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Smart Product-Service Systems in Fashion Industry: A Systematic Review of Sustainability Results

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ABSTRACT

Purpose: This review paper provides an inductive analysis on "Smart product service systems" in fashion industry by explaining how servitization as a form of service innovation is critical for sustainability, and the promise of digital technologies for smart fashion industry based on analysing current challenges, opportunities, and digital technologies for the implementation of Smart PSS in the fashion industry.

***Methodology*:** The study employed an inductive analysis approach to identify the servitization domains, respective Smart PSS applications and the environmental sustainability results. The environmental sustainability results matched with the services were derived from the extensive literature by inductive coding of all identified Smart PSS applications through systematic literature review.

Findings: Fashion industry applications of Smart PSS were matched with the respective servitization domain, and the discussion were extended with the possible environmental sustainability results based on the literature content. Further research questions have been proposed.

Originality: Recent research calls for contributions about the effects of digitalization on different outcomes of servitization beyond financial performance and draws attention to the small number of studies addressing the environmental benefits of digital servitization to the circular economy. This study addresses the research gap for a scholarly discussion about the environmental sustainability results of digital servitization in fashion industry and provides a comprehensive future research agenda.

Keywords: Service Innovation, Smart Product Services Systems, Servitization, Sustainability.

JEL Codes: M1, O30.

Moda Endüstrisinde Akıllı Ürün-Hizmet Sistemleri: Sürdürülebilirlik Sonuçları Üzerine Sistematik Bir Derleme

ÖZET

Amaç: Bu makale, bir hizmet inovasyonu biçimi olarak hizmetleştirmenin, sürdürülebilirlik için nasıl kritik olduğunu ve akıllı moda endüstrisi için dijital teknolojilerin sunduğu potansiyeli açıklayarak, moda endüstrisindeki "Akıllı ürün-hizmet sistemleri" hakkında tümevarımcı bir inceleme sunmaktadır.

Yöntem: Çalışma, moda endüstrisindeki hizmetleri, ilgili akıllı ürün-hizmet sistemleri uygulamalarını ve çevresel sürdürülebilirlik sonuçlarını belirlemek için tümevarımsal bir analiz yaklaşımı kullanmıştır. Hizmetlerle eşleştirilen çevresel sürdürülebilirlik sonuçları, sistematik literatür taraması yoluyla tanımlanan tüm dijital PSS uygulamalarının kodlanmasıyla kapsamlı literatürden türetilmiştir.

Bulgular: Akıllı ürün-hizmet sistemlerinin moda endüstrisi uygulamaları, ilgili hizmet alanı ile eşleştirilmiş ve literatür içeriğine dayalı olarak olası çevresel sürdürülebilirlik sonuçları ile tartışma genişletilmiştir. Gelecek araştırma soruları sunulmuştur.

Özgünlük: Son araştırmalar dijital hizmetin döngüsel ekonomiye çevresel faydalarını ele alan az sayıda çalışmaya dikkat çekmektedir. Bu çalışma, moda endüstrisinde dijital hizmetin getirdiği zorluklar, fırsatlar ve çevresel sürdürülebilirlik etkileri hakkında bilimsel bir tartışma için araştırma boşluğunu ele almakta ve gelecek araştırmalara ışık tutacak kapsamlı bir araştırma gündemi sunmaktadır.

Anahtar Kelimeler: Hizmet İnovasyonu, Akıllı Ürün Hizmet Sistemleri, Hizmetleştirme, Sürdürülebilirlik.

JEL Kodları: M1, O30.

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1. INTRODUCTION

Grand challenges such as climate crisis force the transformation of high-impact manufacturing industries (industries which have triple bottom line effects globally led by their manufacturing operations) into sustainable business models. Servitization, as a form of service innovation, transforms the final products and customer facing solutions as well as sourcing, logistics, and product lifecycle. As Baines et al. (2009) clarified “servitization is the innovation of an organizations’ capabilities and processes to better create mutual value through a shift from selling product to selling product service systems”. Den Hertog et al. (2010) defined service innovation as follows: "A service innovation is a new service experience or service solution that consists of one or several of the following dimensions: new service concept, new customer interaction, new value system/business partners, new revenue model, new organizational or technological service delivery system.". Service innovation and servitization have the potential to significantly transform the fashion industry for sustainability by shifting the focus from traditional product-based models to service-oriented approaches.

