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A Bibliometric Analysis of Product-Service Systems' Design Methodologies: Potential Root-Cause Identification of PSS' Failures

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Abstract: Product-service system (PSS) innovation is acknowledged as a promising way to achieve sustainability through better exploitation of given resources. Nevertheless, PSS implementation is also described as increasing failure risk for companies. Despite that authors have identified paradoxical situations as a source of failure while implementing PSS, few researches have focused on understanding the origin of these paradoxes. In this review, we aim at understanding how methodologies cope with the challenges of designing PSS throughout the complete company perimeter as well as how to manage interactions within this perimeter to avoid potential paradoxes and thus failure. To do so, we will rely on the business model innovation literature and, more specifically, the business model canvas to define and discretize the company perimeter. As for the interactions and their imbrication regarding paradoxes appearance, we will refer to Putnam et al. theory to gain deeper understanding of paradoxes-appearance mechanism. Our bibliometric strategy brought us to analyze 14 international articles via our graph, enabling us to highlight that some poles' interactions during design are partly unaddressed, resulting potentially in the creation of tension sources and therefore potential paradoxes and ultimately implementation failure. Considering this, future research works could focus on defining all significant interactions to consider while designing a PSS as well as the typology of answers to engage while facing tensions. In that respect, these works could provide actionable solutions to lower PSS implementation-failure risk, thus benefiting those who wish to achieve better sustainability through PSS.

Keywords: product-service paradoxes; sustainable product service; product-service system innovation; product-service systems design methodology; product-service systems business model

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1. Introduction

Design of sustainable manufactured systems necessarily suggests the integration of environmental constraints. Consequently, the design of these innovative systems cannot be limited to the usual product and service perimeter.

To design properly, today, designers of sustainable solutions need to gain a broader perspective including all business model spectrum: revenue, market, organization, products, and services. Inevitably, the act of design becomes more and more complex and subject to failure without clear guidelines and methodologies.

Regarding innovative sustainable systems, product-service systems (PSS) are acknowledged as a promising way to achieve sustainability [1]. Indeed literature has demonstrated that green servitization has a positive impact on manufacturing companies' economic and environmental competitiveness [2]. The reason resides in the capacity of PSS to achieve higher use of a given resource while offering constant or greater value [3]. Nevertheless, the design of PSS is described in the literature as one of the most demanding challenges faced by companies [4] and certainly one of the riskiest. Furthermore, even though case studies

indicate PSS as a strategy for performance to consider, others pointed out that the link between product-service innovation and performance was not always clear, therefore asking the research community to further understanding regarding PSS design and implementation [5].

In the attempt to nourish reflection in the product-service systems on to how decrease risk of failure in the design of new PSS and therefore potentially enable more implementations of sustainable PSS, we present a review of the literature related to PSS design methodologies. In this review, we aim at understanding how methodologies cope with the challenges of designing PSS throughout the complete company perimeter as well as how to manage interactions within this perimeter to avoid potential paradoxes. As described in the literature, PSS has been thoroughly studied in a variety of research fields, therefore diminishing "blind spots" [6]. Considering this, our research objective is to conduct our review in an interdisciplinary manner as encouraged by Baines et al. [7] in the attempt to unveil new research paths of viable strategy to overcome the difficulties in promulgating environmentally-friendly innovations though servitization-implementation success [8].

To do so, we will rely on the business model innovation literature and, more specifically, the business model canvas to define and discretize the company perimeter. As for the interactions and their imbrication regarding paradoxes appearance, we will refer to the Putnam et al. [9] theory to gain deeper understanding of the paradoxes-appearance mechanism.

2. Research Context and Methodology

2.1. Research Context: The Paradox of Sustainable Development

To illustrate our discussion, the path to sustainability for the transportation sector seems relevant as it represents roughly a quarter of global CO_2 emissions in 2019 with over 70% coming from road transport. In this sector, light-duty vehicles represent a fair shar at 15% of the EU emissions of CO_2 in 2017 [10]. As for reducing this environmental impact, electrical vehicles (EV) are often portrayed as appealing solutions, with no CO_2 exhaust emissions like combustion engines [11]. Nevertheless, Gonzalez et al. depict a rather less seductive picture, pointing out the dramatic effects of massive soil extractions needed without reduction of the number of cars itself [11]. A far more effective solution to achieve a more sustainable projection would be, according to Grubler et al., a shift in use, as "increasing vehicle occupancy by 25% and vehicle usage per day by 75% delivers the same intra-urban mobility with 50% of the vehicle fleet." [12].

Considering that, the EV-carsharing solution appears to be the ultimate PSS answer to these issues described above. However, design of PSS remains a difficult journey, as the example case of Autolib in France demonstrates. The Autolib project was launched in 2011 following a public tender that selected the Bolloré Company to operate a carsharing scheme in Paris. It rapidly became the biggest EV-carsharing system in the world at the time. Nevertheless, Autolib never achieved profitability and eventually ended in 2018. According to Lagadic et al. [13], who analyzed the Autolib case, "carsharing services are intensively used when they are easily available." They concluded that "Autolib's highest frequency of use was reached with a 24 users per car ratio: Autolib was, however, still not profitable at that point". Moreover, a survey ordered by the French Agency for Environmental Transition in May 2014 gives more insight regarding the Autolib's user personae. [14]. According to this report, the wealthy class is overrepresented. Moreover, adoption of Autolib resulted in a modal shift from public transports toward shared cars. This survey concurs with Amatuni et al. describing car sharing systems as having strong rebound due to the modal shift induced [15].

Considering the elements hereabove, we construe that Boloré Company reached a multiple paradoxical situation:

- Economical: To achieve profitability, we need more users-per-car ratio. However, by doing so, the cars' availability decreases and so does the service use.
- Societal: Wealthy users previously using public transport are overrepresented, meaning, therefore, a negative impact on social diversity within public transport as the service infuses. Without major changes, having less impact would mean having less users.

- Environmental: The modal shift eclipses the expected positive environmental impacts. Without major changes, achieving expected environmental impact and avoiding modal shift would mean reducing service infusion.

Considering the designed business model, Bolloré Company reached paradoxes across the triple bottom line of sustainable corporation as defined by Elkington: economical, societal and environmental [16]. These paradoxes, by definition, could not be solved without disadvantaging part of its model.

As described by Turon et al. [17], the most important factors of success of a carsharing system are infrastructures, fleet conditions, user security, prices, and rental area. We argue that Bolloré failed to design a customer segment (CSe) that would fit properly with resources needed (infrastructure) and the cost structure associated with it as well as the revenue stream linked to this CSe. CSe chosen (or imposed indirectly by the public tender) could also not fit properly with the environmental objectives nor socials. An alternative approach could have been, for example, for Bolloré Company to target outside Paris commuters. Targeting this CSe might have resulted in higher revenue per trip and potentially lower availability acceptance within this CSe. Modal shift would have been smaller, as public transport is less represented outside of Paris's inner center [18].

The context hereabove enables us to illustrate what represents a paradox through the lenses of PSS designers and how paradoxical situations can eventually lead to failure. We were also able to visualize how modification of part of the PSS can influence paradoxes' potentiality.

2.2. Definition of the Fields of Study

2.2.1. PSS: Principles and Stakes

The addition of service in product manufacturing, namely servitization process, is a trend that has been recognized for many years as a mean of increasing competitiveness. This phenomenon appears equally in the opposite direction for service providers tending to offer associated products. [19]. The integration of service into the lifecycle of a product is the potential source of substantial environmental and economic gains through the greater use of initial resources.

Nevertheless, PSS does not appear to be a consistently appropriate response in the quest for competitive advantage, as evidenced by companies with disappointing results [20] and those pursuing a process of de-servitization [21]. Difficulties along the journey of servitization are multiple. Baines [19] describes a few including but not limited to:

- "Language used in service is particular and peculiar."
- "Value dimensions are special and biased towards relationships rather [than] transaction."
- "Products and design processes are different and better enable service support."
- "Integrating service and product delivery systems is challenging."
- "Transformation issues are both particular and pervasive throughout customers, employees, partners, and suppliers."

