Design for Repair - The Self-Repair Practice Model

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***Abstract*—Repair activities have been in a long-term decline in the industrialized world; however, for the circular economy and a more sustainable future, repair is essential. To support repair activities through design, we adopt a practice theory lens to examine the user's computer self-repair dimension. Based on qualitative data from semi-structured interviews and think-aloud sessions with participants with different levels of repair experience, we present a model that can help designers understand and identify the typical factors of computer self-repair practice. This model can aid designers in holistic design solutions that enable, recreate, and continue computer self-repair practice and design systems and solutions accordingly.**

***Index Terms*—repair, practice theory, user perspective, design for repair**

I. Introduction

The urgency to change the way we design Information and Communications Technology (ICT) is becoming increasingly evident. Freitag et al. examined peer-reviewed estimates of ICT GHG emissions, and their analysis suggests that they can be as high as 2. 1% to 3. 9% of global greenhouse gas (GHG) emissions [1]. Approximately 30% of these come from embodied emissions, which means the GHG emissions released as part of the manufacturing process, for example, the extraction of raw materials, the manufacturing process, and transport. Therefore, a shift away from linear production and consumption patterns toward more sustainable alternatives is inevitable to reduce the carbon footprint of ICTs. Several different pathways have been suggested to reduce the rate of disposal, the most promising is repair, which is also a key substrate in circular economy (CE) [2]. The extension of the lifetimes of products through repair is one of the so-called inner loops of CE, and increasing the number of these loops is essential before disposal or recycling [3]–[6]. This has also been acknowledged by several governments around the world. In 2019, France implemented a repairability index with the aim of motivating consumers to choose products that are easier to repair and encouraging manufacturers to improve the repairability of their offerings [7]. More recently, the governor of California signed into action the digital right-to-repair bill, which will require electronics manufacturers to provide parts, tools, and documentation for their products [8]. However, repair is a complicated phenomenon and is transformed by 'material, infrastructural, gendered, political, and socioeconomic factors' [9, p. 319] rather than being a single and independent phenomenon. Therefore, it is critical to understand how repair can be sustained or disrupted to encourage it. Interactive systems design is a key enabler to shape future products towards supporting users' repair activities.

The field of Sustainable Human-Computer Interaction (SHCI) has focused on repair as one of the key strategies to sustainability from the very beginning [10], [11] and multiple approaches have been explored [12], [13]. Repair not only can mitigate the environmental burden, it is also a direct form of interaction where knowledge, skill, and experience are needed. Understanding sites and repair moments could produce better answers to global sustainability problems [14]. In this paper, we see repair as a sustainable way of using and interaction with technology. We argue that by understanding the existing practices of amateur self-repairers, we will be able to facilitate and empower other users' future self-repair activities. We aim to understand how repair emerges and sustains in daily life among amateurs who take it upon themselves to repair their own laptops and computers. Although several prior works focused on professional repair settings in a wide variety of locations [15]–[21] as well as more organized communities such as repair cafes [22]–[24], very little work has focused on independent amateur self-repairers who take it on themselves in their private home to repair devices for themselves and their friends. To transform the vision of the circular economy [2] and the new laws towards repairability [7], [8] into lived practices, it is important to understand what factors are important. To this end, we collect qualitative data from these unorganized amateurs that repair in their own home to reveal the characteristic of self-repair. We suggest that this can be used in design-led repair solutions and that these can be efficient if we can understand the social and material dimensions of existing repair practices. To understand these dimensions, we employ practice theory as a framework [25], [26], which helps to identify the different aspects included in repair activities. On the basis of this, we developed a self-repair practice model for designers, design educators, and repair initiatives. The goal is to learn from these situated repair practices and use the model as a source of ideas that could mediate expanded repair activities through design and empower users in their repair behavior.

II. BACKGROUND

Self-repair activities cover all aspects of maintenance, replacement, and repair of malfunctions. Scholars have investigated repair activities from diverse disciplines, including Science and Technology Studies (STS), Human-Computer Interaction (HCI), and Design for Sustainability (DfS). Blevis already presented repair as one of the important areas to focus on in his seminal paper on SHCI [10]. Maestri and Wakkary explored repair not only from the perspective of extending the lifetime of a product, but also as an act of creativity that involves the repurposing and resourcing of objects [27]. However, how to sustain and or recreate such activities is so far an unsolved problem, as many different factors play a role in such activities. Jackson et al. presented the results of their ethnographic fieldwork on local maintenance and repair practices of mobile phone and computer infrastructure in Namibia [15] and the repair markets in Dhaka, Bangladesh [18]. The results demonstrate that by examining the repair work, we can develop a new understanding of the sustainable design and operation of complex interactive systems [18]. Similar, Wyche et al. focused on mobile phone repairers in rural Kenya and highlight how their knowledge could help design better suited handsets for rural Kenyans [21]. Jung et al. formed the concept of repairedness, negotiating a contingently stable working version from multiple versions of an artifact under repair, based on an ethnographic study of an analog electronics repair community in Seoul, South Korea [28]. In addition, there is a growing body of ethnographic studies of professional electronic device repair, as well as recycling and recycling of electronic waste, and have revealed crucial insights into knowledge, skills, teamwork, efficiency, resourcefulness, values, consideration, and difficulties faced by these repair communities [16], [17], [19], [29]–[33]. We extend this work by presenting our investigation into the practice of amateur self-repair with the aim of extending repair practice to a wider, more general audience that is less organized and does it at home.

