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The Value of Emerging Technologies for Enhancing Consumer Trust and Adoption of Repair Electronics

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Introduction

Consumers often replace electronic products prematurely due to performance issues (Van den Berge et al., 2021). Repair is a promising strategy to extend product lifetime by correcting faults to restore functionality (Pamminger et al., 2017) or realigning the product performance with users' functional expectations via upgrades (Godfrey et al., 2022). However, repair activities declined over the past decades with 60% consumers disregarding repair when products malfunction (Magnier & Mugge, 2022).
Recent consumer studies have revealed the barriers to repair. Consumers often struggle to diagnose product failures (Ackermann et al., 2018; Pozo Arcos et al., 2021), causing uncertainty about repair paths. Previous negative repair experiences further demotivate repair (Sonego et al., 2022), making consumers doubt its value (Svensson-Hoglund et al., 2022). The uncertainty about the availability of spare parts, clear repair instructions, and trustworthy repair services increase concerns about repair (Jaeger-Erben et al., 2021; Sonego et al., 2022). These lead to a lack of consumers' trust, acceptance and adoption of repair practices.
Current "design for repair" studies focus on product architecture, especially ease of disassembly (Dangal et al., 2022). These tackle the technical ability to repair but do not address consumers' willingness to repair (Van den Berge et al., 2022). There are two notable exceptions. Van den Berge et al. (2023) revealed that a sensor-based fault indication enhanced consumers' self-efficacy and repair willingness. Similarly, Tadeja et al. (2023) found that Augmented Reality (AR)-based guidance for 3D-printer repair reduce cognitive workload, thereby boosting users' confidence in repair.
Research in automotive and industrial sectors have demonstrated that emerging technologies can provide many more opportunities for repair (Palmarini et al., 2018). However, a comprehensive overview of the potential impact of emerging technologies on facilitating consumer electronics repair is still missing.
This study explores how the value of emerging technologies, applied in broader repair domains, can be adapted to support consumer electronics repair. It bridges the gap between technology capabilities and consumer repair barriers, contributing to the fields of repair and sustainable consumer behaviour.

Method

We conducted a literature review of patents and academic papers to identify existing tech-enabled repair solutions from broader domains including the industrial and automotive sectors. Through this analysis, we translated these insights into opportunities for technologies to facilitate consumer electronics repair.
The World Economic Forum (2024) has identified 10 emerging technologies. Artificial Intelligence (AI), Immersive Technology, and IoT-enabled applications were selected for this study based on two criteria: 1) consumers can directly engage with this technology, and 2) this technology is applicable to product design or interaction design or product service design.
The selection criteria for design solutions are as follows: (1) the product category should fall within white or brown goods, transportation, industry equipment; (2) the technology implemented should be AI, Immersive Technology, IoT or a combination; (3) the solution should describe the functions related to repair; (4) the solution should indicate the impact on the human workflow in repair.

Preliminary Findings

Through literature review, we have gained a comprehensive understanding of the repair journey, identified several challenges, and explored the potential capabilities of various technologies.

Five Stages in Repair Practice

The repair journey (Figure 1) was iterated from 'five steps of repair' (Lefebvre, 2019; Russell et al., 2022), including: *Repair interest; Repair pathfinding; Repair arrangement; Repair action;* and *Post repair*. Instead of a single decision, we perceive repair as a journey of multiple product value trade-offs, involving 1) choices between DIY repair and service repair, and 2) potential product disposal in every stage.

Repair interest begins when consumers perceive misalignment between a product's condition and their functional expectations (Godfrey et al., 2022). Consumers either adapt to these misalignments, pursue repair or dispose of the product. *Repair pathfinding* is an information gathering process, including fault diagnosis (Pozo Arcos et al., 2020), accessing repair guidance and service information (Güsser-Fachbach et al., 2023). Disposal may occur due to the difficulty in identifying suitable repair paths (Van den Berge et al., 2021). *Repair arrangement* concentrates on gathering necessities, such as purchasing spare parts (Pamminger et al., 2017) and assessing service cost (Godfrey & Price, 2023). Disposal remains possible due to unacceptable cost or inaccessible parts. *Repair action* involves practical steps of adjusting product functionality, including disassembly, parts replacement, reassembly, and functional testing (Pozo Arcos et al., 2018). Failure, such as component breakage during repair (Pamminger et al., 2017) or irreversibility of fasteners (De Fazio et al., 2021), can still lead to disposal. In *Post repair*, normally consumers will continue using the repaired product but it is also possible that they still replace or dispose of the product, for example if they perceive a low product reliability after repair (Raihanian et al., 2016).

