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# Design platform concept for product-as-a-service by electrical and electronic equipment manufacturers

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**Abstract**

Many methods and tools have been developed to help original equipment manufacturers to shift towards circular business models (CBM), however, a gap is observed for decision making support that allows to test different functions of a CBM and their prompt exchange of relevant information. To overcome this, a design platform concept is proposed, aiming to transcend existing frameworks' limitations and link engineering and managerial aspects. Focused on delivering Product-as-a-Service for electrical and electronic equipment, the platform concept aims to reduce global electronic waste and extend product lifespans. Emphasis is placed on a hierarchical product architecture structure, a well-developed service ecosystem involving various stakeholders, and the integration of digital twins, data management, and artificial intelligence. Specific performance and circularity indicators within the design platform concept will address the challenges related to circularity, business model development, and sustainability. These indicators encompass decision tools focusing on both product and business model design and operation with the help of different ease of X decision tools (repair, refurbish, remanufacture, reuse, and recycle). Additionally, sustainability validation tools, including life cycle assessment, critical raw material assessment, life cycle cost analysis, and social life cycle assessment, will support informed decision-making within the design platform concept.



*Keywords:* Design platform; concept; product-as-a-service; EEE; original equipment manufacturer.

## 1. Introduction

In the past, to uphold significant market competitiveness, manufacturing companies had to continually enhance their product design capabilities [1-2]. In contemporary times, facilitating companies to operate economically within a circular economy (CE) involves leveraging the concept of circular business models (CBMs). These models aid in capturing the economic and environmental worth ingrained in product design [3-4] through the adoption of resource efficiency strategies, such as reuse, repair, refurbishment, remanufacturing, and recycling. Although there exist significant legislative and environmental motivations encouraging the advancement of CBMs amid escalating market competition, enterprises encounter limitations in time and funding to comprehensively develop all resources supporting a specific CBM offer. Meaning that any CBM offer will rely more and more on external design resources.

One approach to surmounting these obstacles involves a design platform, which has a potential to enable prompt exchange of relevant information. Platforms are increasingly relevant in the context of XaaS (X as a service) such as equipment as a service as discussed by Tolio et al. [5].

Platforms were researched in engineering design with different purposes, but earlier research points to a property of an integrated design environment for coherency and consistency among different disciplines, design resources, and software solutions [6-7]. The structure and functionality of the design platform should transcend the prevailing limitations imposed by various design frameworks predominantly centered on product design transformation, often disregarding the business perspective.

This neglect results in platforms and frameworks offering guidelines without linking the engineering and managerial aspects within any manufacturing company [8]. Consequently, most of these guidelines remain unutilized in practical applications due to the associated costs of the proposed solutions.

Generating value on a design platform encompasses the provision of design choices associated with the roles of participants utilizing the platform (such as engineers and managers) or affiliating with it (including repairers, refurbishers, remanufacturers, recyclers, and reverse logistics suppliers). It involves diverse design propositions extended to these participants, the resultant effects on value creation stemming from their choices, and the economic, societal, and environmental benefits derived from these decisions.

Hence, it is crucial for a manufacturer to adopt a design platform capable of amalgamating the managerial dimension by encompassing traditional and circular business model designs. Simultaneously, it should address the engineering aspect by evolving the existing product design to accommodate the circular business model and its monetization.

This paper's objective is to delineate the intricacies of a design platform that can serve as guidelines for an OEM' circular transformation on both their products and business models while maintaining profit, environmental, and societal benefits. Section 2 presents the target of the design platform, following the research framework is presented in section 3, and finally in section 4 we show the discussion and conclusions of the research.

## 2. Target of the design platform

The current design platform draft proposal will be directed to Original Equipment Manufacturers (OEMs) of electrical and electronic equipment (EEE) who wish to deliver Product-as-a-Service offers to the market.

