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34th CIRP Design Conference

# Facilitating circularity: challenges and design guidelines of Product-as-a-Service (PaaS) business model offers for electrical and electronic equipment.

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## Abstract

The move towards a circular economy brings a range of practical challenges for product and service designers that will need to facilitate this transformation from a linear take-make-dispose model to a more circular model. The concept of Product-as-a-Service (PaaS) emerges as an innovative business model capable of catalyzing this fundamental shift. In a PaaS context, any product will be used by several different customers during its lifetime through different operational methodologies and value delivery mechanisms, so incorporating circularity into both product and service design is pivotal for the establishment of more sustainable product-service systems. To facilitate circularity, it is imperative to be able to close loops in the current PaaS offerings by the development of reuse, refurbishment, repair, remanufacturing, and recycling. However, different challenges arise from each of them, which translate into different design guidelines. With the help of the literature and through a cooperative ERA-MIN project, different expert partners provided their insights on the proposed PaaS offering for electrical and electronic equipment (EEE). The objective of this paper is to present the main challenges and describe the design guidelines derived from them.

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*Keywords:* Product-as-a-Service; circularity; facilitating; challenges; design implications; EEE.

## 1. Introduction

E-waste is a comprehensive term that encompasses all categories of electrical and electronic equipment (EEE) and their constituent components that have been disposed of by their owners as waste, without the intention of reuse [3]. Every year, approximately 40 million tons of e-waste are generated worldwide [2]. According to data from the international global e-waste monitor, around 54 million metric tons (7.5 kilograms per capita) of electronic waste (e-waste) were generated in 2019. However, only slightly more than 17% of this e-waste underwent appropriate recycling processes [4].

Moreover, the increasing scarcity of specific raw materials has emerged as a major concern [5-6]. EEE typically contains

elevated levels of conventional metals along with lower concentrations of critical raw materials (CRMs) in various composite forms. CRMs play an indispensable role in the development of innovative high-tech applications. The European Commission identified a total of 30 CRMs [7], and within this classification, the EEE sector serves as the final destination for thirteen [8]. Existing e-waste recycling methodologies are insufficient in targeting the CRMs typically present in EEE, primarily due to their limited concentrations [9]. Consequently, alternative approaches beyond recycling have become imperative. The circular economy (CE) can support the reduction of overconsumption of natural resources while delivering economic benefits [10], and circular business models (CBMs) are recognized as key levers in boosting this

transition. CBMs are based on the principle of product economic value retention [11] and seek to improve resource efficiency by keeping products and components longer through efficient middle and end of life processes, such as repair, reuse, refurbishment, remanufacturing, and recycling [11-12].

Product-as-a-Service (PaaS) epitomizes a corporate innovation approach used by traditional, product-centric companies to amplify the attractiveness of their product portfolio, advance the value chain, and broaden their reach [15]. Original Equipment Manufacturers (OEMs) interested in transitioning from their traditional linear business model to a PaaS approach will initially need to integrate some of their existing products into the new business model. This integration, in its initial stage, may limit the scope of product redesign. Both the linear and the PaaS business models will coexist during this transition phase, with the majority of resources being sourced from the traditional linear model.

However, it is important to note that focusing solely on the servitization of products does not guarantee a reduction in the use of critical raw materials or yield environmental benefits. To make the PaaS model more sustainable in the early stages of this transition, products must remain in active use for a longer time and with different users over their lifecycle. This underscores the significance of value retention processes (VRPs), such as reuse, repair, refurbishment, and remanufacturing, as enablers of circularity. In the latter stages of the product's lifecycle, recycling (parts harvesting included) becomes pivotal for the continued viability and environmental sustainability of the PaaS business model. This is because components that are in good condition or have undergone remanufacturing or refurbishment can be incorporated into the repair of other PaaS products. This practice not only cuts costs, but also extends the lifespan of products.

The design of products and processes has an effect on all phases of the life cycle of the EEE offers, as shown in Figure 1. When adapting a PaaS offer for circularity, all the steps need to be considered. The OEM' PaaS developer is encouraged to adopt a holistic system approach when designing a product and processes as a comprehensive solution. Numerous End-of-Use (EoU) challenges hindering the salvage of products and materials are rooted in design decisions. Consequently, it is most advantageous to integrate EoU management considerations during the initial phases of product design.

