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Digital Product-Service Systems: The Role of Data in the Transition to Servitization Business Models

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Abstract: The Circular Economy, as a guiding model for business processes, is attracting interest due to its potential for aligning business and societal goals as it offers companies the opportunity to simultaneously focus on economic value creation and on the mitigation of environmental damage. It is becoming increasingly clear that digital technologies are an essential component of this model as they enable transparency and efficiency in closing material and energy cycles. Additionally, digitalization leads to efficient business models that revolve around adapting the value proposition to the insights gained from the continual analysis of data, shifting the emphasis of Product-Service Systems towards the service end of the spectrum. As such, these new business models are categorized as forms of Servitization. Despite the increasing importance of Servitization and digitalizing business processes, such as the move towards what is referred to as Industry 4.0 in the manufacturing industry, the associated transition towards widespread adoption of the principles of the Circular Economy is slow. This explorative study investigates key themes and challenges in transitioning towards digitally-enabled Servitization in the manufacturing industry and the relationship with the Circular Economy. Through interviews with experts from the realms of digital technology, Industry 4.0, and business sustainability, a set of research questions is developed that forms a research agenda.

Keywords: circular economy; value creation; digital technology; transparency; Industry 4.0

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1. Introduction

The Circular Economy is an approach to production and consumption that aims to create a closed-loop system minimizing the use of natural resources and the creation of waste and pollution. It is increasingly promoted as a means through which developed economies can maintain growth and increase prosperity without fundamentally damaging the Earth's ability to sustain mankind. Many authors highlight the important enabling role of digital technology as a means for businesses to organize their material and energy needs [1], and for environmental damage to be minimized across entire supply chains [2].

Recent research designs and describes the elements of a transition path towards circularity for existing industry [3,4] so that businesses understand the damage that traditional practices cause, the alternatives for closing material and energy cycles, and the impact of these alternatives for their cost and revenue structures. The literature on Product-Service Systems (PSS) particularly highlights the opportunities for speeding up the progression towards a Circular Economy but concludes that research on circular value proposition design through PSS is in its infancy [5]. Additionally, PSS scholars note that not all PSS necessarily contribute to the Circular Economy [6] and that PSS can lead to rebound effects as reducing consumption in one area may lead to increased consumption in other areas [7].

Despite the almost universal realization that sustainable business practices are urgently required, and the widespread uptake of digital processes that offer transparency regarding process efficiency and resource depletion, the full extent to which digitization stimulates circular behavior has remained poorly understood. To date, there has been no clear exploration of the reasons behind this apparent reluctance on the part of business leaders

to explicitly commit to the Circular Economy, and so it remains difficult to understand in what ways change can best be stimulated. This gap requires urgent attention, as recent UN figures suggest that global emissions are set to continue to rise through 2030, despite the commitment of many countries to halve their emissions by that time as compared to pre-industrial levels.

This study adopts a focus on one form of PSS value proposition that is both digitally-enabled and aligned with the principles of the Circular Economy, namely Servitization [8]. The concepts of PSS and Servitization are not necessarily linked to the Circular Economy [9,10], but in this study, this is the relationship of relevance. The value created through Servitization forms a basis for PSS business models that include models where manufacturers sell the use of their products rather than transferring ownership of the physical artifacts themselves [8,11]. As such, the transition to Servitization provides manufacturers with a strong economic incentive to minimize waste and maximize the lifespan of their products, including repairing and recycling [5,12]. What this means is that PSS are a possible source of environmental benefits, particularly when business models incentivize business practices aligned with the principles of the Circular Economy, such as encouraging material resource circularity at the end of a product's lifecycle through designing for repair (See Figure 1).

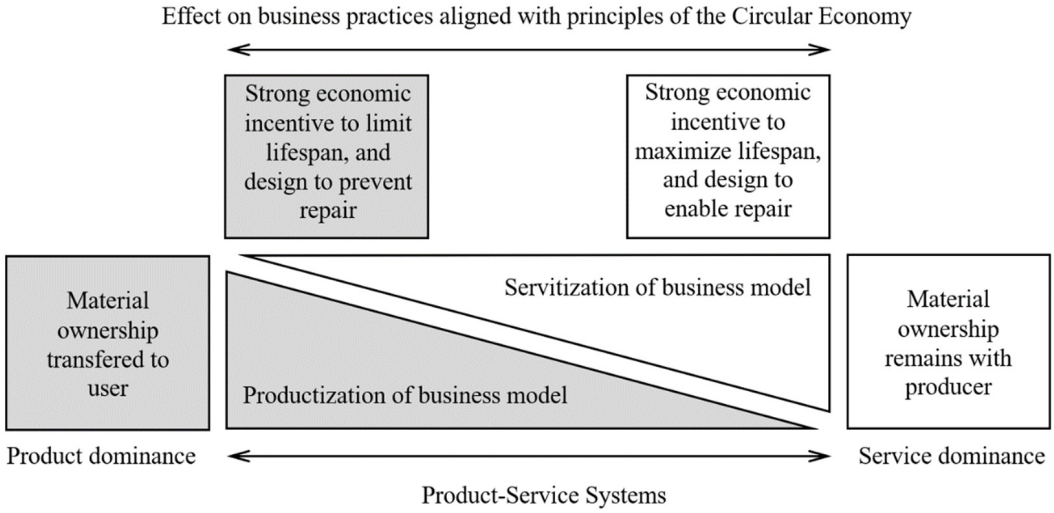

Figure 1. Depicting the relationship between PSS, Servitization, and Circular Economy, following [11].

