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Towards Circular Lean Product-Service Systems

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Abstract

Circular Lean Product-Service Systems (CLPSSs) are a new type of PSS, a combination of a tangible circular product with intangible value-added service elements, and its related supporting closed-loop networks and infrastructure. CLPSSs can lead to dematerialization through reducing the creation of waste in manufacturing and services operations, and the consumption of virgin materials, thanks to a restorative and regenerative operational system by design that can satisfy customers' needs, decouple economic growth from environmental impact and create new revenue streams out of extending the residual value of products. This paper aims to demonstrate the compatibility of circular economy and lean principles in the context of PSSs and contribute to their integration in order to create customer-oriented solutions that minimize resources consumption and enhance the ultimate value-added to the end-user.

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Keywords: Product-Service Systems; Circular Economy; Circular Manufacturing; Circular Products; Lean Manufacturing; Lean Services; Lean Thinking.

1. Introduction

Circular Economy is "an industrial economy that promotes greater resource productivity, aiming to reduce waste and avoid pollution by design or intention. In a Circular Economy (CE), material flows are of two types: (a) biological nutrients, designed to reenter the biosphere safely, and (b) technical nutrients, which are designed to circulate at high quality in the production system without entering the biosphere as well as being restorative and regenerative by design" [1].

In this paper, authors will focus on the technical material flow type, and particularly in bringing together the paradigms of *Circular Manufacturing* [2], *Lean Manufacturing* [3] and *Lean Services* [4] in the context of *Product-Service Systems* [5].

The scope for employing circular & lean principles towards *Circular Lean Product-Service Systems* relies on developing new business eco-systems where *Circular Products* [6] can be designed for ease of maintenance and repair, upgradability and adaptability, and dis- and re-assembly in order to *servitize* them for longer lifecycles and *reclaim* them at their end-of-lifecycle for re-manufacturing and recycling. So that virgin materials extraction could be decreased, materials waste flows reduced and moderate stress put on environmental resources extraction. Furthermore, in these Circular Lean PSS business eco-systems, *lean manufacturing* and *lean services* will help to make sure that no time and effort is wasted during manufacturing activities and service operations. Thus, *Lean Thinking* [7] could support effective and efficient *PSSs' operations* in the marketplace. Such *efficiency* will be of particular relevance for PSS business models where customers will be continuously assessing their solution providers' performance (cf. performance-based PSSs).

This paper aims to demonstrate the compatibility of circular economy and lean principles in the context of product-service systems and contribute to their integration in order to create customer-oriented solutions that minimize resources consumption and enhance the ultimate value-added to the end-user.

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The research method [8] was based on a systemic literature review using the keywords of this paper, and an evidence-based exploration of case studies as the ones presented in Section 4.

2. Base Concepts towards Circular Lean PSSs

2.1. Product-Service Systems

A *Product-Service System (PSS)* is "an integrated product and service offering that delivers value-in-use. A PSS offers the opportunity to decouple economic success from material consumption and hence reduce the environmental impact of economic activity" [9].

In a transition from a linear to a Circular Economy, PSSs are one of the most promising business model solutions [10] where instead of buying products, customers will pay to use them, while the manufacturer will be able to remain the owner of the product in order to provide value-added services along its lifecycle and guarantee an extended producer responsibility.

PSS business models can provide manufacturers with long-term revenue streams that are not as reliant on the potential of new product sales, but on *service offerings* such as consumables, monitoring, maintenance, repairs and even upgrades for product lifecycle extension, and on *revalorization services* like re-use, re-manufacturing and recycling at the product's end-of-life [11].

2.2. Circular Product Design and Circular Business Models

Circular Products are products designed for servitization and lifecycle extension and without a mixture of biological and technological materials in order to make them easier to disassemble for composting and recycling, so their materials can circulate in closed-loops without generating waste. Some examples are products as a service; products based on recycled resources; or products/assets in sharing platforms [1] [6].

According to [6], defining *circular product design strategies* for a long product lifespan starts with the notion that design concerns with the complete economic circle of change. Hence, the terms *Circular Product Design* & *Circular Business Models* are 'interlinked'. Meanwhile *circularity* promotes a *product design* based on designing for attachment and trust, durability, standardization and compatibility, ease of maintenance and repair, upgradability and adaptability, and dis-assembly and re-assembly [6], *business models* need to conceptualize new logics for value creation based on utilizing the economic value retained in products after use and in the design of new service offerings [12].

