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Reviewing the suitability of ICT-centered design methods for smart PSS development

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Abstract

The emergence of smart Product-Service Systems (smart PSS) presents numerous challenges for enterprises. The complexity of designing smart PSS adds to the need for consistent support for manufacturers. Both academia and practitioners highlight the importance of methodological support for successful development of smart PSS. This paper therefore investigates the suitability of existing support for smart PSS. Based on a systematic literature review, 17 support methods are identified and their key characteristics are discussed in the context of real PSS use cases.

Keywords: product-service systems (PSS), systems engineering (SE), smart systems, design methods, literature review

1. Introduction and motivation

In today's ever-changing economic environment, enterprises face new challenges due to advances in information and communication technologies (ICT). Manufacturers in particular struggle to keep pace with the development and implementation of smart product-service systems (smart PSS) because of the complex interactions between hardware, software, and service components (Chowdhury et al., 2018; Paliyenko et al., 2022). Additionally, the need to continuously update and upgrade these systems to meet changing customer expectations adds to the difficulties faced by manufacturers.

To address these challenges and provide increased value to customers, manufacturers are shifting towards service- and solution-oriented business models. This shift involves offering problem-oriented solutions to customers and transitioning from value-in-exchange (solely selling a product) to value-in-use (selling or leasing products and offering additional services along the product's lifecycle) (Mont, 2002; Valencia et al., 2014). In pursuit of this value creation, enterprises develop and offer PSS, which are interrelated bundles of products and service provisions (Mont, 2002; Lugnet et al., 2020).

The progress in ICT has also led to the emergence of smart products that feature sophisticated capabilities enabled by cost-effective and high-performing sensors. These smart products generate vast amounts of data that can be utilized to provide novel services such as remote monitoring, control, and optimization. The integration of smart products with data-based services gives rise to smart PSS (Valencia et al., 2015; Machchhar et al., 2022).

While the concept of smart PSS has developed in various disciplines, there have been different definitions since the early days of smart PSS research. However, there are similar understandings within different research areas that utilize ICT for data-driven value creation (Toller and Bertoni, 2021; Machchhar et al., 2022). To understand related research, it is important to differentiate these concepts such as the Internet of Things (IoT), cyber-physical systems (CPS), smart connected products (SCP), digital twins (DT), e-services, and PSS (Zheng et al., 2021).

SCP refers to physical products embedded with sensors, software, and ICT, allowing them to collect and exchange data. These products can communicate with other devices, systems, or platforms, providing enhanced functionality, automation, and real-time insights (Zheng et al., 2021). SCPs are the basis and a central element of digital twins. DTs consist of physical products in real space, virtual products in virtual space, and data and information that connect the real and virtual spaces (Julien and Martin, 2021). Digital twins are usually distinguished by their maturity as digital mirror, digital shadow, and digital twin, with increasing representation density. CPSs then emerge on the basis of digital twins, with real-time data exchange and computing capabilities interacting closely with the physical product (Julien and Martin, 2021). The IoT encompasses a network of physical devices including SCPs that are equipped with sensors, software, and connectivity for the purpose of collecting and exchanging data (Zheng et al., 2021). In the context of smart PSS, the IoT enables the seamless integration of physical products with digital services, allowing real-time monitoring, control, and optimization of product performance and service delivery. By leveraging CPS and IoT, smart PSS can provide enhanced functionality, personalization, and efficiency, thereby improving the overall user experience and enabling new business models (Machchhar et al., 2022; Hagen et al., 2018). Figure 1 visualizes the relations between the described concepts.