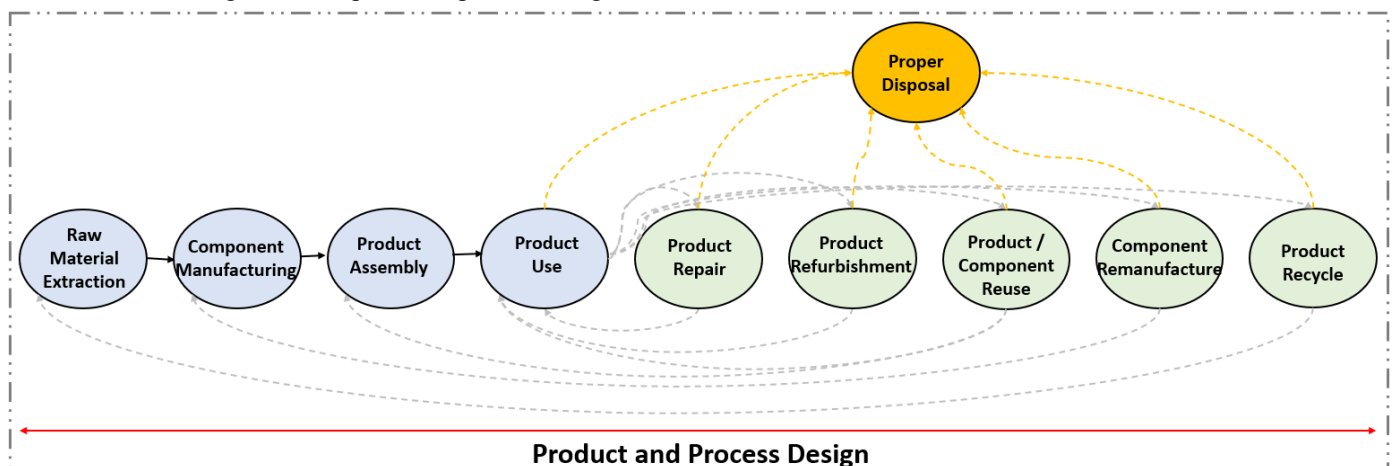


Fig. 1. The role of product and process design in PaaS Life Cycle Phases.

Research on barriers and challenges of circularity enablers for PaaS business models, together with implications for process and product design, is limited, and there is even less related information on electrical and electronic equipment. In fact, a search using the Scopus and Web of Sciences databases revealed a total of 98 articles that mention PaaS, and this value goes down to 5 articles once we specified EEE, as shown in Table 1. When keywords 3<sup>rd</sup> - a and 3<sup>rd</sup> - b were introduced, the same paper appeared in both databases [1].

Nevertheless, circularity enablers face many known challenges, such as rudimentary recycling, low willingness of customers to use refurbished or remanufactured products [13], a limited market for secondary EEE products [14], among others. And, the majority of design strategies state modular design, design for (dis)assembly, repair, recycling, and remanufacturing, however, these are mostly seen from a technical view, and they don't take into account process design considerations that could lead to achieve circularity in a PaaS scheme.

Table 1. Available literature on PaaS challenges and barriers, and process and product design implications.

Search	Keywords	Scopus	Web of Science
1 <sup>st</sup>	"Product-as-a-Service" OR "Product as a Service"	66	32
2 <sup>nd</sup>	"EEE" OR "electrical" OR "electronic" OR "E&E"	3	2
3 <sup>rd</sup> - a	"challenges" OR "barriers"	1	1
3 <sup>rd</sup> - b	"design" OR "design implications"	1	1

The aim of this paper is to investigate the challenges and process and product design guidelines for facilitating circularity in PaaS business models through reuse, refurbish, remanufacturing, and recycling, by providing a hybrid approach study assessment (literature and experts) for the electrical and electronic equipment. The EEE sector has been selected due to the significance of challenges linked to the generation and management of e-waste. The research questions addressed by the study are the following:

(1) What challenges do OEMs face when trying to adopt a PaaS business for EEE?

(2) What process and product design guidelines are needed to address the challenges found from a PaaS perspective?