The approach taken in this study was to interview a range of experts to explore key themes and challenges that businesses face in transitioning towards digitally-enabled Circular Economy practices in the manufacturing industry. Following a three-phase exploration-enrichment analysis methodology [13], the challenges and perspectives from practice were explored and confronted with extant literature.

This study contributes to the academic debate by providing an overview of key issues and challenges relating to digitally-enabled Servitization business models and how they support or hinder the widespread adoption and implementation of the Circular Economy. This leads to the development of a set of research questions intended to guide scholars, which, taken together, form a research agenda in need of urgent attention.

2. Servitization Business Models

Servitization is the drive towards creating value through functionality and assistance whereby a firm maintains a relationship with its customers and aims to better cater to the needs of the customer [8,14,15]. This represents a significant change to many business models that are based upon the transfer of product ownership, and which are characterized by little or no contact between supplier and customer after the point of sale. Servitization implies that service offering is flexible, changing through time to continually meet the fluctuating needs of the user.

What is being offered as a service may take many forms: the use of a product for a given time period, a managed process within a factory, quality control, predictive maintenance, a guarantee of zero down-time for an appliance, and much more. Therefore, Servitization is far broader than the notion of "product-as-a-service" alone and fits within the wider notion of Product-Service Systems. The extent of Servitization may vary on a scale from fully product-focused (0% Servitization) to fully service-focused (100% Servitization) [16]. As such, Servitization may imply that the ownership of the physical device being used remains with its manufacturer, although this is not strictly necessary.

Servitization in the context of increasingly data-rich industries entails the continual, potentially real-time optimization of a value proposition based on data analysis. Although Servitization is possible without data, through simply organizing around functionality and advice, it is becoming increasingly clear that the valuable insights made possible through the analysis of large amounts of data mean that many organizations experience digitalization as a key enabler for the design of new Servitization business models [17]. This includes a greater role for software as an integral part of Product-Service Systems as compared to the basic functionality offered by the hardware alone. Servitization may make use of the data from multiple sources, offering a wider range of functionality than is possible with the data from a single device [18].

There has been a recent proliferation of literature published on the relationship between Servitization business models and the Circular Economy, and a small number of papers connecting both these concepts to PSS (see Figure 2). Prior to 2015, no papers on the combination of these topics had been published.

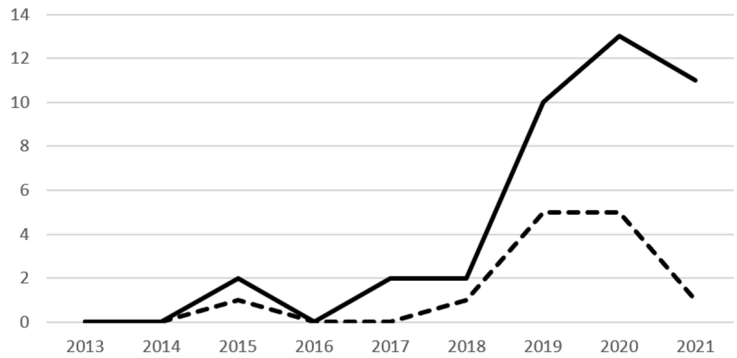

Figure 2. The number of journal papers per year with the terms "Servitization" and "Circular Economy" in the title, abstract, or keywords (solid line), or "Servitization", "Circular Economy", and "Product-Service System" (dashed line). Source: Web of Science.

One theme running through this recent literature is the way that Servitization allows for sustainability gains as digital technology shifts the focus from manufacturing and selling products to understanding customers' processes and using this to transform relationships [19]. Digital applications that include new forms of data analysis, often termed "smart things" [20], are able to produce significant impacts on the overall efficiency of customers' processes. It becomes both economically and environmentally advantageous to implement Servitization through lowering energy consumption rates, improving the utilization of resources, and reducing waste both during manufacturing and at the end of products' lifecycles [19].

Additionally, the use of data as a basis for Servitization enables circular business practices by offering value in use and allowing for new forms of business strategy [21]. Value in use includes four features: (a) remote monitoring, the collection of information regarding the location, availability and status of products; (b) product lifetime databases that continuously record and integrate product lifetime information that is fed from remote monitoring activities, analytics, and business intelligence to facilitate decision making; (c) remote control, where firms and users control product functionalities and personalize

their experience remotely; and (d) automation, where the product acquires capabilities such as self-diagnosis, self-coordination, or autonomous operation [20,21].

The literature connecting PSS to digitally-enabled Servitization has only very recently gathered momentum, and there are three main themes emerging [22]. First, the convergence between digitalization and Servitization is benefitted by a focus on strategic innovation factors [23]. Second, the interactions of digital PSS providers with partners in their ecosystem can facilitate innovative strategies, for example, by providing reciprocal access to data [24]. The third theme emerging from this recent literature addresses how to orchestrate the components required to develop digital Servitization strategies and highlights technological elements as well as complementary assets required to design and implement advanced service offerings [22].

The literature on business models at the firm level provides guidance for aligning business processes with the principles of the Circular Economy. Firms can self-regulate to reuse and recycle products and resources rather than procure scarce natural resources. Additionally, they can optimize production processes to minimize waste, for example, by designing for fewer composite materials and designing for simple repairs to add to their products' lifecycles. They can also optimize energy efficiency throughout the production process, and they can assess the ecological impact of their entire supply chain or business ecosystem [25]. This ecosystem level, and the orchestration and governance of different firms that collaborate within and across supply chains [26], is a theme that is also receiving increasing attention from scholars. Readiness levels for the Circular Economy can help various stakeholders to devise a shared vision of how they want to transform their business processes and, at the same time, understand what each party's next step needs to be [27,28]. Subsequently, circular business practices, which may form part of a Servitization solution, can be implemented through an iterative process of nurturing new knowledge and new improvements, negotiating risks and benefits, and standardizing across the ecosystem [27].

