't her to blame. The design of the product should have given her better indications when it was necessary to clean and decalcify it.

> "Yes, but I should have maintained it better, it was completely clogged, I didn't notice that, but I found that out when I took a closer look and took some parts apart… But, when I bought the new one, I paid very careful attention to that, here, look, I immediately got a full set of anti-limescale tablets, and I also clean it more often now. This won't happen to me again!"

Although it is a shame that the coffee maker did not make it to the end of this thesis, I do think this event is a realistic representation of how we interact with our daily used products. It shows that how these are designed plays a crucial role in the consumer's interactions with products, and this example underlines the problems and shortcomings that prevent them from extending their lifetime. What we can learn from this is that consumers in fact are quite willing to actually act and repair, and if it is successful, they can get satisfaction from caring for their products and are disappointed when this does not work out. However, the repair option should be straightforward, otherwise, it will be very difficult for them as a replacement is far more convenient. To make repair more common, it should become the natural, default first thought in consumers' minds when a product fails. However, changing replacement behavior is not only the responsibility of the consumer. The entire system, including practice and society, should enable more circular behavior. To do so, consumers' underlying drivers for their non-circular behaviors and the way products are designed are crucial to be considered.

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TO BE REPAIRED WASHING MACHINES - R.U.S.Z. REPAIR CENTRUM AUSTRIA

Appendices

APPENDIX A – CHAPTER 3 – INTERVIEW GUIDE

This appendix provides the interview guide to explore consumers' product replacement behavior. The guide was used to explore the underlying reasons of consumers to replace a product instead of prolonging the lifetime or repairing a product, and attitudes towards repair and a product lifetime label

Interview guide:
The replacement of 'X' (X = WM, SM, VC or TV)
[Description of present and old 'X']
Goal: Introductory question to become acquainted with the topic
In this first part of the interview, I would like to discuss with you your replacement of 'X' by purchasing or acquiring a new/other 'X'.

1. Can you please describe the new 'X'?
   a. What does it look like?
   b. What kind of functions does it have?
   c. Could you show a the product to me?
   d. When did you purchase it?

Before you bought your 'x', you had another 'x'

2. Can you describe the 'x' you previously owned?
   a. What did it look like?
   b. What kind of functions does it had?
   c. Could you show the product to me? (If you still own it)
   d. How long did you use this product?

[Reasons for replacement 'X']
Goal: Understanding of the different reasons for replacement
Can you please think back of the moment in time when you decided to replace 'X'?

3. What was the reasons for you to replace 'X'?
   a. When did this happen?
   b. Can you explain what triggered your replacement?
   c. Did you miss things from your old 'x' that triggered your replacement?
   d. Are there things you miss from your old 'x' that you do not have in you new 'x'?
4. You just told me that ...., and ...., [listing the reasons for replacement] were the reasons for you to replace your product:
   a. Is it correct that these were the most important reasons to replace your 'x'?
   b. Can you indicate the order of importance of these reasons? (Most to least important?)
5. How much time was there between the first idea to replace 'x' and the final

decision?

  a. Can you describe why this did (not) take time?
  b. Did you have doubts to replace the product? Why did you have doubts?

[Product, Consumer and Context Characteristics]

6. Did the following factors had influence on the longer use on the choice to replace the product?
   a. Have there been context related changes in your environment? Why?
   b. Have there been product related changes (functionalities)? Why?
   c. Have there been changes in personal needs? Why?
   d. (if not mentioned yet) Was marketing of influence in your decision making?

[Personal evaluation]

7. When you look back on the process replacing your 'x':
   a. Are you satisfied with the new 'x' in comparison with you old 'x'? Why (not)?
   b. Are you satisfied with the aspects of your new 'x' that you took into account while replacing the product? Why (not)?

[Lifetime]

8. When you consider the lifetime of the new 'x'
   a. How long do you think it should last?
   b. How long do you think it will actually last?
9. You just told me your previous 'x' lasted … years/months
   a. Were you satisfied with this? Why (not)?
   b. What could have convinced you to use the product for a longer amount of time?

Possibility to repair 'X'

In the next section, I would like to discuss with you your considerations to decide for either replacement or repair.