Within the DfS and CE literature, repair activities, including maintenance, replacement of parts, upgrading, and customization, are highlighted. Here, the literature can be categorized into three main groups: system-oriented, product-oriented, and user-oriented approaches [34]. System-oriented research is often portrayed as a strategy to extend the life cycle of the product. For example, the CE model suggests that you should have at least one maintenance, repair, and reuse loop before moving on to recycling and remanufacturing a product [2] but there is also an emphasis on the importance of post-use product services at the local level, such as product care, maintenance, repair, reuse, and recycling [35]. Open design is an additional system-oriented approach that emphasizes product openness and transparency, through which repair activities can be enabled [36]. As a product approach, the design for repair and maintenance is a strategy for the long-term sustainability of the product [37]. Stating that (1) the product should identify a malfunction and notify the user, (2) replacing broken parts should be simple and enjoyable, and (3) spare parts should be easily accessible. User-oriented studies focus on the user's repair experience. Lilley et al. [38], explored long-term behavior change. Their results indicate that there are three groups that differ in their repair frequency: Fixers, Sometimers, and NonFixers. Similarly, Lindsay's [39] work identified multiple user roles as 'developers, producers, retailers, advertisers, publishers and technical support staff' (p.50). Kohtala et al. [40] described people who deal with repair and maintenance activities as 'active users'. Understanding these different user groups is important. In this paper, our aim is to understand how we can enable transitions between such groups using user-oriented approaches.

Understanding these aspects is key to creating any potential design-led self-repair activities, as, for example, Brusselaers et al. found that users do not repair their broken products, even when it is possible and economically beneficial [41]. Arcos et al. investigated the diagnosis of faults by users of consumer products and found that product design is the most relevant factor for success [42] indicating the need for fault indicators, which can also increase the willingness of users to repair [43]. Yazırlıoğlu [34] investigated the diversity of repair and maintenance methods and users' competencies and found that repair activities strengthen the emotional relationship between the user and the product and, thus, contributes to longevity. Ackerman [44], [45] presented sources of motivation, ability, and triggers related to repair. Lastly, closely related to this article, Terziolu [46] developed a model that identifies important motivations, abilities, and triggers for user repair activities. In this paper, we add another perspective to this area. To understand these dimensions, we used practice theory as a framework, which helps to identify the different aspects included in self-repair activities.

A. Practice theory

Reckwitz [47] defines practice as routine behavior patterns that encompass bodily activities, mental activities, objects, particular understandings, and know-how. Practice theory examines practices focusing on routine behaviors, including tacit knowledge, and viewing them as the building blocks of social life. Shove et al. describe competencies as those that encompass skill, knowledge, and technique, and meaning as symbolic meanings, ideas, and aspirations [48, p. 14]. The term 'materials' refers to 'things, technologies, tangible physical entities, and the stuff of which objects are made' [48, p. 14]. In the absence of a connection or nonexistence of one of the elements, the practices are disrupted. We, as designers, can mediate the elements and their relationships to contribute to repair activities. Kuijer and Bakker promote the use of practice theory within the literature on sustainable design [49] as a promising approach similar to Creswell [50]. Kuutti and Bannon argue that the turn towards practice theory 'provides a more encompassing frame, giving us a variety of conceptual resources to understand important issues of appropriation and assimilation of technology into everyday life' [25]. It allows us to move beyond the examination of singular interactions between humans and computers. Instead of consistently placing human actors and computational artifacts as the focal point of our analysis, an approach to understand practices is to view them as configurations comprising multiple interdependent elements [26], [48]. However, to the best of our knowledge, the practice theory framework [47], [48] has not been utilized to focus on user repair activities.

III. Method

We approach amateur repair activities from a constructivist epistemological stance, which means that we assume that knowledge is actively constructed by individuals through their subjective interpretations and interactions with their environment, highlighting the role of personal experience and social context in shaping understanding [51]. We seek to elucidate self-repairers' experiences, behaviors, knowledge, and environments. Consequently, a qualitative interpretative strategy is used throughout the data collection process. To obtain detailed information, the research design included semi-structured interviews and concurrent think-aloud techniques [52], [53]. We focus on amateur self-repairers, as we believe that by understanding their existing practices and how these have formed over time, we will be able to facilitate and empower other users in future self-repair. In preliminary investigations, we involved various user groups, including those who repair professionally, for example, professionally repairing house appliances or offer repair courses organized by the municipality for women. However, our results indicate that the professionality aspect introduces a certain bias and that understanding amateur self-repairers has a greater potential for widespread impact, as this practice can be easier brought to the general public. We recruited 13 participants in the cities of İstanbul, Eskişehir, Manisa and Ankara in the Republic of Türkiye, through personal connections, social media promotions, and snowballing from existing contacts. The participants' age ranged from 23 to 35 years (avg. 28.3 years). They had different socioeconomic backgrounds and worked in a variety of different jobs (2 Software Developers, 2 Researchers at a University, 2 Students, 2 Health Technicians, 1 Fashion Designer, 1 Psychologist, 1 Urban Planner, 1 Salesman, and 1 Graphic Designer). Ten of our participants identified themselves as male and three as female. Although we aimed for a more balanced representation of genders, the selection of participants was made based on the level of experience of the participants and we stopped recruiting after we saw a large amount of repetition in the answers. We expected participants to have performed multiple self-repair activities (more than three) on laptop or desktop computers before. Typical activities that were considered appropriate repair experiences are, for example: Cleaning, replacing components, renewing thermal compound, soldering cables of a laptop or its battery, and detecting and repairing component-based malfunctions of a computer.