Nevertheless, it is clear that more research is needed to explain the extent to which these potential benefits of digital PSS and Servitization business models are realized in practice. In a study assessing the potential impact of Servitization on sustainability, involving a sample of 208 European manufacturing companies and investigating corporate sustainability disclosure, environmental performance, and policies, Doni, Corvino, and Bianchi Martini [29] report mixed findings. Their results show that Servitization does result in improved energy consumption, thus enhancing environmental performance. However, the authors find that Servitization had no effect on corporate sustainability disclosure and other environmental policies such as environmental assurance, emissions reduction policies, or environmental supply chain management. This provides a note of warning to scholars of digital PSS and Servitization business models that benefits in theory do not immediately translate into benefits in practice.

Significant challenges remain in order to make the case for transitioning to Circular PSS business models. These include the low level of service maturity in many firms that often have little or no contact with the end-users, the difficulty in improving environmental performance without increasing costs, the difficulty in assessing improved environmental impact and relating those improvements to financial metrics, and the difficulty in managing the transition in the context of a constantly evolving competitive environment [30]. The collection, analysis, and interpretation of the data may provide a path towards resolving some of these challenges, and that is the focus of the rest of this paper.

3. Methodology

A series of workshops and interviews were conducted following best practices of qualitative research based upon multi-stakeholder dialogue to enable the exploration of research priorities [13] as part of responsible research and innovation guidelines. The steps involved are set out below.

In an interdisciplinary exploration phase, two workshops were held, in September and October 2020, with four employees of TNO, an independent technology and inno-

vation intermediary based in the Netherlands. This single-source starting point for the exploration phase was chosen because of this innovation intermediary's independent and cross-industry position in stimulating the exploration and assimilation of new technological and business solutions. One participant specialized in the manufacturing industry and its digital transition, one participant specialized in digital network technology, one participant specialized in strategies for industrial innovation, and the final participant specialized in business consultancy and project management. These participants were selected to cover a wide range of disciplines and viewpoints from this organization, which collaborates with many organizations throughout the Netherlands, with the mission to create innovations that boost the competitive strength of industry and the well-being of society in a sustainable manner. Through the set of workshops, the participants were facilitated to share their experiences and opinions, to reflect on one another's statements, and to highlight important unanswered questions relating to Servitization and the Circular Economy.

In a multi-stakeholder enrichment phase, the findings of the workshops were summarized and discussed with industry experts in a series of interviews held in November 2020. The four interviewees were: (1) the CEO of the Dutch subsidiary of a multinational company specializing in smart infrastructural and agricultural product systems; (2) a professor of technology marketing at a leading technical university; (3) the program coordinator of the national program for Circular Economy at the Ministry of Infrastructure and Water Management; and (4) the COO of a national network for smart maintenance companies covering, among others, road and water infrastructure, airlines, and building and energy industries. Prior to the interviews, a summary of the workshops was sent, and during the interviews, the participants were asked to reflect on the findings and elaborate on their own experiences and opinions. In addition, they were asked to comment on key unanswered questions and to consider the strategic areas in which future research is urgently needed.

In an aggregation phase, the combined findings of the workshops and interviews were analyzed to identify themes and challenges. Additionally, the key questions were aggregated to form a small set of research questions that could form the basis for a research agenda to guide future research into Servitization and the Circular Economy.

4. Findings

The key findings are summarized in Table 1 and described in the following subsections.

Table 1. Key themes and challenges that businesses face in transitioning towards digitally-enabled Circular Economy practices in the manufacturing industry.

Theme	Challenges
Designing Servitization business models	Flexibility
	Source of revenue
	Transition of business model
	Data analysis
	Changing risk structure
	Changing relationships
	Negotiation of incentives
	Unclear societal response
Servitization ecosystems	Changes to existing ecosystems
	Disruption through technology
	Unpredictability
	Changing power dynamics
	Platform dominance
	Ecosystem governance
	Role of trade associations
	Crossing international boundaries
	Interoperability

Table 1. *Cont.*

Theme	Challenges
Servitization legitimacy	Data-sharing risks
	Role of government
	Private sector experimentation
	Data sovereignty
	Trust
	Legal frameworks
	Reliability and validity of data
Digital technology choices	Complexity of decision making
	Mismatch of lifecycles
	Technological reliability
	European design principles
	Hybrid strategies
	Long-term viability
Servitization and Circular Economy practices	Progression towards Circular Economy practices
	Green versus Greening ICT
	Impact analysis
	Sharing responsibility
	Implementing digital product passports
	Wider effects

4.1. Designing Servitization Business Models

Flexibility: Business models define many elements of how organizations function. The central element of any business model is the value proposition, which describes how a product or service adds value from the perspective of the customer or user. Servitization business models imply flexibility, adapting the service contract to meet new needs as they emerge. This flexibility blurs the definition of the service being offered as it may change across time and in different usage settings. As such, this creates new challenges for designing Servitization business models as it becomes difficult for customers to understand exactly what the benefits are of the value proposition of one supplier compared to another. Indeed, many new Servitization solutions result in a worse customer experience as new ways of working have not yet been optimally designed.