### *2.1. Why Electrical and Electronic Equipment?*

In 2022, the global generation of electronic waste reached a record of 62 million tons (Mt) with an increment of 82% from 2010, on track to reach 82 Mt by 2030 [9]. The EEE sector, recognized for its considerable resource requirements, signifies a notable prospect for waste reduction by integrating innovative circular business models [10]. However, a merely 1% of rare earth elements demand is covered by e-waste recycling [9]. These products were chosen due to their electrical and mechanical components which are designed for specific functions, that necessitate user interaction, and that require value retention operations to ensure their proper functionality.

### *2.2. Why Product-as-a-Service?*

The CE offers support in curbing excessive natural resource consumption while yielding economic advantages [11]. CBMs center on preserving the economic value of products [12] and aim to enhance resource efficiency by prolonging the lifespan of products and components via efficient midlife and end-of-life processes, such as repair, reuse, refurbishment, remanufacturing, and recycling [12-13]. Product-as-a-Service (PaaS) exemplifies, a corporate innovation strategy adopted by conventional, product-centric enterprises to enhance the appeal of their product portfolio, elevate the value chain, and expand their market scope [14].

### *2.3. Why OEMs and not retailers?*

The majority of PaaS offerings accessible in the EEE market predominantly originate from retailers. In fact, one previous paper identified different Google online PaaS offers for different EEE, finding a 1/7 relationship between manufacturers and retailers' offers [15]. Typically, these retailers provide two primary options: subscription-based (monthly fee payment) or pay-per-use models (hourly to daily rates) [15]. However, retailers lack a substantial influence on the product, apart from their attempts to facilitate repairs. Consequently, when these products reach their end-of-life, which is often accelerated due to multiple users and varied wear conditions, the products are typically resold, primarily following linear models, merely altering the utilization phase.

Alternatively, OEM involvement in PaaS offerings unlocks a spectrum of opportunities. Initially, retaining product ownership allows for the implementation of various circular strategies, including refurbishment, remanufacturing, parts extraction, and enhanced reverse logistics, thereby augmenting the utilization of recycled materials. And, secondly, there exists the potential to enhance product design, focusing on facilitating ease in repair, disassembly, assembly, remanufacturing, refurbishing, and recycling, pivotal aspects for reinforcing product circularity.

## 3. Framework of the research

### *3.1. Product architecture, service ecosystem and digital technologies*

A design platform for PaaS necessitates a well-defined product architecture capable of accommodating varied service models, a vibrant and collaborative service ecosystem, and the infusion of new digital technologies to deliver scalable, adaptable, and value-driven PaaS solutions tailored to meet customer needs, as shown in section one of **Figure 1**.

#### *3.1.1. Product architecture*

The **product architecture** defines the structural design and functional components of a product. In a design platform, a well-structured product architecture facilitates modularity, interoperability, and ease of integration with various services. It allows for the creation of adaptable and customizable solutions. In the context of product architecture, a hierarchical representation framework (component > module > product) is employed to encapsulate and organize product design insights across varied design options and hierarchical levels (section 2 of Fig. 1).

