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Investigating support strategies for users in repair activity of household appliances

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ABSTRACT: Repair plays a critical role in promoting circular economy principles and fostering resource efficiency. However, the current environment often discourages repair activities. While new policies, such as the Green Deal and EU directives, aim to disseminate and implement repair strategies, there remains a significant need to support users throughout the repair process. This study aims to explore the existing body of knowledge that supports users at various stages of the repair activity, focusing specifically on household appliances. Through a systematic literature review, 12 articles were identified, analyzed, and categorized into five themes. Furthermore, seven key attributes were identified, against which the selected papers were classified. The analysis highlights the need for effective and efficient support, particularly for non-tech-savvy users, during self-repair activities.

KEYWORDS: circular economy, design to x, repair, user centred design, consumer products

1. Introduction

Circular Economy (CE) is a regenerative system in which resource input, waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. (Geissdoerfer, 2017). Repair, one of the strategies of CE, restores an item to an acceptable condition and fulfils the intended use requirement (Hoyle, 2017). It slows down the resource loop (Bocken, 2016) and is less cost and energy-intensive than other recovery options such as recycling. By choosing to repair and reuse products over disposal, users can extend product life and reduce waste, which is crucial for successfully implementing the Circular Economy.

Waste electrical and electronic equipment (WEEE) refers to waste, including all components, sub-assemblies, and consumables that are part of the product at the time of discarding (EU, 2012). While repair activity is a recognised strategy for recovering value from EEE within the circular economy, literature shows a clear gap between user interest and action in repair practices. For example, the Eurobarometer (2014) survey showed that 77% of the interviewed users were willing to make an effort to take broken EEE to be repaired before buying new ones, however, in reality, the repair rate is much lower. For example, Bovea et. al, (2017) studied reuse awareness for small household EEE among consumers/ users in Spain and found that only 9.6% of them take their small household EEE to be repaired and the rest discard it in household trash. Additionally, this rate was found much lower than the repair of ICT devices. For instance, the same research group analysed users' repair behaviour and found that 34.5% of the respondents have ever repaired a small ICT device such as an MP3 player, camera, mobile, laptop, tablet, or hard drive (Bovea, et. al, 2018). Furthermore, the trend of replacing rather than repairing has been increasing over the years. For instance, the research from Oeko-Institut showed that the share of large household appliances replaced due to defects within 5 years increased from 3.5% in 2004 to 8.3% in 2012 in Germany (Prakash et al., 2016). This lower repair rate is attributed to multiple factors such as the shorter product lifespan, the high repair cost, lack of access to repair outlets, etc. Many times, EEE are abandoned even before use or with minimum use, and discarded well before their life.

Agamuthu et al. (2012) noted that in many countries, including Sweden, Denmark, and the UK, about 20-30% of discarded EEE delivered to household waste and recycling centres is capable of further extended use. With the application of visual inspection, function, and safety tests, Bovea, et. al, (2016) assessed the potential reuse of waste household appliances and found that 67.7% of products may have a potential for refurbishment and repair, and 2.1% of them could be directly reused with minor cleaning operations. Furthermore, repair rates for various EEE are found inconsistent. A study of repair centres found that heaters, toasters, and vacuum cleaners are among the most frequently repaired products (Bovea et al., 2017). In contrast, small appliances like kettles and hand mixers are rarely repaired and are often discarded, even when still functional (Hennies & Stamminger, 2016).

The above-highlighted challenges related to EEE underscore the need for targeted measures to support repair activity, enhance the repair rate, and extend product lifespan. This research focuses on understanding the existing practices, methods, and tools that help users in repairing household EEE. The following section explores various policies and approaches currently used to support users in repairing.

2. Supporting users in repair activity

Studies have shown users' intention to prioritise retaining the product over discarding it. For instance, Lefebvre (2019) found that among the surveyed users who were unable to self-repair their products, 32% expressed the intention to retain the product with the hope of repairing it in the future. Additionally, 22% of the respondents actually chose to retain the product, despite being unable to repair it at the time. User's willingness and behaviour to retain non-functional products indicate potential opportunities for support users in repairs.