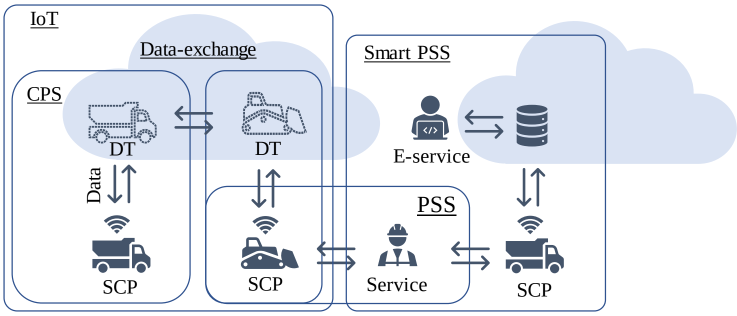

Figure 1. Relationships between SCP, DT, CPS, IoT, PSS and smart PSS

2. Problem clarification and goal

Enterprises face new and unfamiliar challenges in the development of smart products and smart PSS, as they have to design, offer, and operate heterogeneous systems (Cong et al., 2020; Paliyenko et al., 2022). To overcome these challenges, enterprises typically rely on manuals or norms that provide guidance and best practices. The complexity of (smart) PSS design leads to a strong need for manufacturers to have consistent methodological support for PSS development (Idrissi et al., 2017). However, the literature addressing the development of smart PSS is scarce, and existing literature only briefly addresses related issues (Rizvi & Chew, 2018; Chowdhury et al., 2018).

The mere development of services in connection with specific products is insufficient for creating a PSS, as the value structure of services in product-service systems (PSS) differs significantly from classical downstream product-oriented services (Boßlau, 2021). Instead, the development of services must be consciously linked to product development and the creation of a service network, forming an integrated element of a complex business model (Schenkl, 2015; Paliyenko et al., 2023a). Developing smart PSS is not a trivial task, however, as enterprises face challenges in integrating and synchronizing development streams from multiple disciplines and considering novel elements from complex systems during development.

Facilitating advances in adjacent research areas has the potential to accelerate and support the maturity of smart PSS development in the industry. This paper therefore aims to explore and analyze existing methods from different research areas for supporting smart PSS design. The following research questions will be addressed: Which methods exist for the support of the development of smart PSS? And which characteristic elements are relevant or suitable for smart PSS development?

The goal of this paper is to gain insights into different design approaches for smart PSS development and derive characteristic elements for their development. By doing so, we aim to provide a comprehensive understanding and lay the groundwork for the design of a consistent smart PSS development framework.

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This paper is structured as follows: Chapter 3 presents the research methodology used in this study. Chapter 4 features an analysis of existing methods for supporting smart PSS development, including their capabilities and deficiencies. It also discusses the characteristic elements that are relevant and suitable for smart PSS development. Finally, Chapter 5 concludes the paper by summarizing the findings and proposing future research directions.

3. Research methodology

A systematic literature review (SLR) was undertaken to address the research questions and determine suitable methods for developing smart PSS. The SLR took place from January to April 2023, following the procedure outlined by Biedermann et al. (2012). A comprehensive initial understanding of relevant terms, definitions, and concepts was gained through a broad literature review and use-case analysis, as depicted in Figure 2. Search parameters were subsequently established by identifying keywords and corresponding synonyms in relation to the guiding question. By utilizing operators and wildcards, these synonyms were combined to form search strings that were then applied to multiple databases.

Data-sources	Web of Science, Scopus, Cross-references
Guiding question	What methods exist for the support of the development of smart PSS and in adjacent fields?
Search string	TITLE (develop* OR design* OR tool OR approach OR method OR model* OR framework OR process) AND TITLE (smart OR intelligent OR digital OR cyber) AND TITLE-ABS-KEY (pss OR "e-service" OR "smart service" OR "hybrid offering" OR "integrated solution" OR "product service" OR cps OR "cyber physical system")
Publications	Open Access: Books, book-chapters, conference-papers, journal-papers, dissertations

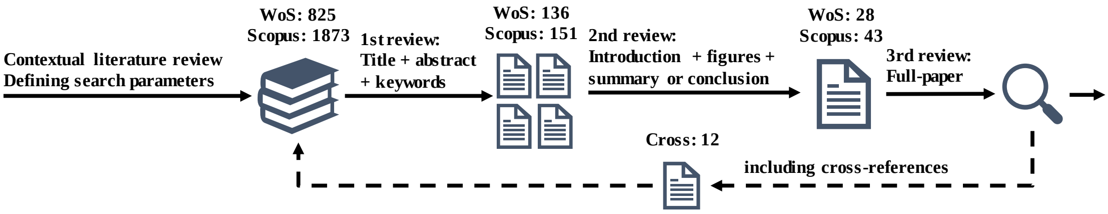

Figure 2. Search parameters and procedure

The SLR delivered a total of 2,698 hits that were screened using a predefined search protocol with the goal of filtering for relevant papers. Therefore, papers that had a detailed description of methods for development support in fields adjacent to smart PSS were included. Papers that merely provided rough concepts or ideas for future methodological support and did not provide detailed information regarding the presented method were excluded. The screening was carried out in three stages, starting with reading the title, abstract, and keywords. The second step was reading the introduction and conclusion of the paper. The last and third step was a full paper review. Additionally, promising references were extracted during the full paper review to enhance the initial literature pool. Those papers underwent the same review process and were screened for relevant methods.

