Long-lasting smart products

Overview of longevity concepts in sustainable ICT and design for sustainability

Özcelik, Aysegül; Löchtefeld, Markus; Tollestrup, Christian

Published in:
DRS2022: Bilbao

DOI (link to publication from Publisher):
10.21606/drs.2022.638

Publication date:
2022

Document Version
Publisher's PDF, also known as Version of record

Jun 25th, 9:00 AM

Long-lasting smart products: Overview of longevity concepts in sustainable ICT and design for sustainability

Ayşegül Özçelik
Aalborg University, Denmark

Markus Löchtefeld
Aalborg University, Denmark

Christian Tollestrup
Aalborg University, Denmark

Citation
Özçelik, A., Löchtefeld, M., and Tollestrup, C. (2022) Long-lasting smart products: Overview of longevity concepts in sustainable ICT and design for sustainability, in Lockton, D., Lenzi, S., Hekkert, P., Oak, A., Sádaba, J., Lloyd, P. (eds.), *DRS2022: Bilbao*, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.638

DRS 2022
Bilbao 25th June — 3rd July

Long lasting smart products: Overview of longevity concepts in sustainable ICT and design for sustainability

Ayşegül Özçelik*, Markus Löchtefeld, Christian Tollestrup
Aalborg University, Denmark
*corresponding e-mail: aoz@create.aau.dk
doi.org/10.21606/drs.2022.638

Abstract: Designing longer lasting smart products need a longevity understanding that is informed by both Sustainable ICT and design for sustainability. By conducting a literature review in both areas, we are able to identify longevity related concepts. We briefly outline these ideas in the two fields before discussing their relationships to reveal how they can contribute to one another. By nourishing the viewpoint from both sides, we broaden our understanding of longevity. We conclude our research by highlighting the gaps that (1) there is a need for applicable coping strategies for smart products, (2) a fair division of responsibilities between the multiple actors, and (3) the need for more interdisciplinary research to clarify longevity considerations.

Keywords: Sustainable ICT, design for sustainability, smart products, longevity

1. Introduction

Since smart products are increasingly becoming part of our lives, their lifespan becomes a critical matter for creating a sustainable future. Smart products are characterized by augmenting a common product (such as coffee machine) with information and communication technology (ICT) to enable new digital services (e.g., remote coffee brewing or creation of specific coffee strength mixtures). Smart product is a blanket term to explain multiple different product categories. Raff et al. (2020) categorize them into: digital (e.g., digital camera, radio station, alarm setting on hi-fi system, iPod first generation), connected (e.g., smart meter, Samsung Hue, wireless printer), responsive (e.g., Amazon Echo, Google home, car lane assist) and intelligent (Nest learning thermostat, driverless vehicles). Even though our focus is on connected products, this paper includes longevity discussions that are relevant for all type of smart products.

Due to their complex characteristics, being able to prolong the lifespan of smart products requires a collaboration and integration between the knowledge of sustainable ICT (SICT) and design for sustainability (DfS) literature. However, to the best of our knowledge, no study exist that discusses longevity by bridging SICT and DfS disciplines. For this we investigate the knowledge of longevity aspects in both SICT and DfS literature by reviewing the literature. We understand that the two disciplines have great potential to inform each other on the concepts that are currently not discussed together. Accordingly, we formulated this study to provide an overview of longevity related concepts to support future long lasting smart products studies. Bridging these two fields might fill the gap in the literature and allow for the design of long-lasting smart products. This study is designed to answer following research question:

How can SICT and DfS inform each other to develop a longevity framework?

To answer this question, we begin by introducing SICT and DfS disciplines and highlight longevity discussions within those disciplines. After introducing our data collection method, we overview longevity related concepts which are currently not discussed together but have large potential to contribute to long lasting smart products. In the discussion, we bridge concepts from both areas through highlighting the connections between them by dividing them into three categories: overlapping, complementary and loosely linked. Then we will conclude this study by showing the significant aspects that might lead future researchers and that might shape future smart product studies.

2. Mapping longevity related concepts in DfS and SICT

Since a smart product is an integrated object, there are several factors that affect its lifetime. Working on longer lasting smart products lead us to consider many requirements and considerations from both SICT and product design literature. Designing longer lasting smart products is a multifaceted problem and bringing together two disciplines increases the problem drastically. From their respective viewpoints, SICT, and DfS approach the longevity challenge differently. In this section, we present the broad perspectives of SICT and DfS under the scope of longevity-related topics.

Sustainability of ICT has become a critical problem and a critical inquiry subject, since its environmental footprint in terms of greenhouse gas (GHG) emissions (Gurova et al, 2020) has drastically increased in the last three decades. Van der Velden (2018) claims that in the sustainability literature ICT is discussed from only two approaches. The first approach advocates that ICT is a neutral tool that might be used on behalf of goodness (or badness) and can be a facilitator of sustainability. Van der Velden points out that the UN sustainable goals (SDG 4,5,6,17) claim that ICT will be a key enabler to reach sustainability. The second approach, on the contrary and not well studied, is uncovering the unsustainability of the ICT itself. Not only does the ICT sector contribute significantly to climate change by energy usage and connected GHG emissions, but also it has embodied energy and material demand created during production that is often bound in non-recyclable hardware (Freitag et al, 2021). Within these studies, longevity related concepts are discussed such as valuable materials, hardware and software obsolescence, open-source software, design for disassembly, as well as maintenance of software and hardware. To solve this problem SICT is also offering company, designer, and user related strategies.