Supporting users in repair activities is crucial for fostering a sustainable, circular economy, enabling individuals to extend the lifespan of products and reduce waste. The European Green Deal (2024) policy, for example, highlights repair as a core activity and establishes a "right to repair" for citizens. It aims to empower users with information on product origin, composition, repair options, dismantling, and end-of-life handling, enabling informed, sustainable choices. The Directive (EU, 2024) aligns with the European Green Deal's climate goals by promoting the repair of goods over their disposal. Its primary objectives are to extend product lifespans, reduce waste, and ensure users have access to accessible repair services. While the Directive (EU, 2024) is transposed into national laws and has been implemented across the EU, it will take time for widespread and uniform adoption for all products. During this transitional phase, it is essential to consider how to effectively support users in repairing their existing household products. Assuming that the owner intends or is interested in reusing the product, this research aims to explore how we can support them in the repair process. By supporting non-professional users, we can help ensure that the goals of the CE are met effectively while the necessary structural changes (e.g., implementation of Directives) are underway.

While some approaches in the literature support the early stages of repair, systems for scoring product repairability that empower users to make informed choices when purchasing products (Dangal et al., 2022), awareness and education programs, or the creation of networks of reuse and repair, Arcos et al. (2020) highlighted a gap related to repair process in existing research. Specifically, while many studies focus on diagnostic techniques before product release or refer to electronically controlled and monitored devices, there is a lack of general guidance for non-professional users diagnosing faults in household appliances. Given this gap, the current research narrows its focus to understanding existing approaches that empower and support users or user communities in self-repairing EEE household appliances. The aim is to fill this gap by providing insights and solutions for non-professional users, ensuring they are better equipped for the repair process.

2.1. User-centric repair process and supporting methods

The repair process from the perspective of product users has been explored and refined in the literature, highlighting the stages and actions involved. Lefebvre (2019), using a mixed-method approach comprising surveys, interviews, and repair exercises, identified a five-stage repair process for small electrical products: Pre-decision (user predisposition to engage in future repair activities), Decision (assessing and deciding repair feasibility), Preparation (gathering tools, parts, and knowledge), Repair (restoring functionality through disassembly, part replacement, and reassembly), and Post-repair (evaluating repair outcomes). Building on this, Russell et. al. (2023) extended Lefebvre's model by integrating sequential user actions, resulting in a more detailed process: Event (breakage or wear), Repair interest, Preparation for decision, Decision, Preparation for repair, Repair, and Use. Svensson-Hoglund et. al. (2023) further expanded this model into an eight-stage cyclic process (Figure 1), incorporating additional stages such as Event, Investigation (information gathering and addressing barriers), and Preliminary Diagnosis (defect identification through inspection or diagnostic tools). This comprehensive model accounts for 1. Predisposition/ Pre-decision, 2. Event, 3. Investigation, 4. Decision, 5. Arrangement/Preparation, 6. Diagnoses, 7. Repair and 8. Satisfaction/ Post-repair. In our study, we adopted Svensson-Hoglunds eight-stage process to examine the existing methods and tools supporting users and communities during these repair stages. The following section discusses the research objective, research question, and methodology followed in the paper.

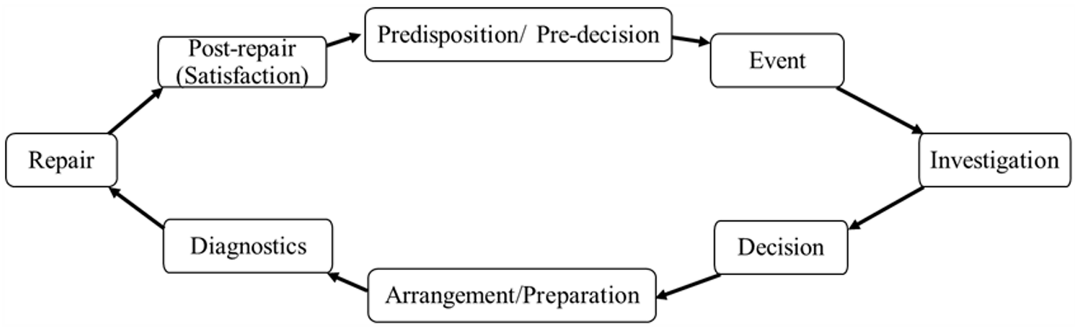

Figure 1. The repair process cycle (Svensson-Hoglund et. al., 2023)

3. Methodology

This research explores strategies to support users in repairing products, assuming that users intend to reuse the item. The research objective of this study is to consolidate and analyse the existing practices, methods, and tools for the repair of domestic electrical, electronics, and mechanical-based household appliances. Based on the research objective, the following research question was formulated: What are the existing practices or supports (methods, tools, guidelines etc.) for domestic electrical, electronics, and mechanical-based household appliances in the process of repair?