Calabrese et al. (2018) addressed the research gap in service innovation regarding sustainability and identified the clear need for further research in sustainability-oriented service innovation with their systematic literature review. "Service innovation" is a "transcendent business logic" to be adopted by firms to be responsive for sustainable development goals of UN agenda 2030 (Den Hertog et al., 2010; Polese et al., 2015). The larger part of GNP in developed countries is dependent upon service sales resulting in higher interest for research in new service development from an environmental perspective (Nijsse et al.,2006). This business logic can bring profound advantages to the fashion industry by extending product lifecycles, encouraging collaborative consumption, executing circular economy principles, and employing data-driven sustainability.

Sustainability can be studied in manufacturing settings by discovering product modifications, repackaging, and processing of materials, resources, and knowledge (Chen et al., 2015; Lin and Chen, 2018). Fashion servitization, as the service innovation in fashion firms, is a fruitful research domain for sustainability challenges. As modern economies are predominantly driven by services, and if they genuinely aim to achieve sustainable development, it's imperative to examine the connection between services and sustainable growth (Djellal and Gallouj, 2016). It is most relevant when immateriality is taken for granted in service innovation. Djellal and Gallouj (2016) argued that service includes direct and indirect sources of materiality, increasing ecological footprint, and environmental externalities. Whilst manufacturing firms acknowledge the transition toward services, making it sustainable is still a challenge given the complexities related to the servitization.

Product service systems and digitalization are at the crossroads of “Digital Servitization-Smart Product Service Systems” for making sustainability as a value proposition in manufacturing firms through enhancing the performance in material sourcing, energy consumption, resource allocation and accurate information sharing, which extends the responsibility of the manufacturing firm to the product recovery and end-life solutions with enhanced digital capabilities (Basáez et al., 2017; Marić and Opazo-Basáez, 2019). The Smart PSS was coined by Valencia et al. (2015) as "smart products and its generated e-services into a single solution by embracing disruptive ICT. Smart PSS was enabled by prevailing digital technologies such as Internet of Things (IoT), cloud/edge computing, and Big Data analytics generated an advanced green service design innovation (Hiekata, 2019). Lee et al. (2019) defined Smart PSS as "the emerging type of PSS that offer market value and dynamic intelligence combining products and services as solutions for bringing new consumer experience based on digital technology such as ICT (Information and communication technology), IoT (Internet of things), cyber-physical systems (CPS), big data analytics, etc". The integration of those intelligent digital systems created new product-service systems nominating Digitalized PSS (Lerch and Gotsch, 2015) or Smart PSS as intelligent systems moving the firms to automated, independent operations that forecast product service requirements and failure modes.

There is a growing research community in servitization and the conversations about the intersection of digital economy and service economy are clarified through many review studies (Green et al., 2017; Kohtamäki et al, 2019) . Recent research also calls for contributions about the effects of digitalization on different outcomes of servitization beyond financial performance (Kohtamäki et al., 2020) and draws attention to the small number of studies addressing the environmental benefits of digital servitization to the circular economy (Paschou et al., 2020)

Bases on those calls for contributions at the intersection of servitization and sustainability, this study addresses the research gap for a scholarly discussion about the environmental sustainability results of servitization in fashion industry by providing a comprehensive review of Smart PSS applications in the industry and presenting a future research agenda.

2. LITERATURE REVIEW

2.1. Smart Product-Service Systems, Servitization, and Sustainability

Servitization (Vandermerwe and Rada, 1988) explains the economic dimension of service domination in manufacturing referring to the Product-Service Systems which has incorporated the sale of use rather than the sale of the product with a major interest in explaining sustainability potential (Annarelli et al., 2016), and impact in business operations. There are many definitions of Product-Service Systems falling under the environmental dimension of triple bottom line (Table 1).

Table 1. Definitions of PSS in environmental triple bottom line

Manzini et al. (2001)	A business innovation strategy offering a marketable mix of products and services jointly capable of fulfilling clients' needs and wants - with higher added value and a smaller environmental impact as compared to an existing system or product.
Mont (2002)	A system of products, services, supporting networks, and infrastructure that is designed to be: competitive, satisfy customer needs, and have a lower environmental impact than traditional business models.
Halme et al. (2006)	Products and services which can simultaneously fulfill people's needs considerably reduce the use of materials and energy.
Evans et al. (2007)	An attempt to use existing industrial and commercial structures to create radically environmentally improved products by treating them as services.
Centenera and Hasan (2014)	A product-service system (PSS) is an integrated combination of products and services for optimal consumption.