Source of revenue: Another key element of any business model is the source of revenue. Many data-driven Servitization revenue models exist, such as pay-per-use (e.g., the use of printers and photocopiers where customers pay for the number of pages printed), pay-per-value created (e.g., the amount of thrust generated by airline engines), and pay for zero downtime (e.g., the provision of predictive maintenance within time-critical manufacturing lines). Revenue models may also include a provision for quality control and may be designed around the principles of business process optimization. For organizations implementing Servitization business models for the first time, finding the right source of revenue is not simple.

Transition of business model: The transition from a product-based business model to one based on Servitization is a major challenge for most organizations. Large corporates typically have resources to make the transition, however, smaller firms may struggle to implement the necessary changes. The transition to Servitization impacts many aspects of a firm. For example, products that are leased as a service instead of being sold directly will only generate revenue on a periodic basis, significantly changing the capital investment structure.

Data analysis: Data systems allow for highly accurate monitoring of the service performance, which can be beneficial, such as incentivizing the service provider to meet key objectives. The analysis of relevant data plays an important role in understanding which changes are needed for a business model, for example, by highlighting where and how

it is possible to reduce inefficiencies. However, too much reliance on data analysis can also be detrimental, for example, by removing the incentive to exceed service level agreements. Some service providers may find it in their short-term interests to monitor and optimize service performance to exactly meet, but not go beyond, the minimum acceptable to a customer.

Changing risk structure: Risks are also an integral part of any business model. Operational risks shift from the customer to the service provider because, whether or not problems occur, customers expect them to keep providing the service. However, the main risk for the customer is that they become increasingly dependent on the service provider and that, in cases in which the service provider ceases its services, they may no longer have the right knowledge in-house to ensure continuity.

Changing relationships: With Servitized business models, the relationship with the customer changes. The service provider needs to show the customer how they will benefit, for example, through lower investment, improved insight into inefficiencies, or reduced risk. Simply offering a technical service is not enough; customers need to be included in defining a performance-based agreement that forms an inclusive approach based on the total cost of ownership or usage. This means that the service provider gets involved in the strategic process of the customer, and the customer needs to be open to that and change their expectations of how the relationship with the service provider will develop. Customers generally want to maintain control of their critical processes and are reluctant to outsource these processes. A service provider and a customer undergo the transition to Servitization together as the balance of costs shifts, and both parties need to agree where key knowledge will reside and be developed and how that knowledge will be shared.

Negotiation of incentives: Obviously, the best business model is one that is mutually beneficial for both parties in partnership rather than a zero-sum game where each party attempts to reduce the margin of the other as much as possible. After this negotiation, some parties will need to significantly change their knowledge base and personnel. A benefit of developing a stronger customer relationship through Servitization is that it leads to customer loyalty, particularly when the incentives for all participants are aligned for efficiency. For example, in the US, maintenance contracts often include bonuses to stimulate high service performance, whereas in the Netherlands, penalties are more common. From this, it can be concluded that organizations adopting a Servitization approach will need to develop strong relationship management competencies.

Unclear societal response: At the present time, it is unclear what societal response Servitization business models will receive as they become implemented in new industry sectors and consumer settings. End-users may have trust issues with Servitized business models as their usage data are monitored, which may be perceived as an infringement of privacy or a risk for commercially sensitive data. A more general societal acceptance of Servitization may take time, as benefits and positive experiences in one industry lead to experimentation in other industries. Some products are easier to adapt to Servitization, such as commodities, and some sectors have been using Servitization business models for decades. The general societal feeling that it is better to own things such as cars or water heating boilers rather than simply having use of them will need to change for Servitization to become prevalent in all areas of society.

4.2. Servitization Ecosystems

Changes to existing ecosystems: Organizational ecosystems are networks of collaborating organizations and their physical, market, and regulatory environments in which there are continuous flows of knowledge, finance, and value in an interactive, open system [31]. The implementation of Servitization implies changes in organizational ecosystems whereby the number, type, and nature of connections between parties in the value chain are changed through Servitization.

Disruption through technology: New technology enabling new ways of data sharing brings about change. For example, the traditional triangle of OEM, asset provider, and

maintenance party is shifting as ICT parties get involved in Servitization ecosystems. This implies that when Servitization and digitalization are combined, significant change can ensue.

Unpredictability: A key challenge for organizations that engage with new parties in such ecosystems is the lack of control that they perceive due to an increase in the number of factors that they have to take into account and the accompanying increase in uncertainty. New partners acting in unexpected ways and external events such as the COVID-19 pandemic lockdown shifting many processes online also bring about rapid change.

Changing power dynamics: For many organizations, the transition to Servitization means the adaptation of their existing supply chain and a change in the roles and power dynamics between actors. Overall, the purpose of this adaptation is to improve the competitiveness of the whole ecosystem and offer the end-users more value; however, not all actors will benefit, and some may even become obsolete. Clearly, when some actors stand to lose out, this causes a barrier to change. For new entrants, these being either startups or organizations expanding beyond their traditional market sector, there is no such adaptation to an existing supply chain and no direct difficulties to existing power dynamics. However, any new entrant can bring about a shift in power as the market share may be reallocated and suppliers are confronted with new expectations, such as regarding price or service level.

Platform dominance: Pervasive digitalization is influencing almost every industry sector, and this lends itself to the growth of platforms, thus enabling Servitization. Platforms are a unique form of an ecosystem, and the expectations are that they will become extremely relevant and change industry dynamics. Platforms offer the benefits of coordinating connectivity, gathering data, and ensuring security. Many organizations do not recognize this impending disruption and are unprepared for it. When Servitization platforms emerge between existing suppliers and users, tension and a shift in the power structure are caused. ICT organizations may have a leading role in these platforms due to the central role of data, and, as is often the case, power resides with the party or parties in the ecosystem that control the data. Therefore, it is important to negotiate which parties control data generation, storage, sharing, and analysis. Platform lock-in is a potential danger, leading some organizations to fear a loss of control and self-determinism. Multi-party or co-operative forms of platform and data governance exist, although many parties are unaware of the range of options possible, with the danger that this leads to sub-optimal choices being made.