## 2. Research Methodology

To answer the research questions, we apply a hybrid approach. First, a literature review was used to identify the main challenges and design guidelines for EEE from the point of view of PaaS regarding value retention processes. The literature was searched in Scopus and Web of Sciences with the same first and second search words EEE, electrical, electronic, E&E, challenges, barriers, design, and design implications as shown in Figure 2. Only papers from the last five years were screened (> 2019), to keep up with the latest and most relevant literature, however, a more extensive literature review is planned for the proposition of a new PaaS design method in the future, and as a third search, different keywords on repair, recycle, remanufacture, refurbish, and reuse gave a total of 5,394 papers.

ASReview Lab was chosen because it uses machine learning to support the finding of relevant publications in a more efficient manner [16]. In ASReview, the screening is still conducted manually, but it is supported with machine learning by reordering the records according to relevance scores that are modelled via the previous choices of the reviewer. At this stage, the chosen criterion was to stop reviewing once 20 consecutive irrelevant papers. Excel files were then exported from the software and fused to one having a total of 113. Thirty-seven duplicates were eliminated with the Excel tool, leaving a total of 76 papers. As a next step, the reading of the introduction and conclusion of the papers allowed us to reduce the total number to 32. Finally, 12 other papers were added to the review through co-occurrence, and after reading the entire text, a total of 28 papers were included in the review.

As a second step, a total of 26 challenges and 24 design guidelines were extracted from the literature. The final third step was to create an Excel format, where all 50 items were located in the first column, and in the second to sixth column, the 5R's. Three options were donated (1. Not important, 2. Moderate important, 3. Highly important) to measure the relevance of each item in terms of reuse, repair, refurbishment, remanufacturing, and recycling from a PaaS perspective. The format was then sent to different expert partners with eleven to sixteen years of experience, on the previously mentioned topics involved in the context of the ERA-MIN Scandere project. A total of four partners participated in the assessment of the importance according to the 3-level scale. Then, the average values of the importance of the items were calculated. Average values lower than 1.49 were considered 'not important', from 1.50 to 2.49, 'moderate important', and more than 2.50, 'highly important'.

## 3. Results

### 3.1. Identified challenges and design guidelines and their importance to facilitate circularity

This subsection provides an extensive review (see Table 2) of the growing literature on the challenges and design

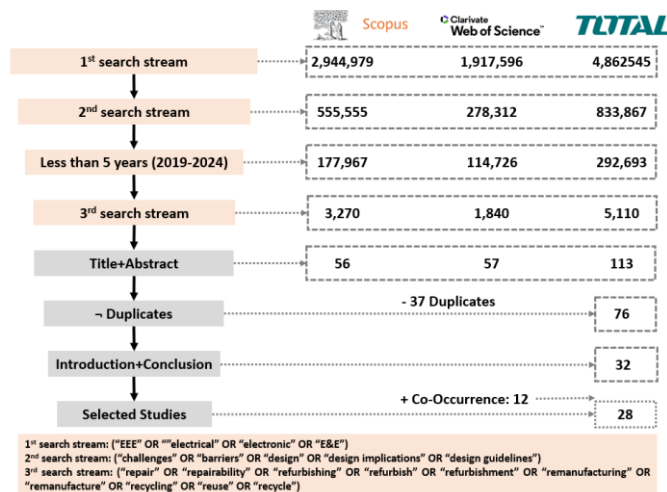


Fig. 2. Literature Review.

guidelines with the objective of preparing a framework for PaaS business models. Following, the importance of the 50 items was contrasted against the five categories to facilitate circularity, as shown in Table 3.

### 3.2. Product and process design potentials

According to our study (see Table 3), some similarities appear in the experts' choices of highly important items. The highly important guidelines for repair, refurbishment, and remanufacturing were:

- Making the product and components easy to inspect.
- Making the exchange of faulty components easily accessible.
- Making easy to dismantle/disassemble the product non-destructively.
- Standardization of components and tools across different products and models.
- Usage of durable and robust components and materials.
- Modular construction available.
- Using joints and connectors that can be easily opened and closed several times.

For the case of recycling:

- Using recyclable and secondary (recycled) materials.
- Considering toxicity and other environmental aspects of the materials.
- Enabling access and removal of hazardous polluting parts.
- Using material combinations and connections that allow easy liberation.
- Minimizing the number of materials used.