The authors conducted a systematic literature review (SLR) to address the research question. To provide a systematic approach with a clear protocol for guiding the study, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) analysis was used (Figure 2). Authors first identified relevant research publications with the use of the Scopus database, which covers a wide range of disciplines, including engineering, technologies, social sciences, environment, economics, business, etc. Aligning with the research question, the search string was developed for the Scopus database where search strings related to “diagnosis or repair or maintenance” were combined with search strings “on practice or tool or method or framework or technique or approach or initiative or strategy or guideline or model” related to “domestic or household or consumer product or appliance or electrical or electronics or mechanical or home equipment”. In addition to Scopus databases, other relevant literature was acquired by employing snowballing strategies to the included studies from Scopus and by searching manually on Google Scholar. The literature review covers studies without specific time or geographic constraints, aiming for a broad analysis of relevant research.

In this study, we analysed a total of 12 papers (including two conference papers and nine journal papers) from our SLR to understand how repair activities and stages are supported. The study included papers that: 1) focus on household appliances, from small EEE devices like electric kettles to large appliances such as air conditioners and washing machines, 2) contribute to the repair process, and 3) support repair centres and non-professional users. Since independent repairers (repair centres) share a common interest with non-professionals (e.g., individual users or repair cafes) in accessing essential resources like information and schematics (Svensson-Hoglund et al., 2021), papers supporting repair centres were included in this study. This inclusion seeks to offer insights that may be valuable to non-professional users. Through this analysis, we identified categories and key attributes of the support strategies. We divided the papers into five categories and tagged each paper according to the identified attributes. This resulted in the development of a current understanding of support for the repair process, providing a structured foundation for future research and applications in this area.