Building on circular product design principles and circular business model strategies, PSSs can contribute to the Circular Economy by *slowing* or *closing resources loops* [13]. On the one hand, designing for long-life products and product-life extension for slowing resources consumption and loops [13] can enable new long-term revenue models based on [14]:

- *Product-oriented PSSs*, where the product ownership will be transferred to the customer and additional life-extension services (cf. servitization) will be provided. Therefore, revenue streams will come from a 'service economy' rather than from new product sales, slowing the extraction of virgin materials for new products. For this type of PSS model, a 'take-back system' must be considered in the context of circular business models.
- *Use-oriented PSSs*, where ownership of the product is retained by the PSS provider, and 'functionality, not ownership' is offered. Thus, an 'asset utility' can be maximized in a 'Sharing Economy' [15] by means of renting, lending, swapping, bartering and even giving it away in order to avoid its idle existence and incentivize unnecessary individual rather than collaborative consumption of a 'shareable asset', so resources consumption can be lowered.
- *Result-oriented PSS*, where products will be replaced by services, allowing the PSS provider to have full lifecycle control of the product and push for designing for long-life products, service revenue streams (focus on product-life extension) rather than product sales, and new sources of value capture from exploiting residual value of products.

On the other hand, designing for technological cycle, so that at the end of a product's final lifecycle, materials can be easily reclaimed and recycled, enables closing resources' loops [13] and alternative revenue models (cf. diversification) that 'create value from waste' [16]:

- *Re-use, re-manufacturing and/or recycling* [17], where wasted materials or resources are turn into new form of value (e.g. second-hand products, spare parts, recycled materials) in order to maximize materials and resources productivity, resources efficiency and waste reduction.
- *Cradle-to-Cradle* [18], where all materials (nutrients) for a product or PSS design are selected based on their 'recyclability nature', so materials can circulate in the technical cycle for as long as they have any value for society and then reintegrate to the biological cycle in a re-generative system.
- *Industrial symbiosis* [19], where residual outputs from one process become feedstock for another process.

2.3. Lean Thinking: Lean Manufacturing and Lean Services

New PSS business models will continue to emerge driven by the desire to combine economic prosperity and sustainable resources management [20]; their *effective* and *efficient* design and operation will shift the competitive arena (value offerings) from pure products to (product) integrated solutions infused with value-added services as the new sources of competitive advantage [21] [22]. In this sense, *PSS - Lean Thinking* can be understood as a business and engineering methodology that aims to provide a new way to think about creating value by understanding that customer satisfaction is paramount when delivering functionality and/or performance offering and by eliminating waste in the manufacturing activities and services operations that affect the PSS efficiency [22] [23].

At this point, it is important to highlight that a *PSS* as a 'system of systems' is composed by a product lifecycle and several associated services lifecycles. *Lean Manufacturing principles* [3] will support the elimination of waste (viz. transport, inventory, motion, waiting, over-processing, over-production, defects, talent, resources, and by-products) within the PSS manufacturing system part, and the development of people within such a system able to relentless solve problems and promote continuous improvement [22]. Meanwhile, *Lean Services principles* [4] will support the elimination of waste

(viz. delays, duplication, unnecessary movement, unclear-communication, incorrect inventory, an opportunity lost to retain or win customers, errors in the service transaction, and service quality errors) at the PSS service systems parts. So *lean principles* will be applied in every operation of the PSS.

3. Towards Circular Lean Product-Service Systems

A *Circular Lean Product-Service System (CLPSS)* is defined as a combination of a tangible circular product with intangible value-added service elements, and its related supporting closed-loop networks and infrastructure. It can lead to dematerialization through reducing the creation of waste in manufacturing and services operations, and the consumption of virgin materials, thanks to a restorative and regenerative operational system by design that can satisfy customers' needs, decouple economic growth from environmental impact and create new revenue streams out of extending the residual value of products.

Circular Lean PPS business models should be seen as a sustainable innovation strategy focused on efficiently offering a system of circular products and value-added services, and supporting circular systems (cf. take-make-return) to the customer. Which jointly can boost value-in-use and extend the residual value of products by means of re-use, re-sale, repair, refurbishment, re-manufacturing, cannibalization and/ or recycling strategies towards zero-waste and new revenue streams.

For the scope of this work, *Circular Lean PSS lifecycle stages* will be divided in two: (a) *design and engineering* - focused on the development of circular lean product-services bundles, and (b) *operations management* - focused on the effective and efficient management of PSS manufacturing and service provisioning activities during its business model operation.

3.1. Circular Lean PSS Design and Engineering

The application of *lean thinking principles* to support PSS design and engineering is emerging in literature [5]. Moreover, PSS business models [20] are often mentioned in literature as business model archetypes supporting the transition from a linear to a Circular Economy [24]. Nevertheless, very limited research works were found formally combining both *lean* and *circular principles* in an integral way, triggering the motivation for this initial work.

