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Circular Lean Product-Service Systems Design: A Literature Review, Framework Proposal and Case Studies

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Abstract

In recent years, the Service Sector has received an increasing attention from both academics and practitioners. The transition from traditional manufacturing to service-oriented integrated systems has given rise to the such called: "Servitisation Revolution", which today is a relevant revenue generator. The definition of "Product-Service Systems (PSS)" calls for an expanded value creation system through the addition of competitive advantages based on value-added services to previous companies' pure product offerings. These product-services bundled solutions have been recognized as being one of the most efficient techniques towards the achievement of resource-efficient and sustainable economies. PSS paradigm has grown beyond expectations, becoming a common term among publications of the most recognized academic journals and international conferences, and a highly discussed topic across a broad range of industrial sectors. However, recent trends based on scientific and grey literature suggest analysing the compatibility of PSS with other principles, methods and tools such as "circular" and "lean" thinking, which may help to enhance the intrinsic environmentally sustainability advantage that is refer at the first PSS definitions, but that has, unfortunately, faded through time. This paper analyses how the PSS paradigm can benefit from the "circular economy" and "lean" principles. The followed research methodology included a literature review, which aims to identify those principles, methods and tools which can help to modify each stage of a traditional PSS towards a Circular Lean PSS. Furthermore, a first Circular Lean PSS Design Framework is proposed and described. This framework is validated empirically through two case studies supported by two vessel-building companies. Further research is suggested to validate the proposed framework in different industries.

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

1. Introduction

Today's manufacturing world has developed an increasing awareness towards creating sustainable solutions (e.g. products and product-services bundles) for the industrial and consumer markets. Thus, in the last decades, different organizations have considered relevant to challenge their "traditional" business models and develop new ones aligned with the everyday more demanded sustainability requirements for products by OEMs, consumers, and governments [1]. As a result, the exploration of the *Product-Service Systems (PSS)* paradigm has become a relevant and commonly discussed topic among organizations for this aim. This paradigm has grown beyond expectations, allowing the creation of new sustainable business models that attempt to fulfil users' needs through dematerialization. Hence, PSS paradigm creates an outline for the sales of use of products, or results, instead of tangible products themselves [2]. This not only suggests the transition into a leasing society, but mainly a big change in consumers' attitudes from products ownership to a service-orientation [1]. Simultaneously, a big-boom was experienced within the environmental concerns of academics and practitioners after the European Commission published the whitepaper: "Closing the Loop – An EU Action Plan for the Circular Economy", at the end of 2015 [3].

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However, there is still limited understanding around how to integrate the trend of PSS business models with the *Circular Economy (CE)* principles, and other principles also contributing towards more sustainable, resource-efficient business models and economies such as *Lean Thinking* (i.e. lean manufacturing and lean services). As an attempt to close this gap, a working definition for – *Circular Lean Product-Service Systems* – was recently proposed by [4], describing it as "a combination of a tangible circular product with intangible value-added service elements, and its related supporting closed-loop networks and infrastructure". Here the authors proposed that it can lead to "dematerialization as result of a reduction in waste creation; all this as consequence of a restorative operational system that can satisfy customers' needs by an extension of value streams". This paper will address the benefits that could be found in the interactions of PSS business models with CE and Lean Thinking principles through the proposal of a Circular Lean PSS (CLPSS) Design Framework and its validation through two industrial case studies.

2. Theoretical Background

2.1 Product-Service Systems

The origin of the concept, *Product-Service Systems (PSS),* comes from the proposal of "servitisation" [5]. *Servitization* aims to explain the process of creating value, or value-adding through the addition of services to products. Some authors have stated that management literature suggests repetitively the idea of integrating services into manufacturing organizations [6].

One of the most accepted definitions for servitisation conceptualizes it as *"a change process where manufacturing companies embrace service-orientation and/or develop more and better services, with the aim to satisfy their customers' needs, achieve competitive advantages, and enhance the firm performance"* [7]. This definition provides an explanation of the line-blurring phenomenon between products and services, which came as a consequence of how, since the 60's industrial marketing literature suggested the introduction of system-selling strategies [6].