Ecosystem governance: Will Servitization in the manufacturing industry follow the dynamic of a single, dominant "winner takes all"? Once network effects take hold, path dependence prevents a "bad" ecosystem design from being changed. At the present time, there is too much focus on the enabling technology and not enough on listening to relevant parties throughout the ecosystem. Transparency throughout the ecosystem is a prerequisite for successful collaboration. Governance must be dynamic and flexible, based on a solid understanding of the changes in behavior and requirements. A co-operative platform governance model with shared ownership and control is needed to prevent the value from being drained out of the industry while stimulating innovation and competition. For example, the Dutch airline KLM is promoting the idea of an independent marketplace for their suppliers at smart industry events.

Role of trade associations: Trade associations are industry-specific organizations founded to provide services to member firms, such as education, publishing, and lobbying. Their main focus is on stimulating collaboration between member firms to generate synergies for an industry-wide advantage. The role of these trade associations in stimulating a transition to Servitization across their industries is presently unclear. When traditional supply chains are in danger of being disrupted due to the changes associated with Servitization, different organizations vie for dominance, such as by developing a platform that their suppliers and competitors are invited to join. However, for a Servitization ecosystem design or platform to become acceptable, all actors need to see the benefits and accept the risks. For example, should a country's trade association of metal processing firms develop or promote an

ecosystem or platform promoting Servitization for its members? Such associations may not have the necessary resources or expertise, although they may be seen as being impartial with the objective of benefiting the national industry.

Crossing international boundaries: Beyond the national setting, and following the borderless nature of many digital developments, for many areas of manufacturing, there is significant international trade that necessitates an international approach to Servitization ecosystems. There has been an important development in the EU, based on the European Commission's Data Strategy [32], towards the development of "data spaces" that allow for responsible data sharing while maintaining data providers' control of the access of other parties to their data. Here, the challenge for organizations participating in Servitization ecosystems is to be aware of, and be able to implement, international data space solutions.

Interoperability: Finally, an important challenge is that systems integration across the ecosystem is more complex than with simple linear supply chains. The above-mentioned European Data Strategy proposes new data infrastructure and services that are modular and interoperable, allowing for seamless integration of different systems. That is the ideal picture, however, in practice, many legacy systems were not developed with such principles in mind. In small, closed value chains, interoperability is relatively straightforward, but for larger, open systems, standardization is required to enable interoperability, which calls for expertise in semantics, ontologies, and data protocols. Currently, with low levels of interoperability, a practical problem slowing the adoption of Servitization relates to how to access and use the data that are stored according to bespoke protocols in devices or at other organizations. Interoperability is needed to allow for data portability, allowing users to switch between providers, which would become important for fostering competition. An interesting example is the Asset Administration Shell, developed in the German Industry 4.0 program, which provides a digital representation of physical assets. Most standardization activities aimed at interoperability are concerned with data security, however, there is also a need for interoperability in data architectures and services to enable sustainability.

4.3. Servitization Legitimacy

Data-sharing risks: Currently, many firms do not view Servitization as a legitimate way of conducting their business, however, this situation is undergoing a period of re-evaluation. If this legitimacy is to be attained, a major challenge to overcome is that sharing commercially sensitive data is seen by many firms as high risk. Trust is extremely important, and the underlying design of data infrastructure plays a key role in providing trust and being perceived to be trustworthy. To boost trust, data infrastructure and services for Servitization will need to be implemented so that each organization remains in control of their own data and they are able to provide and gain access to each other's data under clear conditions.

Role of government: There is an important role for the government in stimulating the legitimacy of Servitization, both by promoting best practices and by leading by example. A case in point is the Netherlands' Directorate-General for Public Works and Water Management, which is forming a data strategy aimed at Circular Economy practices in the infrastructural building sector, and this data strategy is expected to be well-aligned with the principles of data analysis for Servitization.

Private sector experimentation: Additionally in the private sector, the legitimacy of Servitization is developing, such as by the development of Servitization pilot schemes and experimental field labs. In the Netherlands, for example, the national Smart Industry program provides a basis for public–private partnerships to explore novel digital manufacturing solutions, including Servitization. The legitimacy of a transition to Servitization in industry relates to a range of issues: how data are shared, stored, and protected; legal issues; how data from different sources can be usefully combined; and how much trust and reliance firms can have on the services provided.

Data sovereignty: Legitimacy is closely related to good data governance and well-organized data sovereignty. Many questions are related to data sovereignty. Who owns the

data and who controls access to the data? The end-user, the service provider, a platform operator? Where are the data kept? How are the data processed? How are the data protected? The resulting governance framework needs to offer transparency, with clarity on which parties oversee the network of Servitized offers and data flows. Such governance frameworks require a negotiation that is strongly influenced by dependencies, such as in platform-based collaborations and power distances in service-driven ecosystems.

Legal frameworks: Legitimacy is also closely related to legal issues, and the legal compliance of a flexible, ever-changing service is difficult to manage. New legal frameworks are needed to organize data management and ownership, particularly regarding multi-organizational arrangements, such as data portability. New developments in data-sharing technologies and accompanying protocols are offering off-the-shelf solutions, such as that promoted by the International Data Spaces Association, yet challenges remain. For example, services provided under one legislation may be incompatible with others, such as regarding where the data are stored, and the composition of services may be complex whereby there is the possibility that one component renders the overall service illegal. Potentially highly complex legal arrangements and terms and conditions pose a significant barrier to transitioning towards Servitized business practices and offerings.