Note: Adopted and reproduced from Annarelli et al. (2016) with permission

The clear separation from materiality for value delivery has been the main contribution of PSS for sustainability. The upstream transition has been realized at corporate practice level including "pollution emission, waste reduction, efficient use of resources, work safety and health, job creation, impact on local communities" (Szász and Seer, 2018) however downstream transition such as making producers responsible for the future of their products (Hvass, 2015) requires a much more intense change in normative and cognitive institutions in B2C markets.

The socio-economic systems transformed by PSS business models have been named "lease society", "circular economy", "resource revolution" by influential actors (Tukker, 2015) . Potential dematerialization became the core strategy for withdrawing take-make-waste patterns of production and consumption (Kristensen and Remmen, 2019), and PSS business models was recognized by many researchers as a resource and energy-efficient system while increasing revenues and giving access to service data (Yang and Evans, 2019). In their systematic review, Pashou et al. (2020) discussed the benefits of digital servitization for environment and society regarding reduced energy consumption, reduced environmental impacts, building sustainable business and products, impacts on social sustainability, and value delivery to the surrounding society.

Overall, Smart PSS business models and digital servitization offer a range of benefits for the environment and society, including reduced energy consumption, decreased environmental impacts, the development of sustainable practices and products, improvements in social sustainability, and the delivery of value to surrounding communities. These approaches represent a shift towards more resource-efficient, sustainable, and socially responsible systems of production and consumption.

2.2. Impact of Fashion Industy on Sustainability

The fashion industry has a tremendous impact on the environment given the business processes such as material sourcing, production, distribution, retail, and disposal resulting in carbon impact, water consumption, and waste in landfills. The fashion industry is responsible for substantial greenhouse gas emissions throughout its supply chain. From the cultivation of raw materials (such as cotton or leather) to manufacturing processes, transportation, and garment care, the industry contributes to carbon dioxide (CO2) emissions, exacerbating climate change.

The current take-make-waste system uses non-renewable resources, of which less than 1% of the material produced is recycled into new clothing. The fashion industry generates a significant amount of waste, both pre-consumer waste (e.g., fabric scraps, offcuts) and post-consumer waste (e.g., discarded garments). The landfilling or incineration of textile waste contributes to environmental pollution and resource depletion. It means that USD 100 billion worth of materials are lost to an unsustainable industry which uses

oil to produce synthetic fibres, fertilizers to grow cotton, and chemicals to produce, dye, and finish fibres and textiles as well as using non-renewable energy (Allwood et al., 2008; Choi et al., 2012) and 93 billion cubic meters of water annually (Morlet et al., 2017). The fashion industry is water intensive. The production of textiles requires vast amounts of water, particularly in processes like dyeing and finishing. Additionally, water pollution occurs due to the release of untreated wastewater containing harmful chemicals into water bodies, impacting ecosystems and local communities. The industry uses numerous chemicals in various stages of production, including dyeing, printing, and fabric treatment. These chemicals can be hazardous to human health and the environment. Improper disposal and inadequate wastewater treatment can lead to their release into waterways, soil, and the air, causing pollution and biodiversity loss.

The fashion industry relies heavily on materials such as cotton, leather, and wood-based fibers like rayon and viscose. The production of these materials often leads to deforestation, as land is cleared for agriculture or grazing. Deforestation not only reduces carbon sinks but also impacts biodiversity and disrupts local ecosystems. The fashion industry produces 150 billion garments of which 30% is never sold, creating 92 million tons of textile waste; 2.1 million tons of carbon emissions are produced annually; 100 million trees are cut down for producing apparel fabric such as viscose of which 30% are cut from ancient and endangered rainforests (Denuwara et al., 2019).

Those impacts are majorly reflected in developing countries as the fashion industry creates employment to produce cotton in some low-income countries. In addition to the environmental effects, workers are also exposed to dangerous and unsafe working conditions extending to modern slavery and child labour (Morlet et al., 2017). These environmental effects underscore the need for sustainable practices and innovation within the fashion industry to minimize its ecological footprint. From adopting circular economy principles and reducing chemical usage to promoting sustainable materials and responsible consumption, various strategies can be implemented to mitigate the industry's negative impact on the environment.

2.3. Opportunities and Challenges for Smart PSS in Fashion Industry

Reasons for poor PSS implementation in the fashion industry can be traced back to the lack of consumer acceptance or business interest, which promised a need for researching barriers and opportunities in B2C stream (Tukker, 2015). Charity shops and second-hand market is saturated, limiting reuse of current and future stock. There is evidence of the non-linear relationships between increased production, decreasing prices, increasing consumption resulting in fast fashion, short-term use of products, psychological obsolescence, and premature disposal (Armstrong et al., 2015). The fashion industry relies on promoting "throwaway culture" so that consumers replace their clothing before their active lifecycle is completed (Birtwistle and Moore, 2007).