With his critique of the industrial design profession, Papanek (1971) started the questioning into sustainability related considerations, and many have started integrating them into design. From then, it has grown from product focused approaches towards system focused chances and addressed as a socio-technical problem (Ceschin and Gaziulusoy, 2016). Furthermore, thinking beyond linear economy drastically effects the sustainable solutions. Circular economy (Ellen MacArthur, 2013) provided a significant understanding for considering products together with their production system. Withing the scope of DfS, three types of strategies are employed to overcome longevity concerns: product oriented, user oriented and system oriented (Yazirlıoğlu,2021; Doğan& Bakırlıoğlu,2020). Product-oriented strategies, focus on obsolescence, durability, resilience, repairability, modularity, and upgradability. While obsolescence is mostly related to business models and marketing, durability is mostly linked with the production, engineering and life span mostly investigated in relation to user behavior (Jensen et al., 2021). Emotional durability, aging gracefully, product personalization, halfway products, open design are further examples of the user-oriented strategies. Under the system-oriented strategies, integrated scales of design and production for sustainability (see Doğan &Walker, 2008) and product service systems (Vezzoli et al., 2014) can be listed. Furthermore, Circular economy helps us to consider that products potentially can have multiple use- and life cycles (Ellen MacArthur, 2013).

To sum up, while the area of DfS, for example, discusses longevity through concepts such as product obsolescence, product durability or how product-user interactions help the product to last longer, scholars of SICT, focus more on software and hardware to examine longevity-related themes such as software obsolescence. This already demonstrates the different level of maturity between the two fields but also highlights that there is a potential for combining them. Even though these two perspectives have different vocabulary and goals with different directions, we will show how several of them can still be aligned with each other.

3. Methodology

We employed a narrative literature review approach and a scoping study to obtain divergent opinions from two different fields. According to Rozas and Klein (2010), narrative literature reviews report on primary research rather than introducing it, and they all summarize the findings of multiple studies into a single document. We first focused on the concepts of the different fields separately in detail (including reference tracking). However, this was not done systematically, by handpicking and citation and reference tracking - also called snowballing, as summarized in (Shaffril et al., 2021).

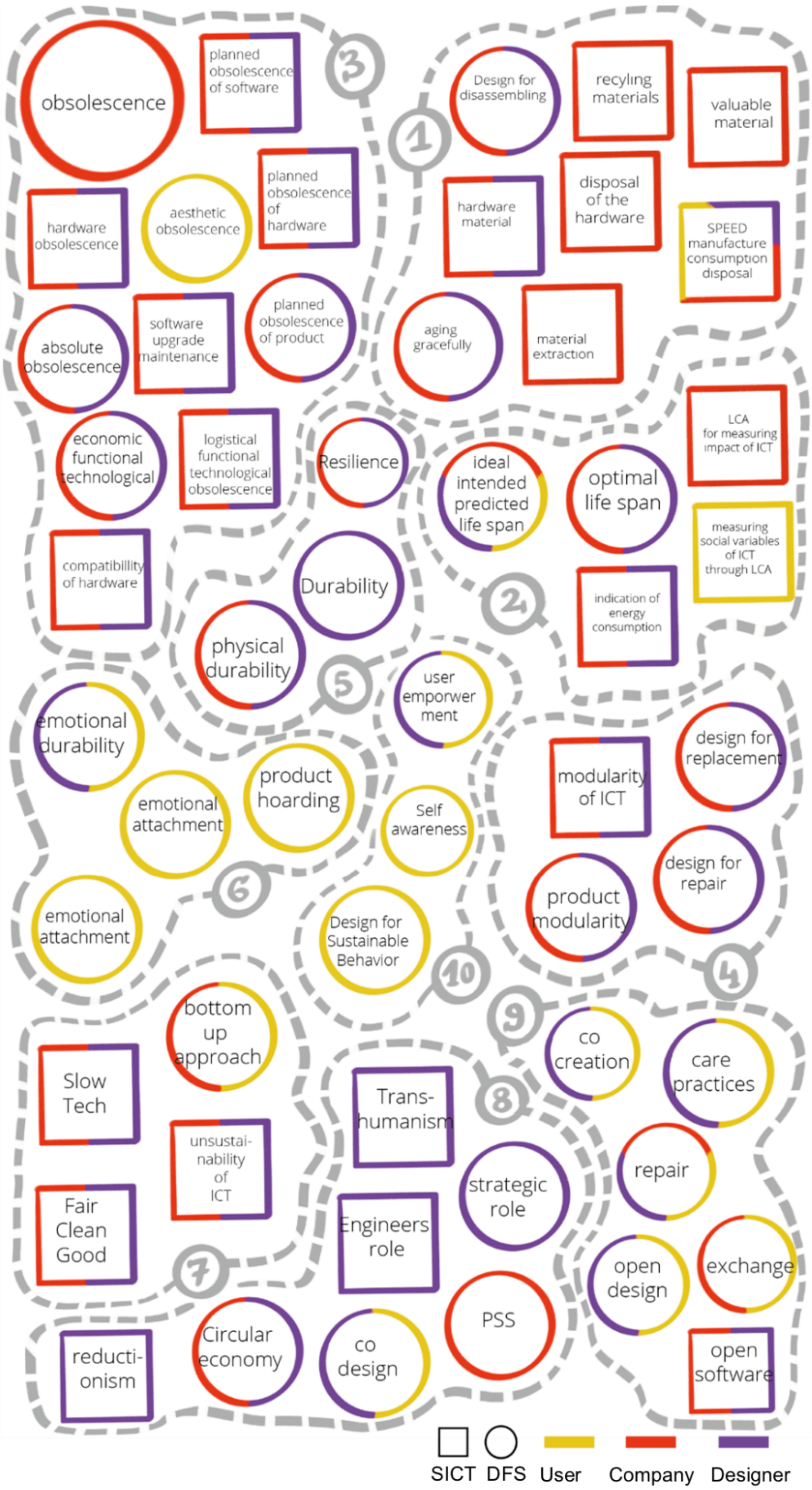

Figure 1. Longevity related concepts clustered as follows: 1-material, 2- life Span, 3- obsolescence, 4- Modularity, 5-durability, 6-acquisition and disposal, 7-social aspect, 8- designer related aspects, 9-user related aspects, 10-design for sustainable behavior. Colors represent the actors that is related with the concept.