For the case of reuse:

- Making the product and components easy to clean.
- Making durable and robust components and materials.
- Extending the warranty period.
- Easing the handling and storage.

### 3.3. Product and process challenges

Table 2. Identified challenges and design guidelines to enforce circularity into PaaS business model offers.

Challenges	References	Design Guidelines	References
C1. Product Obsolescence.	[17-19]	D1. Try to use digitalization, ICT and IoT solutions	[38-40]
C2. Repair charges.	[17, 20]	D2. Make the product and components easy to inspect.	[38-40]
C3. Lack of spare parts or access to them.	[17-18, 21-24]	D3. Make the product and components easy to clean.	[38-40]
C4. Lack of access to appropriate infrastructure.	[17, 19, 25-26]	D4. Make the exchange of faulty components easily accessible.	[38-40]
C5. Return flow volume.	[25, 27-29]	D5. Make it easy to dismantle/disassemble the product non-destructively	[38-40]
C6. Technical/Skilled labor availability.	[25, 27]	D6. Use of renewable materials.	[38-40]
C7. Cost and time.	[25, 27-28]	D7. Use of recyclable and secondary (recycled) materials.	[38-41]
C8. Returning products in varying conditions.	[18, 25, 27]	D8. Consider toxicity and other environmental aspects of materials.	[30, 38-40]
C9. Consumer mistrust.	[25, 27, 29]	D9. Standardized components across different products and models.	[38-40]
C10. Legal and regulatory obstacles.	[19, 25-27, 30]	D10. Standardized tools across different products and models.	[38-40]
C11. Market cannibalization.	[25, 27]	D11. Durable and robust components and materials.	[30, 33, 38-40]
C12. Poor quality performance of repaired, reused, refurbished, or remanufactured products.	[18, 25, 27, 29]	D12. Modular construction.	[38-40]
C13. Optimal disassemble level	[25, 27, 31]	D13. Provide manuals and documentation.	[38-40]
C14. Quality concerns about harvested parts.	[21]	D14. Make spare parts and exchanging components easily available.	[38-40]
C15. The need for large storage facilities.	[21, 32]	D15. Use joints and connectors that can be easily opened and closed several times	[30, 38-40]
C16. Lack of skill from designers	[33]	D16. Minimize the use of different incompatible or dissimilar materials.	[38-40]
C17. Lack of information	[18, 24]	D17. Enable access and removal of hazardous or polluting parts.	[41]
C18. User Profiles/Customer behaviors	[19, 28]	D18. Use of material combination and connections that allow easy liberation	[41]
C19. Intellectual property	[24]	D19. Enable upgrade design features	[42]
C20. Taxation.	[24]	D20. Flexibility of products with parts and interfaces that fit other products.	[42]
C21. Low quality materials and components of the product.	[24, 34]	D21. Extended warranty.	[43]
C22. Lack of disassembly without destroying the product.	[24, 25-36]	D22. Ease of handling and storage	[44]
C23. High heterogeneity of e-waste.	[26]	D23. Minimize the number of materials.	[44]
C24. Increased competition in recycling, refurbishment, and remanufacturing.	[19]	D24. Exchange CRMs for other alternatives.	[31]
C25. Poor separability of components and composites that contain CRMs.	[31]	C26. Lack of possibility of fully automated processes.	[37]

Table 3. Generic Highly Important PaaS challenges and design guidelines. (Note: Only Highly Important challenges and design guidelines were considered).

Category to Force Circularity	Challenge	Design Implications
Repair	[C2, C5, C6, C8, C13, C16, C18, C21]	[D3, D11, D21, D22]
Reuse	[C1, C8, C17, C20]	[D1, D2, D4, D5, D9, D10, D11, D12, D13, D14, D15, D21]
Refurbishment	[C1, C2, C4, C5, C6, C7, C8, C9, C13, C16, C17, C18, C20, C21, C23, C24, C25]	[D2, D3, D4, D5, D9, D10, D11, D12, D13, D14, D15, D19, D20, D21, D22]
Recycling	[C4, C22, C23, C24, C25]	[D7, D8, D16, D17, D18, D23, D24]
Remanufacturing	[C1, C2, C3, C4, C5, C6, C7, C8, C9, C12, C13, C14, C16, C17, C18, C20, C21, C23, C24, C25]	[D1, D2, D3, D4, D5, D9, D10, D11, D12, D14, D15, D19, D20, D22]