4. Results

Overall, the SLR yielded 17 methods with different focus areas, such as CPS design, smart service design, and PSS design. The following chapter introduces the individual methods and examines their characteristic features. When identifying characteristic elements for the development of smart product-service systems (PSS) from adjacent research fields, it is essential to consider criteria that align with the unique aspects and requirements of smart PSS.

Interdisciplinary integration plays a crucial role in the development of smart PSS, recognizing the need for collaboration among experts from diverse fields such as mechanical engineering, information technology, data science, and user experience design (Paliyenko et al., 2023b; Aurich et al., 2019; Idrissi et al., 2017). These areas must combine their expertise to create comprehensive solutions that consider various aspects of smart PSS development.

User-centered development is equally significant, emphasizing the pivotal role of end users and customers in shaping the success of smart PSS (Toller and Bertoni, 2021; Bu et al., 2021). The overarching goal is to ensure that smart PSS not only fulfil functional requirements but also resonate

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with users on a profound experiential level. It is therefore essential to identify characteristic elements that focus on human-machine interactions, usability studies, and iterative user feedback mechanisms.

Data-driven development is a critical criterion that recognizes the transformative power of data in shaping the intelligence of smart PSS (Mennenga et al., 2020; Hagen et al., 2018). In a landscape dominated by technological advancements, characteristic elements that emphasize rigorous data collection, processing, and analysis are key. The ability to derive meaningful insights from vast datasets not only enhances the functionality of these systems but also opens avenues for continuous improvement and adaptation of services and products to suit evolving user needs.

Agile and iterative development underscores the necessity of flexibility and responsiveness in the face of emerging technologies and shifting user preferences (Tardo et al., 2022; Zheng et al., 2021). This means that smart PSS development should not be static but instead evolve dynamically in response to external influences. Identifying characteristic elements that align with agile development methodologies becomes crucial. These methodologies facilitate iterative cycles of development, enabling adaptations to changing requirements and ensuring that smart PSS address the customers' real needs.

This is followed by a classification of the methodological support throughout the extended product development cycle. Finally, key findings are discussed in the context of smart PSS development. The methods found can be categorized across 6 different phases which are based on the VDI2206-Guideline (2021) but has been adapted to common terminology from the investigated areas (i.e., Machchhar et al., 2022; Zheng et al., 2021; Julien and Martin, 2021). The method of classification based on the reviewed literature is visualized in Figure 3. The papers discuss the processes from need finding to implementation with a subsequent learning phase.

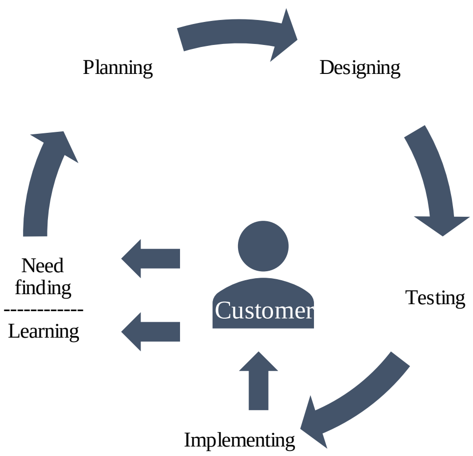

Figure 3. Generic customer-centric development cycle

The initial phase of the product development process involves identifying and understanding the needs and desires of customers. This phase requires extensive market research, user surveys, and analysis of customer feedback to gain valuable insights. The goal is to identify gaps in the market and uncover opportunities for innovative smart PSS solutions. Once the needs are identified, the planning phase focuses on defining the goals, scope, and requirements of the product. Effective planning ensures that the smart PSS aligns with the overall business strategy and customer expectations. The smart PSS concept then starts to take shape in the designing phase. This involves translating the identified needs into product features, functionalities, and user interfaces. The testing phase is critical for assessing the performance, reliability, and usability of the developed smart PSS. Various testing methods, including functional testing, performance testing, and user acceptance testing, are employed to identify and rectify any issues or shortcomings. User feedback is actively sought during this phase to further refine the smart PSS design. Once the smart PSS design has been validated, the implementation phase focuses on developing the necessary hardware, software, and infrastructure components. This involves translating the design into a tangible product or service. Finally, the learning phase emphasizes continuous improvement and learning from user feedback and operational insights. By monitoring the performance and usage patterns of the deployed smart PSS, valuable data is collected to evaluate its effectiveness and identify areas for enhancement.