Concomitantly with the hereabove defined context, today's stake, therefore, seems to be in the capacity of companies to have a cross-functional PSS design methodology allowing them to analyse the viability of projects and their capacity to carry them out considering their stage in the servitization process.

2.2.2. Product-Service Systems

To understand the PSS, it seems essential to us to grasp the historical differences of understanding of what defines a product and a service.

Hill [22] defined service as the change of state of a person or object owned by a customer. Lovelock [23] describes a service as a process or performance in opposition to a physical thing. Many definitions are present in the literature, and Grönroos [24] summarized that all these definitions focus on the customer and the fact that services are provided in a way that solves a customer problem.

Historically, research in the field of services has been organized around the product/service dichotomy. The main arguments advanced by Zeithaml are the fundamentally different characteristics [25]:

- Intangibility: defining service as not being physically accessible.
- Heterogeneity: defining service as difficult or impossible to standardize.
- Inseparability: defining service as being produced in the same time lapse as consumption.
- Perishability: defining service as impossible to inventory.

The definition of a product in the literature and the elements characterizing it are succinct mainly because the concept of product seems intrinsic and universal. The line between product and service is regularly blurred from a product design or marketing perspective. In our study, it is necessary to precisely delineate the product and the service to understand their interactions. As mentioned in the previous paragraph, the service literature has defined the characteristic elements in opposition to the concept of product. Consequently, we chose, in this study, to define the product as being the complementary space to service. Considering this, we choose to adopt the product definition as being characterized by:

- Tangibility
- Homogeneity
- Dissociable state
- Consistency over time

Considering the literature describing the product and service altogether, the notion of PSS appeared in the 2000s with a definition of PSS that we will further use in this study:

A marketable set of products and services capable of jointly fulfilling a user's need. The product/service ratio in this set can vary, either in terms of function fulfilment or economic value [26].

Considering the nature of the PSS as being a mix of product and service, Mont proposed a PSS classification-setting consensus. This is grounded on the product-oriented or service-oriented consonance of the product-service mix. In this study, we will refer to the three categories of PSS defined by Mont [26]:

- Product Oriented: The main characteristic of a product oriented PSS is that the product is the property of the customer. The services composing the PSS are complementary to the product itself [27]. For example, incorporating maintenance into the sale of a product may constitute an increase in added value compared to selling the product alone. This regularly results in the sale of packages where the manufacturer offers its customers installation, financing, maintenance, updating, or even recycling services.
- Use Oriented: The characteristic of the use-oriented PSS is mainly that the manufacturer no longer sells the product but only its use or its functionalities. The property is no longer customer's [27]. A typical example of this type of PSS is product rental, short or long term, or even sharing. The efficiency of this model is based on the high-intensity usage resulting in the overall reduction of the product quantity needed [28].
- Result Oriented: The PSS is completely represented by its service element. The product is the property of the manufacturer and is not always easily identifiable. The typical example is the supply of heat rather than the sale of physical heater. This model has the advantage of creating a virtuous loop by encouraging manufacturers to optimize their product-usage performances to optimize their gains.

These three categories are described in the literature as being each differentiated by their mix of service and product [29] but also by their difference in business-model approach [30], with their respective share defining the type of PSS (Figure 1). It is also interesting to notice that the characterization of PSS types is achieved through different revenue models and therefore business models specific to each type. This highlights the underlying entanglement between business model and PSS.

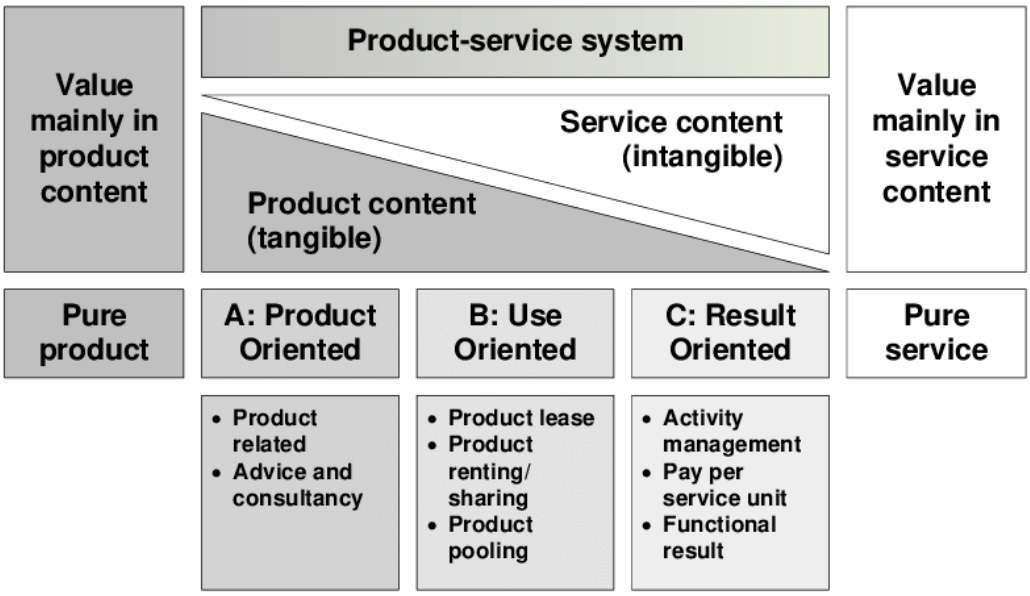

Figure 1. PSS Class [27].

In this chapter, we will retain that PSS can be characterized according to three categories: product oriented, user oriented, and result oriented, each accompanied by their own business model. The representation of business models by the business model canvas will enable us to highlight the concepts of poles within a company, interactions between hereby poles, and the induced creation of paradoxes.

2.2.3. Contradictions, Dialectics, and Paradoxes

PSS design unveils unprecedented situations for manufacture companies, facing drawback, failure, and paradoxical situations, as described earlier. To support our understanding of how design methodologies manage interactions to avoid potential paradoxes, it is therefore needed to add a theorical layer encompassing the notion of interactions, tensions, and paradoxes.

For purposes of defining this theoretical basis of the tensions as well as the paradoxes resulting from them, we will rely on the Putnam paradoxes theory [9]. In this respect, it provides us with a relevant theoretical framework on the description of bi-polar relations (also called interactions in this review) as well as on the typology of the responses provided and their consequences.

Putnam defines several structuring notions:

- Tensions: Stress, anxiety, discomfort, or tightness in making choices, responding to, and moving forward in organizational situations.
- Dualism: The existence of opposite poles, dichotomies, or binary relationships that can create tensions but can be separated.
- Duality: Interdependence of opposites in a both/and relationship that is not mutually exclusive or antagonistic.
- Contradiction: Bipolar opposites that are mutually exclusive and interdependent such that the opposites define and potentially negate each other.
- Dialectics: Interdependent opposites aligned with forces that push-pull on each other like a rubber band and exist in an ongoing dynamic interplay as the poles implicate each other. Focuses on the unity of opposites and the forces or processes that connect them.
- Paradox: Contradictions that persist over time, impose and reflect back on each other, and develop into seemingly irrational or absurd situations because their continuity creates situations in which options appear mutually exclusive, making choices among them difficult.

To illustrate these structures within our field of PSS, we propose some translation below though the Autolib example introduced in Section 2.1.