[Possible repair old 'X']

Goal: Understanding of the different reasons to (not) have a product repaired

1. Was the old 'X' still functioning completely well when you decided to replace it?
   a. If no, can you please explain what was wrong?
      i. Did you consider the possibility to repair the old 'X'? Why (not)?
      ii. What were the reasons for choosing for replacement over repair? (Barrier)
   b. If yes, next question
2. Did you repair the old 'x' before you replaced it?
   a. If yes
      i. what did you repair?

&

ii. Can you describe this process step by step?
iii. Were you satisfied with the result? Why (not)?
iv. Would you recommend others to repair products?

b. If no, repairing a product can also be considered to give a product an upgrade, to improve functionalities
i. Did you execute something like this?
ii. What would be a required to make upgrading interesting for you?

[Future repair of new 'X']

Goal: Understanding of the different reasons to (not) have a product repaired

3. If your new 'X' would malfunction, would you consider repair?
   a. Why or why not? (barriers) Multiple reasons are possible
      i. What could encourage you to repair it? (enablers)
      ii. Are there concrete design elements that would stimulate repair?
   b. Till when would you consider repairing your product? (Till what time?)

[Repairability as a purchase factor]

4. Did you consider the repairability of the product when buying your new 'x'?
   a. Why did you (not) take this into account?

Closing

[Lifetime]

Goal: Understanding of participants' evaluation of the lifetime as a purchase factor

1. When you bought your 'x', did you take lifetime into account? Why (not)?
2. What would you convince you of a product having a long lifetime?

[Labels]

3. Do you think a label about the expected lifetime of the product would be useful?
4. What should be on this label to convince you of a long lifetime?
5. Did you take the environmental impact into account when buying your new 'x'?
   a. If yes, what aspects did you take along? Why these ones?
   b. If not, why not?
   c. Are you aware of the impact of products/ goods we own on the environment?
   d. Are you aware long-lasting products decrease the environmental impact?

[Closing]

6. Can you sign the consent form?
7. Thank you for your participation [hand over the debriefing and voucher]

APPENDIX B – CHAPTER 3 – CODING SCHEMES

This appendix provides the coding schemes of the interview data presented per theme. The 3 tables each represent one of the 3 themes and contain a total of 101 subcodes. All subcodes are supported by at least 3 participant quotes, and subsequently grouped in 42 codes. The codes all fit within the 13 categories, which are used as a foundation to present our research results

4.1 CONSUMERS' CONSIDERATIONS ABOUT PRODUCT LIFETIMES

	Category	*Code*	*Sub-code*	*# Quotes*
4.1.1	Long lifetimes are perceived positively	The length of the product lifetime influences the satisfaction level	Dissatisfaction with short lifetime old product	3
			Good experience with product that lasts for a long time.	7
		It is preferred to use a product for as long as possible	Only replace when necessary	13
			Not wanting to throw things away (too quickly)	6
			Being attached to products	3
			Hoping that a product will last for a long time, the longer the better	14
			A new product should be future proof	4
			The longer a product last, the better for the environment	3
		The breaking down of products is annoying	Getting angry / not satisfied when product breaks too soon	6
			Irritation at product that does not work properly / goes backwards	8
			Breaking down was annoying, is a shame	6
4.1.2	Product value depreciates over time	The functionality of the product depreciates over time	Decrease in product functionality due to age	7
			Wear and tear of the product due to use over the years	11
			The product was ragged / worn	8
			Combination of factors and deterioration leads to replacement	5
			The product broke down, did not function, did not turn on anymore	13
		Product age and costs are considered in the decision to repair	Taking into account age and repair costs when considering repair	16
			Repair is considered, but only if it is worth the money	4
			Repair is considered until a certain number of years (max 10 years)	8

Continued.