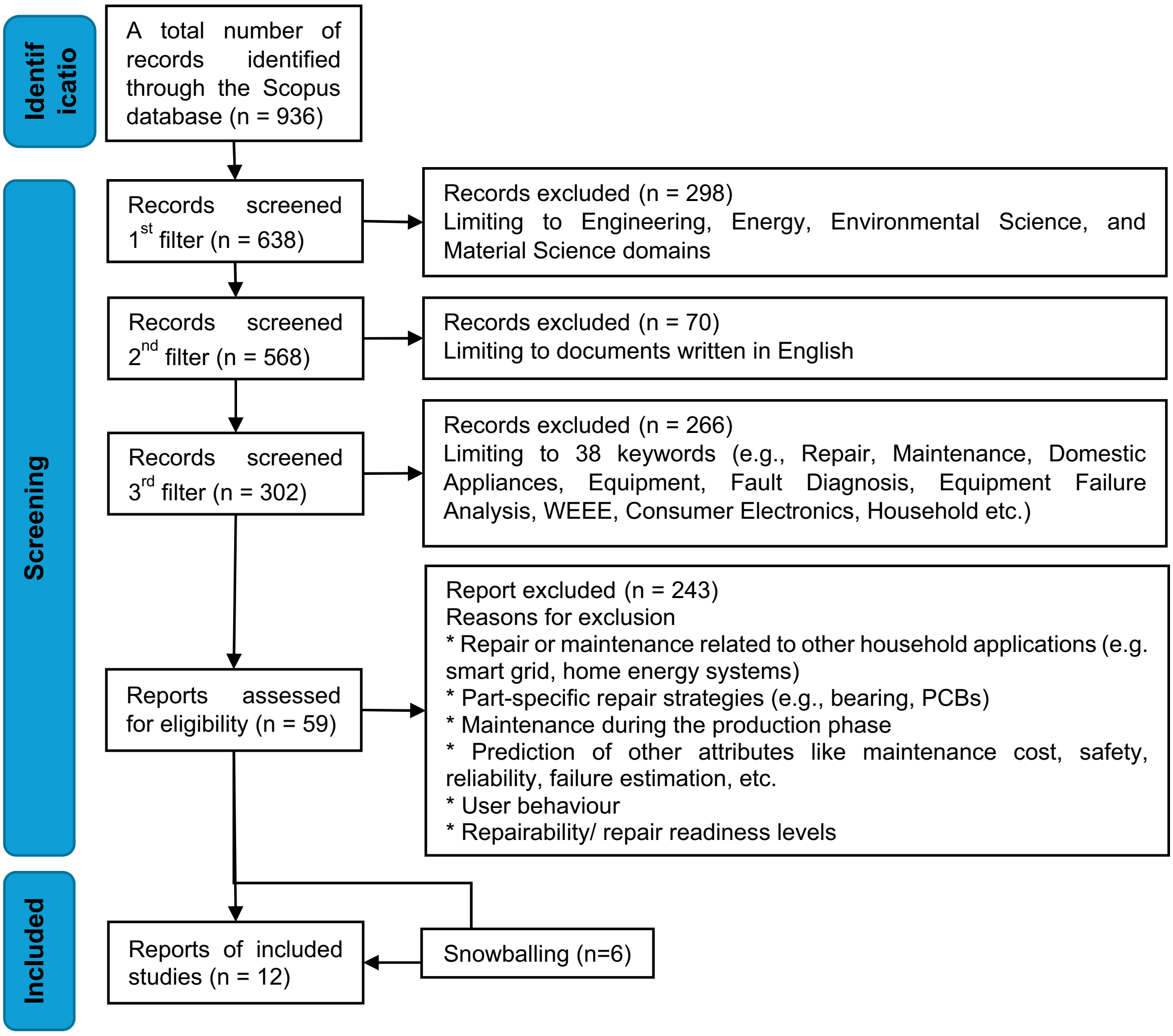

Figure 2. The PRISMA flowchart used in the SLR study

4. Results

To address the research question and to understand the existing practices or supports for domestic household appliances in the process of repair, the selected papers, based on their primary purpose, were categorised into five broad themes, namely 1) Detecting and reporting faults, 2) Assessing product condition for repair decision, 3) Facilitating product-related information, 4) Understanding fault diagnosis and repair, 5) Actively guiding fault diagnosis and repair. Each category, along with its corresponding supports, is explained below.

Category 1: Detecting and reporting faults

The first category covers IoT-based systems for fault detection and diagnosis in domestic appliances. Seabra et. al. (2016) introduced a cost-effective IoT system for monitoring the electrical behaviour of domestic appliances, including older devices. Its functionality was validated through a prototype application on a domestic air conditioner in a controlled laboratory setting. In contrast, de Sales et. al. (2023) utilised sensor data (temperature and humidity) to detect specific faults such as refrigerant leaks or filter fouling, providing users with mobile notifications about the operating condition of their air conditioners. Both studies support users by detecting faults in real time, predicting repair or maintenance needs, and empowering them to address performance degradation early, thereby ensuring sustained appliance efficiency.

Category 2: Assessing product condition for repair decision

The second category focuses on studies that assist users in deciding whether to repair or discard the product. One of the ways to make this decision is by relying on various tests. Bovea et. al. (2016), for example, developed a methodology to assist repair centres or enterprises that are equipped with specialised tools and lab equipment. The methodology involved defining tests for visual inspection, functionality, and safety for ten different types of domestic appliances. Based on these tests, a protocol in the form of an easy-to-apply checklist was created for each equipment type to determine the potential for reuse-whether the product could be directly reused, required further repairability assessment, or needed to be discarded for recycling.

Considering the environmental aspects of repair is another way to help users decide whether to repair or replace product, which focuses on environmental impact, resource conservation, and waste reduction. Perez-Belis et. al. (2017) applied Life Cycle Analysis (LCA)-based support to a domestic vacuum cleaner, highlighting user behaviour as a significant factor. The study concluded that for frequent users, replacing the vacuum cleaner with a more energy-efficient model would be a better choice when the difference between the initial and replacement energy efficiency class exceeded a certain level. In another study, Bovea et. al. (2020) proposed an LCA-based methodology to assist users in deciding whether to repair or replace EEE that breaks before the end of its lifespan. The methodology consisted of three stages: scenario definition, LCA, and identification of the best scenario. It was applied to a sample of nine small household EEE categories. The results suggested that, in most cases, repairing the equipment was generally more environmentally favourable than replacing it. Both the LCA-based studies emphasised the importance of user behaviour and provided insights into decisions regarding repair versus replacement scenarios.

