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Are short product lifetimes ineluctable? An exploration of consumers’ perceptions of lifetime extension strategies

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Abstract: There is consensus that product lifetimes are generally decreasing. To create a sustainable society, the circular economy promotes slowing down the use of resources by lengthening product lifetimes. This is especially important for electronic products that are energy-intensive in their production phase and create vast amounts of waste after use. While design strategies have been proposed to lengthen product lifetimes, it is unclear whether consumers deem them effective. This paper proposes an overview of lifetime extension strategies for electronic products and reports the results of a quantitative study with 617 participants who were asked to evaluate the extent to which these strategies could have extended the lifetime of a recently replaced product. Results indicate that the durability / reliability strategy is most effective. However, consumers are not yet convinced of the effectiveness of most strategies.

Keywords: product lifetime; premature obsolescence; lifetime extension strategies; consumer perceptions

1. Introduction

The production of electronic products contributes greatly to the emissions of greenhouse gases, especially in the stage of raw materials extraction and during the manufacturing of the components. For example, 600 kilograms of raw materials are needed to manufacture a laptop of 2kg[1]. The end of life of these products also creates vast amounts of waste and pollution. In Europe only, electronic products created 12Mt of waste per year in 2020 growing at 3-5% per year[2].

To limit these negative impacts, recycling is important but can only represent a part of the solution. The design of electronic products often makes it difficult and costly to recycle

[1] ADEME (2021). La face cachée du numérique. Available at this link
[2] https://prompt-project.eu/

them. Moreover, as demand for electronic products continues to increase, the amount of recycled materials is not sufficient to cover it. In addition to recycling, it is therefore essential to lengthen product lifetimes (Cooper, 2005). Lengthening product lifetimes enables to reduce the material and energy throughput related to electronic products by fighting premature obsolescence (Hickel, 2020). In this way, it is possible as a society to move to a situation of degrowth and dematerialization, while maintaining the current level of welfare. Literature has highlighted various opportunities to increase the lifetime of products via useful second lives, such as refurbishment (van Weelden, Mugge, & Bakker, 2016; Wallner, Magnier, & Mugge, 2020). However, considering that many replaced products are not resold or do not enter the circuits of refurbishment, much value can be obtained by increasing the lifetimes of products at their first owner by postponing replacement (van den Berge, Magnier, & Mugge, 2021).

Literature in design has defined several product and service design strategies to prolong the lifetime of products. Long-lasting product designs (Cordella, Alfieri, Clemm, & Berwald, 2021; Den Hollander, Bakker, & Hultink, 2017) aim to keep the product attractive and functioning in its initial state for as long as possible. Repairable designs aim to ease the repair of products when a failure occurs (Mashhadi, Esmaeilian, Cade, Wiens, & Behdad, 2016; Van Nes & Cramer, 2005; Vanegas et al., 2018). Design for maintenance strategies aim to facilitate product care acknowledging that a product that is well taken care of tends to last longer (Ackermann, Mugge, & Schoormans, 2018). However, these strategies almost always require an action from the consumer (e.g., by taking into account certain aspects at purchase even though that may result in a higher price or by undertaking repair actions). Only if consumers consider these to be effective, the strategies can either serve as a relative advantage at purchase or can persuade them to take action during ownership and postpone replacement. Consequently, for these strategies to work, consumers need to deem them valuable and effective for postponing a possible replacement. With this research, we contribute to the existing literature on lifetimes, by testing whether the existing strategies to prolong the lifetime of electronic products are deemed effective by consumers for postponing their possible replacement. Furthermore, we compare the perceived effectiveness of these strategies for various product categories.

The remainder of the paper is organised as follows. First, design strategies to extend product lifetimes are structured in three categories: long-lasting product design strategies, design for repair and design for maintenance strategies. Second, we present the results of a quantitative study in which we tested the extent to which these strategies would have been considered effective to prolong the lifetime of a recently replaced electronic product. Eventually, results are discussed and avenues for future research are presented. In addition to the theoretical contribution, we believe that our findings are relevant for companies and policy organisations that aim to lower the environmental impact of consumption.

2. Design strategies to extend product lifetimes

2.1. Long-lasting product design strategies

Durability / reliability

The term *durability* can be defined as the ability for a product to function as required, under defined conditions of use, maintenance and repair, until a limiting state is reached (Cordella et al., 2021). A physically durable design enables to sustain the functional value of a product and as such its longevity (Cordella et al., 2021; Den Hollander et al., 2017; Mugge, Schoormans, & Schifferstein, 2005; Van Nes & Cramer, 2005). A durable design is made of more robust materials and components, which are less likely to break down or show signs of usage.

Additionally, a durable design can indirectly prevent premature obsolescence via consumers' lifetime expectations. Consumers have expectations about product lifetime, which are transferred into the product's mental book value (van den Berge et al., 2021). If consumers expect the product to last relatively longer, for example because it looks very robust (Mugge, Dahl, & Schoormans, 2018), it will take more time before they feel that the product has made its money's worth.