We conducted semi-structured interviews with questions relating to participants' computer repair activities, their first and last repair activity, the most difficult repair activity, their ways to gather information, and their relations with other repair-related people or communities. The interviews were recorded and transcribed. In total 22 hours and 46 minutes of interview data were collected and analyzed; as already mentioned, we stopped further recruitment and interviews as we saw a large amount of overlap and similarities in answers. Furthermore, during the interviews, we also asked the participants if they planned to conduct a repair activity in the near future that we could observe. Five of the 13 participants had planned a repair activity. Therefore, we conducted concurrent think-aloud studies with these five participants (all male) while repairing a device. This was done to gain an understanding of the implicit nature of repair practice in situ. These cases were the following: (1) P1 disassembled, replaced and combined components of two old laptops that were partially functioning to have one fully functioning laptop (51 minutes). (2) P2 renewed the thermal compound on the CPU of his desktop computer. He cleaned the dried thermal paste from the surface of the processors; then he added the new thermal paste (25 min). (3) P3 fixed a non-functioning touch pad (not successful) (77 minutes). (4) P4 worked to fix the Wi-Fi connection of a broken laptop (85 minutes). (5) P5 tried to fix the screen of a laptop that no longer worked (85 minutes). It was made clear to the participants that the outcome of the repair was not important to us, but that we were only interested in their practice. Observing these sessions showed how participants thought, decided, and interacted with components and material throughout the repair process.

For transcription and analysis of interviews and think-aloud recordings, we used MAXQDA (a software for computer-assisted qualitative data analysis[1]). A thematic analysis was done with two cycles to construct codes and concepts in an inductive coding approach, as well as a deductive coding approach, that is inspired from practice theory as outlined above. As a last phase, an affinity diagram was made within the codes related to repair practice to reveal the factors that shaped repair behavior.

IV. Results

We divide the results into two parts. First, we will discuss the self-repair networks and the placement of the activities between the different actors, also visualized in Figure 1. Second, we will discuss in detail the different themes of self-repair practice and how they initiate, sustain, and shape the practice.

A. *Self Repair Networks*

Self-repair has various factors and emerges within social and production networks, although it involves only the user and the product. Networks play a crucial role in extending knowledge, gaining access to spare parts, and exchanging skills. Figure 1 shows the numerous actors in the networks in which repair is a practice. Social networks consist of other self-repairers, friends, neighborhood technicians, schoolteachers, and family

[1] https://www.maxqda.com/

members who help each other by sharing knowledge, collaborating on experiments, and trading tools or components over the Internet or in person. Exchanging and exploring parts in their social network is key: *"We exchange parts with our friends. I can use DDR2 RAM with this frequency gap on my motherboard. And a friend of mine says, 'I got that RAM', and we exchange parts and test the performance of the components'"* (P10). We also observe that repair has been practiced across generations; for example, P8 learned as a child from his father *"I was watching my father: You disassembled it from there, so you need to assemble it here. [...] My father goes like 'Here we have the transistor.' He doesn't bother working with it anymore, but he used to lecture me about it sometimes."*. This also highlights the impact that this practice can be recreated through social connections, and it even extends to tool availability and usage: *"Since my father is a mechanical engineer, we had a lot of tools in hand. You know, the soldering irons that we had since my father was working as an engineer. [...] I had the opportunity to play with them without even knowing what they were"* (P7).

Online interactions are essential for disseminating knowledge and expertise, particularly through forum posts and video courses. Through debate and peer confirmation, these communities generate new knowledge and ensure its credibility. P6 for example highlights Reddit as one important source for (local) information exchange: *"Just because I write on Reddit, I encounter things like where to find a new graphics card or how to repair it, or someone's computer has gotten dusty and says "Unless you clean it, this happens etc." I mean I can I reach up to date information there"*. Online labor that expands, sustains, and improves the practice generates knowledge and experience.

Computer businesses, component manufacturers, technology markets, wholesalers, and authorized technicians are also actors in the production networks. These networks often have the ability to restrict access to spare parts or the product itself, and consequently have a greater capacity to close or open the practice. Nevertheless, personal contacts, internet shopping, and flea markets may assist repairers in locating non-standard or wholesale-only parts. As P1 states, these places are essential for them: *"I usually look for used spare parts from websites. There are treasures, even in the flea market. You can find parts that you cannot find normally. In places where there are scraps, you can find scarce parts for small amounts of money"* In conclusion, actors participate in social and production networks that define self-repairing practices; hence, seeing repair activities connected to these networks reveals how many actors were influenced by self-repairing practices.

B. Self Repair Practice

Through our analysis, we identified the following themes that comprise the practice of self-repair: settings and tools, explicit knowledge, bodily skills, mental skills, identity, perspective, concerns, values. Here we lay out each of the identified themes and corresponding sub-themes of self-repair practice. In the discussion section we explain how these different themes contribute to initiating, sustaining, and recreating the practice in the self-repair practice model.