Category 3: Facilitating product-related information

The third category focuses on studies supporting repair processes by availing product-related information. Sterkens et. al. (2023) developed support using deep learning techniques for automatic model identification from product labels, which was integrated into the SmartRe repair app. This support helped streamline the repair and recycling processes by allowing users to easily capture label images, identify models, and update repair information, ultimately assisting in the preparation and repair stages. The support is useful in the preparation stage to identify the product model and related information from the database.

Wagner et. al. (2021) explored the opportunities and limitations of post-warranty repair data by analysing an unfiltered dataset to derive insights that supported stakeholders in identifying priority parts, enabling symptom-based diagnosis, and implementing minimal repair strategies.

To address the problem of insufficient information available to repair centres during the repair process, Rudolf et al. (2022) developed a repair database and implemented it through a repair portal. This portal comprises knowledge in the form of repair manuals for specific products and problems, which is accumulated during executed repair processes. The portal collects information from users, such as product details and faults, searches the existing internal database as well as external sources (e.g., repair manuals, and tutorials available online), and provides relevant information to repair centres. Additionally, post-repair, the portal gathers feedback from repair centres regarding the usefulness of the information gathered through the external source. If found relevant, this information is stored in the internal database for future use. By creating and sharing this knowledge database, the portal aims to make the repair process more time-efficient, thereby reducing repair costs for customers.

Category 4: Understanding fault diagnosis and repair

The fourth category focuses on studies that aim to provide insights into how users perform the process of fault diagnosis or repair. With insights from both scientific literature and non-academic sources, such as professional repairers, Arcos et al. (2020) developed a conceptual framework for fault diagnosis. This framework outlines a three-step process model: fault detection through symptoms, fault location using causal relationships or heuristic knowledge, and fault isolation by identifying the fault's source. The framework was applied to qualitatively analyse content from iFixit's online repair forum for three types of household appliances. This analysis provided insights into common fault symptoms and the diagnostic approaches typically employed by users. In a subsequent study, Arcos et. al. (2021) conducted verbal and video analyses to capture users' diagnostic activities on defective products. The study revealed that participants iterated between the fault location and isolation stages rather than following a linear sequence.

In another study, Hielscher & Jaeger-Erben (2021) explored how users perform home repairs by employing three methods: cultural probes, participatory workshops, and follow-up interviews with

citizens, academics, and practitioners from repair initiatives. The study identifies key phases in repair activities: pre-diagnosis/diagnosis, fixing, and the re-integration of the object after a successful repair.
Category 5: Guiding fault diagnosis and repair
The study from Category 5 aims to guide users during the diagnosis or repair process, directly. Sandez et. al. (2023) analysed various information sources, such as user manuals, manufacturers' websites, and other platforms like Repair Cafe, iFixit, and YouTube videos, to gather information on repairing a kettle. Based on the collected information, a repair document was created and later presented in three different formats: a video, a guide based on a disassembly map, and step-by-step instructions. The effectiveness of the repair document was assessed through a self-guided workshop in which 60 participants individually engaged in fault diagnosis and repair of two induced electromechanical failures in the kettle. With the help of the repair document, 63.2% of the participants successfully repaired the kettle, while 17.5% identified and repaired both failures but did not fully reassemble the kettle within the allotted time.

Table 1. Attributes of support for repair activity

Attribute	Description							
Repair stage	Pre-decision	Event	Investigation	Decision	Preparation	Diagnoses	Repair	Post-repair
Target group			User			Repair centre		
Product/s under study								
Support applicability	Product-independent				Product-specific			
Dependency on expertise	Minimal to Extensive							
Dependency on resources	Minimal to Substantial							
Fault coverage	Limited to Comprehensive							