Physical and software upgrades

Physical upgrades consist in raising a product's performance to a higher standard by adding or replacing physical components in the product. Upgradeable products are modular and provide options to improve certain components in the future (Khan, Mittal, West, & Wuest, 2018; Michaud, Joly, Llerena, & Lobasenko, 2017). Also referred to as evolvability (Haines-Gadd, Chapman, Lloyd, Mason, & Aliakseyeu, 2018), upgradeability entails that products are designed to adjust to developing needs and/or technology with more advanced parts and additional functionalities. Upgradeability can also enable to improve the physical appearance of a product. While consumers are positive towards upgradeable products (Brusselaers, Bracquene, Peeters, & Dams, 2019; Sabbaghi, Cade, Behdad, & Bisantz, 2017; Ülkü, Dimofte, & Schmidt, 2012), upgrades remain rather underdeveloped in the market.

Software updates and upgrades consist of small, frequent improvements that happen to the existing software programs of a product. Updates are needed for many products to continue running successfully during usage because they fix, for example, new security issues, recently discovered bugs and add support for newly developed hardware that should communicate with the product. The discontinuation of software support represents an important source of obsolescence for smart products (Park, 2016). Software upgrades are less common and provide significant improvements. A software upgrade is a new version of the software that incorporates new functionality. Next to functional value, a software upgrade can make the product feel 'new' (Farhang, Weidman, Kamani, Grossklags, & Liu, 2018).

Graceful ageing

Products can offer emotional value to consumers via their aesthetics (Sheth, Newman, & Gross, 1991). Usually, signs of usage decrease a product's aesthetic appeal, making it less desirable. Past research demonstrated that the dirty appearance of a vacuum cleaner would decrease its lifetime (Harmer, Cooper, Fisher, Salvia, & Barr, 2019). This suggests that a need exists for products' aesthetics to be resilient towards wear (Haug, 2018). It is therefore important to select materials that age gracefully, are not easily damaged or contaminated during use and that are easy to clean (Lilley, Bridgens, Davies, & Holstov, 2019; Lilley, Smalley, Bridgens, Wilson, & Balasundaram, 2016; Mugge et al., 2005). Another novel technological opportunity is the use of self-healing materials and coatings, which have a built-in ability to automatically repair damages to the material surface, such as scratches (Chang, Panhwar, & Zhao, 2020; Sumerlin, 2018). For example, applying these self-healing materials in smartphones would help to mend broken screens.

Timeless design

Products can also lose (some of) their aesthetic value as a result of fashion style changes. However, not all styles are equally susceptible to move to a state of distaste. Some styles enjoy short-lived popularity and disappear quickly, while others remain accepted over a long period of time. By implementing a timeless design, the aesthetic value of a product can be sustained for a longer period of time (Flood Heaton & McDonagh, 2017; Mugge et al., 2005; Wallner et al., 2020). Timeless or classic designs are visually simplistic, ordered and harmonious. Furthermore, timeless designs generally make use of neutral colours. 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, Mugge, & Huinink, 2014; Veryzer Jr & Hutchinson, 1998)

2.2. Design for repair strategies

Extended warranties

Providing extended warranty possibilities may also help in increasing the lifetime of a product (Ertz, Leblanc-Proulx, Sarigöllü, & Morin, 2019). Consumers' attitude towards repair may be different if the malfunctioning takes place within the warranty period. Manufacturers will generally repair the product without any costs involved for the user. Consumers are therefore likely to choose the free repair option instead of replacing their product.

Modularity

Enabling reparability consists in assisting users in repairing the product when it is malfunctioning (Den Hollander et al., 2017; Mugge et al., 2005; Van Nes & Cramer, 2005). Consumers often decide to replace products because of a minor defect. To encourage repair, the product should be designed in a way that repair is possible and easy. In this respect, the product should be easy to disassemble, frequently malfunctioning components should be easily accessible, and standard tools should be used for repair (Flipsen, Bakker, & de Pauw, 2020). Another possibility is to have a modular design that is made up of modules or building blocks (Bonvoisin, Halstenberg, Buchert, & Stark, 2016; Hielscher, Jaeger-Erben, & Poppe, 2020). By replacing defective modules with new ones, it is possible to easily replace certain malfunctioning or damaged components. It is however important to note there may be a trade-off between better reparability through increased modularity and the reliability of the device (e.g., water and dust protection or shock resistance).