Our scoping study (Arksey & O'Malley, 2005) consists of the following steps: we conducted a keyword search for: "ICT", "smart product" "smart electronic", "IOT", "SICT", "Social sustainability and ICT", "environmental sustainability and ICT", "DfS", "sustainability and user" "sustainability and customer", "longevity and product design". By using these keywords, we reviewed EBSCOHost database, citation track forward and backward; search in key journals such as Journal of Cleaner Production and Sustainability which are very well known in sustainable design studies.

We developed clusters based on their focus points after uncovering different approaches across SICT and DfS. For example, whereas material-related thoughts are grouped together in the first cluster, life span concepts are clustered together in the second cluster. We next conducted additional literature searches for each idea to gain a better understanding within these areas (e.g., definition of the concepts, or which actors are related to the concepts). We were able to generate figure 1 and organize the findings section as a result of this procedure. Figure 1 shows the concepts that are retrieved from SICT shown as square, and DfS concepts as circle. Longevity concepts are clustered as follows: 1-material, 2- life Span, 3-obsolescence, 4- modularity, 5-durability, 6-acquisition, and disposal, 7- social aspects, 8-designer related aspects, 9-users related aspects, 10-design for sustainable behavior. While discussing findings, we follow the cluster numbers in figure 1. The colors refer to the involvement of different actors: companies, designers, and users. Afterwards we mapped the connections and links between the concepts of the two fields and analyzed potential for further alignment in the discussion section.

4. Findings

To build a comprehensible framework, this part introduces longevity-related aspects that are taken from both two disciplines. Figure 1 illustrates which concepts are discussed under which cluster.

4.1 Material

Human-centered and technology-centered thinking is a problematic approach in the sustainability of ICT (Van der Velden, 2018), as it may overshadow aspects such as environmental impact. We already exceed our environmental limitations (Raworth, 2017). Therefore, mitigating the environmental impact of manufacturing requires the development of novel sustainable manufacturing information and methods. For these longer lasting materials could be used, however their environmental burden needs to be taken into consideration while making such decisions. However, it is often very challenging to fulfill the sustainability and core requirements of the product simultaneously. Manjunatheshwara and Vinodh (2021) address sustainable electronics production and point out that it requires operational competences, as for example material selection depends on "manufacturing, design, administration and marketing" (p. 546) criteria.

Integration of valuable materials such as iron, aluminum, gold, copper etc. is a necessity for design and production of hardware (Gurova et al, 2020). Designing by considering disassembly of the materials in the recycling phase is a way to preserve valuable materials. However, in line with LeBel (2016), SICT should go beyond recycling and consider slowing down production rate, consumption, and disposal pace. Reuse and remanufacturing are important overcoming strategies that should be promoted more. One example of how this promotion could happen are the medals of the Tokyo Olympics, which were made of metals extracted from recycled consumer electronics.

The concept of aging with dignity is concerned with considering material wear and tear as a factor in the design (Mugge, 2018). That is a strategy to overcome aesthetic aspects of material. Facilitating replacement, maintenance repair of product parts is pointed out as potential functional aspects of materials. Similarly, Van Nes (2010) argues for mitigation strategies for the deterioration of functional materials, such as “make most wearing parts easily changeable, self-detection of defective parts, providing a spare button and ordering of repair parts through the internet”. Terzioğlu (2017), even suggests the visible repair aspect, by indicating the repair as both a creation of aesthetics and practical maintenance of the product. These viewpoints are also taken up again in the discussion on repair later.

4.2 Life Span

One of the key tools to quantify the ecological impact of a product is Life Cycle Analysis (LCA). It examines the environmental impact of all life cycles of a product by considering the phase of material extraction, its production, its use, and disposal (Ayres, 1995). The environmental burden of products can be calculated by LCA. However, Proske and Jaeger-Erben (2019) suggest that estimating environmental impact is insufficient, and that LCA should also consider social variables such as those that influence product acquisition and appropriation.

Wiens and Gordon-Byrne (2017) draws attention to the problem of short life spans of new technologies by comparing smart products and old kitchen mixers. Oguchi et al. (2016) differentiated between intended lifetime, ideal lifetime and predicted lifetime of products. The difference between intended lifetime and ideal lifetime determines the lifespan of the hardware, software parts and their compatibility. From the product design aspect, Bakker et al. (2014) introduce an optimal life span concept that is calculated by comparison of products environmental cost and its energy consumption in use phase. They propose that this comparison should determine the lifetime of the product. However, elements such as energy consumption of most ICT products while “storing, transmitting, retrieving or processing of information” is not clear to the user (Gurova et al, 2020) and no absolute measures exist yet (Freitag et al., 2021), so we are still in need of an LCA equivalent for digital infrastructure.

4.3 Obsolescence

Product Obsolescence (Haug, 2017; Cooper, 2004) is one of the most mature concepts in sustainability literature, and it implies that a product fulfilled its lifetime regarding functional or aesthetical aspects. The idea of obsolescence is generally linked to the company's decision-making role in the production (Jensen,2021). However, obsolescence goes beyond the company's decisions. Haug (2019) divides it into absolute obsolescence - physical product failures - and relative obsolescence - implying that one of the other factors that are independent of the product lead to it being obsolete.