According to the European Union waste hierarchy (Corvellec and Stål, 2017), waste prevention is the most critical practice for waste management, yet applicability in the fashion industry is limited to the nature of fashion and clothing consumption, providing more diverse options for reuse and recycling. Offering take-back options and vouchers for used clothes can increase the total volume of clothes brought to disposal due to uncertainties about the consumption habits of customers who in fact might rent or borrow in addition to purchasing just for enlarging their range of choice (Corvellec and Stål, 2017; Mylan, 2015).

The clothing industry is material-intensive and product-focused as well as emotionally bounding for identity reflection possessing a constant change to be recognized as fashionable (Armstrong et al., 2015). Similar to the case in office furniture (Besch, 2005), PSS business model may not work for industries which rely on consumers demand for branding, fashion, and design creating uncertainties about the coverage of costs with renting time horizon (Tukker, 2015; Tukker and Tischner, 2006). In a business to consumer (B2C) context, PSS implications have been limited due to the intangible value such as self-esteem, sense of control, ease of access attributed to possession of things and artifacts which allow much more behavioral freedom (Tukker, 2015). Consumer and business markets are different in terms of the benefits gained by implementation of PSS.

Cost and revenue structures of PSS are more complicated than a simple product sales model involving transaction costs that occur with contracting and revenue sharing schemes (Tukker, 2015). Lacking interest in gaining new skill sets, redesigning business model and value chain due to cost and benefit reasons such as writing off production equipment and no promise of reduction of material intensity (Halme et al., 2006; Tukker, 2015). Service innovations such as dry cleaning, customization, repairing, take-back are in place as industry standards yet unable to achieve close loops, dematerialization, or sustainability in impactful terms (Armstrong and Lang, 2013).

The absence of ownership should keep consumers caring for the product as they normally would (Armstrong and Lang, 2013). Overcoming "rebound effect" led by unsustainable use of leased or shared

products requires a significant transformation of the consumer mindset. Offering insurance service might create additional revenue as well as promoting increased product utilization (J. Larsson et al., 2019).

Exploiting apparel disposal reasons such as fit, fashion change, boredom, damaged products provide ideas for new service innovation (Armstrong and Lang, 2013). Life-cycle optimization in leasing, which applies to technology obsolescence context, can be used in the fashion industry delivering the "renewal of season wardrobe" value (Intlekofer et al., 2010). H&M adopted selling DIY garment-care products such as sewing kits, repair patches, or environmentally friendly washing detergents for informing customers how to prolong the lifetime of their clothing (J. Larsson et al., 2019).

Industry willing to separate business performance from material consumption (Armstrong and Lang, 2013) will lead the transition. In cases, when many components and parts could be re-introduced into the production rather than producing entirely new components, producers might gain on sourcing benefits.

Dematerialization of the fashion industry through moving from product-oriented PSS to the result-oriented PSS does not guarantee to minimize the waste effect. A product-oriented PSS might prevent the clothes being waste through maintenance than a use-oriented PSS encouraging increased reuse. Corvellec and Stål (2017) claims that the degree of servitization is not a measure of dematerialization and PSSs should adopt waste-centric analysis for their potential contribution to dematerialization. They advocate studying the material dimensions of services, of which waste is just one result.

Value creation on the consumption side through designing a user experience is the service innovation domain. If garments are easy to access and repairing them is perceived as not-worthwhile, then what is the thing that pulls manufacturers to move from producing for frequent purchases to life-cycle orientation? (Niinimäki and Hassi, 2011). In the book review by Lowe (Lowe, 2010) of Verganti's Design Driven Innovation, creating radical new meanings for products is essential for transforming traditional industries. This new meaning should be an evident detachment from material consumption, creating end desire for quality and longevity where styles and colors are classical, and the materials age well (Adam, 2018; Niinimäki and Hassi, 2011).

Delivering co-creation services to consumers affects attachment to the product, which in turn increases the utilization time. A design mindset for a deeper understanding of consumer emotions creates meaning, which secures a long life span for the product and eliminates the psychological obsolescence (Niinimäki and Hassi, 2011).