Reliability and validity of data: Finally, another key component of the legitimacy of Servitization is the reliability or validity of the data that are used to adapt the services to the needs of users. Many approaches to organizing dynamic service delivery use the data from various actors in a supply chain, which poses challenges for the reliability and validity of the entire value chain. This point relates to the governance of the business ecosystem in order to efficiently manage the entire multi-party system, as described in Section 4.2 on Servitization ecosystems. The reliability of Servitization is inherently a long-term issue so that customers and other stakeholders can make decisions based on trustworthy insights relating to a device, material, or service for years to come. Little attention has been paid to data quality throughout the lifecycle, for example, to maintain the validity of the data after bankruptcy or the acquisition of the service provider.

4.4. Digital Technology Choices

Complexity of decision making: The connection between technology choices and Servitized business models is important but difficult to get right. The list of enabling technologies is growing, and this poses significant challenges for organizations whose expertise is not traditionally in the ICT domain. These technologies not only include devices fitted with digital sensors but also relate to infrastructure, including the European development of open-cloud computing called GAIA-X, and virtualization developments, including so-called containerization to allow for the running of applications in dedicated user spaces regardless of type or vendor. Additionally, there are various standardization protocols, edge computing solutions, network developments moving from the new implementation of 5G towards 6G, and increasing implementation of AI or local intelligence analysis technologies. Regularly, there is a lot of hype around new digital technologies such as blockchain or distributed ledger technologies, which may be justified or not, but companies that are not specialized in digital technology will struggle to understand these. All in all, for many non-ICT organizations, the complexity and the difficulty of decision making with respect to digital technologies is a major factor in slowing the move to Servitization.

Mismatch of lifecycles: Even when an organization decides to enhance its digital capabilities, investments in technology may be delayed due to a fear of missing out on better alternatives in the future. For example, many manufacturing systems' lifecycles are not as fast, which means there is a mismatch with rapidly evolving digital technology developments. Organizations need to have an easy way to access information about upcoming technologies and receive support in understanding the relevance of these technologies to their own business.

Technological reliability: Technological reliability is an ongoing issue for Servitized offers, particularly those based upon reducing downtime in factory processes, and many

digital solutions are currently far less reliable than their analog predecessors. In some firms, such as air traffic control, highly reliable legacy systems are slow to change. Added to this, many Servitized products and devices require a constant internet connection, which is not always possible to guarantee.

European design principles: Recent developments in data-sharing architectures, infrastructure, and applications have led to the emergence of unified design principles in the European Union that Servitization solutions will increasingly follow. This includes ensuring data sovereignty and federated and distributed access through data brokerage coupled with open and inclusive interoperability for identification, authentication, and authorization as well as underlying semantic models based on FAIR principles (meaning that data should be findable, accessible, interoperable, and reusable). Particularly in relation to AI, it is important to make sure that algorithms are trusted and explainable.

Hybrid strategies: Digital technology is changing quickly, and organizations need to develop a hybrid strategy based on their traditional processes combined with technology-driven Servitization. In industrial settings, there is an increasing emphasis on large-scale Internet of Things (IoT) technologies as many industrial firms implement advanced sensors and edge and far-edge data analysis solutions with large numbers of IoT devices with their own low-latency computing capabilities. The expectation is that the current reliance on intelligence in the cloud will shift to a majority of Servitization solutions using distributed intelligence.

Long-term viability: In the long term, maintaining important knowledge in the organizations is a challenge as the wider industry and education shift to new technologies. An important question facing managers in the transition to Servitization is regarding how much of their primary process they outsource to service providers. For example, a firm that sold road sweeping machines to the local government made the shift to swept roads as a service. In this shift, they found that they were also able to optimize sweeping routes, which had previously been a task covered by local government officials. Some organizations have benefitted from Servitization in the short term only to realize that they are no longer able to make technology decisions themselves due to a lack of in-house expertise. Besides this, many key performance indicators included in Servitization contracts are reliant on technology choices. For example, in software, the quality of code is important for accurately and reliably optimizing energy usage.

4.5. Servitization and Circular Economy Practices

Progression towards Circular Economy practices: In general, sustainability has not been a major driver of change in business models, but this appears to be changing. Some are of the opinion that once data-driven Servitization is implemented, there will be a slow but natural progression within many industries towards Circular Economy practices, including recycling, reuse, and refurbishment, therefore improving environmental sustainability. When Servitization implies that the ownership of the device remains with the manufacturer, it is in the self-interest of the manufacturer to design, operate, and maintain the device for long-term reliability and elimination of waste. Increasing an appliance's lifespan results in large sustainability gains, and predictive maintenance allows for sustainability improvements in energy use and emissions reductions. Taken to its ultimate extent, a Servitization business model follows the principles of the Circular Economy because waste is eliminated from all energy and material loops. The greater the extent of Servitization, the further along the path to a full Circular Economy and the implementation of higher levels of circular practices, such as the principles of refuse, reimagine, and redesign.

Green versus Greening ICT: There is a distinction to be made between two forms of sustainability in relation to digitalization. First, Green ICT represents the data technologies and infrastructure that can be sustainable and developed through circular practices, for example, their energy consumption can be optimized, and this is mostly driven by costs. Second, Greening ICT enables many other products and processes to become sustainable

and circular, therefore, this is the most impactful form of digital sustainability. Data-driven Servitization is an implementation of Greening ICT.