Tensions in choice occurred when designing the CSe that would fit with needed revenue stream (RS) associated without resulting in important modal shift. CSe and RS are in a situation of dualism, as they can be separated and can potentially create tension (CSe do interact with RS). Duality appears as wealthy users targeted (outside and inside Paris) seems to be the best suited segment to generate revenue but, at the same time, part of this segment is subject to modal shift (inside Paris commuters). Choosing CSe of wealthy users inside Paris by concentrating charging stations mainly in the centre eventually led to contradiction. Indeed, inside Paris, the CSe needed to generate revenue was one that would generate modal shift ultimately. With key resources (KR) set (charging station in this case) mostly inside Paris, where concentration of public station presents high density [18], contradictions between CSe and RS occurs as CSe of wealthy users inside Paris not using public transport represent a too narrow RS regarding the KR set for this CSe, and modifying RS (targeting outside Paris commuting) would not fit with KR set and CSe associated with it. Eventually, an environmental paradox appears as described earlier: The modal shift eclipses the first expected environmental impacts. Without major changes, achieving expected environmental impact and avoiding modal shift would mean reducing service infusion.

Putnam et al. thus created a hierarchisation in such a way that each notion encapsulates the previous one. A contradiction is a duality that is itself a dualism. These notions, therefore, allow us to understand the entanglement of the levels possibly leading to the birth of a paradox or how, from a situation of tensions in a bipolar relationship, the result can be a paradoxical situation.

The Putnam et al. theory also sheds light on the typology of responses that organizations provide to these contradictory/paradoxical situations. Putnam classifies these responses as follows:

- Either-Or Approaches
  - *Defensive Mechanisms:* Treats opposite tensions as independent.
  - *Selection:* Choosing one pole over the other.
  - *Separation:* Keeping poles separate and independent.
- Both-And Approaches
  - *Paradoxical Thinking:* Seeking valued differences between poles.
  - *Vacillation/Spiralling Inversion:* Focusing on segmenting then connecting poles.
  - *Integration and Balance:* Compromises tensions through a forced merger.

Only an overview of response typologies is given here, but, interestingly, Putnam et al. described defensive or selection strategies as resulting in "reactions, such as splitting elements (severing the contradictions)" or "selecting one pole often results in neglecting duties linked to effective job performance". More generally, Putnam et al. described the "either-or approaches" type as being "treat contradictory poles as distinct phenomena that function independent of each other".

Thanks to the Putnam et al. theory, it is therefore possible to provide a theoretical framework for understanding the contradictions and paradoxes appearing during PSS design. It is also stressed that the absence of responses to tensions/duality can lead to the appearance of paradoxes.

2.2.4. Business Model Innovation

As evoked above, the apprehension of PSS design methodologies demands theorical framework to define the company's full spectrum. It is also required to apply the Putnam et al. theory [9] to a framework to discretize company poles. Hereafter, business model innovation (BMI) is introduced, as it represents an efficient way to cover both aspects.

In the marketing management literature stream, BMI emerges, like the PSS, as a means of business innovation. This allows companies to respond to regulatory and technological developments and thus maintain or develop their competitive advantage. BMI gained

in interest in a period when the notion of commoditization of services and products appeared [30–34]. The exact definition of BMI is subject to debate; however, the authors in the literature agree on a common definition of the purposes of BMI:

- to describe, understand, and analyse the current business logic of a company, the value-creation mechanisms, how that value is monetized, and to link the "inside" with the "outside" of the firm [35,36]; to classify businesses [34,37,38];
- to support strategic decision making by designing and simulating new business concepts [39]; and
- to act as a "recipe" for managers [36,37,40,41].

To describe and categorize the different business models, the BMI literature defines poles with authors' aim being to cover the entire spectrum of the company defining the business model. These poles also empower to discretize BMI's research, which calls on a wide variety of skills. To allow the visualization of these poles, several frameworks have emerged, each grouping a certain number of these poles. Although there is no consensus on the exhaustive list of poles that constitute a business model, in this article, we will take those described in the business model canvas (Figure 2). This model describes nine most frequently observed poles as below [36]:

- Customer Segment (CSe): An organisation serves one or several customer segments.
- Value Proposition (VP): It seeks to solve customer problems and satisfy customer needs with value propositions.
- Delivery Channel (DC): Value propositions are delivered to customers through communication, distribution, and sales channels.
- Customer Relationship (CR): Customer relationships are established and maintained with each customer segment.
- Revenue Stream (RS): Revenue streams result from value propositions successfully offered to customers.
- Key Resources (KR): Key resources are the assets required to offer and deliver the previously described elements.
- Key Activities (KA): Key activities are the actions to be performed to offer and deliver the previously described elements.
- Key Partners (KP): Some activities are outsourced, and some resources are acquired outside the enterprise.
- Cost Structure (CSt): The business model elements result in the cost structure.

Even though the design of some poles in a PSS context are straightforward, it is interesting to clarify how PSS design might look like using the case of Autolib:

- The design of VP in this context could be to offer a sustainable, alternative way of mobility in the Paris area.
- The design of CSe would then be to target customers willing to use the PSS at a certain price tag without negatively impacting environmental outcome though damaging modal shifts.
- The design of DC relies on the way the service (sustainable mobility) and the product (the car) are delivered to the user. It can be through a smartphone application to book and localise the car and through charging station to, in a manner of speaking, stock and deliver the car.
- The design of CR refers to defining ways to create durable and retaining relationships. This can be a loyalty program or sponsorship, for example.
- The design of KA relates to defining which activities will be needed to provide the PSS. For example, this could be maintenance of the cars, rebalancing cars between stations at night, installing station, etc.
- The design of KR in this case refers to the assets that are needed to provide the PSS, namely the cars, the station, and the human resources, for example.

- The design KP would then be related to the partner needed to operate the previous poles. This could be, for example, a car constructor, the city of Paris, and the developing company for the booking app.
- The design of CSt follows as gathering all the cost inferred while operating the previously defined poles.
- Finally, the RS pictures what incomes would be generated with regards to previously defined poles.

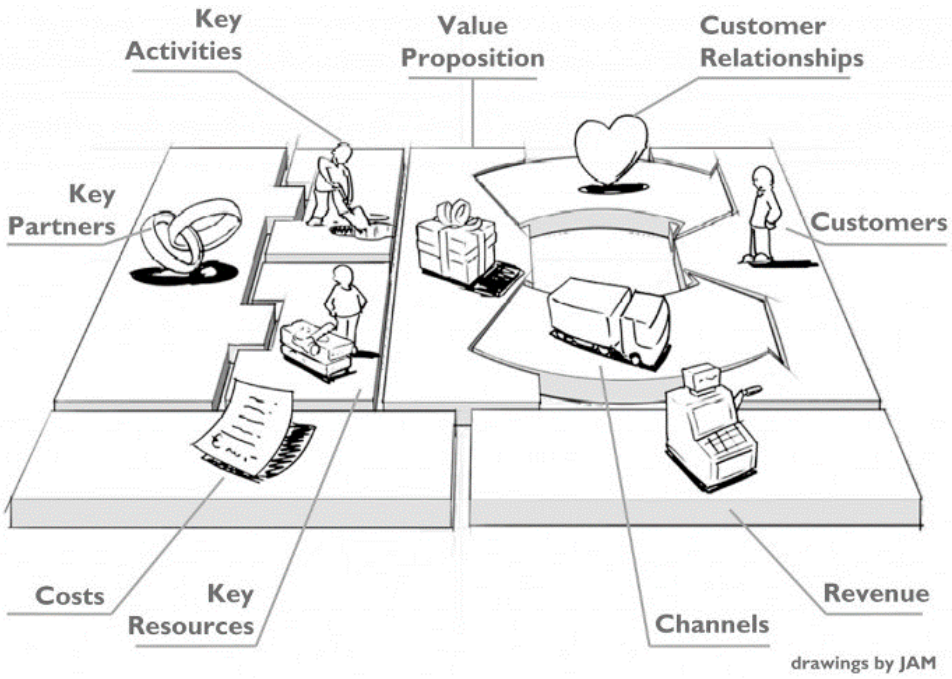

Figure 2. Business model canvas [36].

Naturally, the objective of the designer lies in achieving CSt < RS while maintaining a certain fit between the poles to achieve the VP.

Interestingly, the BMI literature describes likewise the phenomenon of servitization of the economic model by which companies transit from a tangible offer to an intangible one [4]. This phenomenon is described as a profound evolution of companies' economic models and therefore the modification of their various poles.