Thru the evolution of this concept, the terms servitisation and PSS can be found in literature used indistinctly [8]. However, they are most commonly found in different contexts. *PSS* is usually referenced when there is major interest in the sustainability potentials of the offering, while the term servitisation is mostly used in a purely economic context [9]. Other authors support this perception of PSS by describing it as *"a business innovation strategy offering a marketable mix of products and services jointly capable of fulfilling clients' needs and/or wants – with higher added value and a smaller environmental impact as compared to an existing system or product"* [10].

2.2 Circular Economy

In 2015, Murray et al. [11] explained the lack of common agreement from different academics on the true origin of the Circular Economy concept. However, the understanding of this concept is relatable to different propositions, including those that use different terminology, such as: closed-loop economy. Their relevance lies in their common goal, which is to reduce environmental impact of production and ensure as least waste generation as possible through a product's lifecycle. In this sense, Ellen MacArthur Foundation (EMF) defines a *Circular Business Model* as a business model that allows the retention of a capital at its highest value over time and support enhancement of natural capital [12]. At the same time, it is explained that several business models might be required, and even overlapped in different stages of a product's or asset's lifecycle for value maximization.

These type of business models have been linked with PSS business models due to the fact that they shift the responsibility related to the end of products' lifecycles to their suppliers, thus supporting closed-loop industrial systems where materials are recovered, reused, and recycled [13]. Anyhow, there has been strong questioning towards the PSS international community, where its researchers' argument that a panacea has been constructed around the fact that PSS business models can trigger a more sustainable development. This has caused a significant increase in the number of publications and case studies aiming to explain and demonstrate the specific path and design/engineering aspects that should be applied to achieve the desired sustainability objective. To successfully dissolve the idea of this false-environmental benefits, authors search for convergence with disciplines that analyse lifecycle management in terms of both products and services. In this way, a holistic solution will take into consideration every aspect of a system existence.

2.3 Lean Thinking

Lean Thinking, is a resource-efficient philosophy that can be applied to multiple organizations across every industrial sector [14]. It was originated early in the 1980's through the increasing interest to improve product development processes through increased competitiveness, "*doing more with less*" [15]. At this point, researchers started to identify and rationalize the diverse paradigms applied in Western Corporations and rapidly growing Japanese automotive market. Early works such as "The Machine that Changed the World" [16], worked towards the shaping of this philosophy and spread the field across all major industries.

Considering the aim of this research work, it is necessary to define *Lean Production* by first examining its historical evolution and identifying the different perspectives that are commonly involved in its description. Currently, there are numerous academic and practitioner books and articles, yet academia still do not have a precise and agreed upon way of defining or measuring Lean Production [15] [16]. In the early 90's, the *Lean Manufacturing* concept was viewed as an alternative to the traditional Ford manufacturing model. Therefore, Lean Manufacturing is commonly traced to the Toyota Production System (TPS) [14], which was pioneered by Japanese engineers Taiichi Ohno and Shigeo Shingo [16]. Lean Production is generally described from two points of view, either from i) a philosophical perspective related to guiding principles and overarching goals, or ii) from the practical perspective of a set of management practices [16]. This difference does not lead to disagreements, but does create conceptual challenges.

3. Research Methodology

This research work consists of three stages: i) a literature review, ii) a framework proposal, and iii) two case studies.

For the literature review, the databases SCOPUS and Web of Science were explored through a keyword search explained in Fig. 1. The selected keywords for PSS included: “product service systems”, “product-service systems”, “productservice systems” and “servitisation”. The main findings from this literature review are described further in the next section. Additionally, the results obtained were synthetized in a framework proposal explained in Section 5.

Integration Definition for Function Modelling (IDEF0) [17] was selected as modelling language to design this first attempt to develop a *CLPSS Design Framework.* This decision was taken based on the fundamental IDEF0 approach, which is the study of manufacturing process and business process of re-engineering. This modelling and communication tool provides domain expertise involvement and simplifies decision-making processes through a logical flow procedure. These models are constantly created as one of the first tasks of any system development effort.

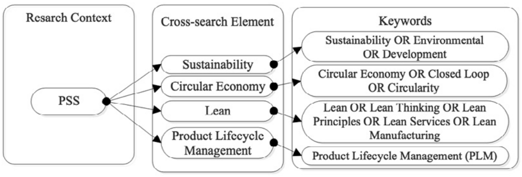

Fig. 1. Selected Keywords for the Literature Review

4. Main Findings from the Literature Review

Since the first appearance of PSS term in literature, academia made huge efforts to define this innovative solution to migrate traditional manufacturing into services. Through this process, several definitions were provided for PSS; most of which are presented in the five most cited literature reviews on the topic: [1], [8]. [18-20], where popular definitions are addressed, some of which go back to the 90’s to analyse and visualise the whole evolution of the PSS concept through the years.