Impact analysis: A major challenge is to achieve a valid and reliable environmental impact analysis of Servitization wherein it is important to define which sustainability metrics to assess and how to measure them. The data on usage coupled with Servitization impact can make it clear how to redesign appliances to improve sustainability. An impact assessment related to the Circular Economy should assess which "R"s are affected by data-driven Servitization (Refuse, Reimagine, Redesign, Recirculate, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover). At the present time, it is unclear whether Servitization leads to net consumption reduction or to only more efficient resource use.

Sharing responsibility: Rather than placing all the sustainability responsibility with the service provider, a better solution would be to ensure that the clients of Servitization also feel partially responsible, such as by charging the environmental costs of the CO_2 footprint to the client. Additionally, in a Servitized industry, it is important to assess the ecological (and social) impact across the entire value network rather than for an individual firm. Transparency between firms is important in order that those procuring the services have a realistic picture of the sustainability credentials of all the components that contribute to the service they are buying. One potential solution to offer this transparency is the idea of a digital product passport to monitor and certify the ecological footprint of a product, including what it is made of, how it was made, certifications, and how it can be reused.

Wider effects: At a societal level, it is important to understand the wider effects of Servitization. Scholars and practitioners need to be aware that rebound effects may mean that sustainability savings in one area are canceled out by excesses in other areas. Servitization may also affect wealth distribution, for example, by fostering the volatility of economic activity, meaning that when labor costs are fractionally lower somewhere else, the business may move some tasks away at the expense of existing employment opportunities. As a general digital trend, platformization is showing this tendency already.

5. Discussion

This paper explores the link between digital technologies, Servitization as a form of a PSS business model, and their impact on environmental sustainability. Through a series of expert workshops and interviews with practitioners from different domains, important themes and key challenges for the implementation of digitally-enabled Circular Economy business practices were explored and elucidated. An overall conclusion is that there are huge benefits to be achieved through Servitization, but that the challenges are significant and wide-ranging. One result of this exploration is that this paper provides both PSS researchers and managers with a structured set of information about these challenges so that informed decisions can be made, thus helping Servitization to realize its benefits for organizations and their customers.

The main contribution of this paper to the ongoing discussion on digital PSS is the nuance and explication of risks and concerns that emerge from the confrontation of developments in digitalization with the practical needs of business. The transition to Servitization business models would appear to be a major shift in business practices, and there are significant concerns that emerge from this paper's exploration. Specifically, the paper adds to this discussion in four ways: (1) the attainment of sustainability improvements; (2) value in use; (3) service capability maturity; and (4) orchestrating ecosystem innovation.

5.1. Attainment of Sustainability Improvements

At the firm level, the current literature offers a mixed picture of the effect of Servitization on realized environmental sustainability improvements. Servitization may improve energy consumption [33,34], however, it has been shown to have no effect on corporate sustainability disclosure and other environmental policies [29]. Others highlight the theoretical sustainability gains achieved through improving the utilization of resources and reducing waste both during manufacturing and at the end of products' lifecycles [19]. This

paper contributes to this mixed picture as a number of other challenges emerge that could seriously limit net sustainability gains. Three points may be emphasized in this regard.

First, once Servitization firms and their clients agree on terms, a new incentive becomes salient: to exactly meet, but not go beyond, the minimum acceptable performance level. This could cause the development of an ever-improving sustainability impact to stagnate. Second, besides the unintended contractual stagnation, a similar effect could arise relating to the legal compliance of a flexible, ever-changing service. This is difficult to manage, and it could lead to highly complex legal arrangements that deter firms from developing an ambitious sustainability performance through Servitized business practices and offerings. Third, many sustainability gains will depend upon the reliability and validity of data from multiple parties that are used as a basis for Servitization. In particular, when looking across the entire lifecycle, coping with changes such as mergers and acquisitions or bankruptcies may result in potential sustainability benefits remaining out of reach practically. Taken together, these findings on sustainability outcomes add weight to the notion that the theory of Servitization and its practical implementation in this regard remain far apart.

5.2. Value in Use

PSS scholars highlight "value in use" as a perspective used to focus on new forms of business strategy [35]. Value in use stimulates firms to adopt the viewpoint of the end-users and understand how the service provides value through remote monitoring and analytics to facilitate decision making, control product functionalities, and personalize their experience in real-time. The Servitization business models of PSS provide a business perspective on such strategies [21,23], and three of the findings show how this must take shape.

First, the complexity of digital developments, including 5G networks, Internet of Things and associated sensors, distributed ledger technologies, and intelligence at the edge, means many firms struggle to understand their options and how specific choices may impact their customers' value in use. This complexity matched with limited digital expertise slows the transition to Servitization. Second, even once firms have made their technology choices, there is a clock-speed mismatch between manufacturing systems' lifecycles and rapidly evolving digital technology developments. Firms will struggle to make the decision to invest heavily now in digital solutions that they fear will quickly become outdated. Finally, manufacturing norms and standards for reliability and downtime are different from those of digital innovations. Downtime or connection interruptions are difficult to avoid and pose a threat to Servitization quality. In other words, PSS literature acknowledging the importance of value in use may have underestimated the technology-related difficulties of enabling that value to be captured in practice.