In addition to the above categories, by analysing the selected papers and using an inductive approach, seven attributes were identified (Table 1). These attributes indicate the practical aspects influencing the application of repair support. Together, they help assess the scope, feasibility and effectiveness of different repair supports. The first attribute pertains to the stage or stages of the repair process that the support addresses. Support can be beneficial for one or multiple stages of the repair process. The second attribute is the target group. Support is designed to assist either users or repair centres. The third attribute focuses on the product or products for which the support is intended. Support may be developed for one specific product or multiple products within the repair process. The fourth attribute relates to the applicability of the support. The support utility may be product-specific or independent of product type and model. The fifth attribute concerns the required expertise, encompassing knowledge, skills, and experience needed to use the support. The required level of expertise can range from minimal to extensive, depending on the nature of the support. The sixth attribute involves the required resources, such as tools, equipment, and standards, needed to utilise the support. The dependency on specialised resources can vary from minimal to substantial, based on the nature of the support. The seventh attribute relates to the ability of the support to address faults in a single product. The coverage can range from limited to comprehensive in terms of addressing faults. These seven attributes can be applied to classify the supports for further analysis or evaluation. Based on these identified attributes, each paper was subsequently classified accordingly (Table 2).

5. Discussion and future work

Key findings based on the review of supports across the identified categories are discussed below, with the results referenced in Table 2.
1. An IoT-based fault detection system (Category 1) can support repair stages from Event to Diagnosis by leveraging real-time data and smart analytics. It minimises the time required for fault awareness (Event), provides precise fault-related information (Investigation), and supports informed decision-making (Decision). Additionally, by predicting necessary tools or parts, it reduces preparation effort (Arrangement/Preparation), while remote diagnostics streamline the initial assessment (Preliminary Diagnosis). In practice, some companies (e.g., Bosch, 3Temp) offer support

to users through product-service systems. For example, product apps can interpret error codes or flashing lights and provide users with the necessary information and actions to be taken.

Table 2. Classification of supports for repair activity based on identified attributes

Article	Category	Supports short description	Repair stage	Target group	Product/s under study	Support applicability	Fault coverage
Seabra et. al. (2016)	1	IoT based	Event to Diagnoses	User	Air conditioners	Product-independent	Limited
de Sales et. al. (2023)		IoT based	Event to Diagnoses	User	Air conditioners	Product-independent	Moderate
Bovea et. al. (2016)	2	Test based approach	Decision, Diagnoses	Repair centre	Vacuum cleaners, irons, microwaves, toasters, sandwich makers, hand blenders, juicers, boilers, heaters, and hair dryers	Product-specific	Moderate
Prez-Belis et. al. (2017)		LCA based approach	Decision	User	Vacuum cleaner	Product-independent	Moderate
Bovea et. al. (2020)		LCA based approach	Decision	User	Vacuum cleaner, hand blender, coffee maker, heater, juicer, iron, sandwich maker, hair dryer, and toaster	Product-independent	Moderate
Sterkens et. al. (2023)	3	Information from product labels	Preparation	User	Washing machine	Product-independent	NA
Wagner et. al. (2021)		Information from repair records	Event to Repair	Repair centre	Washing machine	Product-independent	Comprehensive
Rudolf et al. (2022)		Information from web content	Event to Repair	Repair centre	Domestic products	Product-independent	Limited
Arcos et. al. (2020)	4	Model for diagnoses	Diagnoses	User	Kitchen blenders, vacuum cleaners, and refrigerators	Product-independent	NA
Arcos et. al. (2021)		Model for diagnoses	Diagnoses	User	Vacuum cleaner, blender, radio CD player, coffee maker	Product-independent	NA
Hielscher & Jaeger-Erben (2021)		Model for diagnoses and repair	Diagnoses, Repair	User	Domestic products	Product-independent	NA
Sandez et. al. (2023)	5	Repair document	Diagnoses & repair	User	Kettle	Product-specific	Limited

2. Although IoT-based supports explained in the literature (e.g., de Sales et. al., 2023) are designed to work with older devices, the type of faults the system can detect depends on the number and capabilities of the sensors connected to it. These sensors may be limited to identifying specific faults, such as filter fouling and refrigerant leaks (de Sales et. al., 2023). Additionally, not all domestic appliances can be equipped with IoT technology due to factors such as the initial investment required and the ongoing operational costs.
3. The test-based decision-making support (Category 2) developed by Bovea et. al. (2016) requires specialised tools, equipment and standards for assessing product conditions and therefore it cannot be directly useful for users. However, it may have the potential to support the repair community such as repair cafes. Also, visual inspection-based tests, as explained in the support, can be directly used by users. Finally, along with the decision-making, the support can also be adapted and simplified for diagnoses and repair activity.
4. For the LCA-based decision supports of Category 2 (i.e., Perez-Belis et. al., 2017; Bovea et. al., 2020), the interpretation of the resulting matrix does not require much scientific background from users. However, creating the matrix requires knowledge related to LCA, as well as information to configure the scenario and access to LCA tools. Additionally, a unique matrix is required for each product category.
5. Providing access to product-related information (Category 3) using data-cleaning techniques used by Wagner et. al. (2021) is product-independent and can be adaptable to other repair datasets. Further, if the

processed data is made available to users or communities along with the repair centres, it could assist them in the preparation and repair stages.