Circular Lean PSS design and engineering is strongly related to the efficient use of resources, improved functionality and/or performance of the customer value proposition, and development of innovative integrated solutions via product-services packages or bundles, which guarantee an extended producer responsibility and/or stewardship service(s) for extending product value at the end of its life.

Based on the aforementioned, at the Circular Lean PSS design and engineering stage:

- *Efficient use of resources* refers to use of renewable resources flows and the elimination of waste [25].
- *Improved functionality and/or performance of the customer value proposition* focuses on all possible (customer) requirements associated to satisfaction and acceptability [26].
- *Development of innovative integrated solutions via product-services packages or bundles* concentrates on the synchronization processes of the product and the services by incorporating the input from the customer in the process [27] and the enabling of a synergic design between product and services [28] [29] [30] [31] [32] by means of a front-end of innovation process [33].
- *Guaranteeing an extended producer responsibility and/ or (product) stewardship service(s)* refers to the 'design for circularity excellence', including design principles for attachment and trust, durability, standardization and compatibility, ease of maintenance and repair, upgradability and adaptability, and dis-assembly and re-assembly [6]. Other relevant related Design for eXcellence (DFX) principles (guidelines) may include: Design for Serviceability, Design for Maintainability, Design for (Active) Disassembly, Design for Repair - Reuse - Remanufacturing - Reconfigure - Recyclability, and Design for Environment [34] [35].

The *circularity* idea of closed-loop resources flows in PSSs design and engineering can be summarized in the need to manage sustainably resources, especially scarce and non-renewable ones [36]. Meanwhile, the *lean* idea of creating value and eliminating waste in PSSs can be summarized in the 5C approach: Clear out, Configure, Clean and check, Conformity, Custom and practice [37].

Moreover, *continuous improvement* in Circular Lean PSS design and engineering will be of extreme relevance due to the long-life nature of product-services and product-life extension services, where *circular lean product-services* will be designed for upgradability, adaptability, re-configurability, serviceability and possibilities for exploiting their residual value (e.g. re-manufacturing and cannibalization and/or recycling).

3.2. Circular Lean PSS Operations Management

The application of *operations management principles* to PSS operations requires a combination of 'manufacturing' and 'services' operations management best practices. Meanwhile, the literature in Manufacturing Operations Management (MOM) is extensive; the case for Service Operations Management (SOM) is different, where in the discipline, the topic of 'services' is not deeply investigated and no clear statement of a unified service reference framework is reported [38] [39].

MOM is concerned with the design, management and continuous improvement of manufacturing systems, including optimization of equipment, inventory, process execution, and staffing towards cost reduction, quality control and throughput. While, *SOM* is concerned with the design, management and continuous improvement of service systems, including the service staff, technology, practices and processes involved in the achievement of a certain level of service system performance and service quality whilst minimizing costs and maximizing the use of scarce and expensive resources [38].

According to [39], SOM focuses on tailoring service systems balancing service quality and cost-benefit (revenue) objectives by means of effective service content and process design, via matching service requirements to customer needs, and proper service process execution and service staff management.

When it comes to the availability of integrated *Manufacturing & Services Operations Management (M&SOM) approaches* for PSSs, very few research works where found in literature: [40] [41] [42] [43] [44] [45]. Which calls for further 'Operations Management' discipline investigation in the topic, considering the integrated combination of products (and their manufacturing systems) and services (and their service systems) in PSS business models operation [32] [43].

By extending the traditional offering of products to include services their underlying operational delivery systems and processes become a more complex but controlled value chain to manage and coordinate, creating new implications and possibilities for M&SOM in order to operate PSS business models in an effective as well as efficient way [46] [47].

[48] has identified (3) critical challenges for *PSS operations management:* a) organizational culture, b) external effectiveness at the customer interfacing 'front-end', and c) achieving internal efficiency of operations at the 'back-office'. In addition to the obvious one of integrating manufacturing-services operations.