As mentioned in the previous paragraphs, the use of BMI as an analytical prism in the design of PSS seems relevant to us. Other PSS studies have chosen the BMI framework and business model canvas for similar reasons [30,42–44]. Likewise, Di Francisco Kurak et al. [45] argued the relevance of the use of the business model as follows: "In addition to these broader characteristics, the fact that PSS requires new processes and activities within its business models compared to traditional ones is another relevant point that was taken into account. Therefore, it was considered appropriate to classify the barriers and challenges identified in the literature according to business model poles, since it might help in the design of the new PSS model."

2.2.5. PSS: Failure and Success; Examples of Interactions and Paradoxes

The implementation of PSS in the corporate world has experienced successes and failures that are interesting to observe to identify the causes.

The Rolls-Royce case study provides us with an example of successful PSS design implementation. The Rolls-Royce power-by-the-hour program began to gain attention in the 2000s. It is nonetheless a program taking its roots in the 1960s with its value proposition being a fixed price-per-flight-hour including all cost centres for the use of a

reactor (Maintenance, Repair). Rolls-Royce's success lies in modifying its product design processes to respond to the service issue: design for service. Thus, the product necessary for the performance of the service (here the reactor) is designed taking into consideration the problems related to the service, such as the maintenance downtime, for example [46]. We consider it as success since the offer has been around for more than 20 years now, allowing Rolls-Royce to be today among the world leaders in reactor manufacturers alongside General Electrics and Pratt and Whitney.

Another interesting case study is amongst the reverse logistics services in manufacturing, as described by Marić et al. [47] and, more specifically, the example of IBM presented by Keh at al. [48]. In this example, it was described how IBM has implemented a European platform of reverse logistic to reuse, recycle, or remanufacture used products recovered from customer sites. Interestingly, IBM succeeded to implement this PSS, unveiling economic opportunities as well as positive environmental impacts. The article described several success factors of the design of this PSS. One of them was to deploy this service in a manufacture that already existed and managed similar activities. By doing so, they managed to create synergies in terms of resources and activities, reducing costs compared to a brand new return centre. We considered this case a success as IBM has been running the service for decades and is presented as profitable.

Regarding failures of PSS implementation, Baveja et al. [49] revealed that some companies do not achieve planned profitability by adding services mainly because of the poor estimate of the costs of providing the service. On his side, Valtakoski [21] studied the phenomenon of servitization and de-servitization, assessing the possible causes of failure through knowledge-based view theory. It concluded with several possibilities about the root cause of service-integration failure (Servitization), such as the company's deficiency of capacity and resources to provide the planned services.

Another example of failure of implementation of product-service is the carsharing service Autolib by the company Bolloré. Launched in 2011, it quickly became the largest carsharing web in the world in term of users or size of its fleet. However, it never achieved profitability and was eventually dismantled in 2018. Lagadic et al. analysed that the success of the service was linked to the high availability of the cars [13]. The increase of user/car to achieve profitability eventually ended by disengagement in term of usage and ultimately incomes.

The failures and successes presented here are partly correlated with the management of the interactions between poles defined in business model theory:

- Concerning Rolls-Royce, interactions between poles materialize in the integration of constraints of maintenance resources and activities to deliver the maintenance service during product design (hereby the reactor). The poles interacting here, in the case of BMC, are the poles of proposition value/delivery channel/key resources/key activities/cost structure.
- Considering IBM, interactions addressed properly partly lies in finding an existing factory where resources and activities could be designed in a cost-saving manner through synergies with existing manufacturing activities. The poles interacting in the case of BMC are the poles of key activities/key resources/cost structure.
- In the case of Baveja et al. and Valtakoski, the known tackled interaction was between the poles of proposition value/key resource/cost structure. The emerging paradox is: To provide this new service, I must increase my number of resources, but to make my service profitable, I must reduce my resource cost.
- Similarly, for the company Bolloré, interactions to be managed to achieve success were between the poles of customer segment/key resource/cost structure. The paradox emerging is: To increase adhesion, I need to increase shared resources, diminishing profitability (yet not achieving it).

Simply adding service to a product offering is a failed strategy. We find this in a study carried out in 2004. In this study, only 21% of companies observed a financial gain, with the majority of companies abandoning their servitization strategy after a few years [49]. The understanding that "the transition from a product-centric enterprise to a PSS-centric

enterprise is first and foremost a global change in the company's business model" seems to be essential. As evidenced in a study of 122 companies reports that a consideration of the company as a whole is a key success factor in the transition to the creation of PSS: "a thorough and comprehensive organizational transformation is required to generate significant financial value" [20]. This same observation is made in a 2014 study concluding: "In general, too much emphasis is placed on new service development, without providing sufficient clarity about innovations in other business model elements" [50].

Confirmed by Putnam et al. theory, we consider it essential in the context of our study on PSS design methodologies to integrate the notions of interaction. The notion of interaction is defined here as the set of relations between poles (bipolar or multipolar), with the ability to lead to the appearance of paradoxes and therefore failure in the implementation of PSS.

2.3. Bibliometric Research Objectives

As mentioned earlier, the literature addressing PSS is now well established and many publications deal with existing methodologies to design a PSS [51]. Given the previous paragraphs, it has been highlighted the importance of evaluating how existing methodologies embody a company's full perimeter as well as interactions within it. The presented theoretical frameworks explains that PSS implementation failures partly result from unexpected situations that sometimes are inextricable. These situations, described as paradoxes, as design options appear mutually exclusive. Moreover, this theoretical framework defines the root cause of these contradicting situations as that which occurs within a bipolar relationship, here called interactions. Therefore, to fulfil our research objective to attempt to unveil new research paths of viable strategy to overcome the difficulties in promulgating environmentally friendly innovations through servitization implementation success, we relied on this theoretical base and concentrated on understanding in which extent interactions are integrated while designing a new PSS. We intend to provide bibliometric results supported with theoretical frameworks on how design methodologies address this objective to ultimately determine potential future research paths.

To achieve that, we conducted our study towards PSS design methodologies unambiguously appealing to business model innovation notions. Firstly, the reason for studying methodologies resides in the belief that actionable solutions to address tensions and paradoxes might reside during the design itself. Secondly, the reason why we focused on methodologies relying on BMI is in our capacity to apply both frameworks (BMI and paradoxes) with minimum interpretation. We therefore propose two questions that our bibliometric research aimed to answer:

Q1: Are PSS design methodologies transversal with regard to the perimeter defined by the BMC?
Q2: Do the PSS design methodologies integrate the interactions between the poles discretized by the BMC?

The choice not to search for failures or paradoxes literature was deliberate however discussable. To get deeper understanding of our approach, we argue that the objective of this review was to identify possible root causes; we positioned our questions to look for root causes instead of observed consequences, namely interactions.

2.4. Bibliometric Analysis Method and Software

2.4.1. Bibliometric Principles

In order to remove the presence of a subjective bias, we proposed to carry out a review of the existing literature using bibliometric techniques in order to extract the research lines associated with the chosen keyword [52]. The database was chosen to avoid bias in field of study. Database requests were made on titles, abstract, and keywords. The Boolean keyword combinations were chosen to combine the field of interest and the specific topic of interest within this field. We decided to use a visualization method to ensure our field and topic keywords were relevant and matched the current research trend.

The successive semantic filters were applied by the authors successively reviewing titles, abstracts considering field of interest, and finally abstracts considering topic of interest.

Finally, the authors further investigated each article assisted by a classification grid in order to analyse each one with the minimum reader bias.

2.4.2. Choice of Database

The database chosen in this review was SCOPUS®, as it constitutes a generalist database in term of articles and journals distribution when comparing engineering and social sciences (Figure 3). Therefore, our results are not pre-constrained by a database orientation.