5.3. Service Capability Maturity

PSS literature describes the challenges for Servitization in manufacturing firms, including the low level of service maturity in many firms because they often have little or no contact with the end-users [36], which is necessary for optimizing service quality [12]. The findings from the present study provide a potential pathway towards Servitization maturity. During the development of a Servitization capability, a service provider and a client undergo the transition together. In this transition, each party needs to understand the needs and long-term knowledge requirements of the other, and they need to agree where key knowledge will reside. This negotiation will help a client to understand which certain areas of expertise to outsource to the service provider and which to maintain in-house, and it will help the manufacturer to understand how far into the business of the client its own expertise needs to develop.

Another capability-related question that has been noted in the PSS literature is how manufacturers may experience difficulty in assessing their service performance [9,10], including improved environmental impact, and relating those improvements to financial metrics, particularly in the context of a constantly evolving competitive environment [30]. The findings of the present study highlight the role of both data-sharing capabilities and

trust in the digital infrastructure as prerequisites for high-quality Servitization. In terms of data-sharing capabilities, the literature appears to have underemphasized the difficulty that firms face in understanding that it is possible to both provide access to other parties in the ecosystem and at the same time remain in control of what data are used for what purpose and by what party. In terms of trust in the digital infrastructure of Servitization, digital solutions such as data spaces and their associated trust frameworks need to be implemented such that each organization remains in control of their own data and that they are able to provide and gain access to each other's data under clear conditions. At the present time, many firms considering a transition to Servitization do not believe that this is achievable.

5.4. Orchestrating Ecosystem Innovation

At the ecosystem level, Servitization poses new challenges for collaborating stakeholders to design a shared vision or blueprint of how they want to transform each firm's business processes and, at the same time, optimize each firm's benefits [24,26–28]. This paper contributes to this by adding detail to the notion of ecosystem orchestration [22].

On the one hand, increasing platform dominance in many markets requires manufacturing firms to negotiate which parties control data generation, storage, sharing, and analysis. Good multi-party solutions exist, but many firms are unaware of how to make suitable choices. On the other hand, the decision space may be limited by difficulties arising from a lack of interoperability between legacy systems. The ecosystems of firms considering a transition to Servitization need to address semantics, ontologies, and data protocols that will satisfy all the relevant parties. Considering the increasingly extensive nature of many supply networks, there is a natural tendency for platform operators to solve these difficulties with their own proprietary solutions, but this can prove restrictive to their customers in the longer term. A key step in the orchestration process is the negotiation of data sovereignty governance frameworks, and this is strongly influenced by dependencies across the ecosystem.

6. Conclusions

The present study explored leading knowledge on how digitalization affects PSS and Servitization business models and how this might offer manufacturing firms the ability to embrace the Circular Economy. It then confronted industry experts with these insights, and the resulting findings are intended to guide scholars in carrying out impactful research on this important topic. The PSS and Servitization business models hold enormous potential for enabling a sustainable manufacturing industry while at the same time offering continued competitiveness and innovation. Only through an increased understanding of the nuances of such business models will this potential be realized. Besides the discussion on the contribution of this paper in the previous section, this current section also presents some limitations and brings together important research questions into a research agenda (see Table 2).

6.1. Limitations

The explorative approach applied in this study may be characterized as an investigation based upon insights from the field, both from business leaders with an interest in Servitization and ICT specialists within an innovation intermediary who are engaged with business. A limitation is that academics from the sustainability or Circular Economy perspectives are underrepresented. The intention was to engage with relevant scholars through this paper and stimulate further theory development based upon the findings.

Table 2. A research agenda into how digitalization shapes PSS and Servitization business models.

Theme	Research Questions
Designing Servitization business models	What is an optimum methodology to clarify cost and value mechanisms between parties considering a transition to Servitization? How can firms increase their strategic flexibility so that they can continually align their service proposition and their underlying processes towards changing customer needs?
Servitization ecosystems	What is an optimum process for orchestrating the inception and scaling-up of co-operative governance models for data-sharing ecosystems? Some companies may be more effective and more competitive in the non-Servitized economy while others may benefit greatly from Servitization. Can this be predicted and acted upon to accelerate the implementation of Servitized ecosystems?
Legitimacy	How can we monitor and influence firms' trust in Servitization arrangements, taking into account all relevant factors that influence trust (including data sovereignty, legality, interoperability, and data validity and reliability)? Is it possible to describe a standard set of data management agreements that ensure data quality throughout the service lifecycle?
Digital technology	Can we develop a generic technology assessment instrument to support business decision making regarding Servitization technologies, including specifying the implications of the choices? As technology choices impact data sovereignty, how can firms know which choices ensure that data will always be under the control of the appropriate party?
Circularity	How can we develop a sustainability impact assessment instrument to provide a reliable assessment of actual impact realized across the entire value chain? To what extent does transparency in sustainability impact change business processes towards higher levels of the Circular Economy?

Another limitation is brought about by the broad scope of the issues touched upon in the data collection process. Inevitably, in a single study, the more different issues that are raised, the less each issue can be dealt with in-depth. Various topics covered here deserve more attention than this paper has been able to provide, and the growing attention in PSS literature to digitally-enabled Servitization may be fueled to some extent by the presented findings.

Finally, a limitation of this study is its focus on a single country of the European Union. There is an accelerating divergence of data infrastructure and related policy-making between the EU and other parts of the world, notably the US and China [37]. A number of the key issues highlighted in this paper are particularly sensitive to these developments, including concerns about providing access to sensitive data, data sovereignty, and risks of vendor lock-in. This means that the topics covered here provide only a cross-sectional view that will require continued attention from scholars in the coming years.

6.2. Research Agenda

In Table 2, the themes and challenges described in the findings from Section 4 are condensed into a small number of research questions that, taken together, form the priorities and a research agenda for enabling the transition to Servitization. These research questions have been distilled from the key themes described above.

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