Self-repair guide

Consumers often do not have the knowledge and skills to repair products and feel it is unsafe to do it themselves (Arcos, Dangal, Bakker, Faludi, & Balkenende, 2021; Bakker, Mugge, Boks, & Oguchi, 2021; Jaeger-Erben, Frick, & Hipp, 2021). It is therefore important to provide consumers with more guidance in the fault diagnosis to initiate repair. For example, it would be valuable if products communicate the most frequently occurring faults directly to the consumer. Consumers can then use the (online) manual to obtain a step by step guidance on how to proceed in order to tackle this fault successfully.

Professional repair services

It should be noted that 'design for repair' does not necessarily imply that repair is conducted by the consumer him/herself. Companies may offer or team up with professional repair services that can help to execute the repair. However, similar barriers may be relevant for these services. Consumers will only contact repair services if they have confidence in a successful repair that is not too expensive (Jaeger-Erben et al., 2021). Furthermore, other service characteristics, such as the time needed for repair, the responsiveness of the helpdesk, and the availability of a temporary replacement product can increase the likelihood to use these services.

Cheaper and available spare parts

The unavailability and the high price of spare parts often constitute a major barrier to repair (Jaeger-Erben et al., 2021). Consequently, to increase the ability of consumers to repair their products, companies may give the rapid supply of spare parts for their products at an affordable price a central place in their business model.

2.3. Design for maintenance strategies

Design for user care behaviour

Maintenance[3] is defined as an "action carried out to retain a product in a condition where it is able to function as required". Product maintenance (or product care) consists of activities of care and maintenance as well as other protective measures (e.g., a smartphone cover)

[3] EN 45552:2020

that can keep the product in a proper working condition for a longer period of time (Ackermann et al., 2018; Den Hollander et al., 2017). By supporting the user to take good care of their products, the functional value of the product can be kept at a high level for a longer period of time. Furthermore, proper maintenance can positively affect the emotional value as it can result in a better preservation of the aesthetics of products. For most products, some advice on maintenance activities is provided. For example, in online or physical manuals or labels (e.g., for clothing items) specific care instructions are generally provided to consumers. Unfortunately, many consumers still fail to execute maintenance activities on their products on a regular basis (Ackermann et al., 2018), often resulting in a premature loss of value. This implies that design for maintenance should not only focus on providing instructions on how to execute maintenance activities but also on truly supporting users to do this when the time is right.

Maintenance subscription

Regular maintenance service can be provided by professional service companies (e.g. via a maintenance contract)(Ackermann et al., 2018). Such maintenance services are already common for heating system and cars but could also be valuable for other products. Especially for products that are difficult to maintain because it would require technological equipment and/or knowledge, regular maintenance services can provide a solution to keep the product's value at the original high level, thereby postponing replacement and lengthening its lifetime (Ertz et al., 2019).

3. Study method

3.1 Selection of product categories

In this study, we decided to focus on four different categories of electronic products: smartphones (SP), vacuum cleaners (VC), televisions (TV) and washing machines (WM). These appliances are used frequently and are widely present in households. Furthermore, extending the lifetimes of these products can have a significant impact on the environment because the carbon emissions during production are substantial and much waste is produced when they are disposed of. Finally, these product categories score differently on a series of criteria that may explain differences in terms of product longevity (see Table 1).

Table 1 Criteria used to select a diverse range of product categories.

Criteria	SP	VC	TV	WM	Explanation
Portability	√	√			Portable products may be more susceptible to external, or appearance damages.

Utilitarian		√		√	Products that are used for cleaning activities may have strong utilitarian functions to the user
Symbolic	√		√		Products that are visible to other people may have symbolic functions to the user.
Hedonic	√		√		Products that are mostly used for leisure/pleasurable activities, may have hedonic functions to the user
Battery	√	(√)			Products with a battery, such as smartphones and cordless vacuum cleaners, may be more prone to be replaced early in their lifetime because of reduced battery capacity

Distinguishing these four different categories can help to get a broader view of how consumers perceive lifetime extension strategies across different product categories.

3.2 Recruitment of participants and final sample

We recruited participants who had recently replaced one of the target product categories to ensure that they still remembered accurately, the reasons why and the conditions in which they decided to replace their old product. To reach these participants, we conducted a pre-screening study using the Prolific panel. Participants were presented with a list of products and asked to select the product(s) that they had replaced in the last 6 months (*Please indicate for all of the following product categories whether you have replaced these in the last 6 months. With replaced, we mean that you acquired a new product that is intended to take over the function of another 'old' product. The 'old' product can be disposed of or kept as a back-up product. Multiple answers are possible. Please tick the products that you replaced in the last 6 months*). In order to prevent opportunistic behaviours from panelists who wanted to receive the compensation for completing the questionnaire without actually having replaced their product recently, we included our four products in a broader list of 9 electronic products (also including a dishwasher, laptop, coffee machine, camera, and refrigerator). In addition, the option 'None of the above' was available to participants.