In summary, value creation through designing a user experience, detachment from material consumption, and creating new meanings for products are essential for transforming the fashion industry. Co-creation services and a design mindset can enhance attachment to products, increase utilization time, and eliminate psychological obsolescence. By implementing these strategies and adopting a holistic approach, the fashion industry can reduce its negative environmental impact, promote sustainability, and address social issues related to labor conditions.

3. METHODOLOGY

The purpose of this study is to elaborate servitization domains in fashion industry, the smart PSS behind those servitization domains, the potential environmental sustainability results of those PSS and a future research agenda. The study employed an inductive analysis approach (Miles and Huberman, 1994) and syntesis through a systematic literature review. Firstly, author formulated the research questions as: What are the servitization domains in fashion industry? What type of Smart PSS implementations are grounded in those servitization domains? Which environmental sustainability results can those Smart PSS implementations have? Those questions guided the entire review process. Clear criteria were established to determine which studies should be included and excluded in the review. The author was interested in the fashion industry so all other studies in other industries were excluded from the review process.

The author conducted comprehensive research through Google Scholar literature database as it gives access to the largest number of different outlets that is not normally listed in different databases. The author adopted the systematic review research protocol as following: On Google Scholar database, the search queries were run starting from 2014 for the contemporary content. Initially, titles and abstracts were screened, followed by a full-text review of selected studies with the search terms:

- ("fashion industry" sustainability "servitization" digital) resulting in 180 articles.
- (fashion "product service systems") resulting in 10 articles.
- ("fashion industry" sustainability "product service systems" digital) resulting in 387 articles.

Through the screening of the initial articles, tracking backward and forward citations (including the articles published before 2014) and removing duplications, a second set of 27 articles were selected to be reviewed consistent with the inclusion/exclusion criteria mentioned above. This set of articles were extracted with the author, title, journal and year of publishing (Table 2).

To synthesize the selected literature content, the author organized the extracted data into themes of servitization domains emerging through the analysis process. Then, each category of the servitization domain was matched with the sustainability result it might create and with the smart product service system applications through exploring the patterns, similarities, and differences across studies. The environmental sustainability results matched with the servitization domains were derived from the extensive literature by inductive coding of all identified smart PSS applications through systematic literature review (Jesson et al., 2011). The findings were summarized in the table (Table 3) aided with a narrative description in discussion representing the key outcomes of the review. A comprehensive set of research questions was developed and presented for future research agenda.

4. FINDINGS and DISCUSSION

The environmental sustainability results derived from the literature in servitization domains and Smart PSS applications indicate that a servitized fashion industry can create tremendous effects for the environment. Whether in raw material sourcing, fiber production, fabric production, garment production, distribution or in-store processes, competitive companies adopt the latest technologies and smart product-service systems such as 3D scanning and printing (Štefko and Steffek, 2018), mass-customization, augmented reality, virtual try-on, virtual personal assistants (Liang et al., 2020).

RFID technology has much value offers for the fashion industry, such as "inventory management, asset tracking, product, and personnel tracking, item-level identification, supply chain management, shipping, payments, counterfeit prevention" (Denuwara et al., 2019). RFID in the recycling process eliminates wasting time and resources by identifying recyclable polymers in each garment. Recycling facilities can track the location of relevant recyclable garments through mobile platforms. The number of fibers recycling increases, creating energy savings 53%, chemical savings 88%, and water savings 99% higher than virgin fibers. RFID technology also encompasses inventor accuracy by forecasting demand for each stock. It means that unnecessary garments will not be produced and transported, resulting in less Greenhouse Gas emissions and no stock excess in stores that will be disposed. Out of nearly 100% textile recycling, only 15% of consumer-used clothing is recycled due to misinformed consumers about caring instructions, and recycling options, which can be easily tracked on an RFID tag (Denuwara et al., 2019). The environmental consequence of extending the lifetime of a clothing product is impactful in terms of a decrease in carbon emissions, water uses, and waste generation. Digital receipts provide documentation and transparency for used chemicals and materials, making information accessible to enhance recycling, which is currently dependent on costly labor-intensive processes. Those integrated information systems optimize processes for reverse logistics and servitization.