1) Settings and tools: The first element that was highlighted as of high importance by all participants is the setting and tools (compare Figure 2) used during self-repair. This element has three sub-variables, the first theme is *temporary setting*. All except one participant did not have a permanent setting and temporarily used domestic spaces (compare Figure 2 left) when doing repairs: *"I have a table lamp for this work. I have tools and a toolbox to do repairs, and all of them are usually stored on the balcony. I clean, disassemble, and assemble the computers on my desk. Sometimes I need to remove the dust or I have to grease the fans. I do this on the desk in my study room."* (P6). P7 could use a workshop at his workplace equipped with basic tools (soldering irons, screwdrivers, etc.), but he stated that some of his repairs occur at home, as he does not want to carry his desktop computer to work. Most of the participants used a kitchen table or desk that is usually reserved for other purposes. However, due to the temporary nature, participants also have to create temporary storage solutions for spare parts and tools. The possibility of creating good temporal workspace is crucial for self-repair practice; however, it is equally important to understand that one does not need a specific workshop but that they can be conducted at one's home. The second subvariable is *standard tools:* Participants generally used basic equipment like screwdrivers, prying tools, and materials such as a variety of screws and thermal compounds. The availability of these essential tools and soldering irons democratizes self-repairing practice; however, it also means that products need to be designed appropriately and cannot rely, for example, on proprietary screws (e.g., the Apple pentalobe screws were mentioned). Keeping these organized and at hand was also considered important to allow quick repairs, for example, compare Figure 2 (right). Compared to these tools, the last subvariable found was *alternative tools*. Participants used products from their daily lives, such as plastic cards to pry open covers, tweezers to catch small things, or toothbrushes (to clean dusty fans). The ability to envision such improvisational tools is formed through experience or inspiration; for example, P4 often heats a screwdriver on a stove as a makeshift soldering iron. He mentioned that he saw this idea on a repair forum (highlighting again the importance of repair networks).

2) Explicit knowledge: The element that was frequently highlighted to be of equal importance was explicit knowledge, which refers to descriptive explanations, rules, or instructions. This can be written information in forums or guidelines or verbally instructed in repair videos. We identified four different types of explicit knowledge forms that were used and referred to as essential in self-repair practice. The first is step-by-step repair *Instructions*, which was the most common method used by all participants. Experts or other users share these instructions through face-to-face interactions or through online forums and videos. Users collaborate to create, test, and share their knowledge and experiences while applying

Fig. 1. Self repair practice is embedded in what we frame as repair networks with social- and production networks, containing different actors that are crucial for the development of repair activities.

Fig. 2. Left: P4's temporary setting at a dinner table. Right P4's repair toolbox with a variety of common tools and makeshift tools as well as materials.

these instructions in different forums, for example, Reddit, and videos, for example, on YouTube. The second type of explicit knowledge was *specific requirements* of components. Repairers must be aware of the unique handling requirements of the different components. For example, mechanical hard disks should be kept away from magnets, sunlight, or dust because their mechanisms may be affected. Users should minimize risk by learning to handle the specific requirements of the components before doing so. Similarly, understanding the *structure of the product* is essential to dismantle a complex product in the right order. The participants stated that they tried to follow the order of assembly of the product, starting from the outside layer and continuing layer by layer inward. As each product has a unique structure, different disassembling steps should be followed. Here, particularly so-called teardown videos were mentioned as a great source of information. This process also led the participants to reflect on what could be improved: *"This is what I call reverse engineering. I would ask myself, for example, if I were in charge, how would I produce it? Can I do it better? Do I have any idea how to improve this object?"* (P2). Lastly, if general *safety precautions* are neglected when disassembling an electronic product, users may harm themselves (e.g., electric shock). Following basic safety precautions, such as wearing insulated gloves when working with components, is essential: *"We work with electricity and everyone has this fear. There are some safety measures, such as working with soldering iron. How should you put it on a surface so that it does not burn the carpet or wooden surfaces? I was paying attention to safety measures to not do something wrong the first time. "* (P6).

3) Bodily skills: Another theme that emerged was bodily skills, which are abilities developed by participants through and for material interactions when self-repairing. Bodily skills, unlike explicit knowledge, can often not communicated verbally but require participants to try and error or observe others: *"I am trying to watch all the fingers of the repairer, especially the dismantling phase of the monitor is a bit more sensitive issue. That is because there are weird, strange clicks [...] While watching [the video that shows how to disassemble the monitor], I pay attention to the main steps, first, where do we start, which is how much pressure I need to apply while forcing some points"* (P2). We identified six types of bodily skills as critical to perform self-repair activities. The most basic bodily skill is to learn *using tools* such as screwdrivers and soldering irons. These can be learned from a variety of sources; P2, for example, stated that he learned it in school, and P7, on the other hand, learned this from his father. Personal help at this step was highlighted as easier compared to following teardown or repair videos. Another important bodily skill is *mimicking instructions*, for example, the instructor's hand movements in videos or personal sessions. This is also closely related to *acting sensitive and precise*. As certain parts of products are fragile, sensitive, precise actions are required to not break or cause any failure. One of the participants compared the sensitivity and precision required of his hands when repairing with that required for a surgical procedure. Some participants also commented on how they adjust their body to such a sensitive task and *control rhythm and speed* of their movements. Instead of performing impulsively, slowing down can be extremely important to avoid damage to the product, especially in dismantling and interacting with the components. An element that can help on top of that is including more *sensorial information*, such as tactile, smell, sound, or visual. Participants reported that they developed sensory knowledge when performing a repair and adjusted the interaction accordingly. Exploring how far you can force materials when opening a product's plastic casing or plugging on and off sensitive components depends on this skill: *"Motherboards in laptops are hidden underneath the keyboard. People are afraid of breaking the body, as it is not easy to open the motherboard. You need to apply a sort of power to disassemble it, and when you do that, there come crackle sounds. You say "Oh my God! I broke it!" You feel like some parts are torn away inside. It is what it is. People hesitate to do something for its fragility."*(P9)

4) Cognitive skills: In the interviews and the think aloud studies we observed several distinctive thinking styles, which the participants employed and improved during their repair activities. In the following, we present the six cognitive skills that we uncovered through interviews and think-aloud approaches. The first one is *processual thinking*. As most of the participants pointed out, the repair is a processual and situated practice that requires the person to think and make decisions along the way. *"[A]s long as you perform these repair tasks, you will understand that all of these are processual. As you gain the ability to see the whole process, you can parse your steps... It becomes a skill; you can repair when something is not working, or when you are asked about a mechanical or repair-related process."* (P7). Repair is not a discrete event that is strictly scripted, but it happens as a process. Along the way this requires *risk assessment*. Disassembling a product involves several risks, for example when touching the delicate motherboard or soldering components incorrectly. Assessing these risks involves anticipating potential risks and issues during repair, and acting accordingly is crucial to avoiding permanent damage.