In a next step, and after some research initiatives, which aimed to find synergies and compatibility aspects between PSS and Lean Thinking principles, four literature reviews came to try to synthetize those definitions generated. So is the case of additional work, where not only definitions and literature analysis are provided, but uniformization in the use of concepts is proposed and case studies are presented like in [21] to [24].

However, there are still limited insights into a Circular Lean PSS vision, which was only defined recently through a call for research and proposed compatibility check in [4]. However, the provided working definition could be strengthened through industrial feedback to provide a more practical and applied point of reference.

The main findings obtained through the literature review conducted are now presented in three categories:

4.1 CLPSS Sustainability-Fostering Lifecycle Stages

In recent literature, various authors claim that transformation from a regular revenue model to a sustainable PSS requires several considerations at the beginning of its lifecycle. This means to develop changes early during the PSS system design. Although different authors emphasize the need to consider every step of the PSS lifecycle, the Beginning of Lifecycle (BoL) is highlighted as decisions-taken stage that will require further monitoring. So it is the case of the plastic mould case study [25], which states that environmental aspects should be considered and prioritized since the beginning of the product design for the inclusion of recycled materials in order to close-loops. This study states that actions taken at this stage, could lead to desired dematerialization, which could also foster circularity through the production system. Regarding PSS design, some academics and practitioners express their concerns about the customer’s behaviour when testing *use-oriented PSS.* So was the case of baby prams [26] and baby clothes [27], which showed that customers need diverse value propositions in order to compromise with the service supplier.

Some designers have taken the leap of developing PSS where offerings are retained by customers for short periods of time. Previous case studies shoe what *product-oriented PSS* under short-period schemes, have not received proper care and usage recommendations have not been followed properly. This behaviour causes short revenue streams, where products need to be replaced constantly, leading the PSS business model to failure.

The integration of “lean” into PSS design also shows a gap in literature. Some authors suggests that the thought that PSS is naturally more efficient in the use of resources, can lead to the so-called “servitisation paradox” [22].

4.2 CLPSS Design Enablers for Sustainability

Recent research has developed a growing interest in PSS, mainly due to the promising sustainability advantages that it claims to provide to its adopters. To achieve the desired improvement in sustainability indicators, implementers should verify compatibility with their management capabilities, such as a strong ERP system (Enterprise Resource Planning) and data collection thorugh smart-sensing devices that support decision-making processes [28].

Recent literature suggests the use of quantitative tools to assess *use-oriented* and *contract-based PSSs,* and the effects on products costs and maintenance, such as on risk sharing in mining-haul truck tires [29]. Some of the papers found in the literature review state that there is a lack of literature in practical and systematic validation of PSS requirements and design frameworks, as most of the literature regarding *Lean PSS* provides state-of-the art analysis [30].

Recently, some researchers suggest a shift in the “traditional” PSS, to an innovative PSS model where digitalization takes a bigger place in the picture. Through a higher involvement of digital technologies, benefits such as mechanical component simplification, evergreen design enhancement, remote services development, and a diminishment in the logistic requirements of physical goods could be achieved over task optimization and supply chain synchronization [31].

4.3 CLPSS Circularity-fostering elements

The *Circular Lean PSS vision* aims to achieve closed-loop processes through “servitisation”, “lean principles”, and well-understood “information” and “material flows”. Through the literature review, findings suggest that benefits can be obtained if there is a correct planning of material flows. This statement encourages the interaction of *PSS designers/engineers* with *waste managers* to benefit from their knowledge on raw material taxes and Extended Producer Responsibility (EPR) systems, in addition to other variations of material-flow management [32].

Although some literature highlights a limited availability of methodological tools for *sustainable PSS,* other researchers propose frameworks or ontological models that aim to provide evidence of "circularity" achievement through "servitization" revenue models. So is the case of a collaborative platform for users and engineers which was recently proposed to address special manufacturing needs [33]. This multisensorial system provides inputs for KPIs calculations that would manage information of the middle- and end-of- a product lifecycle based on its characteristics [33].