In the case of challenges, our analysis shows similarities for refurbishment and remanufacturing:

- Product obsolescence.
- Lack of spare parts or access to them.
- Lack of access to appropriate infrastructure.
- Technical/Skilled labor availability.
- Cost and time.
- Legal and regulatory obstacles.
- Quality concerns about harvested parts.
- Lack of information.

- User profiles/Customer behaviors.
- Intellectual property rights restrictions.
- Low quality materials and components.
- Lack of disassembly without destroying the product.
- Increased market competition in the refurbishment and remanufacturing.

For the case of recycling, reuse, and repair:

- Lack of access to appropriate infrastructure (Recycling).
- Volume of return flows (Recycling).
- High heterogeneity of e-waste (Recycling).

- Increased market competition for recycling (Recycling).
- Product Obsolescence (Reuse).
- User profiles/Customer behaviors (Reuse).
- Low quality materials and components (Reuse).
- Lack of spare parts or access to them (Repair).
- Technical/Skilled labor availability (Repair).
- Cost and time (Repair).

#### 4. Discussion

##### 4.1. Current and future role of process and product design for the remanufacturing and refurbishment of EEE into a PaaS business model.

The economically and environmentally viable refurbishment and remanufacturing is dependent on the durability and quality of the products and their attractiveness to customers (robust to technological obsolescence). The shift in the design is crucial to provide products that are feasible for non-destructive disassembly, time and cost-efficient inspection and assessment of their state-of-health, and which are prone to upgrading. Most of the current PaaS products, especially on the consumer markets (B2C), use linear products, which are not designed for multiple lifecycles. The adoption of modular design is important to gain economic benefits due to reduced components' damages and less workload needed for upgrades during remanufacturing or refurbishment [45]. Designing with easy-to-remove joints for non-disruptive disassembly, preferably semi-automatically or robotically, can enable long-term economy of scale in the remanufacturing of electrical and electronic equipment.

The design of a product shall also support the creation of sectoral product quality standards for remanufactured/refurbished EEE. It shall focus on incorporating the feedback from use-phase in multiple PaaS contracts into the re-design or developing of new products. PaaS offers a unique relationship with customers where there are information links between usage stages (as opposed to linear sales) and OEMs. Digital technologies and IoT devices are often applied in PaaS to simplify the use of products and to monitor their “health of state.” This information is very valuable to understand the usage patterns and behavior of customers and products in different settings.

##### 4.2. Current and future role of process and product design for the reuse, repair and recycling of EEE into a PaaS business model.

Whereas the impact of design choices on the ease of reuse, repair, and recycling are generally recognized, product designers still have limited insights in the challenges faced today, let alone future challenges when novel technologies are implemented. Nonetheless, when designing products today, it is important to consider that there is a chance that they will be reused, repaired, and recycled with technologies under development. For this reason, it is believed essential to also align research on product and process design to support the transition towards a more circular economy. At the same time, it is crucial not only to design products and processes for

sustainable PaaS offerings, but to design them with as many reused components and recycled materials extracted from products offered in linear business models. Where for most OEMs, linear and PaaS business models are expected to coexist, it is also crucial to not separate both activities from a business and technical perspective. Also, here there will be a role to align the product and process design to assure the economic viability of more sustainable product and process designs. For example, in a modular design approach, there is an opportunity to share many but not all modules in product designs tailored for either a linear or a PaaS product offering.

#### 5. Conclusions

To finish, this study delves into the intricate landscape of circularity within Product-as-a-Service (PaaS) business models, with a specific focus on the challenges and design guidelines pertinent to the electrical and electronic equipment (EEE) sector. By employing a hybrid methodology combining literature review and expert assessments, the research successfully identifies key challenges and design principles crucial for promoting circular practices in PaaS. In essence, this study contributes valuable insights for businesses, policymakers, and researchers seeking to advance circular economy principles within the realm of PaaS, especially in the context of the EEE sector.

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