Given the complexities of *Circular Lean PSS operations* and the limited literature available and specialized for PSS M&SOM, authors and readers can draw upon: [44]'s operations strategy framework that proposes a set of principles, structures and processes that can guide a manufacturer in the delivery of product-centric servitized offering. [45]'s characteristics and principles for 'lean operations' in product-oriented PSSs. [49]'s service design framework, which incorporates both product and service design principles, and parallel, series and specialization tasks. [50]'s methodological framework to identify and visualize dependencies and interactions between services lifecycles and product lifecycle management. e.g., *Exchange of information* - information about available sensor data that can be used for a digital service. *Coordination* - synchronizing the change management for service with product development. *Solving conflicts* - identifying incompatibilities at data interface and defining common standards. *Negotiation* - if parameters like the frequency of measurement does not fit together and adaptions have to be made on both sides to make product and services work together. [51]'s collaborative organizational framework, based on green virtual enterprises (forward [52] and reverse [53]), which can be used to support the creation of dynamic closed-loop (circular) value networks.

Circular Economy rests on three principles, each addressing several of the resource and systems challenges that industrial economies face [1]. The authors propose *Circular Lean PSS* to support and foster the accomplishment of such *principles (P).*

P1: Preserve and enhance natural capital "by controlling finite stocks and balancing renewable resources flows". *CLPSSs* respond to this principle by accomplishing its guiding principle of waste reduction (leanness) along the overall PSS design, engineering, and manufacturing and services operations, including supporting closed-loop networks and infrastructure environment. Waste banishing at manufacturing and service operations level is strongly linked to both reduction of energy and raw material consumption, as well as efficient resource flow. *Lean design* and *engineering* supports the smart selection of proper resources to be used to develop *circular PSSs*, through an intensive knowledge-based development process. Moreover, *Circular Lean Thinking* supports the proper choice of technologies and processes that use renewable or better-performing resources with the purpose of eliminating waste and continuously improve to reach the ultimate ambition of an overall zero waste (resource, environmental, energy) system.

P2: Optimize resource yields "by circulating products, components, and materials at the highest utility at all times in both the technical and biological cycles". *CLPSSs* support this principle by not only designing 'circular products' [6], but also promoting 'circular business models' [13] [16] [54], as a strategy for guaranteeing extended product lifespan. *CLPSSs* largely use Design for eXcellence (DFX) techniques (guidelines) to accomplish this aim with a special focus on Design for Lasting [6], Design for Serviceability, Design for Maintainability, Design for (Active) Disassembly, Design for Repair - Reuse - Remanufacturing - Reconfigure - Recyclability, and Design for Environment [34] [35]. Hence, DFX techniques are strongly related to how a PSS and their components should be designed in order to support a smart selection of resources to be used, technologies to be adopted, and methodologies to be followed when conducting lean operations and delivering product-services offerings *designed for circularity.*

P3: Foster system effectiveness "by revealing and designing out for negative externalities". *PSSs* link tangible (product) and intangible (services) components to achieve higher customer value delivery, but also to increase value for the whole society. *CLPSSs* start with the prevalent lean principle of respect for people and developing independent problem solvers able to constantly reduce waste and improve the system they are working in. Furthermore, *CLPSSs* foster not only waste elimination (leanness), but also promote a circular way of thinking (restorative and regenerative by design), to be adopted at every single level of a PSS value chain, from design to service delivery and reverse logistic. Wastes occurring in a PSS lifecycle and all along its tangible (product) component lifespan have an impact on the environment and society, both in form of raw material and energy consumption as well as environmental impact. *Lean thinking* enables, above any other discipline, the ability within every single person in the system (the PSS) to develop awareness around waste impact on the surrounding system (nature and society) and the ability to relentless eliminate such waste and improve the system. Therefore, *CLPSSs* will lead to the huge consequence of creating a system able to improve itself while driven by the culture of circularity, with beneficial results in terms of overall system efficiency, for both enterprise and humanity.

4. Early Manifestations in the Industrial Landscape

Not only Lean Circular PSSs are new to the academic world; they are also at their embryonic stage when it comes to industrial implementations. So far, only few attempts have been conducted in adopting *lean thinking* to foster circular economy reasoning within enterprises. Despite the focus does not explicitly involve PSS development at such (by introducing specific services and circular PSS business models), the results look more than promising.

The first admirable manifestation in industry comes from SunPower, a vertically integrated solar company that designs and manufactures solar cells and panels for residential roofs, commercial buildings and wholesale power plants that went

through substantial changes from 2009. SunPower moved from "cradle to grave" to "cradle to cradle" paradigm [18], by adopting *lean thinking* as a leading way of thinking and acting in every day operations. Adopting the idea promoted by *Circular Economy*, such as being at the highest ecological standard of production or having zero waste to landfill target, boosted the engagement of SunPower staff and encouraged them to ask more questions, as for *lean thinking attitude*. The company makes of *Circular Economy* the ideal to strive for, by making product that are entirely beneficial by design. *Circularity* is the ultimate goal, *lean thinking* is the way to achieve it thanks to people engagement at all levels. SunPower claims that without *lean* it would not be possible to achieve the level of motivation needed to move from linear to circular thinking: "cradle-to-cradle" [55] [56].