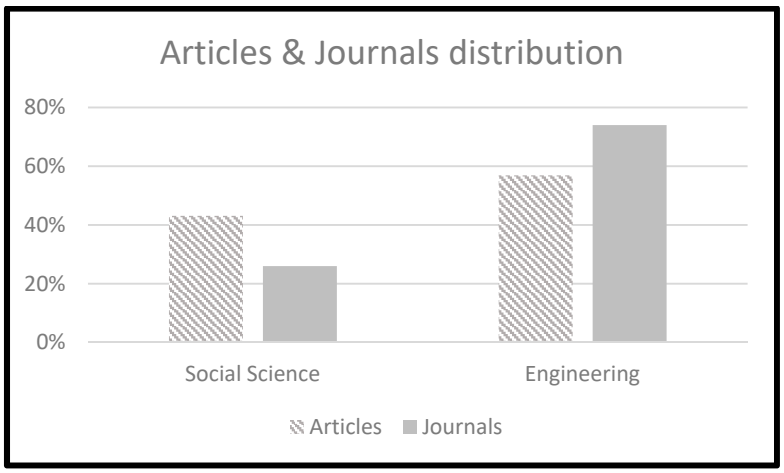

Figure 3. SCOPUS® articles and journals distribution (May 2021).

2.4.3. Choice and Keywords Relevance

To conduct our bibliometric study and then our analysis of the articles emerging through the prism of the BMI, we first developed a filtering strategy based on relevant keywords. The objective of this article residing in the analysis of existing methodologies in the field of PSS, we chose the following keywords:

"Product Service System" AND Design
"Product Service System" AND Method
"Product Service System" AND Methodology
"Product Service System" AND Development

Note that all the variants of PSS were added in the search (PSS/Product-service-system/Product-services systems/Products Services Systems). The Boolean keywords association were composed by a field filtering keyword and another one with a topic interest. As such, the choice of orienting the topic in methodology rather than in a more general framework or change process way was deliberate. As mentioned before, we believe the actionable solutions lied potentially within the methods that were used to design PSS.

To determine whether the chosen term of PSS is relevant in the literature, we decided to use a bibliometric mapping methodology representing the importance of the keywords chosen in the targeted literature. To do so, we used Vosviewer© software with the co-occurrence of keywords as mapping parameters and the occurrence of keywords for weighting. The following method was applied: Search on SCOPUS® for all articles since 2002, including in their title the terms service and product by the Boolean search "SERVICE" AND "PRODUCT". The research period was determined by the emergence of a consensus on the definition of PSS in 2002 as well as in identifiable literature [26]. The SCOPUS® requests were made on the 29 January 2020. We selected only article and article in press as eligible in our results. Finally, we excluded articles with foreign languages other than English.

The result is 1824 articles. All the keywords with an occurrence greater than 40 are shown in Figure 4. We saw that the keywords associated with these articles are mostly PSS, thus justifying the relevance of our choice.

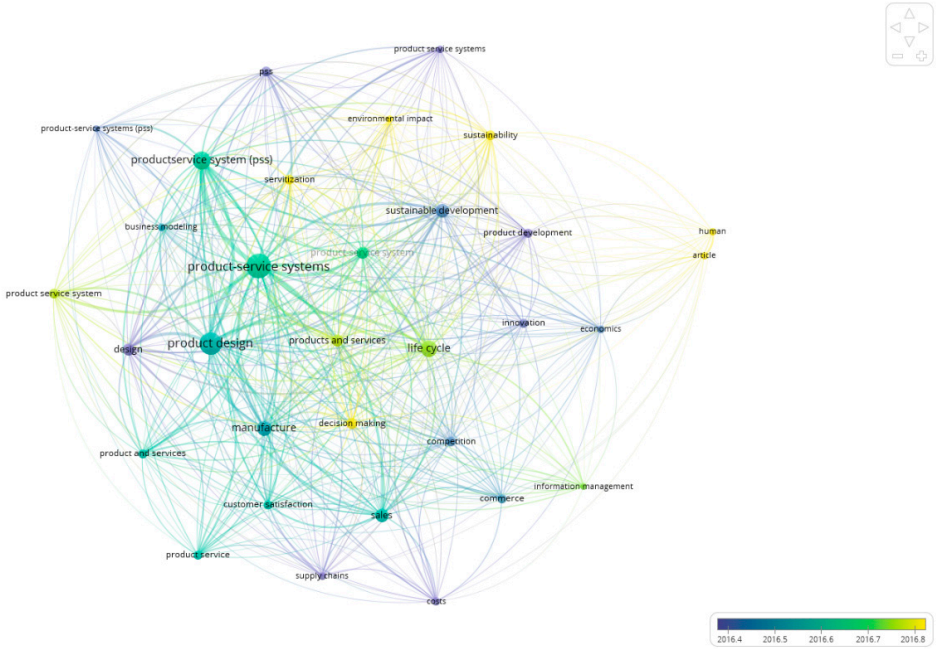

Figure 4. Bibliometric keywords "SERVICE" AND "PRODUCT".

To justify the topic keywords, we used the same approach. Considering the Product-Service term as relevant, we requested SCOPUS® on all articles containing Product-Service in their title. The result was 758 articles. We then used Vosviewer© with keywords co-occurrence to evaluate which terms were commonly used in the field. As shown in Figure 5, among all keywords, design appears as the most relevant term relative to the act of conception.

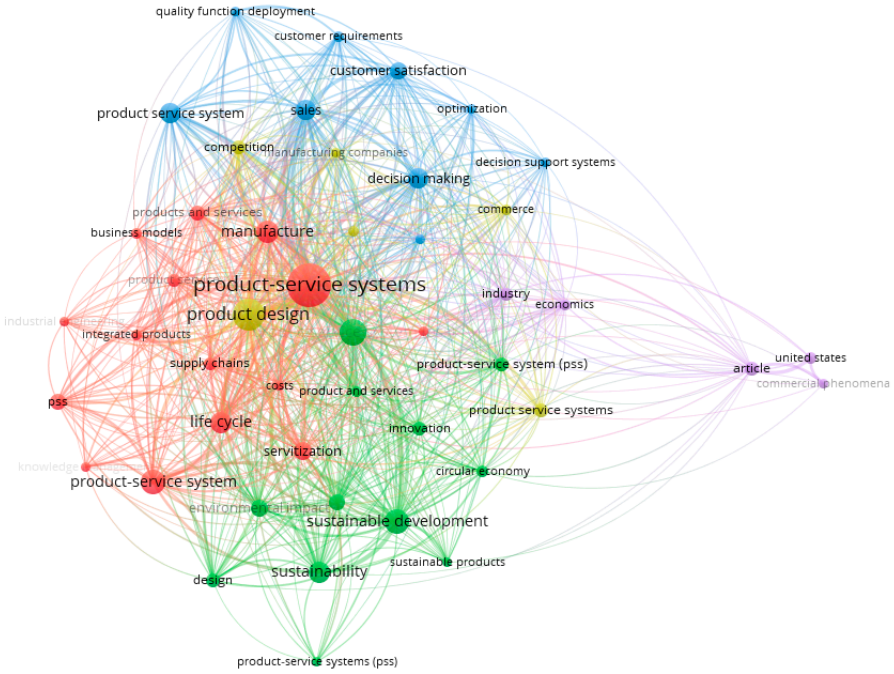

Figure 5. Bibliometric keywords "Product-Service" articles.

Finally, we requested SCOPUS® database with all publications containing in their title "Product-Service" AND "Design" to evaluate if other terms could be related to design. A total of 341 articles were returned; the result is presented in Figure 6. Considering this result, we chose to define 4 topic terms: design, development, method, and methodology, as they were the ones similar in the meaning to design and outline in Figure 6.