To get more diversity in our responses, the pre-screening was sent to Prolific panelists in six European countries (United Kingdom, France, Germany, the Netherlands, Belgium and Spain). The pre-screening questionnaire was therefore translated from English to French, Dutch, German and Spanish by native speaking researchers. We used the Qualtrics platform to collect responses and participants were given the opportunity to select their preferred language in a drop down menu. In total, we reached out to 2477 individuals (UK: *N*=513; Germany: *N*=478; Spain: *N*=500; The Netherlands: *N*=412; Belgium: *N*=238; France: *N*=336).

The participants that were recruited during the pre-screening survey were invited to participate in the main questionnaire using their unique Prolific identifier. Each participant was allocated to the product category that they declared having replaced. The four questionnaires were sent to 691 individuals (smartphone: N=211; vacuum cleaner: N=175; television N=162; washing machine: N=143) with a specific note that they had been selected to participate to an extensive questionnaire about the replacement of their [product] based on their responses to a pre-screening questionnaire. After participants who had failed the attention check were removed, the final sample consisted of 617 participants (response rate 89.3%). Overall the sample was diversified in terms of gender (Female=314) and age (Min_{age}=20; Max_{age}=72, M_{age}=34.64, SD=9.54). Upon completion of the questionnaire, participants received a small monetary compensation.

Development of the main questionnaire

Data for the main questionnaire was gathered in May 2021 through an online questionnaire. The purpose of this questionnaire was to uncover whether participants considered that the design strategies to prolong product lifetime would have been effective to postpone the replacement of their old product. Participants were therefore presented with a short description of each of these strategies and were asked to think about the extent to which the design features and behaviour could have prevented or postponed their decision to replace their product. In the instructions, we acknowledged that the proposed features may not have been present in their product but asked them to answer the question based on the assumption that they would have been. First, strategies related to long-lasting product design were presented to participants. These strategies were durable / reliable design, upgradeable design (physical and software), design for graceful ageing (i.e. self-healing materials), and timeless design. Second, participants were presented with strategies of design for repair. These strategies consisted of extended warranty, modularity, presence of a self-repair guide, subscription to a contract including repair services, better availability of spare parts, and cheaper spare parts. Third, the strategies of design for maintenance, users' care behaviour and subscription to maintenance services, were presented to them. The extent to which they believed the strategies could have postponed the replacement of the old product was measured on 7-point Likert scales going from 1='very unlikely' to 7='very likely' for each of these strategies.

4. Results

4.1. Most effective strategies to postpone replacement per product category

It is important to note that the analysis of the means shows that on average participants rated the effectiveness of almost all strategies below the neutral midpoint (cf. table 2). This demonstrates that participants were generally doubtful about the extent to which the strategies could have postponed the replacement of their products. Participants only perceived durable design to be somewhat effective in the product categories smartphones, vacuum cleaners, and washing machines.

Among the strategies to postpone the replacement of *smartphones*, a durable design (M=4.37) was the most likely to be effective. Next, the ability for the user to replace a component by one of higher standards, that is physical upgradeability, was ranked second (*M*=4.31). Third, modularity (*M*=4.03) was also considered as one of the more effective strategies for the smartphone category. With regards to *vacuum cleaners*, the most effective strategies to postpone replacement in the eyes of participants were a durable design (*M*=4.73), a better availability of spare parts (*M*=3.81) and cheaper spare parts (*M*=3.88). For *televisions*, the most effective strategies rated by participants were physical (*M*=3.70) and software (*M*=3.68) upgradeability, followed by a durable design (*M*=3.46). Finally, the most effective strategies to postpone the replacement of *washing machines* were a durable design (*M*=4.81), followed by modularity (*M*=4.07) and cheaper spare parts (*M*=3.89).

Taken together and although participants did not rate these strategies as very likely to postpone or prevent the replacement of their product (i.e. mean scores were close to the neutral mid-point scale), durable design (*M*=4.34), physical upgradeability (*M*=3.80) and modularity to increase reparability (*M*=3.74) appeared to be the most effective strategies to postpone the replacement of product and thereby preventing premature obsolescence.

4.2. Differences between product categories in the likeliness of the strategies to postpone replacement.

To determine whether the proposed strategies were more likely to postpone replacement for some product categories than for others, we conducted a series of analyses of variances (ANOVAs) or Kruskal-Wallis tests – when the assumptions for parametric tests were violated - with the extent to which the different strategies could have postponed replacement as dependent variables and the product categories as independent variable. When the analyses of variance or the Kruskal-Wallis tests were significant, we conducted post-hoc tests adjusted with the Bonferroni correction for multiple tests to determine where the differences occurred between the conditions. Only significant differences are presented in this section.

4.2.1. Long-lasting product design strategies

A Kruskal-Wallis test showed significant differences (*H*(3)=31.037; *p*<.001) between the product categories in the extent to which participants thought that *a durable/reliable design* could have postponed the replacement of their product. Specifically, the effectiveness of a durable design was rated significantly lower for televisions than for all other product categories (smartphones: *p*<.01; vacuum cleaners: *p*<.001; washing machines : *p*<.001).