The planned obsolescence notion (Cooper, 2010) refers to the decision to plan the product's lifetime and determine when it will become obsolete. It is generally said that companies create products with planned obsolescence to increase consumption. This is obviously not valid for every company, especially for the ones that actively fight against fast technology and consumption such as Fairphone - which is a well-known example in academia. However, even these companies can face obsolescence problems. Fairphone for example, claimed to make "devices for extending usable lifespan, enable reuse, support safe recycling" (Fairphone-2015 as cited in Kannengiesser,2020, p.42)," build to last" (Fairphone-2019 as cited in Kannengiesser, 2020), through providing spare parts to enable upgrade and repair of the smartphone. However, the company stopped reproducing spare parts for their first model four years after its production due to insufficient cost and profit balance (Kannengiesser, 2020).

As the example indicates, we can discuss obsolescence from various aspects. DfS discusses product obsolescence by approaching technical, functional, economic, and aesthetic aspects (Ertz et al., 2017 as cited in Jensen, 2021). Related to this aspect in the SICT literature, Sandborn (2007) divides software obsolescence into three categories: functional, technological, and logistical obsolescence which refers to hardware and software compatibility, license agreements, maintenance problems, and digital media obsolescence. A high cost of software maintenance is revealed by Proske and Jaeger-Erben (2019). They looked at three modular phone strategies and concluded that open-source software and operating systems, with the help of technology enthusiastic users and a basic amount of market saturation, could be a solution to decrease software upgradability cost. It might be argued that management strategies and collaboration with users might decrease software obsolescence.

Lasly, software obsolescence might also trigger hardware obsolescence, for example if the hardware cannot support new software updates, the product might become obsolete. A recent paper mentioned that companies need larger awareness regarding their app upgrade strategies (Møller, 2021). They highlight that app updates are a critical decision point for companies, and it requires a strategic plan including decisions around frequency and impact of updates.

Obsolescence has been extensively discussed by SICT and DfS literature. It can be approached holistically by researchers, especially those working on smart products. Many of the needed concepts and tools to evaluate the features that have an impact on the product's software and hardware already exist and can help with overcoming obsolescence.

4.4 Modularity

ICT is often perceived as “by default” modular, as the software usually enables the user to e.g., adapt the graphical user interface as well as adding or removing functionality (through apps) and content as the user desires it. However, this is not the case when we reach the hardware level of ICT or smart products. Van Nes (2010) summarized five strategies for longevity: “design for reliability and robustness, design for repair and maintenance, design for upgradeability, design for product attachment and design for variability” (p.128), which all can be achieved through modularity. Modularity is a strategy that initially seems to be promising to prolong the product lifetime as in the case of e.g., the Fairphone- which is a modular smartphone based on modularity. Proske and Jaeger-Erben (2019) highlight there is an optimum balance of modularity. They have three conclusions as (1) products have to be seen in their specific business context, (2) multiple choices are required to fulfill different user needs, (3) technical and user needs have to be balanced.

4.5 Durability

Physical durability of the product itself might decrease technical malfunctions nevertheless it might not be enough to prevent the disposal of the materially longer lasting object as other factors influence the disposal decision as well (Mugge et al., 2005). Especially, the psychological and emotional aspect of durability is contributing to product disposal (Chapman, 2005). It is based on the idea that users tend to keep and maintain the product that they are emotionally attached to. According to Hough (2017), the durability concept is insufficient in terms of covering all aspects of longevity and its leading to certain aspects such as durability of material, construction, or aesthetics. The concept of ‘resilience’ introduces “the ability to ‘recover’ or ‘adapt’ when damaged, decayed or similar” p.16), namely the ability to “bounce back” (p.24) and to embrace up to date aspects of durability and expand understanding of longevity (Haug, 2017). Haug (2017) highlights concepts that are up for debate, including repair quality, replacement quality, upgrade quality, extension quality, reconfiguration quality, new fashion trends, new technologies, and new user needs, and he emphasis the need to improve product adaptability, including timelessness, exclusivity, emotional, design process, and use service. We discuss the emotional aspect of durability in the following part.

4.6 Acquisition and disposal

The emotional durability concept challenges that the lifetime of a product is solely linked to the objects' material life. The concept advocates that if the emotional bond between the user and the product is strong enough, the user will care about the product and keep it for a longer time (see also Chapman, 2009). Accordingly, attachment and detachment tendencies that affect acquisition and disposal decisions are critical phases when examining a product's lifetime. Hebrok (2014) uses dis-domestication as a concept to refer to how furniture is discarded by reversing the process of domestication. Her approach to the disposal is a process rather than an end activity. She identifies how factors such as changing life phases, social status or financial capital, aged material, difficulties of construction, repair related problems, stylistic features, and strong emotional bonds, might impact the life of the furniture.

Exploring disposal behaviors such as storing, throwing away, donating, reusing, and recycling of products, as well as drivers for object detachment, is critical in terms of creating a meaningful life cycle of products. Choi et al. (2018) proposed a design toolkit that tries to increase the longevity of objects by influencing user's sustainable disposal behavior through evoking caring emotions such as "responsibility, commitment and benevolence" (p.492). They proposed a tool that can be used during idea generation. They aim to evoke the internal instinct of users to lead them to disposal inspired by core carative factors nursing practice.