The problems and causes of failure are identified utilizing *reasoning* skills, and a fix is projected. They allow participants to make assumptions regarding the causes of failures by examining the links between the component, software, and breakdown in greater detail. These are often only acquired through experience; however, the ability to *transfer learning* is crucial. With this, participants can apply repair expertise to various items and have a general understanding of the repair process and the ability to think in a similar way for different products. A closely related skill is *repurposing*, where components are used in different ways than intended. This provides a space for creative approaches within repair practice. We consider this a cognitive skill, since participants can only find a different context for specific components when they are aware of the mechanism of this component, thus demonstrating learnings. When communicating in person or online *using technical terminology* is key. During the interviews, most of the participants regularly used technical terms. This has the obvious benefit of easing the search for fixes or discussing with others and gives the user access to technological knowledge accumulated in the technical literature of repair practice.

Reverse engineering crosses all the skills mentioned above and refers to being able to imagine the potential steps taken when manufacturing a product. This ability facilitates the acquisition of extensive knowledge about manufacturing procedures and allows participants to advance to the next level by overcoming the object's alienation. Participants increase their knowledge of production procedures and product-related viewpoints by participating in fictional production which may bring the participant closer to the repair activities. However, again, this can only be reached through experience.

5) Perspective: This theme deals with the user's specific perspectives, perceptions, and mindset of electronic products. We identified different perspectives that are decisive for motivating and encouraging self-repair. The first important perspective to take on is, instead of seeing a product as one part, becoming aware of the different *layers* and subcomponents it is assembled of. Understanding these subcomponents and their relation to the united version of the product helps the participant engage and break down the monolithic large problem into smaller, more manageable subsets. This can be achieved through *observation* of repair activities of other people, as this was reported to have affected the willingness to repair of participants in most cases. This helps the user to understand that the malfunction is temporary and can be fixed. It also brings an understanding of the temporal nature of a malfunction. For example here P8 (interview only) describes her specific approach to product care: *"Thanks to my assumption that everything can malfunction and everything can be fixed even at home within my family's house, it's not a big deal that an electronics device is broken. That's because I think that it can be fixed somehow. That's why electronics are not that important; they can be fixed anyways when broken. I never take good care of my electronic devices or tools. So, I don't hesitate to disassemble them with the fear of not being able to fix it. I don't think I don't have that mentality that keeps people away from taking action."* (P8). Here this participant partly also relates to the last perspective we observed, being to see *repair as an experiment*. When participants started to see repair more as a leisure activity than a necessity, they were more willing to try out the components' functions or try increasing the performance. Or simply the fact that there was nothing to break anymore as P8 describes it in the following way: *"I thought: It is already broken; I have no chance to spoil it any more. If I take this to service, they will fix it anyway so I can try it. Maybe I can fix it. So, at least I have a chance to experience it because it is already in bad condition, so I have no chance to make it worse"*

6) Identity: This theme deals with the identity that participants constructed in their self-perception and their social circle's perceptions. Here we uncovered four sub-themes. The first is that the participants developed the perception that they have an *intervention right*. This means that they perceive their competence as high enough to disassemble a variety of products. This is often supported by their social circle asking them to repair other products than computers, which they have not tried before. This makes them feel as *expert user*'s who are proud of their skills and see themselves above other users who do not repair. One of the participants compared himself to non-repairers by describing them as "ordinary users". This comparison highlights the divide between people who can repair or not. Furthermore, some of the participants compared their knowledge with those of professional technical repairers. For example, here P6 compares himself with a professional repairer and highlights how he sees himself as a person who has a higher level of competence: *"Their job [repair services] is to replace the motherboard. I can do that as well. If they say your RAM is broken, they will change it with new RAM. I know that. [...] In that sense, I consider computer services as people who can use a screwdriver or who know how to assemble or disassemble a computer rather than people who know how to repair a computer."* (P6).

Most of the participants stated that they are often asked for advice and speak with friends about repair-related topics and have often adopted the role of being an authority that is *guiding others*. This extends even beyond repair: *"When I built my computer at home, I became a computer mechanic for neighbors and was a free-of-charge technician. My mother was telling others that her son is repairing his computer and that he can install software himself. And then they were calling me even for the simplest problems. In the phone call, I was explaining how to click the next button"* (P9). However, we also found *Gendered perspectives* supporting the misconception that repair is a male-dominated activity. Some male participants claimed it was (*"of course, men are more interested in repairing computers; they play games, watch films etc. but girls just use it" (P11)*. Reactions like that lead one of the female participants to state that, since she is annoyed by this perspective, she prefers to repair by herself, rather than asking for help.