Similarly, there were significant differences between product categories in the likeliness of *physical upgradeability* to postpone products replacement (*H*(3)=18.301, *p*<.001). Specifically, this strategy was rated higher for smartphones (*M*=4.31) than for all other product categories (vacuum cleaners: *p*<.01; televisions: *p*<.05; washing machines: *p*<.01). When it comes to *software upgradeability* (*H*(3)=36.534, *p*<.001), this strategy was rated as significantly more likely to postpone the replacement of smartphones and televisions compared to vacuum cleaners (*p*<.001; *p*<.001, respectively) and washing machines (*p*<.01, *p*<.01, respectively). Furthermore, this strategy was rated significantly higher for washing machines than vacuum cleaners (*p*<.05).

Next, the likeliness of *self-healing materials* to postpone product replacement was also significantly different between product categories (F(3,613)=7.436, p<.001). This strategy was rated significantly higher for smartphones than for televisions (*p*<.001) and vacuum cleaners (*p*<.05). Additionally, it was rated higher for washing machines than for televisions (*p*<.05).

When it comes to *timelessness* as a design strategy, there were no significant differences between product categories in their likeliness to postpone participants' replacement (*p*>.26).

4.2.2. Design for repair strategies

There were also differences between product categories in the likeliness of an *extended warranty* to postpone product replacement (F(3, 613)=3.775, p<.05). Specifically, this strategy was considered more likely to postpone replacement for washing machines than for televisions (*p*<.01).

An analysis of variance showed that there were also significant differences between product categories in the likeliness of *modularity* to have increased the lifetime of participants' products (F(3, 613)=7.847; p<.001). Here again, the effectiveness of modularity was rated significantly lower for televisions (M=3.07) than for all other product categories (smartphones: *p*<.001; vacuum cleaners: *p*<.05; washing machines: *p*<.001).

The availability of a *self-repair guide* also led to differences between product categories (H(3)=30.405, p<.001). This strategy appeared less likely to postpone the replacement of televisions than all other product categories (smartphones: *p*<.001; vacuum cleaners: *p*<.001; washing machines: *p*<.001).

The results of an ANOVA with *subscription to repair services* as a dependent variable (F(3,613)=8.698, p<.001) appeared to be significantly more likely to postpone the replacement of washing machines than all other product categories (smartphones: *p*<.01; vacuum cleaners: *p*<.05; televisions: *p*<.001).

The *better spare parts availability* (H(3)=41.285, p<.001) was less likely to postpone the replacement of televisions than all other product categories (smartphones: *p*<.001; vacuum cleaners: *p*<.001; washing machines: *p*<.001).

Similarly, *cheaper spare parts* (F(3,613)=9.960, p<.001) were less likely to postpone replacement of televisions than all other product categories (smartphones: *p*<.001; vacuum cleaners: *p*<.001; washing machines: *p*<.001).

4.2.3. Design for maintenance strategies

A Kruskal-Wallis test with the extent to which *user care activities* could have postponed replacement as a dependent variable also led to significant differences between categories (H(3)=38.213, p<.001). Specifically, this behaviour was less likely to postpone the replacement of televisions (*M*=2.39) than all other product categories (smartphones: *p*<.001; vacuum cleaners: *p*<.001; washing machines: *p*<.001).

A Kruskal-Wallis test showed differences between product categories in how likely a *subscription to maintenance services* would postpone product replacement (*H*(3)=24.773, *p*<.001). Precisely, such a strategy was more likely to postpone the replacement of washing machines than all other product categories (smartphones: *p*<.01; vacuum cleaners: *p*<.05; televisions: *p*<.001). Moreover, results showed that a subscription to maintenance services was less likely to postpone replacement for televisions than for smartphones (*p*<.05) and vacuum cleaners (*p*<.01).

Table 2 Descriptive statistics of the effectiveness of the strategies to prolong lifetimes (7-point scales)