	Category	*Code*	*Sub-code*	*# Quotes*
4.1.3	Lifetime expectations influence actual lifetimes	Expecting a failure after lifetime expectations have been met	Reconcile when a product is defective after x number of years In general products stop working at some point	4 5
		Having certain expectations or assumptions about the lifetime	Having a certain expectation of the lifetime of a product Assume that something will continue to do so / last at least a few years	7 3
		Products are not made to last for a long time	Products are not made to be repaired Products are not made to last anymore Manufacturer has no interest in products lasting / products being repaired	3 8 5
4.1.4	Inability to make well-founded lifetime estimations	Using personal and experiences of others to make estimations	Lifetime estimation based on experiences of family/friends Reading product reviews (regarding lifetime)	14 6
		The brand reputation is important for the lifetime estimation	Buying a new product with the same brand because of a good experience The trustworthiness of the brand is important for the lifetime. Certain brands are known to last a long time	12 14 9
		A robust and solid appearance are important for a long lifetime	Product that looks solid lasts longer	7
4.1.5	Use intensity and care(less) behavior influence lifetimes	The product use intensity influences the lifetime	Product age depends on intensity of use	7
			The use of the product is important for lifetime	5
		Wrong product usage or neglect as a reason for defect/malfunctioning	Not following/executing the maintenance guidelines Wrong usage as a reason for product failure	3 7
		Handling a product with care	Taking protective measures for products (e.g., cover)	7
			Being careful with the product during usage	8
		Maintaining and cleaning the product	Performing maintenance and cleaning activities	7
			Software upgrading of the product / clean-up the product	7
		The product use intensity influences the lifetime	Product lifetime in terms of years depends on intensity of use	7
			The use of the product is important for lifetime	5

4.2 CONSUMERS' BARRIERS TO EXTENDING PRODUCT LIFETIMES

	Category	*Code*	*Sub-code*	*# Quotes*
4.2.1	Repair knowledge and ability is lacking	(External) support is needed for repair	Support from producer movies or internet used for repair	4
			Unable to repair him or herself	7
		Not having the knowledge about repair and repairability of products	Arranging a professional to execute the repair (no able to do it myself)	9
			Unable to make an estimation about the repairability/no information available	5
		Many products are not made or able to be repaired	Unable to understand/estimate/know what is wrong with the product	5
			Repairing an electronical product is different from repairing a mechanical product	3
			Product could not be repaired according to seller/retailer/expert	6
		Balancing repair costs with costs of a replacement	Purchase price of new product important in repair consideration	6
			Repair is considered if the product is relatively expensive	4
			Weighing repair costs with the costs of a new product	18
		Repair costs are known to be high	The (high) price of replacement parts	4
			Call-out charges and labor costs of repair are expensive	14
		A repaired product depreciates in value	After first repair, second repair greater consideration	3
4.2.2	Replacement services are more convenient than repair services	Convenience and speed are determining the choice for the type of service	A convenient delivery service is important during replacement	9
			A seller known for its good service is preferred	5
			The product must be replaced product, a new product was needed	3
			The speed of the service is important	6
		A service supporting in the physical movement the product is important	A service to get the product in the right place is important	3
			It is a barrier to bring the product physically to a repairer	4
		The current repair infrastructure does not stimulate repair.	Not knowing where to repair of find support for repair	3
			The replacement of a product takes time/is an effortful endeavor	3
4.2.3	Deals and subscriptions shorten lifetimes	Deals and marketing influence consumers' replacement decision making	Deals of the of the seller convinced to replace the product	4

Continued.

	Category	*Code*	*Sub-code*	*# Quotes*
4.2.4	New developments and software updates accelerate replacement	The market develops fast (IoT etc.)	Influenced by flyers, offers	6
			(Software) updates product no longer possible	4
			Linking products to the internet, smart IoT	6
		New functionalities are often redundant	The new product does not have essential new functionalities	14
			New functions are often not necessary	19
			Not the newest/most expensive model is good enough	7
			Only a few functionalities needed, not more	14
			The function/use of product is most important	21
		Attractive and desirable functionalities could be a reason for replacement	New functionalities make a product attractive	5
			The product was still functioning when it was replaced	10
			New technological functions as a reason for replacement	6
		The new product works better than the old product	The new product has improved functionalities	14
			The new product is an improvement/ performs better than the previous model	7
		The old product worked better and more conveniently	The old product functionality was better compared to the new product	10
			Higher complexity of new product	6