7) Values: Connected to the identity that self-repairers create, are also the values that they have and that create their motivation. All except 2 of the participants reported that they were drawn into repair to *save money*. They were all proud that they were solving a malfunction by spending a minimum amount of money. But for some repair, also developed into a *hobby*. Motivation comes from the pleasure of learning new things about their devices. The participants are enthusiastic about repair activities, without attaching importance to the practical value of the information, as they have fun. *"Frankly it makes me happy. There is a plus of that happiness; other than that, [repairing] has never been an extra income source in my life. It remained something that I do as a hobby"* (P9). However, for the majority of the participants' the main motivation arises from the purpose of using the computer again.

There is also some skepticism towards professional technicians. Several participants wanted more *transparency*. The risk of getting misinformation from the technician and being unsure how they carry out the task led them to consider self-repair instead. Specifically, the problems of the time it takes (*"Then the technician would tell them to come back in three days and three days would be wasted." (P6)*) and the prices they charge came up multiple times: *"They try to cheat me by giving me a high price. But I know the cost of the components therefore I won't be cheated."* (P12). More than half of the participants were motivated by solving their problems themselves. One participant framed it as her repair problem and she wanted to b *self-reliant*. This was particularly observed in cases where there was only a small risk. Some participants also stated that if any damage occurs, it can still be fixed by a professional repairer.

Only a single participant stated *sustainability* as a concern. Although generally it is a significant aspect of repair activities, only P10 emphasized that her goal is to "save the objects" at her house instead of throwing them away.

8) Concerns: The last theme that emerged was the constant concerns that participants had with their self-repair activities during the process. These are important to highlight, as they can be decisive in stopping a repair process. First is the *cost & complexity* of the repair, which is a major determining factor. Is it worth carrying out? Do I have appropriate levels of knowledge and skill? Questions that are driving user decisions. *Data loss* - permanently losing data due to a mistake during the repair process - is another major concern and most back up their data before any repair activity. Similarly, while participants were generally aware that their repair could create irreversible changes in the usability and form of the product, they also showed great concern to limit *permanent damage*. But even if the participants succeed in their repair they were concerned about the *durability*. Depending on the urgency or cost of the solution, participants may also choose more temporary solutions. Here often also *time* required was considered important. Most of the participants were reluctant to leave their computers for a long time with a professional repairer. In this case, participants might prefer to solve the problem themselves. Lastly, participants also took into account *health risks* when repairing, and some deliberately reported not doing a repair even if they know the potential fix for a problem because of it. For example, one of the participants (P10) was knowledgeable about changing battery cells, but was concerned that she would hurt herself in the event of any mistakes and got professional help in this case.

V. Discussion

Our result replicates the findings of several previous studies [14]–[17], [19], [20] even though besides [44], [46] the studies had a very different focus and a different regional context. This means that elements that influence user repair practices are similar in terms of motivations, barriers, triggers, abilities, and prevalent types of users involved in repair activities. The only themes that did not directly emerge were aesthetic and symbolic value, emotional attachment, and the negative stigma attached to repair by Terzioglu [46] as well as aesthetic, appearance, rebellion against the brand policy' by Ackermann [44]. However, a theme that was not found in previous work that we uncovered was bodily skills, and the connected subthemes, as well as the identity and perspective themes are original contributions from this study.