	Smartphones	Vacuum cleaners	Televisions	Washing Machines	Total
Durable / reliable design	**4.37[a]**	**4.73[a]**	**3.46**	**4.81[a]**	**4.34**
	(2.06)	(2.02)	(2.05)	(2.06)	(2.17)
Physical upgradeability	**4.31**	3.58[a]	**3.70[a]**	3.44[a]	**3.80**
	(2.09)	(2.08)	(2.06)	(1.85)	(2.05)
Software upgradeability	3.71[a]	2.34[b]	**3.68[a]**	2.96[b]	3.26
	(2.13)	(1.88)	(2.26)	(2.10)	(2.17)
Self-healing materials	3.70[ac]	3.07[bc]	2.69[b]	3.32[c]	3.22
	(2.06)	(1.90)	(2.02)	(2.04)	(2.04)
Timeless design	2.92[a]	2.83[a]	3.10[a]	2.64[a]	2.88
	(1.94)	(2.10)	(1.96)	(1.89)	(1.97)
Extended warranty	3.10[ac]	3.08[ac]	2.78[bc]	3.63[a]	3.13
	(2.05)	(2.20)	(2.13)	(2.28)	(2.17)
Modularity	**4.03[a]**	3.76[a]	3.07	**4.07[a]**	**3.74**
	(1.99)	(2.14)	(2.02)	(1.96)	(2.06)
Self-repair guide	2.92[a]	3.19[a]	2.25	3.33[a]	2.91
	(1.89)	(2.08)	(1.84)	(2.04)	(2.00)
Subscription to repair services	2.90[a]	2.97[a]	2.44	3.61[a]	2.96
	(1.89)	(2.08)	(1.90)	(1.88)	(1.98)
Better spare parts availability	3.51[a]	**3.81[a]**	2.44	3.70[a]	3.37
	(2.02)	(2.18)	(1.88)	(2.09)	(2.11)
Cheaper spare parts	3.68[a]	**3.88[a]**	2.72	**3.89[a]**	3.54
	(2.11)	(2.20)	(2.14)	(2.11)	(2.18)
User care activities	3.37[a]	3.38[a]	2.39	3.61[a]	3.19
	(1.83)	(1.97)	(1.68)	(1.92)	(1.90)
Subscription to maintenance services	2.71[ac]	2.89[ac]	2.30[a]	3.30[b]	2.79
	(1.76)	(2.05)	(1.75)	(1.81)	(1.87)

SD in parentheses
Best scores per product category in bold
Identical superscripts indicate no difference between the means

4. Discussion and conclusion

The present research suggests that overall consumers were not truly convinced that different lifetime extension strategies could have postponed the replacement of their product. These findings contribute to the existing literature on the topic of product lifetime in which these strategies are presented as promising routes to lengthening lifetimes. While research has demonstrated that the lifetimes of many electronic products have decreased in the past decades, it seems that overall this decrease does not necessarily create dissatisfaction among consumers (Echegaray, 2016). This could explain the fact that consumers do not yet seriously seek ways to extend the lifetime of their products. In addition, literature has demonstrated that consumers believe that companies do not have incentives to increase the lifetimes of the products they put on the market (Echegaray, 2016). Consequently, they may lack trust that these strategies would be really effective to extend the lifetime of products. Finally, consumers often replace well-functioning products when they feel they have made their money's worth (Okada, 2001; van den Berge et al., 2021). In that case, lifetime extension strategies may not be deemed effective to postpone replacement because consumers do not perceive much value in their product anymore and are psychologically ready for their replacement.

Among the strategies that were considered effective, a durable/reliable design, which may help to keep the perceived value of a product high for a longer amount of time, generally seemed to be the most effective. This also confirms prior literature demonstrating that consumers have a higher preference for durability over reparability (Cerulli-Harms et al., 2018). However, products with a durable design logically often come with a higher price tag, which can put off price-sensitive consumers. Lifetime labels could in this case be useful to put a higher price into perspective as consumers then have additional evidence that the product is expected to last longer (Gnanapragasam, Cooper, Cole, & Oguchi, 2017), which on the long run may cost less money than buying new products more often. Future research could therefore study how the presentation of lifetime information on labels may positively influence the choice for a reliable yet more expensive product, among price-sensitive consumers.

Consumers were generally not convinced that strategies enabling them to repair their products more easily would help them to do so, which confirms prior literature advancing that consumers generally do not seek reparability in products (Bovea et al., 2018; Sabbaghi, Esmaeilian, Cade, Wiens, & Behdad, 2016). Too often, consumers do not consider product repair a necessary step towards a sustainable society. Instead they often wrongly consider that it would be a bad investment and consider replacement as a more rational decision (Makov & Fitzpatrick, 2021). Future research should therefore investigate how to decrease the (perceived) costs of repair on the one hand and how to increase the perceived environmental value of repair as well as the perceived effectiveness of each of these repair strategies on the other hand.

When comparing the differences between product categories, it appeared that strategies were considered the most ineffective for the television category with all scores below the neutral midpoint. All in all, many of the strategies were considered less effective for televisions than for other product categories. This could be explained by the fact that televisions are hedonic products with evolving technology and that, nowadays, a majority of them are replaced for reasons other than malfunctioning (e.g. screen size, screen quality) (Hennies & Stamminger, 2016).To decrease the ecological impact of electronic products, government bodies and not-for-profit organisations should raise awareness about the importance of keeping electronic products for as long as possible. Policy-makers should also introduce policies that promote upgradeability as well as repair over replacement. The right-to-repair is a proposed legislation that would for example give product owners the practical means to repair their products. In addition, many of the strategies presented are not (yet) included in the design of products, which may have hindered participants' ability to imagine that these strategies could be effective. While some companies have already paved the way to product longevity by applying the strategies described in this paper, a majority still needs to incorporate these principles into their product design. Designers and managers in these companies should therefore urgently strive to develop new designs for long-lived electronic products and our strategies can help them to do so. Nevertheless, we also realise that some companies may not be easily persuaded to change their practice of producing cheap and short-lived products. Then, policy regulations may be needed to evoke change. For example, it is possible to implement true cost of ownership in the pricing of products, by adding taxes for products with low recyclability or with high carbon emissions. Also, policies may ban marketing campaigns that encourage premature replacement.