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4.3 CONSUMERS' RESPONSES TO A PRODUCT LIFETIME LABEL

	Category	*Code*	*Sub-code*	*# Quotes*
4.3.1	A lifetime label should provide relevant and reliable information	Objectivity is important for the trust in a label	Objective tests are important for a lifetime label	7
		Difficult to incorporate the use (intensity) on a label	Expected use / number of hours should be included on label	5
			Mistrust in lifetime label because dependent on use (intensity/behavior)	9
		Varying responses regarding usefulness of a label	Interested in and seeing the value of a lifetime label	7
			Lifetime label is not useful / not manageable	6
		The importance info of spare part availability on a label	Availability of spare parts and repair service is important for lifetime label	4
4.3.2	Discouraging attitudes toward product repairability	Potential repairs or repairability are not considered by the consumer	Repairability was not considered during purchase	22
			Repair was not considered because this was not necessary	15
		Repairability can have negative associations	Promoting repairability is a negative thing; worries about breaking down easily	4
			The risk of another defect after repair	6
4.3.3	Extended warrantees can stimulate lifetime extension	Repairing a product within warrantee period	Within warranty period, contact seller / manufacturer for repair	13
		A warrantee for a certain lifetime would be preferred	Guarantee of the number of years on the lifetime label is desirable/influential	9
4.3.4	Awareness of environmental impact may encourage lifetime extension	The mentality of consumers to replace, not to repair products	Consumer behavior / mentality of wanting to replace when something is broken	4
			New product (relatively) cheap, repair not worthwhile	7
			Being forced to buy a new product to keep up to date	3
		Low level of knowledge about the environmental aspects of products	Hope that product is recyclable / not sure	6
			The inability to estimate/know if the production was environmentally friendly	4
			Interested in environmental impact, lacking the knowledge	8
		Interest in environmental aspects and moving away from consumption society	The importance of and interest in knowing where products are coming from	3
			Not wanting to go along in consuming society	5

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APPENDIX C – CHAPTER 4 – SCENARIOS FROM STUDY 1A, 1B AND 2

Coffee maker (CM)	Fault indication - Absent	Fault indication – Present	
	Imagine you own a coffee maker. The coffee maker is a mid-range model, and you own it now for 3 years. Until now, it has had a normal performance compared to similar types of coffee makers. When you wanted to use the coffee maker today, you noticed it failed. It was not able to brew coffee properly.		Imagine you own a coffee maker. The coffee maker is a mid-range model, and you own it now for 3 years. Until now, it has had a normal performance compared to similar types of coffee makers. When you wanted to use the coffee maker today, you noticed it failed. It was not able to brew coffee properly. The coffee maker indicated 'fault 2' in its display. The (online) manual indicates 'the rubber seal of the water reservoir is damaged' and needs to be replaced.
Handstick cordless vacuum cleaner (HCVC)	**Fault indication - Absent**	**Fault indication – Present**	
	Imagine you own a stick vacuum cleaner. The stick vacuum cleaner is a mid-range model, and you own it now for 3 years. Until now, it has had a normal performance compared to similar types of stick vacuum cleaners. When you wanted to use the stick vacuum cleaner today, you noticed it failed. It would not turn on and did not function anymore.		Imagine you own a stick vacuum cleaner. The stick vacuum cleaner is a mid-range model, and you own it now for 3 years. Until now, it has had a normal performance compared to similar types of stick vacuum cleaners. When you wanted to use the stick vacuum cleaner today, you noticed it failed. It would not turn on and did not function anymore. A red-light icon appears on the stick vacuum cleaner when placed in the charging station. The (online) manual indicates 'the battery is damaged' and needs to be replaced.

Cylinder vacuum cleaner (CVC)	Fault indication - Absent	Fault indication – Present	
	Imagine you own a vacuum cleaner. The vacuum cleaner is a mid-range model, and you own it now for 4 years. Until now it has had a normal performance compared to similar types of vacuum cleaners. When you wanted to use the vacuumcleaner today, you noticed it had lost its suction power, and did not function properly anymore.		Imagine you own a vacuum cleaner. The vacuum cleaner is a mid-range model, and you own it now for 4 years. Until now it has had a normal performance compared to similar types of vacuum cleaners. When you wanted to use the vacuumcleaner today, you noticed it had lost its suction power and did not function properly anymore. A red-light icon appears on the vacuumcleaner. The (online) manual indicates 'the filter is damaged' and needs to be replaced
Washing machine (WM)	**Fault indication - Absent**	**Fault indication – Present**	
	Imagine you own this washing machine. The washing machine is a mid-range model, and you own it now for 6 years. Until now, it has had a normal performance compared to similar types of washing machines. When you wanted to use the machine today, you noticed it failed. You were not able to activate the wash programs anymore.		Imagine you own this washing machine. The washing machine is a mid-range model, and you own it now for 6 years. Until now, it has had a normal performance compared to similar types of washing machines. When you wanted to use the machine today, you noticed it failed. You were not able to activate the wash programs anymore. The washing machine indicated fault 5 in its display. The (online) manual indicates 'the drum bearings are damaged' and need to be replaced.