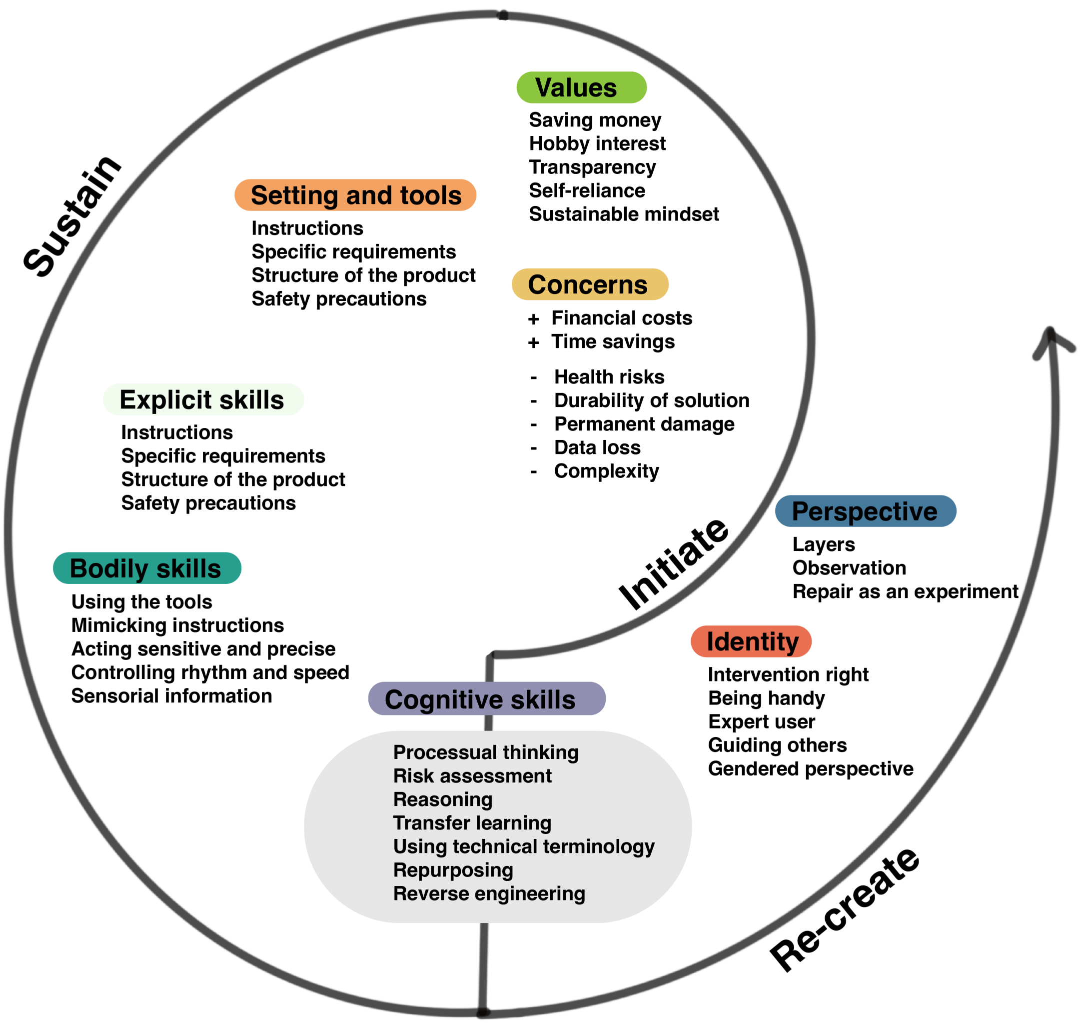

Fig. 3. The different factors of the Self-Repair Practice Model in their relation to how they initiate-, sustain-, and re-create repair activities.

Based on our findings, we developed the self-repair practice model which can be seen in Figure 3. Practice theory describes elements as self-creating, shaping, sustaining, and disrupting practices. Taking this into account, we reframe user repair activities as a self-repair practice, and thereby identify those that initiate, support, and recreate repair behaviors. In this way, we can provide a comprehensive understanding of self-repair through an explicit list of elements and variables that inherently create the repair behavior among the users. The practice is often initiated from concerns, for example financial benefits, which are then turned into values that were reported to be some of the main reasons our participants got interested in repair. However, here identity and perspective are important as well, as these need to change for the user to see themselves as capable enough. Subsequently, the participants made clear that the first elements they considered afterward were the settings and tools and the necessary skills. These are not only important in getting into self-repair but also important in sustaining the activity (e.g., creating makeshift tools that can be used over time, such as old toothbrushes for cleaning dusty parts). Once the participants developed the necessary reasoning skills and realized that they can apply their knowledge and skills to a variety of computer self-repair tasks, they become proficient and then also develop a stronger identity out of this, actually leading them to perspectives that allow them to question manufacturers' design choices. Furthermore, the spiral model should also reflect that several of these factors completely materialize only over multiple iterations.

One of the underlying themes that came up many times was that self-repair activities should be better supported through design [42]. So what can be done about this? With the self-repair practice model presented here, we try to make the situated variables of these activities more explicit to create a space for novel contributions from designers and design researchers. However, while generally self-repair should be supported as much as possible, designers should carefully approach putting all responsibility for repair on the users, as it could end up being seen as a burden by users. This could reduce their interest and motivation all together [54]. Furthermore, the artifact itself might have a smaller role in facilitating such a behavior change. In the real world, the user is codependent on appropriate places, people, and other technologies [55] as highlighted above. But for example, providing easy access to tools, instructions and parts is a much more important element, that often prevented participants from delving deeper into self-repair (e.g., compare results on self-repair networks).

The factors that shape, sustain, or maintain the repair behavior of users are shown in Figure 3. The figure illustrates a comprehensive model of self-repair practice by explicitly showing the influence of each element on the different repair phases. By showing them all together, we emphasize the requirements of coexistence and interdependencies of these elements of repair practices. That is to say, since repair is not a scripted activity but rather a situated, complex phenomenon that includes multiple elements, we advocate that to empower a users' repair activity more holistic solutions are needed. By visualizing the parameters that constitute repair, we provide an opportunity for those who could develop ideas to support repair activities. It is clear that simply making repairable products does not ensure that users take advantage of this opportunity [41], [42]. Designers could encourage repair by providing subsolutions or comprehensive solutions that assist, maintain, and strengthen the repair elements or the link between these elements.

A. Design Directions

In this section, we articulate some key design directions when developing new technologies that aim to also support user self-repair behavior or ways to promote sustainable engagements between products and users. It should be noted that the division of these factors into three different phases is a simplification of reality, and most factors play an important role in all three phases. Here, we try to highlight the most important factors in each phase and how design could support this in the future.

1) How to initiate self-repair behavior?: Identity and perspective are critical to allowing the user to think about repair. To ensure initiation of repair behavior, a change in perspective on the act of repair is usually needed. The user will have to make an effort to understand the problem and, depending on the result, they tend to do the self-repair or else take the product to the technician for repair. A good example of this can be seen in products such as the Fairphone[2] or the Framework Laptop DIY Version[3]. Here, the idea of self-repair is part of the advertisement, and in the case of the Framework DIY laptop a mandatory element to use the device. The mental model and the possibility of repair is given to the user at the moment of purchase. More of these could be initiated, or it could be clarified that this can be done during use. This is also created through elements such as the repairability index in France, which aims to motivate consumers to choose products that are easier to repair, thus immediately establishing the idea that this can be done [7]. Citizen initiatives such as the right to repair movement[4], further fight not only for laws that allow them to repair [8], but also to create awareness around this issue, thus again changing the user's mindset. Apart from these, another strategy can be to get users to interact with the product at a slightly deeper level. For example, minimal maintenance activities such as cleaning the product or replacing the battery in a laptop can be facilitated more easily and do not require a complete redesign of a product. These behaviors can also be facilitated before any malfunction occurs, thus familiarizing the person with the object (and its different layers). This kind of understanding can be created during the use face, and can even be retroactively addressed in software for existing hardware. In this way, the user may feel their right to intervention, and their perspective on the product can be changed. In addition to that, concerns of the user have an impact on the decision on what to do. For example, the risk of data, time, or money loss has to be mitigated. For example, cloud backups that are common on phones could also be advertised as a self-repair advantage.