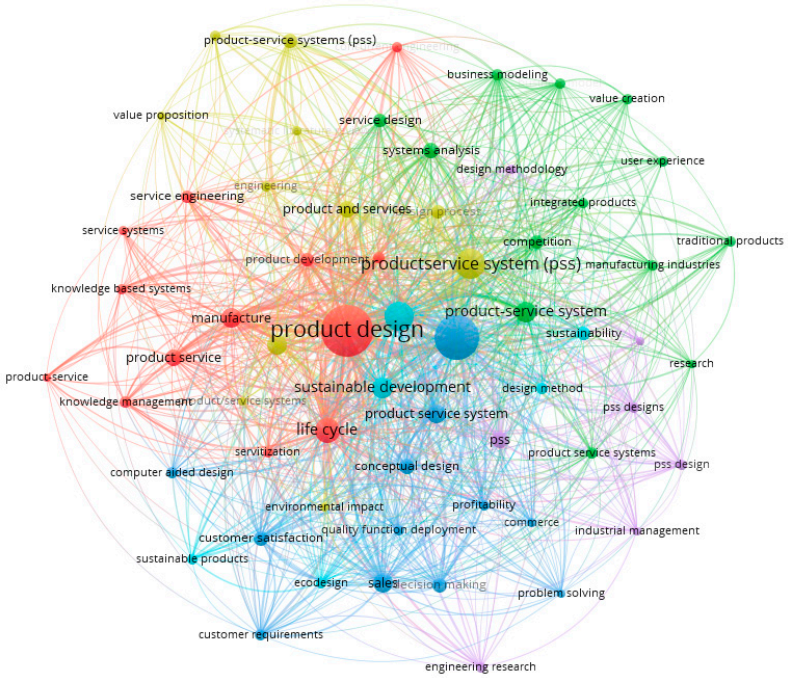

Figure 6. Bibliometric keywords "Product-Service" AND "Design".

The choice to not include BMI keyword relied on our bibliometric strategy in which BMI aspects were assessed during abstract overview. This idea there was to include papers that would not directly declare BMI keywords but would describe their work in a way that authors can translate to BMI.

3. Results

3.1. Descriptive Analysis

The results of our database requests are presented in Table 1 below. As mentioned, before, we applied successive semantic filters as described below:

- With regards to titles, it is verified that the article does indeed deal with PSS.
- With regards to abstracts:
  - It is verified that the theme is methodological.
  - It is verified that the BMI is explicitly mentioned or that the economic model aspect is suggested.

We therefore retained 17 articles, which, according to our bibliometric, are concerned with PSS design methodologies considering the BMI aspects or more broadly economic notions. Upon in-depth reading of each of the 17 articles, only 14 were retained. The main reasons for exclusion were the absence of a methodological aspect or an unambiguous mention of business model's pole. The 14 articles are presented in Table 2.

Table 1. Bibliometric strategy.

Key Words	Results
"Product Service System" AND Design	211
"Product Service System" AND Method	104
"Product Service System" AND Methodology	20
"Product Service System" AND Development	70
Total	405
Steps	**Articles Remaining**
Without Doubles	367
"PSS" filter on titles	120
"method" filter on abstract	78
"BMI" filter on abstract	17

Table 2. List of reviewed articles.

Authors	Title	Year	Source Title
Joore P., Brezet H.	A Multilevel Design Model: The mutual relationship between product-service system development and societal change processes	2015	Journal of Cleaner Production
Hu H.A., Chen S.H., Hsu C.W., Wang C., Wu C.L.	Development of sustainability evaluation model for implementing product-service systems	2012	International Journal of Environmental Science and Technology
Tran T.A., Park J.Y.	Development of integrated design methodology for various types of product-service systems	2014	Journal of Computational Design and Engineering
Trevisan L., Brissaud D.	Engineering models to support product-service system integrated design	2016	CIRP Journal of Manufacturing Science and Technology
Nemoto Y., Akasaka F., Shimomura Y.	A framework for managing and utilizing product-service system design knowledge	2015	Production Planning and Control
Chiu M.-C., Kuo M.-Y., Kuo T.-C.	A systematic methodology to develop business model of a product-service system	2015	International Journal of Industrial Engineering: Theory Applications and Practice
Kim S., Son C., Yoon B., Park Y.	Development of an innovation model based on a service-oriented product-service system (PSS)	2015	Sustainability (Switzerland)
Costa N., Patrício L., Morelli N., Magee C.L.	Bringing Service Design to Manufacturing Companies: Integrating PSS and service design approaches	2018	Design Studies
Pezzotta G., Sassanelli C., Pirola F., Sala R., Rossi M., Fotia S., Koutoupes A., Terzi S., Mourtzis D.	The Product-Service System Lean Design Methodology (PSSLDM): Integrating product and service components along the whole PSS lifecycle	2018	Journal of Manufacturing Technology Management
Andriankaja H., Boucher X., Medini K.	A method to design integrated product-service systems based on the extended functional analysis approach	2018	CIRP Journal of Manufacturing Science and Technology

Table 2. *Conts.*

Authors	Title	Year	Source Title
Chiu M.-C., Chu C.-Y., Chen C.-C.	An integrated product-service system modelling methodology with a case study of clothing industry	2018	International Journal of Production Research
Li T., He T., Wang Z., Zhang Y.	A QFD-Based Evaluation Method for Business Models of Product-Service Systems	2016	Mathematical Problems in Engineering
Kwon M., Lee J., Hong Y.S.	Product-service system business modelling methodology using morphological analysis	2019	Sustainability (Switzerland)
Chen Z., Lu M., Ming X., Zhang X., Zhou T.	Explore and evaluate innovative value propositions for smart product-service system: A novel graphics-based rough-fuzzy DEMATEL method	2020	Journal of Cleaner Production

The year distribution of papers is presented in Figure 7. All papers were published after 2010 and most of them, 12, after 2015.

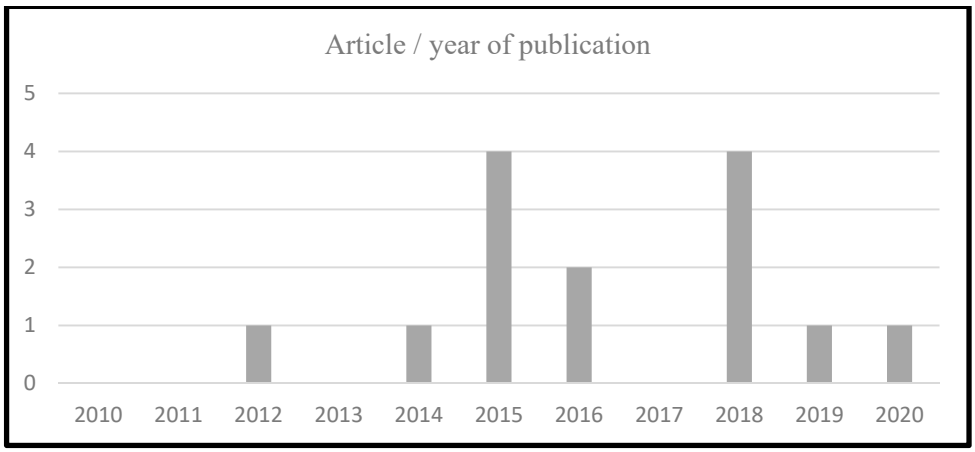

Figure 7. Article/year of publication.

The impact factor distribution of papers is presented in Figure 8. Most of the papers were published in a source with an impact factor above 2 and 3 of them within sources with an impact factor above 4. The unknow impact factors are mainly sources not rated with this notation to our knowledge.

Considering Table 2, it is interesting to notice that all articles are related to engineering journals even though there was no filtering on the area of interest of the journals. Keywords in this regard are determinant. Keywords more generally used in the management field, such as generation or innovation, could have resulted in a different outcome. Aside of the Vosviewer determining methods presented above, we believe that these keywords refer to an approach that was mainly macroscopic, while our objective was to seize articles providing exhaustive ways to conceive PSS.