4.1. Depiction of the discovered methods

The development of smart PSS requires the utilization of various methods and approaches to ensure a holistic and effective outcome. Table 1 offers a structured summary of discovered methods containing descriptions and classifications for each method.

Table 1. Depiction and characterization of the discovered methods

Method (Reference)	Description of support	Emphasis	Phase
Conceptual framework for modeling and design of CPS (Dumitrache et al., 2017)	The framework builds upon RAMI 4.0 with a focus on the technical viewpoint in CPS design, highlighting systems modelling and information routing.	Integrated product design and synchronized software development	Planning and design
QFD for smart PSS (Fargnoli and Haber, 2023)	A QFD-based approach for the integrated development of SCP and e-services aiming at analyzing customer requirements and deriving system features.	Integrated product design, customer involvement and service-orientation	Planning and design
Service innovation of smart PSS (Zheng et al., 2018)	A conceptual framework for analyzing operational data from smart PSS for the identification of opportunities for innovating services.	Service-orientation and data reintegration	Learning and planning
User-centric design of smart PSS (Bu et al., 2020)	A conceptual approach for utilizing VR to capitalize on UX (user data and VR data) for user-centric design of smart PSS, which provides VR-based services.	Data reintegration, customer involvement and user-centricity	Implementing and learning
ICT prototyping framework for smart service development (Tardo et al., 2022)	Reference architecture for the rapid development of smart service prototypes to enhance the value proposition of new and existing smart products.	Synchronized software development, service-orientation	Design and testing
DT for smart manufacturing (Damjanovic-Behrendt and Behrendt, 2019)	A conceptual model that presents a novel DT architecture with an emphasis on data management for the development of smart services.	Service-orientation and data reintegration	Planning and design
Integrated cyber-physical production system (CPPSS) development (Mennenga et al., 2020)	Architecture for combining PSS and CPPS, thus integrating the customer involvement of PSS and computing capabilities of CPPS.	Integrated product design and service-orientation	Planning
Business model engineering for smart PSS (Boßlau, 2021)	Development method heavily focusing on the design of the smart PSS business model, service process, and value delivery.	Service-orientation and early business model design	Planning and design
Support for the development process of CPS (Pokojski et al., 2022)	Method for structuring design activities using knowledge modelling in order to improve the effectiveness of the CPS design process.	Integrated product design and requirement translation	Planning
CyProF (Kolberg et al., 2016)	Framework for supporting engineers in structuring and analyzing CPS using a novel description architecture.	Integrated product design and synchronized software development	Planning

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Engineering tool for CPPS (Kannengiesser et al., 2021)	Support for simplifying CPPS software design to reduce the risk related to transforming traditional automated production systems in CPPS.	Integrated product design and synchronized software development	Design
Kano-FBS model for smart PSS development (Ying et al., 2022)	Conceptual model for mapping of user requirements to the functional, behavioral, and structural domain while following a Kano-styled questionnaire to assess importance.	User-centricity and requirement translation	Planning and design
Framework for smart PSS ecosystems (Zheng et al. 2017)	Conceptual framework for structuring the interaction of multiple smart PSSs as an ecosystem with an emphasis on identifying customer demands and customer involvement in value creation.	Integrated product design and customer involvement	Need finding and planning
Risk-oriented smart PSS engineering framework (Coba et al., 2020)	Conceptual framework of risk management activities in the early development phases of classic and smart PSS, which follows the logic of the Incremental Commitment Spiral Model.	Early business model design and customer involvement	Need finding and planning
Method for modelling a smart PSS value network (Paliyenko et al., 2023)	Model for structuring and visualizing the value network of smart PSS with an emphasis on relations between involved stakeholders and respective data streams for value creation.	Early business model design, customer involvement, and user-centricity	Planning and design
Systematic design of CPPSS (Rizvi and Chew, 2018)	Meta-model for structuring the value creation of PSS and the implementation of CPS, thus integrating both concepts in order to support their development.	Integrated product design, service-orientation and data reintegration	Planning and design
Framework for value creation with digital twins (Barth et al., 2023)	Conceptual reference framework for the development of lifecycle-oriented product-service bundles utilizing the capabilities of DTs to offer data-based services.	Integrated product design, synchronized software development and service-orientation	Planning and design