5. CLPSS Design Framework

The development of a *CLPSS Design Framework* follows the traditional PLM lifecycle stages division of a) Beginning-of-Life (BoL), b) Middle-of-Life (MoL), and c) End-of-Life (EoL).

The first lifecycle stage, BoL, is where the PSS is imagined and the tangible part, the product, is manufactured. The *CLPSS Design Framework* proposes three internal steps: i) CLPSS Requirement Analysis, ii) CLPSS Ideation & Design, and iii) CLPSS Engineering & Manufacturing (see Fig. 2).

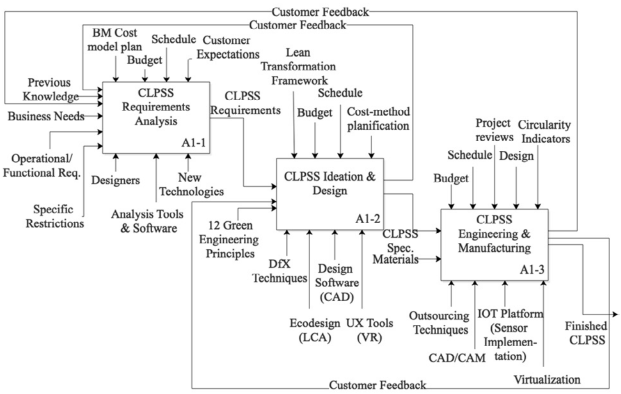

Fig. 2. CLPSS Beginning of Life

The second lifecycle stage, MoL, makes reference to those steps where the CLPSS is in its usage stage and in direct contact with the customer. This stage includes two internal steps: i) CLPSS Delivery, ii) and CLPSS Maintenance & Upgrading (see Fig. 3). In the third lifecycle stage, EoL, the CLPSS has lost its first-intended purpose and planned usefulness. It includes only one internal step, defined as: CLPSS Product & Spare-parts Recovery (see Fig. 4).

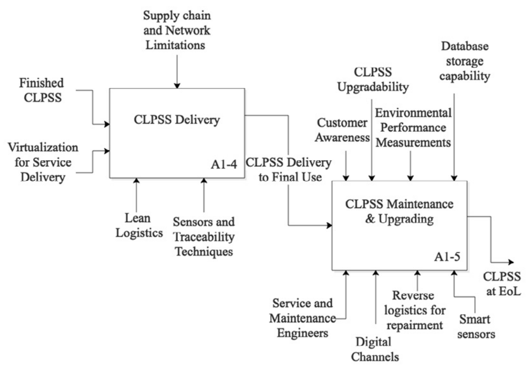

Fig. 3. CLPSS Middle of Life

According to the IDEF0 methodology, inputs to the system are indicated through arrows on the left side of the stages, represented as boxes. Arrows that appear on the upper side of the boxes are showing the controls of the system. Arrow entries appearing on the lower part of the boxes show resources. Finally, arrows on the right part of boxes indicate outputs of each stage.

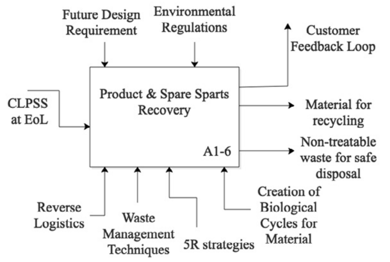

Fig. 4. CLPSS End of Life

Each of the following boxes show a set of principles, methods and tools that result from the literature review and are suggested to become beneficial in the design of a CLPSS. This framework aims to integrate holistically these concepts into a first attempt of successful design a *CLPSS Framework.*

6. Case Studies

In Section 5, a first design framework for CLPSS is proposed. Linking this proposal to real industrial applications increases its value, and provides insights about the feasibility of its implementation. Access to data and industrial contacts from the LINCOLN project was possible through collaboration between Politecnico di Milano & Tecnológico de Monterrey universities.

The European Commission (EC) is deeply interested in the development of smart, sustainable and inclusive growth to defeat structural opportunity areas within European's economy. Towards the achievement of this goal, the Agenda of Europe 2020 was proposed for the improvement in competitiveness and productivity for a sustainable social market economy [34]. Based on this statement and objectives, the Horizon 2020 programme was created. This initiative is the biggest European Union Research and Innovation programme proposed in history with billionaire funding available and strong linkage to private investment. Through this incentives, the EC aims to promote the migration of knowledge from labs and educational institutions to the direct application in market and industry [34].