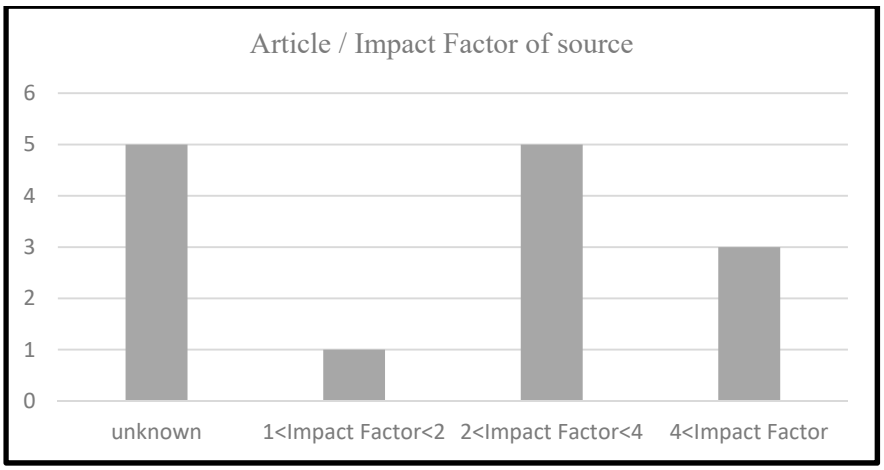

Figure 8. Article/impact factor of source.

3.2. Content Analysis and Visualization

In this part, we attempt to analyse the articles filtered through the prism of BMI theory and, more specifically, the visualization of the business model canvas (BMC). To achieve this purpose, we use an analysis grid to minimize reader bias.

The BMI theory as presented in Section 2.2.4 aims at describing, understanding, and analysing the current business logic of a company. For purpose of construction of a comprehensive framework to study business model, the discretization of the major components representing the full spectrum of what composes a company is a major trend. As mentioned before. there is no consensus today. As shown by Barquet et al. [44], the framework proposed by Osterwalder [36] is relevant, as it represents the consensus of a large group of experts from academy and industry.

To analyse our filtered article through the lens of BMC, we determined for each of the 14 articles the BMI poles discussed as well as evoked interactions between poles.

The poles (components) of the business were considered to be addressed when the methodology explicitly mentioned the element or describes characteristics that may be associated with it.

Interaction was considered when there was an explicit mention of considering one or several poles of the business model when designing another pole. An example of interaction is that the value proposition must consider the target customer segment.

These two axes of analysis (poles treated/interactions treated) allowed us to establish our analysis graph.

The graph is designed to fulfil the purpose of answering our two questions:

Q1: Are PSS design methodologies transversal with regard to the perimeter defined by the BMC?
Q2: Do the PSS design methodologies integrate the interactions between the poles discretized by the BMC?

In that respect, we choose to represent the poles of business models as the node of the graph. The size of the node represents the number of articles incorporating the notion. Therefore, a pole described in all articles will appear bigger than one with few articles mentioning it. The edges of the graph represent interactions of the poles according to the articles reviewed. The weight of the edge noticed by a number represent the number of articles describing the involved interaction. Therefore, an edge with a high weight will represent an interaction described in many articles.

Considering the graph in Figure 9, we can establish direct observations:

- Firstly, the graph is organized around the proposition value (PV) pole.
- Secondly, the other poles are organized in two main clusters:
    - Cluster A represents key partner (KP), key resources (KR), and key activities (KA).

- Cluster B represents cost structure (CSt) and revenue stream (RS)

- Thirdly, the three remaining poles, delivery channel, customer segment, and customer relationship, are left separate only connected with PV.

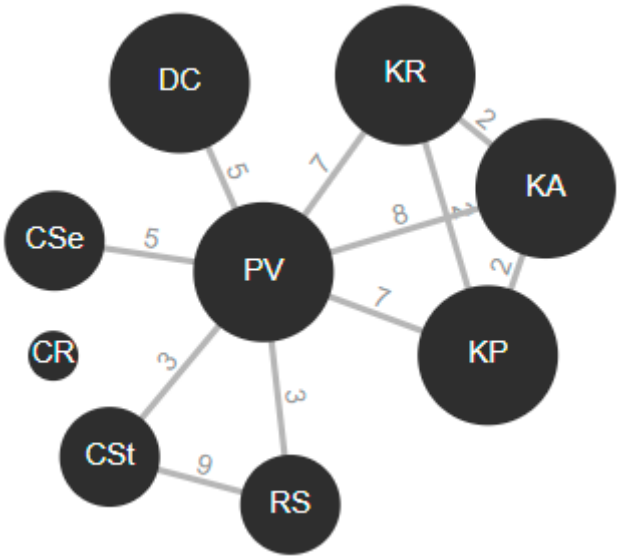

Figure 9. Interaction graph.

In the next paragraph, we describe and analyse more in depth each of the graph characteristics.

The poles' sizes: These characteristics represent if articles' reviews were considering various poles. As we can see, the size of the poles are almost the same size except for customer relationship, with only 2 articles mentioning it.

The plausible interpretation for this would be that the convergence of the two PSS/BMI trends is indeed effective and that there is, therefore, a significant number of methodologies dealing with all the BMC's poles. Nevertheless, it is possible to observe a difference in treatment between Cluster A (key partner, key activities, key resources) and Cluster B (customer relationship, customer segment, revenue stream, cost structure). The mean size of Cluster A poles is 14 (all articles), while the mean size of Cluster B poles is 9.7. The interpretation made here of this higher mean size in Cluster A is the correspondence to the core competencies of NPD (New Product Development). Areas specific to BMI and marketing management are treated to a lesser extent. This reflects that the PSS design methodologies do not systematically consider the overall impact of PSS implementation on the business model's poles. Interestingly, Allen Hu's [53] methodology incorporates all the poles of the business model by prioritizing each pole thanks to multidisciplinary teams and the fuzzy Delphi method. However, in this method, we will notice that interactions between these prioritized poles are hardly represented.

The clusters: The two clusters described earlier are gathered around the proposition value pole. The Cluster A, composed of key partner, key activities, and key resources, shows strong interaction consideration. This is demonstrated by a relatively high mean weight of edges within Cluster A and PV pole, at 7.3. In comparison, the mean weight of edges within Cluster B and PV is 3.

The interpretation given in this study is that these interactions represent what we will call natural relationships. By natural, we imply relationships corresponding to the classic design system, namely requirement specifications. In the same manner as poles' sizes, interactions are better represented between poles of the competencies of NPD reflecting, as before, the engineering orientation of PSS methodologies. We can cite in particular the methodology proposed by Trevisan et al. [54], depicting a design methodology considering

key partners as interacting with design resources and activities: "This paper proposes modelling the actor's link through a Flow model [. . .] It shows the actors concerned by the value creation while expressing their respective responsibilities or roles in this process through the links that are represented". In the Trevisan et al. study, the activities of each of the key partners were represented, thus making it possible to delineate the necessary resources as well as the key activities for the company designing the PSS. Thus, there are interactions between key partners, activities, and resources during the design of the PSS.

The missing edges: What we needed to analyse is also what we could not see in the graph. Here, we are more precisely interested with interactions not identified during our reviewing. These interactions are not necessarily all relevant or significant, explaining partly their absence in the literature. However, the study of certain interaction could prove to be interesting to make the design of PSS more reliable by ensuring that all interactions and therefore source of tensions and paradoxes are treated. Furthermore, the proof that a certain number of interactions are overlooked would lead the path for future actionable solutions, namely incorporating better interaction comprehensiveness within PSS methodologies.

Finally, it is interesting to notice that customer relationship is not seen as interacting with other poles while analyzing methodologies. This could seem surprising, as service is often depicted as highly relying on customer involvement. The understanding of the authors resides in the definition of customer relationship which, in the BMC case, is limited to developing and maintaining commercial engagement. All customers' involvement in the delivery of a service would therefore be listed in other BMC poles, such as delivery channel or key activities.

3.3. Relevance of Missing Edges Spaces

As mentioned in the previous paragraph, the fact of highlighting little or no studied interactions does not predict their relevance for the design of PSS. We offer here an example leading us to think that at least some of these missing interactions are relevant and significant. Accordingly, if at least one undescribed interaction is relevant, it becomes legitimate to explore all the missing interactions.