Radical thinking emerges not only in technology but how the fashion industry does business, such as the case of open-source fashion (Niinimäki and Hassi, 2011) where end-users as "Makers" contribute to the design process by collective decision making. Made-to-order knitted, and 3D print brand Feetx represents a smart manufacturing turn in service design, putting customization and co-creation at the core of their business model (Bertola and Teunissen, 2018). Knit-on-demand project provided manufacturers and retailers increased agility in production and logistics, minimizing overproduction, which means textile material, energy in the cultivation of crops, fabric manufacturing, and garment manufacturing are saved (Larsson, 2018). As Larsson (2018) furtherly presented Roll to Bag project with 3D virtual customization and fitting, made to measure MTM, digital printing and automated cutting allowed precise estimations for desired functionality minimizing material, chemicals, and water and DigiMode project with a virtual fitting room with personalized avatar minimizing material which becomes cut waste. In-store real-time demand production can also reduce clothing waste (Sandvik and Stubbs, 2019).

Artificial Intelligence and Big Data analytics enhance the decision making for product lines by identifying consumer trends instead of watching fashion weeks. It helps to decrease returns and improves purchase rates by gaining insights into refund/return data as well as cutting waste from overproduction and excess inventory environmental costs with accurate demand forecasts (Silva et al., 2019). Beyond visualization and marketing, 3D digital design can be embraced as a prototyping tool for zero-waste design practice addressing waste made in the design process (McQuillan, 2020). As sustainable intelligent manufacturing practice becomes mainstream (He and Bai, 2021), fashion industry adopts Digital-Twin technology for reducing product defects, production costs, monitoring the product and process in real-time, shortening time to market, and extending the life of the equipment and the assets without having physical samples which in turn results in less waste.

Table 2. Set of articles selected for review

Study	*Publication Title*	*Journal*
Armstrong et al. (2015)	'Sustainable product-service systems for clothing: exploring consumer perceptions of consumption alternatives in Finland'	Journal of Cleaner Production
Adam (2018)	'The role of human resource management (HRM) for the implementation of sustainable product-service systems (PSS)—an analysis of fashion retailers'	Sustainability
Hvass (2015)	'Business model innovation through secondhand retailing: a fashion industry case'	Journal of Corporate Citizenship
Larsson et al. (2019)	'Feasibility of servitization: Transforming fashion value chains to circularity through service innovation'	Re: textile Project, University of Borås
Niinimäki and Hassi (2011)	'Emerging design strategies in sustainable production and consumption of textiles and clothing'	Journal of Cleaner Production
Denuwara et al. (2019)	'Sustainability benefits of RFID technology in the apparel industry'	Sustainability
Sandvik and Stubbs (2019)	Circular fashion supply chain through textile-to-textile recycling'	Journal of Fashion Marketing and Management
Silva et al. (2019)	'Big Data in fashion: transforming the retail sector'	Journal of Business Strategy
Marić and Opazo-Basáez (2019)	'Green Servitization for flexible and sustainable supply chain operations: A review of reverse logistics services in manufacturing'	Global Journal of Flexible Systems Management
Liang et al. (2020)	'Implementation of Artificial Intelligence in Fashion: Are Consumers Ready?	Clothing and Textiles Research Journal
Štefko and Steffek (2018)	'Key issues in slow fashion: Current challenges and future perspectives'	Sustainability
Lang and Armstrong (2018)	Fashion leadership and intention toward clothing product-service retail models	Journal of Fashion Marketing and Management
Ricchiardi and Bugnotto (2019)	Customized Servitization as an innovative approach for renting service in the fashion industry	CERN IdeaSquare Journal of Experimental Innovation
Pal (2016)	Extended responsibility through servitization in PSS: An exploratory study of used-clothing sector	Journal of Fashion Marketing and Management
Corvellec and Stål (2017)	Evidencing the waste effect of Product-Service Systems (PSSs)	Journal of Cleaner Production
Todeschini et al. (2017)	Innovative and sustainable business models in the fashion industry: Entrepreneurial drivers, opportunities, and challenges	Business Horizons
Antikainen et al. (2020)	Sustainable circular economy value propositions in clothing as a service -model	The ISPIM Innovation Conference – Innovating in Times of Crisis, 7-10 June 2020
Stål and Jansson (2017)	Sustainable Consumption and Value Propositions: Exploring Product–Service System Practices Among Swedish Fashion Firms	Sustainable Development
Moorhouse and Moorhouse (2017)	Sustainable Design: Circular Economy in Fashion and Textiles	The Design Journal An International Journal for All Aspects of Design
Pal and Gander (2018)	Modelling environmental value: An examination of sustainable business models within the fashion industry	Journal of Cleaner Production
Thorisdottir and Johannsdottir (2019)	Sustainability within Fashion Business Models: A Systematic Literature Review	Sustainability
Yan and Chiou (2020)	Dimensions of Customer Value for the Development of Digital Customization in the Clothing Industry	Sustainability
Yang et al. (2017)	Sustainable Retailing in the Fashion Industry: A Systematic Literature Review	Sustainability
Bertola and Teunissen (2018)	Fashion 4.0. Innovating fashion industry through digital transformation	Research Journal of Textile and Apparel
Larsson (2018)	Digital innovation for sustainable apparel systems Experiences based on projects in textile value chain development	Research Journal of Textile and Apparel
Zheng et al. (2019)	A survey of smart product-service systems: Key aspects, challenges and future perspectives	Advanced Engineering Informatics
McQuillan (2020)	Digital 3D design as a tool for augmenting zero waste fashion design practice	International Journal of Fashion Design, Technology and Education