Similarly, Wang et al. (2020) explore how personal and collective nostalgia decreases throwaway behavior. Personal nostalgia is linked with self-continuity that leads individuals to reuse and keep the products while collective nostalgia linked with collective efficacy influences people to donate and recycle the products (Wang et al. ,2020). Sarıgöllü et al. (2021) address product hoarding, which is also described as product hibernation by Bakker et al. (2014, p.12), meaning that products are kept and not recycled thereby material sources are lost or redistribution of unwanted products is impossible. In order to facilitate the redistribution of unused products, investigating how to decrease product hoarding behavior is important. For example, through waste minimization and waste aversion concepts which are main drivers of product detachment. Haines-Gadd et. al (2018) introduces a guide for designers that aims to support longevity through emotional durability.

4.7 Social aspect

The concepts of Clean, good and Fair ICT (Patrignani & Whitehouse, 2014; Patrignani & Whitehouse, 2018) offers a desirable by society, environmentally friendly and ethical approach. The authors offer slow tech concepts with a focus on long term implications, instead of focusing on short time pleasure. Similar to the slow food movements (Manzini, 2014), Slow tech and Clean good and Fair ICT concepts can be a compass in order to reach long term sustainability goals (Patrignani & Whitehouse,2018).

Manzini (2014) highlighted the importance of bottom-up approaches for sustainability. However, it seems that in SICT it is more common to focus on top-down approaches to overcome sustainability related issues. Raworth (2017) highlighted investigations of the social aspect of ICT are not still satisfactory. Only little research has contributed to the social component of SICT by uncovering the unsustainable nature of ICT and by demonstrating its inequity for a certain set of individuals (Van der Velden, 2018). Optimistically, we are currently starting to witness a shift towards social inquiries of SICT though.

4.8 Designer related aspect

Both SICT and DfS studies discuss and employ the term "designer" with ICT studies typically referring to software or hardware engineers and DfS studies referring to product designers. To harmonize different designer-related aspects, we include occupations such as computer engineers, electric engineers or product designers who are involved in the design process in this section.

Developing sustainable hardware production methods and expertise, is a very complex problem already, however, combining these with the need to cover all requirements in a product make it even more challenging (Manjunatheshwara & Vinodh, 2021). Moreover, the human needs that should be fulfilled also increase the complexity of the task. Computer engineers might tend to adopt a reductionism approach - as they were often educated to think this way (Patrignani & Whitehouse,2018) - and develop ideas based on simplified scenarios. Similarly, some of the ICT designers might employ a transhumanism approach that is based on decreasing human factors (as cited by Patrignani & Whitehouse, 2018). Rather than simplifying or eliminating these elements, investigations on DfS began to apply user-centered techniques. Multiple sustainability studies have used co-design and participatory methodologies as a fundamental method.

Additionally, the role of the designers is discussed in various studies, specifically, Sumter et al (2017) conducted a study to uncover the role of the designer towards the sustainable transition. They identified three points related to this: (1) product designers fulfill a strategic role in the transition to a circular economy, but they face some barriers such as: lack of know-how and working on a predetermined solution rather than in a strategic role. (2) Designers face more barriers when they have opportunities to explore and experiment. (3) They would like to be critical thinkers to mitigate the environmental and social impacts of their designs.

4.9 User related aspects

The users are decisive actors when it comes to the product lifetime (Yazirlioglu, 2021). Patrignani and Whitehouse (2018) discuss users' concerns regarding technology - human relationships such as fair trade, repairability and environmental impact within ICT. Currently, knowing the users and meaning making, is becoming an inherent part of designing a long-lasting sustainable product or system. For instance, relying on consumers by encouraging personal engagement through halfway design products (Ozan Avci, 2019), or supporting exchange it through freecycle networks (Özçelik & Kaplan, 2021), secondhand shops, or leasing companies is a way to extend the life cycle of a product. Especially, designing for product circularity (Rexfelt & Selvefors, 2021) by empathizing users' concerns and aspirations is an significant approach to extend the product's lifespan.

Differently, users might overcome the product lifetime barriers to a certain extent by taking the lead on through repair competences (Özçelik, 2020). Supporting users repair activities is discussed by multiple authors, as a multifaceted experience (Terzioğlu, 2021), as a practice

(Özçelik & Kaygan, 2021). a way to create an emotional bond (Yazirlıoğlu, 2021) and as a user's right (Ackermann, 2018). Furthermore, scholars did motivation and barriers (Terzioğlu, 2021) and product care tool (Ackerman, 2021) to inform design practice on how to encourage users to repair and maintain their devices to extend the product's lifetime.

Similarly, open design (Thackara, 2011), which is built on supporting diverse combinations of components to achieve different goals (Bakırlıoğlu, 2017), can be utilized as a prolonging tactic. Open design is inspired by the open-source software movement that allows everyone's contributions, including amateurs and the professionals (Tooze, 2014). Users may contribute, share, and employ design ideas, systems, and ideologies through things via the internet (Tooze et al., 2014). Open design allows users to reuse, modify, and transform elements based on their needs and the items' longevity (Bakırlıoğlu, 2017).

4.10 Design for sustainable behavior

The main objective of Design for Sustainable Behavior Studies (DfSB) is understanding user behavior and exploring design opportunities to promote a more sustainable behavior (Bhamra, Lilley & Tang, 2011). Kuijer and Bakker (2015) discuss the limitations of DfSB (see also Shin & Bull, 2019) as it is only considering users' intentions. Daae, Chamberlin and Boks (2018) introduced the nine dimensions of behavior change towards a circular economy: control, obtrusiveness, timing, exposure, meaning, importance, direction, encouragement, and empathy. Hakio and Mattelmäki (2019) question the inner dimensions of sustainable behavior change such as self-awareness, speculative and embodied exercises and initiating co-creation. Shin and Bull (2019) present a three-dimensional conceptual framework based on the DfSB literature: empowerment, information, and motivation. This framework tries to present a comprehensive approach to situated behavior in a larger social context. It might be elaborated that the sustainable behavior depends not only on users' intentions and motivations, like the designers, it has interdependencies to the social material cultural roots.