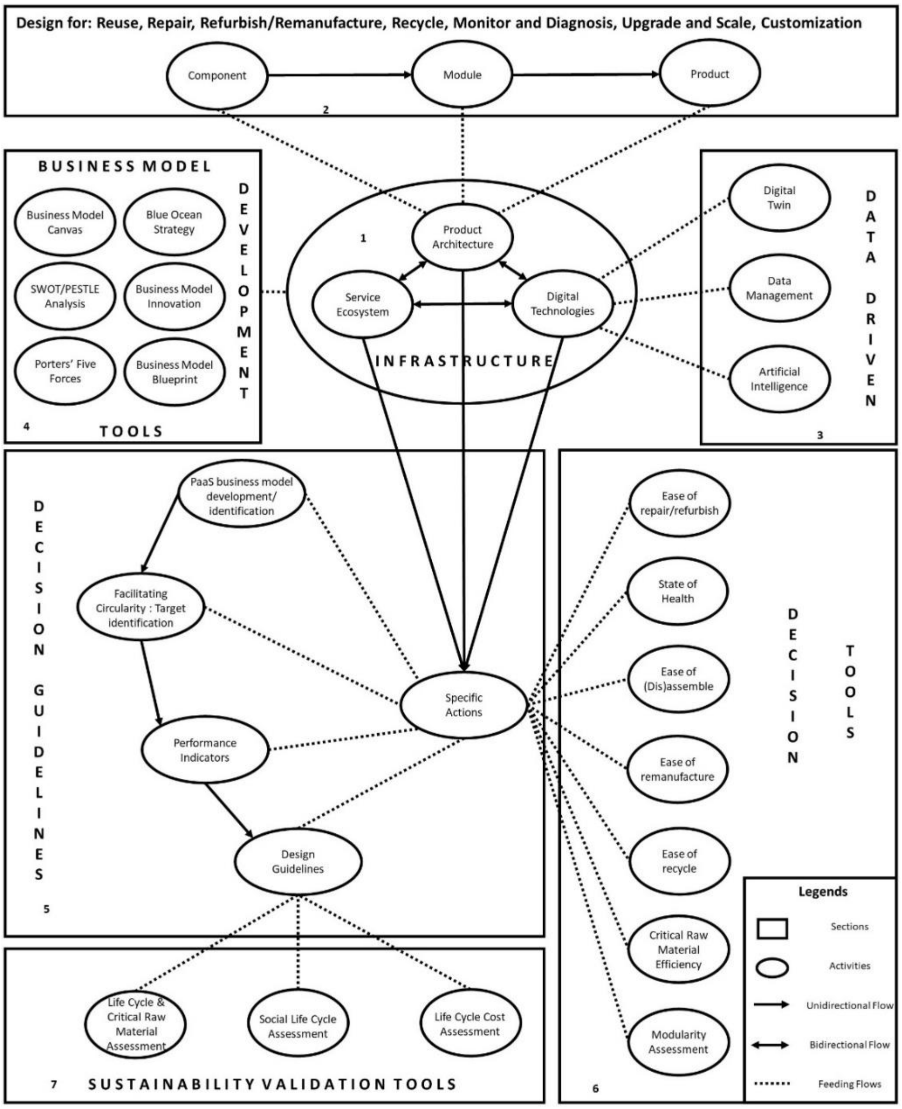


Fig. 1. PaaS design platform blueprint for electrical and electronic products.

**Components** are individual building blocks or units within the product architecture that encapsulate specific functionalities or services. These components are designed to be modular, reusable, and interchangeable. **Modules** are self-contained, functional units within the architecture that encapsulate a set of related components or functionalities. They promote cohesion by grouping related components, offering greater flexibility and ease in managing complex systems. Finally, the **product** serves as the overarching entity that integrates various components and modules to deliver the intended functionalities or services. It represents the end result of combining different elements within the architecture and it ensures that the assembled components and modules work harmoniously to meet the desired objectives and cater to user needs effectively.

We meet the **D4X (Design for X)** family of tools when we come to product realization. During our work in the context of an ERA-MIN project code "SCANDERE" for the development of PaaS for EEE, we have identified the most important product architecture design tools with the help of our OEM partners and university associates, being design for reuse, repair, refurbish/remanufacture, and recycle, the most important ones to improve the product design for value recovery once the CBM has been implemented. This is followed by DfX strategies that can improve the CBM while profiting from different new digital technologies such as design for monitoring and diagnosis, upgradability and scalability, and customization. We have identified that these eight DfX are the most relevant ones for a PaaS offer to succeed and to ensure circularity.