Table 3. Environmental sustainability results of servitization/smart PSS applications in fashion industry

Servitization Domain	*Result for Environmental Sustainability*	*Smart PSS*
Tracking recycling	Eliminates wasting time and resources by identifying recyclable polymers in each garment.	RFID tags
Stock Accuracy	Eliminates unnecessary customer visits, excess stock, logistics and transportation	RFID tags
Informed Recycling	Extends the lifetime leading a decrease in carbon emissions, water uses, and waste generation	RFID tags
Warranty and Insurance	Extends the lifetime leading a decrease in carbon emissions, water uses, and waste generation	RFID tags
Caring/ Repairing Clothes	Prolongs garment's lifetime Increases product longevity Reduces landfill waste	Pay per use for washing, sewing, ironing services
Make it yourself/ Customization	Increase product longevity through custom fit/style &attachment	Plug and play digital knitting machines with distributed manufacturing User softwares for co-creation
	Prolongs lifecycle of products through fitting services and repair	3D Body Scanning
	Enables savings in the use of materials compared to the industrial scale for manufacturing textiles; production is based on existing orders in lieu of surplus production.	Digital textile printers, embroidery, and laser cutting machines, and digital weaving machines
Redesign	Increases product longevity Reduces landfill waste Saves textile material for several life cycles	Augmented reality for the redesign of current garments
In-store or online renting or exchanging	Reduces landfill waste Increases interest in reuse	Online platforms
Insight and Consultancy	Increases product longevity Increases responsible purchasing	Artificial Intelligence for styling and consumption Virtual Personal Assistance IoT based consumer behavior analytics
B2C Renting/ Clothing as a Service/ Fashion as a Service	Product longevity Reduce landfill waste	Pay per wear or pay per period/ Subscription Services
Fashion Look Delivery	Increases product utilization Reduces redundant consumption Decreases excess inventory and returns	Big data analytics
In-store production	Reduces clothing waste by producing garments based on real-time demand	3D Printing
Retail services	Prolongs lifecycle of products through fitting services	Virtual Fitting Rooms Magic Mirrors
Open-Source Fashion	Increase product longevity through custom fit/style &attachment	Online Crowdsourcing
B2B Reverse Logistics	Recycles	Digital Receipts
Design with Trends Accurate Demand Forecasting	Decreases waste from overproduction	Big Data Analytics
Zero-Waste Design	Prevents the creation of waste when the garment is cut and sewn	3D Digital Design
Smart Manufacturing	Eliminates failure and boosts efficiency	Cyber Physical Systems/ Digital-Twin

5. CONCLUSION

As fashion industry is accused of being one of the most polluting industries in the world (Thorisdottir and Johannsdottir, 2019), this paper contributed to the literature about sustainability in fashion industry by exploring what kind of environmental sustainability results can emerge through servitization and Smart PSS applications in the industry. Such studies provide a comprehensive synthesis for developing new research questions in further empirical research. Those further research questions might include but are not limited to:

- How can Smart PSS applications be utilized to identify consumer trends and enhance decision making for product lines in the fashion industry?
- What are the effects of utilizing Smart PSS on return rates and purchase rates in the fashion industry, and how do these insights into refund/return data contribute to the reduction of returns?
- How does the integration of Smart PSS in the fashion industry contribute to the reduction of waste from overproduction and excess inventory, and what are the associated environmental cost savings?
- In what ways can 3D digital design be effectively employed as a prototyping tool to facilitate zero-waste design practices in the fashion industry?
- How does the adoption of Digital-Twin technology in the fashion industry contribute to the reduction of product defects and production costs, while also enabling real-time monitoring of products and processes?
- What are the impacts of Digital-Twin technology on the time-to-market for fashion products, and how does it contribute to extending the life of equipment and assets?
- How does the adoption of sustainable intelligent manufacturing practices in the fashion industry influence the overall sustainability and environmental footprint of the industry?
- What are the challenges and opportunities associated with implementing Artificial Intelligence, Big Data analytics, 3D digital design, and Digital-Twin technology in the fashion industry?
- How do consumer perceptions and behaviors change when fashion brands embrace sustainable intelligent manufacturing practices and employ advanced technologies such as Artificial Intelligence and Digital-Twin?
- What are the potential economic, environmental, and social benefits of integrating these advanced technologies into the fashion industry, and how do these benefits compare to traditional manufacturing practices?
- What are the key characteristics and implications of open-source fashion in the fashion industry, and how does collective decision making by end-users contribute to the design process?
- How does the integration of customization and co-creation in the business model which utilizes made-to-order knitted and 3D printing technologies, impact the overall manufacturing process and customer experience?
- What are the environmental benefits of the knit-on-demand project in terms of minimizing overproduction, reducing textile material waste, and saving energy in crop cultivation, fabric manufacturing, and garment manufacturing?
- How does the implementation of 3D virtual customization and fitting, made-to-measure (MTM) techniques, digital printing, and automated cutting in projects contribute to minimizing material waste, chemicals, water usage, and cut waste in the fashion industry?
- What are the consumer perceptions and acceptance levels towards virtual fitting rooms with personalized avatars, and how do they contribute to reducing material waste in the fashion industry?
- How does in-store real-time demand production impact clothing waste reduction in the fashion industry, and what are the key factors influencing its effectiveness?
- What are the challenges and opportunities associated with implementing open-source fashion, made-to-order manufacturing, virtual customization, and in-store real-time demand production in the fashion industry?
- How do the environmental benefits of these innovative business models and technologies compare to traditional manufacturing and production methods in the fashion industry?
- What are the economic implications of adopting radical thinking and innovative business models in the fashion industry, particularly in terms of cost-effectiveness, resource utilization, and supply chain management?
- How can the lessons learned from successful case studies, such as Feetx, the knit-on-demand project, Roll to Bag project, and DigiMode project, be applied to other fashion brands and sectors to promote sustainable practices and minimize waste?

Zheng et al. (2019) discussed that Smart PSS is an open innovation perspective to solve societal challenges in a profitable and sustainable way as it creates value in resource efficiency, extended lifespans, and closed loops through the collaboration of different stakeholders. A stable and reliable technological infrastructure provide the stakeholders real-time communication and processing networks for digitalized servitization (Lerch and Gotsch, 2015). Managing the innovation ecosystem for a sustainable smart fashion industry address the need for the adoption of "Extended Producer Responsibility-EPR" which is implied through legislations in many countries (Goworek et al., 2020). The implementation of servitization on a broader scale is dependent on designing a product-service system including information transparency and platform-enabled participation (Larsson et al., 2019).

The sources of materiality of Smart PSS applications are still the challenges for sustainability to be explored by further research. Smart PSS aims to represent a closed-loop lifecycle management system in the circular fashion economy (Zheng et al., 2019), ultimately turning back the garments to the system for recycling through advanced digital technology (Larsson, 2018), yet the environmental externalities of the digital innovation itself should carefully be considered. For example, RFID tags made of non-biodegradable materials are another environmental externality connected to the digital technology used for Smart PSS as the global tag consumption exceeded some trillion bags per year (Thomas, 2008).

In conclusion, the fashion industry is undergoing a transformative shift driven by radical thinking and innovative approaches to business. The integration of technologies such as Artificial Intelligence, Big Data analytics, 3D digital design, and Digital-Twin technology is revolutionizing decision-making processes, reducing waste, and enhancing sustainability. Open-source fashion and collaborative design processes empower end-users as active participants in the fashion creation process, leading to collective decision-making and increased engagement. Many brands exemplify the power of made-to-order manufacturing and customization, placing the customer at the center of the business model. The adoption of virtual customization, personalized avatars, and real-time demand production further contribute to waste reduction and resource efficiency. These advancements not only have environmental benefits, such as minimizing overproduction and reducing material waste, but also hold economic potential by improving efficiency and cost-effectiveness. However, challenges remain in implementing these transformative practices industry-wide. Continued research and exploration of these topics will pave the way for a more sustainable, customer-centric, and waste-minimizing fashion industry.

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Compliance with Ethical Standards

It was declared by the author that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement

It was declared by the author that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.

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