We summarized longevity-related themes in both SICT and DfS in this section. We'll go through the different types of relationships between longevity-related concepts in the next part, as well as how this correlation can help us understand longevity.

5. Discussion

In this section we use the themes above to inform the longevity discussion through the three types of links among longevity-related ideas as overlapping, complementing, and loosely related.

5.1 Overlapping aspects

When two disciplines address the same subject, we refer to it as overlapping concepts. We recognize that, while there are common concepts that are explored by both groups, there are distinct focal points and methodologies. Covering different aspects of shared concepts might contribute to future long lasting smart products solutions by providing a comprehensive perspective.

Material selection is discussed in both areas. The awareness regarding depletion of valuable materials is highlighted in both areas which is an environmental aspect of sustainability and the solution of keeping the product longer in the use cycle is well known due to its environmental burden being high in the production phase. The area of SICT is focusing on integration of the materials and trying to save valuable materials by proposing designs for disassembly or reuse of the valuable materials. DfS focuses on the concern of aging gracefully materials and proposes aesthetic solutions. Modularity is another shared concept; however, since we are faced with more and more integration in the hardware, and components of the product, real world application of modularity can be quite challenging. Also, it should be balanced to a certain degree by taking into account social and production aspects. Making a product modular, does not guarantee that it will last longer. In that point, balancing an individual's contributions and different needs and production considerations might be used as a strategy while designing long lasting modular smart products. Obsolescence is a very mature concept in both areas, planned, physical, and technical obsolescence create a shared understanding. Here we for example can concretize the idea of absolute obsolescence by Haug (2019) through Sandborn (2007) classification into functional, technological, and logistical obsolescence. The SICT literature, furthermore, did not look for relative obsolescence such as aesthetic obsolescence which is closely connected to emotional durability. Openness of the software and design are also already shared concepts. Comparing however, the development and studies around open-source software, the open design strategies need further improvements and tools. Creating an open smart product (including, open-source software, hardware and design) seems very promising but is also very challenging. To adapt the new technological development, future studies might focus how to combat complexity while achieving resilient, long-lasting and adaptable and open software-hardware systems.

5.2 Complementary Aspects

Complementary ideas might support and contribute to the other discipline. It can broaden the discussion by showing less explored point of views. In order to enhance durability of the smart product, apart from the quality of the material or production, resilience strategies that are provided by sustainable production design, might be adopted. In this way, the social aspects of the durable hardware and software might be also discovered. Software and hardware of the product might bounce back against the new technological development that requires higher capacity hardware.

Direct involvement of different stakeholders (specifically users) is a promising aspect for long lasting smart products. Here, sustainable behavior studies in the product design discipline might be complementary by providing a different perspective and methods. SICT studies might use these aspects while designing for specific user groups, instead of approaching user groups with general categorization. Enabling users to carry out maintenance and repair activities as suggested in DfS can be a complementary idea for software maintenance. This might also decrease costs of upgrading software. Furthermore, expert users can also maintain hardware, however, companies seem mostly to ignore this possibility. This strategy might be supported by open design and software, as well as modularity aspects. Generally, the emotional attachment of the user might be strengthened through direct involvement e.g., in repair or maintenance.

5.3 Loosely related aspects

We named the concepts that have the potential to inform each other as loosely related to each other. By allowing for the inclusion of the needs of various stakeholders, personalization or midway product strategies may inform software and hardware obsolescence. Firstly, an LCA-inspired method could aid in the study, planning, and maintenance of software across its lifespan. This might also enable investigation of how users' contributions through personalization, maintenance, or open design techniques affect the smart product's lifecycle. Secondly, Emotional obsolescence and aesthetic obsolescence notions may aid in the long-term vision of ICT to overcome software obsolescence. Lastly, the slow tech concept might be promoted through sustainable behavior strategies.

6. Conclusion

In sum, understanding the long-term viability of smart products necessitates a comprehensive understanding based of both disciplines: SICT and DfS. During our preliminary literature research, we realized that both areas have discussed longevity related concepts in line with their perspective and suggested solutions accordingly. To create a shared understanding and combine existing knowledge to expand our understanding, we first introduce the longevity related ideas and bring them together. The research question "How can SICT and DfS inform each other to develop a longevity framework?" is addressed in this paper by introducing concepts and highlighting connections between the literature on SICT and DfS. We conclude this with three pointers for future work:

1. Given the strong overlap, and the numerous links between the two areas, their mitigation strategies could overcome longevity issues when combined. Both provide various strategies, however, there isn't a simple one-size-fits-all approach to achieving longevity. There is a need to expand the scope of coping tactics and try to make them more applicable for smart products.
2. Many of the different longevity concepts discussed in the literature point towards a specific actor, however, long-term success necessitates collaboration among multiple actors and a fair division of responsibilities. While initial investigations have been conducted (e.g., maintenance of software or co-design), there is still a need to support practical sharing of responsibility to help one another.

3. Longevity is a wicked problem, and boundary objects (Bertoni, Panarotto & Larsson, 2016) such as smart products dramatically raise the problem's complexity while designing longer lasting smart product. However, being informed by several areas helps identify and understand the longevity problem and design considerations better. To understand design considerations for long lasting smart products, there is a clear need to be informed by interdisciplinary studies that focus on technological aspects as well as product design aspects.

We reviewed the main concepts, therefore the discussions related to each individual concept might be shallow. We must note that this research is still in progress. Further, this study only includes concepts that are already existing in at least one of the two fields. We aim at creating a dialog between the two fields; however, we are aware that contradictory arguments are also valuable for longevity of smart products and should be included more in the future as well.