Similarly, the LEANGO initiative (launched in 2016 at Politecnico di Milano - University) uses *lean thinking* to boost 'sustainable development' in developing countries. Playing upon the opportunities emerging countries have to "do it right the first time" and avoiding falling into the same mistakes of developed countries did when embracing the self-destroying linear economy, LEANGO supports developing economies, with the help of local non-profit organizations to smartly take advantage of their still-to-be-modeled economies. With its first successful implementation in Myanmar within 18 Burmese SMEs, LEANGO makes actionable the *Circular Economy principles* by adopting *Lean Thinking* as a leading way of approaching companies' behaviors and management, by creating awareness around lifecycle thinking, circular economy, sustainable development, waste (either process, environmental or energy wastes). An simple, actionable, questions-driven framework at the basis of the initiative links value creation with waste elimination within companies while promoting at the same time resource saving, environmental impact reduction and 'circularity' [57].

5. Discussion, Conclusions and Further Research

This paper has introduced the first (working) definition for "Circular Lean Product-Service Systems".

The main objectives of the emerging *CLPSS paradigm* proposed in this work, aim to evolve traditional businesses and PSS business models:

- From sustainable integrated manufacturing and services operations to restorative and regenerative ones.
- From isolated value offerings (stand-alone products and services) to integrated product-services solutions.
- From product-service systems (system approach) to product-services eco-systems (holistic approach).
- From sustainability as a requirement to a new source of revenue streams through servitization and circular business models.
- From environmental sustainability to environmental sustainability, social capital and decupled economic growth form environmental impact.
- From a linear economy to a circular economy.

Within this research work, the following challenges and progress made towards facing such have been identified for *CLPSSs:*

- Defining a 'circular value offering' that will satisfy the customer and CLPSS business model stakeholders.
  - Design for Circularity approaches [6].
  - Design for Multiple Stakeholders [51] [58].
- Designing and managing CLPSSs operational systems to deliver circular value offerings.
  - Original PSS body of knowledge, e.g. [40] [41] [42] [43] [44] [45].
  - Recent literature in Lean PSSs, e.g. [5] [22].
  - Current literature in Circular Business Models Archetypes, e.g. [10] [12] [13] [16] [54] and Circular Capabilities [59].
  - Exiting body of knowledge on Collaborative Networked Organizations (CNOs) [60], and in particular Green Virtual Enterprises literature [51] [52] [53].
- Delivering circular value offerings through a network of partners.
  - CNOs methods and tools [61], and particularly frameworks, models, methods, processes and tools for Green Virtual Enterprises [51].

Circular Economy and *sustainable development principles* are claimed to be in the target of many enterprises nowadays, all over the world. While theoretically, *CLPSS* have a huge impact on making those principles actionable, not only there is a lack of practical experiments and contributions, but also this looks to be the first academic research attempt towards the direction of defining how *lean thinking* enables the achievement of *circularity* when introducing *PSSs* into the marketplace. Clearly, there is lots of academic research to be done. Authors are confident that such research will be as applied as possible to assure *CLPSSs* will exhibit the potential they have in being ready to prove their utility to foster *circular economy* and resulting in improved use of resources for the entire society benefit. This paper has the ambitious aim to be a first, strong and loud call for contribution in such a research direction, and provides an initial framework of thought and work (Fig. 1).

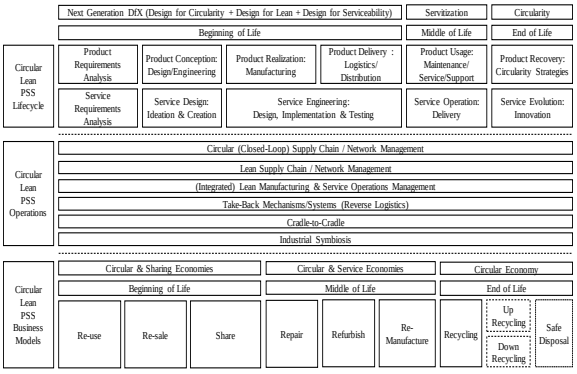

Fig. 1. Toward CLPSS Framework

Finally, based on this first research effort and discussions found in literature, main challenges for PSS providers as a single or networked enterprise(s) to materialize CLPSSs will rely on better understanding the relations between products and services in a PSS along their lifecycles [e.g. 50] and the coordination of a closed-loop value chain or network [e.g. 51].

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