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5. References

Ackermann, L., Mugge, R., & Schoormans, J. (2018). Consumers' perspective on product care: An exploratory study of motivators, ability factors, and triggers. *Journal of Cleaner Production, 183*, 380-391.

Arcos, B. P., Dangal, S., Bakker, C., Faludi, J., & Balkenende, R. (2021). Faults in consumer products are difficult to diagnose, and design is to blame: A user observation study. *Journal of Cleaner Production, 319*, 128741.

Bakker, C., Mugge, R., Boks, C., & Oguchi, M. (2021). Understanding and managing product lifetimes in support of a circular economy. In: Elsevier.

Bonvoisin, J., Halstenberg, F., Buchert, T., & Stark, R. (2016). A systematic literature review on modular product design. *Journal of Engineering Design, 27*(7), 488-514.

Bovea, M. D., Ibáñez-Forés, V., Pérez-Belis, V., Juan, P., Braulio-Gonzalo, M., & Díaz-Ávalos, C. (2018). Incorporation of circular aspects into product design and labelling: consumer preferences. *Sustainability, 10*(7), 2311.

Brusselaers, J., Bracquene, E., Peeters, J., & Dams, Y. (2019). Economic consequences of consumer repair strategies for electrical household devices. *Journal of Enterprise Information Management*.

Cerulli-Harms, A., Suter, J., Lanzaat, W., Duke, C., Rodriguez Diaz, A., Prosch, L., . . . Svatikova, K. (2018). Behavioural Study on Consumers' Engagement in the Circular Economy. Final report. LE Europe, VVA Europe, Ipsos, ConPolicy, Trinomics. In.

Chang, T., Panhwar, F., & Zhao, G. (2020). Flourishing Self‐Healing Surface Materials: Recent Progresses and Challenges. *Advanced Materials Interfaces, 7*(6), 1901959.

Cooper, T. (2005). Slower consumption reflections on product life spans and the "throwaway society". *Journal of Industrial Ecology, 9*(1‐2), 51-67.

Cordella, M., Alfieri, F., Clemm, C., & Berwald, A. (2021). Durability of smartphones: A technical analysis of reliability and repairability aspects. *Journal of Cleaner Production, 286*, 125388.

Den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product design in a circular economy: Development of a typology of key concepts and terms. *Journal of Industrial Ecology, 21*(3), 517-525.

Echegaray, F. (2016). Consumers' reactions to product obsolescence in emerging markets: the case of Brazil. *Journal of Cleaner Production, 134*, 191-203.

Ertz, M., Leblanc-Proulx, S., Sarigöllü, E., & Morin, V. (2019). Made to break? A taxonomy of business models on product lifetime extension. *Journal of Cleaner Production, 234*, 867-880.

Farhang, S., Weidman, J., Kamani, M. M., Grossklags, J., & Liu, P. (2018). *Take it or leave it: A survey study on operating system upgrade practices.* Paper presented at the Proceedings of the 34th Annual Computer Security Applications Conference.

Flipsen, B., Bakker, C., & de Pauw, I. (2020). *Hotspot Mapping for product disassembly: A circular product assessment method.* Paper presented at the Electronics Goes Green 2020+(Virtual/online event due to COVID-19): The Story of Daisy, Alexa and Greta.

Flood Heaton, R., & McDonagh, D. (2017). Can Timelessness through Prototypicality support sustainability? A strategy for product designers. *The Design Journal, 20*(sup1), S110-S121.

Gnanapragasam, A., Cooper, T., Cole, C., & Oguchi, M. (2017). Consumer perspectives on product lifetimes: a national study of lifetime satisfaction and purchasing factors.

Haines-Gadd, M., Chapman, J., Lloyd, P., Mason, J., & Aliakseyeu, D. (2018). Emotional Durability Design Nine—A Tool for Product Longevity. *Sustainability, 10*(6), 1948.

Harmer, L., Cooper, T., Fisher, T., Salvia, G., & Barr, C. (2019). Design, Dirt and Disposal: Influences on the maintenance of vacuum cleaners. *Journal of Cleaner Production, 228*, 1176-1186.