The example chosen originates from an article by Kurak et al. [45]. In this article, the author gives the example of a company manufacturing ophthalmologist equipment. The company has set up a PSS offering equipment rental, including maintenance and updates. The article points out the company failed to implement this PSS. The advanced elements are mainly the resistance of customers not to own the equipment. This issue, regularly encountered in the design of PSS [55], is emphasized by the customer segment targeted: "However, the medical market considers this equipment relatively cheap. The reason for this sense is that the only people allowed to operate the machine in Brazil are doctors, who are a class of high purchase power".

In our study, this is represented through the interaction between revenue model and customer segment. Indeed, the Brazilian doctor segment is not ready to rent equipment with a low purchase price given the segment's purchasing power. Consequently, the design of PSS to offer a rental model to this segment in this price range was a wrong choice from the early phases of the PSS design.

This example of failure shows us that the design of a revenue model without considering the bi-polar customer segment/revenue stream relationship can generate the appearance of paradox. More precisely here, the inclusion of services resulted in a lower PSS adoption.

Expressed in our graph, the relevant edge is customer segment/ revenue model, which is not studied in the methodologies filtered.

By means of this example, we therefore spotlight that there is an interaction that is described little or not at all in the literature but is nevertheless relevant in the design of a PSS. Hence, we can conclude that it appears legitimate to explore each of the spaces to determine their impact in the design of a PSS.

3.4. Study Limitations

This study aims to highlight research trends for PSS design methodologies as well as the role of methodologies in the emergence of paradoxes. The analysis through the prism of the business model canvas is performed to encompass the overall scope of the company.

The first limitation of this study is its exhaustiveness. In fact, keyword research and successive semantic filters do not prevail over the exhaustiveness of the methodologies analyzed. However, it could be argued that since the objective is given to trends, representativeness is sufficient despite lack of exhaustiveness.

The second limit is found at the level of the semantic filters specific to the reader. Although fallible, we can again argue that since the goal is the trend, the interpretation gap between readers does not introduce a significant difference in the graph topology.

The third limitation lies in the use of a single search engine (SCOPUS®). This one was chosen because it enables grouping marketing and engineering journals together to have a representative spectrum. However, completeness would be better by querying multiple databases. Since the objective of the analysis is the trend, we can argue that the difference is, again, not significant.

The fourth limit is the inference between lack of observed interactions design and causality with tension and paradoxes' creation. Future research could strengthen this inference through experimentation compared to the observations made herein that have inherent limitations.

4. Discussion

4.1. Observations and Answers to Our Research Questions

Considering the results of our bibliometric research and the interpretation of the results according to our graph, what are the observations? To what extent can we answer our research questions?

Q1: Are PSS design methodologies transversal with regard to the perimeter defined by the BMC?

It appears that all the poles of the BMC retained in Section 2.2.4 are addressed in the PSS design methodologies. However, there is a disparity in the frequency of appearance within the different poles expressing a natural influence of engineering rather than industrial marketing on PSS methodologies. To apprehend the complexity and cross-competencies needed in the business model approach, some PSS methodologies incorporate ponderation of poles as a mean of prioritizing which poles to consider and to what extent [53]. Thus, despite some disparities, we believe that the infusion of business model innovation in PSS methodologies is today well engaged. In consequence, we believe that the potential actionable solutions to decrease future risk of failure during the design phase do not reside in the change of deep mindset or understanding of the perimeter that PSS designers must cover.

Q2: Do the PSS design methodologies integrate the interactions between the poles discretized by the BMC?

Regarding the relationships between the BMC's poles explicitly defined in the design methodologies, disparity in interaction consideration appeared. It is therefore appropriate to analyze these disparities in the literary treatment of interactions in Section 3.2. We can conclude that the interactions between the poles of the BMC are sparsely described in the literature. Interactions between poles other than the value proposition are almost non-existent. By construction, all the spaces describing an interaction might not be relevant

in a PSS design methodology. However, the example given in Section 3.3 demonstrates some can be.

4.2. Authors Propositions, Futures Research Paths

In the light of our bibliometric analysis, we advanced three propositions, each of them discovering a new research agenda for interdisciplinary research.

P1: Interactions within the complete perimeter of the company need to be more closely defined, prioritized, and addressed during PSS design to achieve successful implementation.

Considering the Putnam et al. theory, all paradoxes take their root in initial tensions. The fact that poles' interactions are barely discussed in the literature tells us that they are probably, or at least partly, a root of some of the paradoxes observed in PSS design. Indeed, these bi-polar or multi-polar relationships can be a source of tension in the sense described by Putnam et al. Failure to respond or either-or-approaches-type responses to these tensions during design can then lead to contradictions and ultimately paradoxes. Thus, we believe than actionable solutions to decrease future risk of failure during the design phase may reside in a more exhaustive consideration of interactions in PSS methodologies. As to defining which interactions to be considered, we argue that future research could take interest in assessing other frameworks to discretize poles and define which interactions are relevant depending on the situations. Such future research paths would enable designers to manage more widely the potential tensions before implementation of the PSS, consequently avoiding the resulting paradoxes.

To illustrate our point, we can notably encourage research on the interactions between customer segment and delivery channel. The need to consider this interaction could be understand, as for an unchanged value proposition (iteration amongst poles' design without changing VP), the designer might have to adapt the delivery channel, therefore influencing the customer segment and ultimately cost structure and revenue stream.

As integrating interactions might be time costly, we argue that future paths of research could also rely on defining ways to prioritize relevant interactions to help designers make conscious choices between which interactions to address depending on the situations and resources available.

P2: Sustainable BMI framework needs to be applied to enrich the interactions addressed during PSS design.

As discussed before, our objective was to attempt to unveil new research paths of viable strategy to overcome the difficulties in promulgating environmentally friendly innovations through servitization-implementation success. Therefore, we concentrated on providing insights on how to successfully implement PSS as a first and generalist approach. To get a deeper grasp of the unique, sustainable interactions, we believe that future research could focus on applying sustainable BMI framework, enabling new interactions to arise. As an example, we encourage the use of the triple-layered business model canvas created by Joyce et al. [56]. Based on the triple bottom line defined by Elkington [16], this framework could produce more valuable, relevant interactions while designing PSS with sustainability purposes. However, we advocate that previous research paths regarding P1 need to be probed, as they constitute a necessary basis before extending the perspective.

P3: Paradoxes theory should be explored to better understand how tensions could be diffused more efficiently during PSS design.

Identifying interactions has been our main objective in this review. Nevertheless, identifying interactions and integrating them as early as possible will not mean erasing tension appearance but rather only unearthing them early enough to address them. Therefore, interesting future research paths would be to translate ways of answering tensions in the paradox literature to PSS design methods. By doing so, researchers would be able to give a usable toolbox for designers to cope with unknown, new tensions that they are more likely to face during PSS design.

Moreover, considering our representation graph in Figure 9, it could be acknowledged that the overall PSS sustainability should be assessed throughout all poles (nodes). Indeed, a sustainable design of one green pole would not necessarily induce the sustainability of the system. Considering that, the present research work causes us to formulate new questions for future research to answer: To what extent would the design/transformation of a green pole predict the sustainability of the overall PSS? Does a sustainable PSS necessarily mean individually sustainable poles?

Furthermore, future research could interestingly give further insight about how our propositions articulate within current research. As an example, Bustinza et al. [57] demonstrated how collaborative partnership could enhance service innovation. Considering the previous paragraphs, this trend could be interpretated as an expression of companies bypassing their difficulties to successfully implement services in new (to themselves), strategic fields by collaborating with partners that have already overcome tensions and paradox creation within their respective fields.

Considering all previous paragraphs, we finally argue for interdisciplinary research as first considered by Baines et al. [7] regarding PSS design methodologies. Indeed, the intrinsic, asynchronous nature of design paired with the necessity of addressing cross-field interactions could not be resolved otherwise.

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