2) How to sustain repair behavior?: This part covers the factors that have an impact on the actual practice of self-repair and are needed to support the practice of repair itself. Here, we see more explicit themes that are critical for repair of the product. For example, knowing the structure of the product helps to plan the repair process. The structure of the product can be explicitly shown, as well as the vulnerable parts. The explicit rules can be given in a visual format, for example in the form of a layered schematic or explosion view on the inside of a laptop. Furthermore, manufacturers should provide concrete examples and instruction, i.e. tear-down videos. At the same time, these could also highlight potential risks, for example that a part is a more sensitive part of the product that might be affected by the repair actions easily. Again, the Framework DIY laptop is a good example, as the user is forced to put together the device and close the different layers before using it. But giving easy access to the proper material is important. During repair, the user must learn to interact with the material in a bodily manner. The human body can employ the implicit rules of repair by watching other persons' bodily behavior and practicing it. To facilitate it, visuals or sensory examples could be given (also as part of teardown videos). Moreover, interaction technologies and games can transfer bodily experience with materials, for example, as part of serious games [56]. Maybe even Virtual Reality instructions could be created that allow users to try different steps virtually before. Additionally, collaboration plays a crucial role. One possibility is, for example, that repair cafes and initiatives become places where users learn how to interact with product parts during repair. In addition to that, manufacturers could provide ideas for needed tools or potential makeshift tools used for repair. Companies can provide materials, e.g., through iFixIt, to support their customer's repair activities. In addition to the already mentioned Fairphone, we see, for example,

[2]https://www.fairphone.com/en/
[3]https://frame.work/products/laptop-diy-13-gen-intel
[4]https://repair.eu/

that Nokia has chosen this as a way to support the right to repair[5]. And while these devices were also partly designed for repairability, Google has for the Pixel 8 line started to provide parts via iFixIt and has complete component lists and instructions available on their own website[6]. Although the devices are still not easy to repair, they actively support knowledgeable self-repairers. Such collaborations provide a platform to get help based on combining bottom-up and top-down approaches. In this way, the practice can be practiced and the responsibility for the support can be distributed. Moreover, the repair process can not usually be scripted but is a complex process. Therefore, more than a step-by-step guide might be needed to support it. Learning processual thinking can help the user reason and understand what the failure is, thereby identifying connected problems and predicting interdependent failures. Hardware failures can be to a certain extent supported by designing digital solutions, for example, a digital failure identifier to support risk assessment and reason. When using such a solution, users' concerns can be navigated through feedforward and feedback mechanisms. Information on health risks, permanent product damage, data loss risk, or estimated time and cost to solve the problem can be provided.

3) How to re-create repair behavior?: To recreate repair behavior, specifically values, perspectives, and identity are the important factors that can motivate users. Different values motivate different groups of users. For example, being self-reliant, increasing the performance of the device, spending less money to fix a product rather than buying it, or being more sustainable can be a motivation to repair a product and continue to repair other products. Highlighting multiple values might increase the number of people who employ repair behavior. Here, particularly, strategies from persuasive computing could potentially be helpful [57]. Users could be motivated by demonstrating different potential identities and benefits through the product design. Another factor that has a big influence here is of course previous successes. Therefore, all the factors discussed above are also important for recreation. Promoting a particular perspective has a crucial impact on guiding users towards a more sustainable behavior. The change in perspective can help the user break free from a throwaway mindset and enable the user to search for repair solutions. For instance, if they can see the product as multiple layers (either physically or digitally presented), they could understand that the part malfunction might be fixable rather than seeing the product as one united object, which implies that once it breaks, it can not be fixed. Accepting the temporariness of the failure and normalizing failure can help the user to lean toward repair.

Since design is situated and is a context-dependent practice, we addressed design directions for future sustainable interaction design solutions instead of providing one solution for all cases. Rather than making users lean on companies and large-scale organization, we can increase their resilience and enable them to become impactful and responsible actors. Mastering devastating situations, such as natural disasters or pandemics, will require increasing the resilience of users. For example, users had to deal with technical breakdowns themselves during the COVID-19 pandemic with limited experience since their connection to the repair service was interrupted [58]. Several of the design discussion here also followed the devices perspective; however, to make self-repair a more common practice, we cannot rely on manufacturers. For example, serious games, gamification or persuasive technologies could help as well. The self-repair practice model presented here can be a valuable source of inspiration not only for designers but also for other organizations, such as repair initiatives, to improve their products and organization and sustain their initiatives.

[5]https://www.ifixit.com/collaborations/nokia-phones-eu

[6]https://support.google.com/pixelphone/answer/14257407

VI. Conclusion

In this paper, we present a self-repair practice model developed by examining users who take it upon themselves to repair their own devices. This study sought to understand repair activities among users and learn from existing repair practices. The self-repair model can be used as an analytical tool to examine existing computer repair practices, as well as a design tool to create future repair practice. Our results highlight the following crucial points. Users must be empowered by providing information, motivation, technical support, and tools. Collaboration between repair initiatives and companies is needed. A support network can distribute responsibility and increase the number of people who employ repair behavior.

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