APPENDIX D – CHAPTER 6 – PRETEST OUTCOMES STUDY 1

Table showing the average means of the importance of each attribute

'Please indicate your personal preference for each characteristic on different levels'	Scale 1: Preferred 2: Acceptable 3: Undesirable 4: Unacceptable	M(SD)
Speed of the repair service		
The repair is done while you wait (within 1 hour)		1.10(.40)
The repair is done within 3 hours		1.40(.52)
The repair is done within 12 hours		1.80(.64)
The repair is done within 24 hours		**2.00(.66)**
The repair is done within 1-3 working days		2.76(.79)
The repair is done within 3-5 working days		3.26(.68)
Distance of the repair service		
The product is picked up and sent back to you		1.96(.86)
A repair service is available within a total traveling time of 10 min		1.24(.53)
A repair service is available within a total traveling time of 20 min		**1.73(.59)**
A repair service is available within a total traveling time of 30 min		2.05(.71)
The product should be sent from a local post office and sent back to you		2.85(.78)
Costs of the repair service		
50 euros		**1.15(.40)**
100 euros		**2.30(.71)**
150 euros		3.04(.65)
200 euros		3.58(.59)
250 euros		3.77(.42)
Warranty of the repair service		
A warranty of 12 months		1.12(.33)
A warranty of 6 months		**1.93(.58)**
A warranty of 3 months		2.58(.75)
A warranty of 1 month		3.18(.75)
No warranty		3.80(.43)

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APPENDIX E – CHAPTER 6 – SCENARIOS FROM STUDY 1 AND 2

For study 1, 6 condition were used. In the 5 different score conditions, the visuals on the bottom right were used. In the control condition, the reliability score visual and text were removed (nb. the (dashed) lines were not visible for the participants).

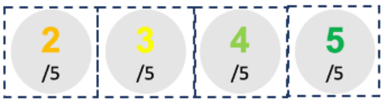
Imagine you own this **smartphone**. The smartphone is from a known brand and has a normal performance compared to similar smartphones. The purchase price was around 500 euros, and you have owned it for 2 years and 2 months.

When purchasing this smartphone, you were informed about the product's **reliability** compared to other smartphones (i.e., the robustness and how well the product will retain its original quality over time) with a score. The score was presented on a **label** and determined by an **independent and trustworthy institution**.

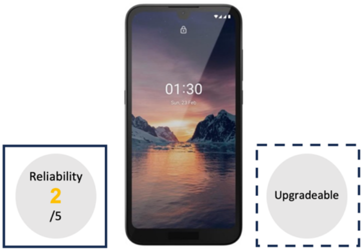
The smartphone scores a 1/2/3/4/5 out of 5 (1: lowest – 5: highest) for the reliability label

Due to a drop on the floor, the smartphone's screen is cracked in such a way that you can no longer use it properly. You found a professional repair service with the following offer:

- The repair is done within 24 hours
- The service is reachable within 20 min traveling time
- A warranty of 6 months is offered
- The repair costs are 75 euros



For study 2, also 6 conditions were used. In the different conditions, the different scores and upgradeable visuals on the bottom right were used. In the control condition, both the reliability and upgradeability visuals and texts were removed (nb. the (dashed) lines were not visible for the participants)



Imagine you own this **smartphone**. The smartphone is from a known brand and has a normal performance compared to similar smartphones. The purchase price was around 500 euros, and you have owned it for 2 years and 2 months.

When purchasing this smartphone, you were informed about the product's **reliability** compared to other smartphones (i.e., the robustness and how well the product will retain its original quality over time) with a score. The score was presented on a **label** and determined by an **independent and trustworthy institution**.

The smartphone scores a 2/5 out of 5 (1: lowest – 5: highest) for the reliability label

Additionally, the smartphone is upgradeable. This means the product's performance can be raised to a higher standard (i.e., upgraded) by adding or replacing physical components.