6. Although studies from Category 4 are exploratory, focusing on how users diagnose and repair, they provide important directions for researchers to consider how we can effectively and efficiently support users in their existing repair practices (e.g., understanding symptoms, locating the correct cause, and determining the source).

7. The support for actively guiding users in Category 5 (i.e., Sandez et. al., 2023), in the truest sense, aims at the do-it-yourself (DIY) strategy by providing synthesised knowledge of the diagnosis and repair stages to users in a structured format. This reduces the efforts of individuals seeking repair advice for their products within online communities, forums, or by consulting product-related manuals, tutorials, or repair tools. However, the support covers only a few failures/ faults and related diagnoses through the repair document. Further, the developed repair document can only be effective for a particular product model, and each such model may require a unique document which can be a time-consuming process. Lastly, the information synthesised from online forums such as iFixit is limited by queries raised and information provided. Further, the quality of the information depends on the knowledge, experience and expertise of contributors.

From the above findings, we can conclude that the existing support systems for users have their own advantages and limitations with respect to their attributes, particularly when considering practicality. While studies from Category 1 can support most stages of the repair process, not all household appliances are equipped with digital twins, IoT-based features, or built-in diagnostics. Further, the decision-making supports focus either on technical or environmental performance but does not integrate both factors together with economic considerations. In addition, supports that provide product-related information or directly guide users in diagnosis and repair have been either tested and evaluated with limited applicability or heavily depend on past knowledge or publicly available online databases, limiting their ability to systematically and holistically support users across a wide variety of product types and models. In an ideal scenario, support systems for repair activities would be designed to assist non-tech-savvy (non-professional) users across the majority of repair stages. Such systems would ideally provide broad coverage across a wide range of household appliances while remaining largely product-independent. Furthermore, these systems would minimise the need for specialised tools, equipment, or advanced expertise, ensuring accessibility for non-professional users. Additionally, they would comprehensively address the full spectrum of potential faults associated with a given product, thereby offering a holistic and user-friendly solution for repair challenges.

In the current study, the selected papers were not classified with respect to two attributes, such as dependency on knowledge and resources. First, the authors realised that categorising the papers requires the development of appropriate scales for both attributes. Second, categorisation may require additional information beyond what is provided in the literature.

A future direction lies in the development of prescriptive studies focusing on user-centred diagnosis and repair activity, with only a few studies having been identified so far. Support should not only assist users in fault detection, location, and isolation but also provide information about diagnostics, causes, actionable steps, and repair feasibility. As common users have lower skills (Karsli et al., 2024), support should also help them in decision-making about repairing the product themselves versus taking it to a service centre. Further research is required to examine how repair and maintenance activities are conducted, along with the associated support systems, in other advanced domains such as the power industry (e.g., Moleda et. al, 2023), aerospace (e.g., Wang et. al, 2023) and automotive (Rajpathak et. al, 2020) industries. This exploration should focus on identifying the methodologies, tools, and strategies employed in these sectors, which can be adapted to develop support empowering users in the diagnosis or repair process. By leveraging insights and best practices from these highly specialised fields, it may be possible to enhance the efficiency and effectiveness of repair activities for a broader range of applications.

6. Summary

This study investigates support strategies for users and repair centres in the repair activity of household appliances. The systematic review of existing literature reveals a gap in effective support for users, especially those lacking technical expertise, during the repair process. The identification of key attributes and categorisation of supporting strategies demonstrates the need for comprehensive, accessible support systems to guide users through the various stages of self-repair, particularly for household electrical and electronic appliances. Addressing these needs could play a pivotal role in encouraging repair activities and fostering a more resource-efficient, circular economy.

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