Haug, A. (2018). Defining 'resilient design'in the context of consumer products. *The Design Journal, 21*(1), 15-36.

Hennies, L., & Stamminger, R. (2016). An empirical survey on the obsolescence of appliances in German households. *Resources, Conservation & Recycling, 112*, 73-82.

Hielscher, S., Jaeger-Erben, M., & Poppe, E. (2020). Modular smartphones and circular design strategies: The shape of things to come? In *The Routledge Handbook of Waste, Resources and the Circular Economy* (pp. 337-349): Routledge.

Jaeger-Erben, M., Frick, V., & Hipp, T. (2021). Why do users (not) repair their devices? A study of the predictors of repair practices. *Journal of Cleaner Production, 286*, 125382.

Khan, M. A., Mittal, S., West, S., & Wuest, T. (2018). Review on upgradability–A product lifetime extension strategy in the context of product service systems. *Journal of Cleaner Production, 204*, 1154-1168.

Lilley, D., Bridgens, B., Davies, A., & Holstov, A. (2019). Ageing (dis) gracefully: Enabling designers to understand material change. *Journal of Cleaner Production, 220*, 417-430.

Lilley, D., Smalley, G., Bridgens, B., Wilson, G. T., & Balasundaram, K. (2016). Cosmetic obsolescence? User perceptions of new and artificially aged materials. *Materials Design, 101*, 355-365.

Makov, T., & Fitzpatrick, C. (2021). Is repairability enough? big data insights into smartphone obsolescence and consumer interest in repair. *Journal of Cleaner Production*, 127561.

Mashhadi, A. R., Esmaeilian, B., Cade, W., Wiens, K., & Behdad, S. (2016). Mining consumer experiences of repairing electronics: Product design insights and business lessons learned. *Journal of Cleaner Production, 137*, 716-727.

Michaud, C., Joly, I., Llerena, D., & Lobasenko, V. (2017). Consumers' willingness to pay for sustainable and innovative products: a choice experiment with upgradeable products. *International Journal of Sustainable Development, 20*(1-2), 8-32.

Mugge, R., Dahl, D. W., & Schoormans, J. P. (2018). "What you see, is what you get?" Guidelines for influencing consumers' perceptions of consumer durables through product appearance. *Journal of Product Innovation Management, 35*(3), 309-329.

Mugge, R., Schoormans, J. P., & Schifferstein, H. N. (2005). Design strategies to postpone consumers' product replacement: The value of a strong person-product relationship. *The Design Journal, 8*(2), 38-48.

Okada, E. M. (2001). Trade-ins, mental accounting, and product replacement decisions. *Journal of Consumer Research, 27*(4), 433-446.

Park, M. (2016). Defying obsolescence. In *Longer Lasting Products* (pp. 103-132): Routledge.

Sabbaghi, M., Cade, W., Behdad, S., & Bisantz, A. M. (2017). The current status of the consumer electronics repair industry in the US: A survey-based study. *Resources, Conservation and Recycling, 116*, 137-151.

Sabbaghi, M., Esmaeilian, B., Cade, W., Wiens, K., & Behdad, S. (2016). Business outcomes of product repairability: A survey-based study of consumer repair experiences. *Resources, Conservation and Recycling, 109*, 114-122.

Sheth, J. N., Newman, B. I., & Gross, B. L. (1991). Why we buy what we buy: A theory of consumption values. *Journal of Business Research, 22*(2), 159-170.

Snelders, D., Mugge, R., & Huinink, M. (2014). Using social distinctions in taste for analysing design styles across product categories. *International Journal of Design, 8*(3), 23-34.

Sumerlin, B. S. (2018). Next-generation self-healing materials. *Science, 362*(6411), 150-151.

Ülkü, S., Dimofte, C. V., & Schmidt, G. M. (2012). Consumer valuation of modularly upgradeable products. *Management Science, 58*(9), 1761-1776.

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.

Van Nes, N., & Cramer, J. (2005). Influencing product lifetime through product design. *Business Strategy and the Environment, 14*(5), 286-299.

van Weelden, E., Mugge, R., & Bakker, C. (2016). Paving the way towards circular consumption: exploring consumer acceptance of refurbished mobile phones in the Dutch market. *Journal of Cleaner Production, 113*, 743-754.

Vanegas, P., Peeters, J. R., Cattrysse, D., Tecchio, P., Ardente, F., Mathieux, F., . . . Recycling. (2018). Ease of disassembly of products to support circular economy strategies. *135*, 323-334.

Veryzer Jr, R. W., & Hutchinson, J. W. J. J. o. c. r. (1998). The influence of unity and prototypicality on aesthetic responses to new product designs. *24*(4), 374-394.

Wallner, T. S., Magnier, L., & Mugge, R. (2020). An exploration of the value of timeless design styles for the consumer acceptance of refurbished products. *Sustainability, 12*(3), 1213.

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