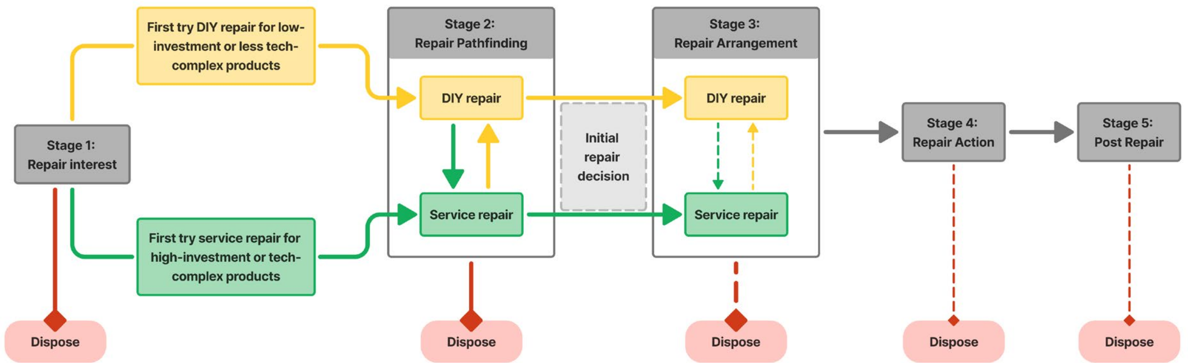

Figure 1.Overview of Repair Journey

Technology Capabilities

A literature review was conducted to define the capabilities of IoT-enabled applications (Ingemarsdotter et al., 2019), AI (Baltrėnaitė-Gedienė et al., 2020; Nishant et al., 2020), and Immersive Technology (Eswaran et al., 2023; Tadeja et al., 2023) in the context of repair. This resulted in the initial framework of technology capabilities and repair opportunities (Figure 2).

Analysis of Design Solutions

After collecting design solutions, we categorised them according to the following criteria: 1) Repair Type: DIY repair/service repair/both; 2) Product Category; 3) Implemented Technology. We include repair type because the design for service repair and DIY repair differs largely in terms of functional requirements and interactions.

Each design solution is mapped onto the framework to show the technology capabilities it implements and how it effectively facilitates consumer repair. We discuss: 1) effective technology capabilities in facilitating consumer electronics repair, 2) ways in which technologies could impact different stages of the repair journey. We demonstrate the initial findings with examples in Figure 2, an AR assisted repair of industrial machine (Aromaa et al., 2018), an IoT repair system for automotive manufacturing equipment (Chen et al., 2019) and AI predictive maintenance implementation (Ucar et al., 2024).

	Technology Capabilities	Definition	Example in Facilitating Consumer Repair Process
IoT- enabled Applications	Tracking	Ability to collect the up-to-date information of the product's identity and/ or location.	Track the availability and location of spare parts to ensure service transparency and reduce waiting time based on demand forecasting (Chen et al., 2019). *- Repair Arrangement Stage*
	Monitoring	Ability to provide the information of a product's use, condition, including alerts and notifications.	Continuous monitoring of the equipment's condition could provide consumers with early notifications about potential issues (Chen et al., 2019). *- Repair Interest Stage*
	Control	Ability to change the product and system parameters (remotely and locally)	Adjust the operation of product in time to prevent further destroy (Chen et al., 2019), indicating the potential impact of malfunction and urgency of repair. *- Repair Interest Stage*
	Optimization	Ability to improve the product operations through the algorithms and analytics to in-use or historical data.	Schedule maintenance beforehand based on fault prediction to optimize product performance and repair system operations (Chen et al., 2019). *- Repair Arrangement Stage*
Artificial Intelligence	Learning	Ability to collect real-time and historical data from products and users to generate information that didn't exist before.	Learn from historical product data and past repair logs to generate specific, up-to-date repair steps (Ucar et al., 2024). *- Repair Action Stage*
	Pattern recognition	Ability to detect trends, correlations within the real-time and historical data.	Detect the potential faults based on real-time prognostics data (Chen et al., 2019), reducing the perceived technical barrier in fault diagnosis. *- Repair Pathfinding Stage*
	Reasoning	Ability to deduce the root causes based on the input information.	Deduce causes based on the predicted failure mode and the current state of the equipment to decide on the appropriate repair strategy (DIY/service/mix) (Chen et al., 2019). *- Repair Pathfinding Stage*
	Natural interaction	Ability to understand and respond to humans via speech, text and visual data.	AI repair assistant can give instructions through natural, conversational interactions (Ucar et al., 2024), enhancing understandability to reduce knowledge barriers *- Repair Action Stage*
Immersive Technology	Real environment capture	Ability to collect spatial information of the object and the context.	AR enables 3D visual repair reports (Aromaa et al., 2018), improving the understandability for consumers to enhance service transparency and build trust. *- Repair Arrangement Stage*
	Object positioning	Ability to identify a specific object and correctly position the virtual scene over real-world physical objects.	The system identifies components and visualizes clickable hotspots (Aromaa et al., 2018), allowing users to check component health for fault diagnosis. *- Repair Pathfinding Stage*
	Real-time rendering	Ability to process and display virtual information seamlessly overlaying it onto physical objects or environments.	Overlay system runtime data visually on the physical equipment (Aromaa et al., 2018), creating a tangible and urgent reminder for timely repair. *- Repair Interest Stage*
	Multi-sensory interaction	Ability to interact with digital elements within the physical space through gestures, touch, or gaze etc.	Gesture-based interaction with virtual repair guidance streamlines the repair workflow (Aromaa et al., 2018), eliminating the need to pause to check instructions. *- Repair Action Stage*
Design Evolution		Ability to provide diverse data feedback from product lifecycle back to design.	The new 3D repair logs benefit knowledge sharing among technicians and design team (Aromaa et al., 2018), optimizing the repair service and product iteration.

Figure 2.Capabilities of technologies defined in the context of repair

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