Acknowledgements: I am thankful to Jedrzej Jacek Czapla for his contribution during the drawing process of the Figure 1.

7. References

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology: Theory and Practice*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Ayres, R. U. (1995). Life cycle analysis: A critique. *Resources, conservation and recycling, 14*(3-4), 199-223.

Bertoni, M., Panarotto, M., & Larsson, T. C. (2016). Boundary objects for PSS design*. Procedia Cirp, 47*, 329-334.

Bhamra, T., Lilley, D. and Tang, T. (2011). 'Design for sustainable behaviour: Using products to change consumer behaviour'. *The Design Journal, 14*(4), 427–445.

Bakırlıoğlu, Y. (2017). Open design for sustainability: An exploration on practices shaped around small kitchen appliances. [Doctoral dissertation]. Middle East Technical University].

Bakker, C., Wang, F., Huisman, J., & Den Hollander, M. (2014). Products that go round: exploring product life extension through design. *Journal of Cleaner Production, 69*, 10-16.

Ceschin, F., & Gaziulusoy, I. (2016). Evolution of design for sustainability: From product design to design for system innovations and transitions. *Design studies, 47*, 118-163.

Chapman, J. (2005). Emotionally durable design: Objects, experiences and empathy. Earthscan.

Chapman, J. (2009). Design for (emotional) durability. *Design Issues*, *25*(4), 29-35.

Choi, Y. J., Stevens, J., & Brass, C. (2018). Carative Factors in the Design Development Process: Towards Understanding Owner–Object Detachment and Promoting Object Longevity. *Design Journal*, *21*(4), 477–497. https://doi.org/10.1080/14606925.2018.1468166

Cooper, T. (Ed.). (2010). *Longer lasting products: Alternatives to the throwaway society*. Gower Publishing.

Daae, J., Chamberlin, L., & Boks, C. (2018). Dimensions of Behaviour Change in the context of Designing for a Circular Economy. *Design Journal*, *21*(4), 521–541. https://doi.org/10.1080/14606925.2018.1468003

Doğan, Ç., & Walker, S. (2008). Localisation and the design and production of sustainable products. *International Journal of Product Development, 6*(3-4), 276-290.

Doğan, Ç, & Bakırlıoğlu, Y. (2020). Design for Sustainability Approaches Enabling Maintenance, Repair and Upgrading and Empowering User Engagement. *Tasarım Kuram, 16*(30), 96-108. https://doi.org/10.14744/tasarimkuram.2020.42204

Ellen MacArthur Foundation. (2013). *Towards the circular economy Vol.1: Economic and business rationale for an accelerated transition*.

Ertz, M., Lecompte, A., & Durif, F. (2017). Dual roles of consumers: Towards an insight into collaborative consumption motives. *International Journal of Market Research, 59*(6), 725–748. https://doi.org/10.2501/IJMR- 2017-040

Freitag, C., Berners-Lee, M., Widdicks, K., Knowles, B., Blair, G. S., & Friday, A. (2021). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations. *Patterns*, *2*(9), 100340. https://doi.org/10.1016/j.patter.2021.100340

Gurova, O., Merritt, T. R., Papachristos, E., & Vaajakari, J. (2020). Sustainable solutions for wearable technologies: Mapping the product development life cycle. *Sustainability (Switzerland)*, *12*(20), 1–26. https://doi.org/10.3390/su12208444

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.

Hakio, K., & Mattelmäki, T. (2019). Future skills of design for sustainability: An awareness-based co-creation approach. *Sustainability (Switzerland)*, *11*(19). https://doi.org/10.3390/su11195247

Haug, A. (2017): Defining 'resilient design' in the context of consumer products, *The Design Journal, 21*(1), 15-36. https://doi.org/10.1080/14606925.2018.1395265

Haug, A. (2019). Psychologically durable design - definitions and approaches. *The Design Journal, 22*(2), 143-167. https://doi.org/10.1080/14606925.2019.1569316

Hebrok, M. (2014). Design for longevity: Taking both the material and social aspects of product-life into account. *Journal of Design Research*, *12*(3), 204–220. https://doi.org/10.1504/JDR.2014.064232

Kannengießer, S. (2020). Fair media technologies: innovative media devices for social change and the good life. *The journal of media innovations*, *6*(1), 38-49.

Kuijer, Lenneke, and Conny Bakker. (2015). Of chalk and cheese: behaviour change and practice theory in sustainable design. *International Journal of Sustainable Engineering, 8*(3),219-230.

Jensen, P. B., Laursen, L. N., & Haase, L. M. (2021). Barriers to product longevity: A review of business, product development and user perspectives. *Journal of Cleaner Production, 313*, 127951 https://doi.org/10.1016/j.jclepro.2021.127951

Manzini, E. (2014) Making Things Happen: Social Innovation and Design. *Design Issues, 30* (1), 57–66. https://doi.org/10.1162/DESI_a_00248

Manjunatheshwara, K. J., & Vinodh, S. (2021). Sustainable electronics product design and manufacturing: State of art review. *International Journal of Sustainable Engineering*, *14*(4), 541–551. https://doi.org/10.1080/19397038.2021.1900448

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

Mugge, R. (2018). Product design and consumer behaviour in a circular economy. *Sustainability, 10(*10), 1-4.

