Designing for Disassembly and Reuse: A Modular Repair Model Proposed in the Manual of Good Practices for the Production and Recycling of Waste from Electrical and Electronic Equipment

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Abstract This paper proposes a modular design approach based on Design for Circular Disassembly (DfCD) to reduce waste and repair costs in Electrical and Electronic Equipment (EEE). Drawing from practical examples and aligned with European circular economic directives, the study demonstrates how product architecture and repair protocols can be restructured to enable component-level maintenance and reuse. The methodology includes design criteria, a conceptual case study, and an implementation roadmap. The results suggest that DfCD improves sustainability, extends product lifespan, and supports circular business models.

Keywords: Design for Circular Disassembly, Sustainable Product Design, Waste from Electrical and Electronic Equipment, End-of-Life Strategies, Circular economy.

1. Introduction

The rapid growth in the production and consumption of electrical and electronic equipment (EEE) led to a significant increase in waste generation. Waste from Electrical and Electronic Equipment (WEEE) contains hazardous materials whose improper disposal poses risks to human health, and to the environment (Sandez et al., 2024). Simultaneously, the increasing scarcity and cost of raw materials have increased interest in the recovery and reuse of components in discarded electronic products. WEEE differs from other waste streams due to its rapid innovation, which challenge the recycling systems and require adaptive strategies (Köpman, Majava, 2024). At the same time, the environmental impacts of raw material extraction, and greenhouse gas emissions linked to EEE manufacturing processes call for a systemic change (Kerwin et al., 2022)[1].

In response, the Circular Economy (CE) model emerged as a viable alternative to the linear take-make-dispose paradigm. It promotes "closing the loop" by reintegrating waste materials into production cycles and "slowing the loop" by extending product lifespans through repair, refurbishment, and reuse (Köpman, Majava, 2024; Bovea et al., 2018). These principles have been reinforced by European policies, such as the European Green Deal, the New Circular Economy Action Plan (2020), and regulatory frameworks including the Waste Framework Directive (WFD) (2008/98/EC), Directive 2018/851/EU, RoHS (2011/65/EU), and REACH.

Central to the CE approach is Product Design, as it determines up to 80% of a product's environmental impact. Approaches like Design for Circular Disassembly (DfCD) and Design for Reuse (DfR) help designers in integrating circularity from the earliest design phases (Sassanelli et al., 2020; (Köpman, Majava, 2024). However, many EEE products are still designed with planned obsolescence in mind, using low-grade materials, and non-standard fasteners that hinder repair and material recovery (Kerwin et al., 2022).

In complement, Life Cycle Assessment (LCA) has proven essential in evaluating the environmental performance of EEE from raw material extraction to End-of-Life, LCA provides a database for optimizing product design within circular economy frameworks (Sandez et al., 2024).

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This work presents one practice proposed in the Manual of Good Practices for the Production and Recycling of WEEE, developed in the scope of Agenda MicroEletronica, a national RRP project, focusing on the use of DfCD to extend the useful life of products, repairability, and reduce environmental impact. The goal is to demonstrate how DfCD can enable repair and reuse of EEE components, in alignment with circular economy and European directives.

2. Methodolgy

This study adopts an exploratory approach, combining literature and policy review with case applications. Initially, a critical review of European regulatory frameworks such as the RoHS, REACH, and the Ecodesign for Sustainable Products Regulation was conducted to define the DfCD strategies in the EEE sector. Scientific contributions on DfCD, modularity (Köpman, 2024; Sassanelli, 2020) were also analyzed.

Following this, a set of DfCD criteria was defined, emphasizing modular architecture, ease of access to components, and the integration of repair documentation. These criteria were then applied to a case study involving a router, an LED tailight and industrial electronic equipment.

Based on the case, an implementation roadmap was outlined, covering stages from fault diagnostics and modular redesign to technical documentation. This framework aims to support manufacturers in applying the DfCD principles.

3. Results and Discussion

Design for Circularity meets several obstacles that hinder its applicability. The analysis of current repair practices for EEE reveals structural inefficiencies in product design that limit the potential for circularity. In many cases found in our field work with companies, entire components are replaced when only a single element is defective. For example, routers returned for repair often have their circuit board replaced due to failure of a component. Similarly, high-performance connector blocks that include multiple ports are discarded in their entirety when only one port malfunctions.
In another example, now in the automotive industry, attempts to adopt modular PCBs for LED taillights, one per function, proved economically unviable. The labor cost of replacing a single indicator PCB exceeded the cost of a full replacement, rendering the design circular in theory but not in practice. In contrast, certain industrial equipment uses modular PCB configurations, where each board is removable and can be replaced or repaired, demonstrating the viability of modularity.

Our study proposes a modular design integrated with DfCD principles. Products are designed such that components can be quickly and affordably replaced, minimizing manual labor. In this model, the faulty part is identified, and only the affected module is shipped to the client or replaced on-site. A clear repair guide maps specific failure modes to procedures and components.

Furthermore, failed units are returned to the producer and are reintroduced into the supply chain as certified second-life components at a lower price. This not only reduces the cost for the end-user but also extends the material life cycle and decreases electronic waste.

4. Conclusion

This work proposes the integration of DfCD and modularity into the design of EEE can reduce waste and facilitate repair, aligning product development with the circular economy. Through real-world examples, it becomes clear that current design practices often hinder component-level repair, leading to unnecessary material loss and increased environmental impact.
Shifting toward modular architectures that support fast, accessible, and affordable repair can extend product lifespan, recover components, and reduce costs. The proposed approach also enables new business models based on component refurbishment and second-life distribution.
Future work will focus on refining the process, implementations, performance monitoring, and development of circularity indicators to support industrial adoption.

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