Unfortunately, the smartphone's camera was damaged when it fell and you can no longer use it properly. You are deliberating if you would repair or replace this smartphone. While deliberating, you come across a professional repair service that has the following offer:

- The repair is done within 24 hours
- The service is reachable within 20 min traveling time
- A warranty of 6 months is offered
- The repair costs are 125 euros
- The broken camera will be upgraded with one of improved quality (i.e., higher camera resolution)

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PRESENTING AT CIRCULAR DESIGN FORUM - DUTCH DESIGN WEEK 2022 EINDHOVEN

ABOUT THE AUTHOR

Renske van den Berge was born on 17th of May 1992 in Leeuwarden, The Netherlands, where she obtained her grammar school degree in 2010 at Stedelijk Gymnasium Leeuwarden. She pursued in Delft a bachelor's degree in Industrial Design Engineering at Delft University of Technology with a minor in Biomedical Engineering at the faculty of Mechanical Engineering. In her bachelor's, she developed her interest in Sustainability and organized the Cleantech Challenge in 2014 to support young entrepreneurs in developing their green business ideas.

During her master's Strategic Product Design in Delft, she was involved in two internal projects at Unilever and Eneco and did an 6-months internship at Sunidee, a strategic design agency. Following her interest in Sustainability, she did a graduation internship at De Groene Grachten, which was about customer engagement in the process of making historical buildings more sustainable. After graduating in 2017, she worked for 1,5 years at a multinational FMCG company. This is were she learned that selling as much products as possible was not for her.

She became eager to change this and went back to Delft to start her Ph.D. in 2019. She joined the PROMPT project as a work package leader and studied the consumer aspects of product lifetime extension of electronic products. In this role, she wrote several academic papers, project reports, and presented her work to field-related researchers, policymakers, and industry. She took the lead in developing testing criteria to prematurely assess the consumer and market aspects of premature product replacement for which she organized and facilitated several (online) workshops. Furthermore, she was involved in both bachelor's and master's courses as a coach and lecturer and supervised multiple graduation students. During her Ph.D. she exhibited her work at Dutch Design Week in 2022 and presented her work at multiple international conferences.

It is Renske's both professional and personal mission to contribute to the transition to a more sustainable and circular society. In the future, she is eager to pursue her career within the field of circular economy and sustainability. She aspires to apply the acquired knowledge and skills of the Ph.D. into both research and practice.

LIST OF PUBLICATIONS

JOURNAL PUBLICATIONS

- Van den Berge, R., Magnier, L., & Mugge, R. (2023). Sparking the Repair "Can-Do" Attitude: Enhancing Users' Willingness to Repair through Design Support in Fault Diagnostics. International Journal of Design, 17(3), 25-39. https://doi.org/10.57698/v17i3.02
- Van den Berge, R., Magnier, L., and Mugge, R. (2023). Until death do us part? In-depth insights into Dutch consumers ' considerations about product lifetimes and lifetime extension. Journal of Industrial Ecology, 27(3), 908-922. https://doi.org/10.1111/jiec.13372
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- Van den Berge, R. B. R., Magnier, L. B. M., & Mugge, R. (2023). The influence of a modular design and facilitating cues on consumers' likeliness to repair electronic products. In *5th PLATE (Product Lifetimes and the Environment) Conference Espoo, Finland, 31 May – 2 June* (pp. 1108-1114). Aalto University
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PROMPT PROJECT REPORTS

- Mugge, Van den Berge & Magnier (2023). Design guidelines to prevent premature obsolescence from a user/market perspective, D5.4 Report for the PROMPT project
- Van den Berge (2023). Testing Procedures for Premature Replacement form a user/market perspective: an iterative workshop-based approach, D5.3 Report for the PROMPT project
- Van den Berge, Magier, Mugge (2023). Premature replacement of well-functioning products and choice for replacement over repair, D5.2 Report for the PROMPT project
- Van den Berge & Thysen (2020). State- of-the-art knowledge on user, legal and market related issues of premature obsolescence, D2.6 Report for the PROMPT project

The production and consumption patterns of electronic products exceed the limits of what one planet can handle. Prolonging product lifetimes decreases value losses caused by the destruction of existing products and lowers the amount of waste within a circular economy. Repair is one of the most impactful strategies to prolong product lifetimes. However, at date, most discarded electronic products are never repaired during their lifetime.

The objective of this thesis is to explore the role of design in stimulating consumers to prolong product lifetimes through repair. A consumer perspective investigates how and why consumers decide to prematurely replace their products and their barriers towards repair. Several strategies to stimulate lifetime extension are identified. Their effectiveness, boundaries and the required conditions are tested in multiple empirical consumer studies.