Møller, K. P., Frydkjær, N. S., & Haase, L. M. (2021). Smartphone updates as a longevity barrier for electronic consumer products. In *ISPIM Conference Proceedings* (pp. 1-16). LUT Scientific and Expertise Publications: ISBN 978-952-335-467-8

Oguchi, M., Tasaki, T., Daigo, I., Cooper, T., Cole, C., & Gnanapragasam, A. (2016). Consumers' expectations for product lifetimes of consumer durables. In *Electronics Goes Green 2016+(EGG)* (pp. 1-6). IEEE. https://doi.org/10.1109/EGG.2016.7829850

Özçelik, A. (2020). Encountering the inner face of products: Computer repair practice and amateur computer repairers [Master's thesis, Middle East Technical University].

Özçelik, A., & Kaplan, A. (2021). Multiple Lives of The Products: An Investigation of Products' Journey in Freecycle Community. *In Proceedings of Nordic Design Research (NORDES), 9,* (pp. 153-159).

Papanek, V. (1971). *Design for the real world: Human Ecology and Social Change.*

Patrignani, N., & Whitehouse, D. (2014). Slow Tech: a quest for good, clean and fair ICT. *Journal of Information, Communication and Ethics in Society*, *12*, 78–92.

Patrignani, N., & Whitehouse, D. (2018). Applying Slow Tech in Real Life. In N. Patrignani & D. Whitehouse (Eds.), *Slow Tech and ICT*, 113–127. https://doi.org/10.1007/978-3-319-68944-9_8

Proske, M., & Jaeger-Erben, M. (2019). Decreasing obsolescence with modular smartphones?–An interdisciplinary perspective on lifecycles. *Journal of Cleaner production*, *223*, 57-66.

Raworth, K. (2017). *Doughnut Economics: 7 Ways to think like a 21st century economist.* Chelsea Green Publishing.

Rexfelt, O. & Selvefors, A. (2021) The Use2Use Design Toolkit—Tools for User-Centred Circular Design*. Sustainability, 13,* 5397

Rozas, L. W., & Klein, W. C. (2010). The value and purpose of the traditional qualitative literature review. *Journal of Evidence-Based Social Work*, *7*(5), 387–399. https://doi.org/10.1080/15433710903344116

Sandborn, P. A. (2007). Software obsolescence - Complicating the part and technology obsolescence management problem. *IEEE Transactions on Components and Packaging Technologies*, *30*(4), 886–888. https://doi.org/10.1109/TCAPT.2007.910918

Sarigöllü, E., Hou, C., & Ertz, M. (2021). Sustainable product disposal: Consumer redistributing behaviors versus hoarding and throwing away. *Business Strategy and the Environment*, *30*(1), 340–356. https://doi.org/10.1002/bse.2624

Shaffril, H. A. M., Samsuddin, S. F., & Abu Samah, A. (2021). The ABC of systematic literature review: the basic methodological guidance for beginners. *Quality and Quantity*, *55*(4), 1319–1346. https://doi.org/10.1007/s11135-020-01059-6

Shin, H. D., & Bull, R. (2019). Three dimensions of design for sustainable behaviour. *Sustainability, 11(*17), 4610.

Sumter, D. X., Bakker, C. A., & Balkenende, A. R. (2017). The role of product designers in the transition towards the Circular Economy: A Reality Check. In *PLATE: Product Lifetimes and The Environment* (pp. 391-396). IOS Press.

Terzioğlu Özkan, N. (2017). Do-fix: Creating deeper relationships between users and products through visible repair. [Doctoral dissertation, Royal College of Art].

Terzioğlu Özkan, N. (2021). Repair motivation and barriers model: Investigating user perspectives related to product repair towards a circular economy. *Journal of Cleaner Production, 289*, 125644.

Thackara, J. (2011). Into the open. In B. Van Abel (Ed.), *Open Design Now: Why Design Cannot Remain Exclusive*, 42-45, BIS Publishers.

Tooze, J., Baurley, S., Phillips, R., Smith, P., Foote, E., & Silve, S. (2014). Open design: Contributions, solutions, processes and projects*. The Design Journal, 17*(4), 538-559. doi:10.2752/175630614x14056185480069

Van der Velden, M. (2018). ICT and sustainability: Looking beyond the anthropocene. *IFIP Advances in Information and Communication Technology*, *537*, 166–180. https://doi.org/10.1007/978-3-319-99605-9_12

Van Nes, N. 2010. Understanding Replacement Behaviour and Exploring Design Solutions. In T. Cooper (Ed.), *Longer Lasting Products: Alternatives to the Throwaway Society* (pp. 107–132). Gower Publishing.

Vezzoli, C., Kohtala, C., Srinivasan, A., Xin, L., Fusakul, M., Sateesh, D., & Diehl, J. C. (Eds.). (2014). Product-service system design for sustainability. Greenleaf.

Yazirlıoğlu, L. (2021). *Sustainable Design Considerations for Emotional Durability And Product Longevity Through Product Care Activities By Repair Enthusiasts* [Master's thesis, Middle East Technical University]

Wang, Y., Tian, H., Sarigöllü, E., & Xu, W. (2020). Nostalgia prompts sustainable product disposal. *Journal of Consumer Behaviour*, *19*(6), 570–580. https://doi.org/10.1002/cb.1832

Wiens, K., & Gordon-Byrne, G. (2017). The fight to fix it. *IEEE Spectrum, 54*(11), 24-29.

About the Authors:

Ayşegül Özçelik is an PhD student at Aalborg University, Denmark. Her research interests are design for sustainability and human product interaction, and STS.

Markus Löchtefeld is an Associate Professor in Interaction Design at Aalborg University. He has published 100+ peer reviewed scientific papers in the intersection of Ubiquitous Computing and Human Computer Interaction with a focus on Wearable Computing and Prototyping.

Christian Tollestrup is Head of Industrial Design Section and Associate Professor at Aalborg University. He holds a Ph.D. in Concept Development and is part of AAU Design Lab. He has been researching design expertise and design education for two decades.