*3.1.2. Service Ecosystem*

The **service ecosystem** (section 4 of Fig. 1) encompasses a collaborative network involving OEMs, service providers, users, and other stakeholders. The prosperity of a corporation hinges on its operational strategy and network [16], emphasizing the critical need to revamp the BM for PaaS provision. Since PaaS shall sell value instead of a product or of a function, a business model perspective is at the heart of our platform. PaaS design begins with need and value, addresses mainly life cycle activities with particular dimensions addressed for solutions, and ends with value [17]. An understanding of the business model simplifies the process for a company to effectively harness and orchestrate all the essential prerequisites for transforming from product-sellingcentric approaches to solution-offered-oriented strategies, through the implementation of service-centric business models [18].

A well-developed ecosystem fosters collaboration, co-creation, and innovation among participants. It supports the integration of various services, facilitates personalized offerings, and ensures efficient resource utilization, all contributing to a rich and dynamic PaaS experience. Our design platform reenforces the idea of having the business model development at the center of the design of the product architecture, service ecosystems, and digital technologies.

A succinct examination of business model development literature [10, 19] underscores the widespread acknowledgment of the Business Model Canvas (BMC) as a potent tool for streamlining the design process of PaaS. Consequently, the BMC (section 4 of Fig. 1) assumes a pivotal role in PaaS design. During our work in the SCANDERE project, two generic business model were developed for both subscription and pay-per-use models [15] together with their repairability and life cycle costing potential. These two models will be presented first in our design platform and the life cycle cost analysis will be based on them.

*3.1.3. Digital technologies*

**Digital technologies** inclusion in PaaS offers play a crucial role in guiding the integration, implementation, and optimization of every day operations of the business model. They facilitate the development of robust, efficient, and user-oriented PaaS solutions aligned with technological advancements and user expectations. **Digital Twins, data management, and artificial intelligence** shown in section 3 of Fig. 1, are among the rising technologies of Industry 4.0, and their implementation may bring many benefits to industrial processes, including predicting supply chain disruptions and anticipating consumer demand, effective monitoring, diagnostic, and prescriptive analytic capabilities, among others. However, their utilization will depend on the software used for the platform (capacity), the already in place technologies and the data available for the lineal model by the OEM. These three digital technologies should be used in a PaaS design platform at some point to reach financial, social and environmental sustainability.

*3.2. Specific actions*

The facilitators of circularity confront various recognized challenges, including limited recycling infrastructure, consumer reluctance to adopt refurbished or remanufactured products [20], and a constrained market for secondary electrical and electronic (EEE) products [21], among others. To address these challenges comprehensively from a holistic design perspective driven by the business model, our design platform guidelines comprise from four different **specific actions**: 1) Development/Improvement of PaaS business models, 2) Facilitating circularity through target identification, 3) Performance indicators, and 4) Design guidelines. One previous research identified different challenges and design guidelines for PaaS offers for EEE through an extensive literature review and experts' judgement [22] and those design guidelines will become part of the design platform.

*3.2.1. Facilitating tools*

The **state of health** (**SoH**) of a product provides information on the degree of degradation of the product in its current state compared to its initial state. Assessing the state of health of a product is not an easy task, as it requires data on the state of the product and data analysis skills to train a machine learning model and ultimately be able to interpret the result. Our aim for this design platform is to utilize a standard and flexible method for assessing the SoH of a product in a circular context currently in development [23-24].

The **ease of repair/refurbish** becomes critical in sustainable design because it allows a product to be functional throughout its life cycle rather than having to go through a complex reverse logistic process and take-back systems [25]. Sabbaghi et al. [26] discovered that encouraging repairability via providing manuals or repairing information, among other things, had a positive impact on future purchases of repairability products.

Product lifetime extension options including repair, reuse, and product harvesting for component reuse all necessitate easier access to product components. As a result, it is critical to define requirements for the **ease of assembly/disassembly** for housing components in order to improve access to internal components for inspection, maintenance, and repair [27-28].

For the **ease of remanufacturing**, all operation phases, such as inspection, disassembly, reprocessing, reassembly, and testing, must be considered when adapting items for remanufacturing [29]. It is important to remember that the primary purpose of remanufacturing is part reuse. As a result, if a part cannot be reused as-is or after repair, the ease of cleaning or reassembly has less value in terms of remanufacturing [30].