LINCOLN project is a research project funded by this Horizon 2020 initiative and it has an established duration of 36 months, which run from October 2016 to September 2019. This project is part of the Blue Growth long-term strategy to support sustainable growth in the marine and maritime sectors and proposes the use of innovative design methods and tools for the development of three types of new vessel concepts through dynamic simulation testing. For the successful development of the three main vessels (i.e. Multi-platform Catamaran, a Module-based High-Speed Patrol Boat Platform, and an Emergency Response and Recovery Vessels series for Coastal Rescue Activities). LINCOLN project will use a *Lean Fact-based Design Model approach,* IT customized tools and High-Performance Computing and Simulating [35].

LINCOLN project is designed and defined to meet business case and industrial needs to significantly innovate technologies and solutions known but not fully developed or adjusted to the sought business effects for European SMEs. Each LINCOLN business case (i.e. Hydrolift, Super Toys, Techno Pro, and Aresa) is approached through a series of on-site visits and interviews [35].

To validate the model proposal interviews were conducted with representatives from industrial partners Aresa, Supertoys and members of the team from Politecnico di Milano. Aresa is a company dedicated to the construction, repair, refit, maintenance, services and marketing of all types of commercial and military vessels, Supertoys works on the improvement of inflatable and fiberglass vessels. Both companies represent diversification on the business cases utilized by the LINCOLN project.

6.1 CLPSS BoL

The most relevant insights from this stage, include a strong requirement for customer involvement in the "Requirement Analysis and Design" step. Also, companies suggested that iterative communication loops would be beneficial.

In the particular case of boat patrols, companies have not yet explored potential services, which could be incorporated to their product offerings. One of the main reasons is that the idea of "vessel-as-a-service" finds constraints in the lack of customer commitment to be careful and responsible with their usage, particularly when they do not have product ownership. This has also led to a lack of exploration on potential cost models that warranty economic benefits to the company.

Questions regarding the usage of digital technologies such as UX for customer visualization are still in early-stages and have not yet been explored. Information obtained from sensors and Internet of Things technologies provide highly valuable information. Today, this scenario is still in future plans.

6.2 CLPSS MoL

This lifecycle stage constantly represents a challenge, due to the fact that the elevated maritime distances represent high-costs and expenses. Nevertheless, communication with customers and visualization of the CLPSS usage can represent highly-valued data. So, this opportunity still is in the first stages of development. However, data acquisition would aid in the planning of preventive maintenance and in the identification of factors that cause failures and damages in the boat. Maintenance is an opportunity area for new revenue streams if customer's mindset evolves altogether with the business model. Further exploration is needed.

6.3 CLPSS EoL

This point changes abruptly from client to client. There is a lack of information on regular boat use from past clients due to the limited existent communication.

7. Conclusions & Future Research

The *Circular Lean PSS vision* represents a challenge in terms of PSS design. Through the last couple of decades, a considerable number PSS design models were proposed by literature. However, it is essential to understand the interaction and compatibility between the (circular) product and its value - added services. With the consideration of *Circular Economy principles,* this understanding transforms into a strong PSS requirement for designers and engineers.

In today's perception of CLPSS, it is essential to break barriers found between PLM and SLM and integrate them into a holistic enterprise-oriented PSS development and management process. Nonetheless, a small number of documented approaches have been proposed in order to find and visualize interactions between this two essential processes [36] [37].

It is necessary to take a deeper look in the possibilities that *Circular Lean PSSs* can provide to organizations, in any scale. There is still a lack of systematic integration in the existing elements which consist of principles, methods and tools. Also, this research strives to motivate companies to explore and analyse the possibilities that could be achieved through CLPSS.

This research work aimed to analyse the challenges and constraints of the implementation of a *CLPSS Design Framework* from an industrial point of view. Challenges are mainly focused on available technologies, as companies are restricted by the risks they are willing to take. Based on these decisions, cost calculation is a relevant point to consider. However, this point should not be considered as a demotivator, but as a challenge that can be conquered with the correct team, as researchers and practitioners have proposed creative and valuable solutions [38] [39].

Further research is recommended in the implementation of the proposed *CLPSS Design Framework* in other sectors of industry. Also, the design process should be fully validated, by analysing every suggested tool in every stage of the *CLPSS Design Framework.*

Acknowledgements

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