For the **ease of recycling** the most relevant assessment criterion is ensuring operational economic feasibility for companies involved in treating or recycling WEEE (Waste Electrical and Electronic Equipment). It involves the simplicity of recycling the products and the secondary valuable materials within their composition [31].

The **efficient use of critical raw materials** should be improved by the development of PaaS offers by increasing the rate of material circulation and resource productivity [32]. Additionally, circularity measures are essential to reduce the dependency from primary resources.

The **modularity assessment** for EEE involves evaluating the degree to which a system or product is designed with modular components or features. Modularity refers to the extent to which a system is composed of relatively independent modules that can be easily replaced, upgraded, or interchanged without significantly affecting the overall functionality of the system [33]. Through the modularity assessment we can identify opportunities for improving the flexibility, efficiency, and sustainability of the products by incorporating modular design principles. This can lead to benefits such as easier maintenance and repair, reduced downtime, and the ability to adapt to changing requirements or technologies over time [34].

*3.2.2. Sustainability validation tools*

Lastly, this design platform finds that the proposed design solutions studied can support a range of activities within the business model patterns. To select the appropriate design decision, we will use the three spheres of sustainability, society, environment, and economics, to demonstrate the impact of the decisions on the three spheres. For this matter, life cycle assessment, critical raw material assessment, life cycle cost analysis, and social life cycle assessment will be used to define the total sustainability impacts.

**Life Cycle Assessment** (LCA) is concerned with identifying the impacts of a supply chain leading to delivery of a product or service. LCA started with industrial applications, only subsequently developing into a way of thinking which engaged the attention of the academic community [35]. Additionally, the increasing scarcity of specific raw materials has emerged as a significant concern [36-37]. EEE typically contains elevated levels of conventional metals alongside lower concentrations of **critical raw materials** (CRMs) in various composite forms. The European Commission identifies a total of 30 CRMs [38], and within this classification, the EEE sector serves as the final destination for 13 of these materials [39]. All these statements serve as the reason of our decision to incorporate critical raw material assessment into the life cycle assessment for the environmental validation.

**Life Cycle Costing** (LCC) has been noted to augment companies' understanding and recognition of particular challenges they face [40], thereby aiding in the acquisition of knowledge and skills required to overcome these hurdles [41]. Thus, integrating LCC into business model development proves valuable in comprehending the implications of the transformation.

Finally, **social life cycle assessment** (S-LCA) offers a standardized methodological structure enabling the measurement of social and socio-economic impacts throughout the life cycles of products and services [42]. Its objective is to measure and comprehend potential social and socio-economic impacts associated with a product system. [42] delineates potential social impacts as "the probable existence of a social consequence arising from the actions/behaviors of organizations connected to the product or service life cycle and from the product's utilization itself."

## 4. Discussion and Conclusion

This paper delineates a design platform aimed at aiding OEMs in their circular transformation efforts, specifically focusing on EEE with PaaS. However, its generic essence allows it to be used for other types of products than EEE and also for different business models than PaaS. The framework includes product architecture, service ecosystems, digital technologies, and specific actions such as development and/or improvement of PaaS business models, circularity facilitators, addressing performance indicators, and proposing design guidelines to answer them. Decision tools and sustainability validation tools, encompassing diverse factors like repairability, remanufacturing, ease of recycle, monitoring, and sustainable material procurement, reinforce the platform's comprehensive approach to sustainability across economic, environmental, and societal dimensions.

This paper makes a substantial academic contribution by bridging the gap between circular economy principles and design platforms, specifically within the context of Original Equipment Manufacturers (OEMs) transitioning towards circular business models (CBMs). By offering a comprehensive framework for integrating design platforms with CBMs, the paper advances understanding in the emerging field of circular economy research. An immediate future work of ours is to further concretize the platform and implement it as software, and apply it for validation to a business case on the market in Europe involving practitioners of the PaaS provider.


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