The analysis of the discovered methods highlights several key methods that address different elements of smart PSS development, from which characteristic elements for a holistic smart PSS development framework can be deduced.

Customer involvement and user-centricity are essential elements of smart PSS development. By involving customers throughout the development process, organizations can gain valuable feedback and insights, ensuring that the final product meets their needs and preferences. Incremental development and testing allow for quick feedback loops, enabling organizations to make timely adjustments and improvements based on real user needs. Early business model design is another important element highlighted by Boßlau (2021). By considering key customers, partners, activities, and ICT requirements/needs for data and information, organizations can develop a solid foundation for their smart PSS (Paliyenko et al., 2023a). Focusing on the early stages of development in the business case enables the identification of potential challenges and opportunities, allowing for better decision-making and resource allocation throughout the development process.

Translating requirements into functions, as highlighted by Ying et al. (2022), is a method that ensures alignment between customer needs and the functionality of the smart PSS. By clearly understanding and

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addressing customer requirements, organizations can develop products and services that provide the desired functionalities and meet customer expectations. Service-oriented methods emphasize the importance of the service delivery process and customer involvement. These methods recognize that the success of a smart PSS relies not only on the product itself but also on the quality and efficiency of the services delivered, both classical and e-services. By involving customers in the development process and considering their needs and preferences, organizations can create PSS models that prioritize customer satisfaction and compliance.

Synchronized software development is emphasized by Kannengiesser et al. (2021) as a crucial aspect of smart PSS development. This method aligns software development with existing product and process structures to minimize risks. By integrating software development early in the product development process, organizations can ensure seamless integration between the physical product and the digital services it offers. The capability of smart systems to reintegrate data from various fields to support product development is another important aspect emphasized by Ying et al. (2022). This method enables organizations to leverage data from different sources, such as sensors and user feedback, to improve the design and performance of their smart PSS. By utilizing data-driven insights, organizations can make informed decisions and continuously optimize their products and services. The concept of the digital twin is often mentioned as a means of testing smart products in early design stages and extracting valuable data for learning purposes. This method allows for virtual simulations and analysis, reducing the need for physical prototypes and enabling quick iterations and improvements. By integrating digital twin technology, organizations can enhance the efficiency of their product development process and gain valuable insights for further optimization.

4.2. Discussion

As the research field of smart PSS matures and becomes more prevalent in enterprises, there is an increasing need for methodical support in its development. However, there are different definitions and understandings of smart PSS across various disciplines that utilize ICT for data-driven value creation. It is important to differentiate the concepts with their respective methods for supporting development.

The analysis of those development methods highlights the importance of a holistic approach to smart PSS development that considers elements such as integrated product design, synchronized software development, service-oriented methods, early business model design, requirement translation, data reintegration, customer involvement, and user-centricity. By incorporating these elements into a comprehensive framework, organizations can effectively develop and deliver customer-centric smart PSS solutions that meet the evolving needs of customers and the market (Aurich et al., 2019; Verdugo et al., 2018; Hagen et al., 2018). However, further research into and development of specific methods for smart PSS are needed to address the unique challenges associated with smartness in PSS. The study by Hagen et al. (2018) supports the need for integrating appropriate methods that address the specific requirements of smart PSS, while additional research by Kuhlenkötter et al. (2017) and Böhmann et al. (2018) highlights the need to reconsider and adapt existing methods for smart PSS development. This suggests that developing an integrated approach for smart PSS remains a research challenge due to the multidimensional nature of the transformation toward smart PSS for companies.

The literature also highlights the essential role of intentionally integrating product and service design in smart PSS development. The value creation in PSS relies on collaboration and interaction among different stakeholders in a value network, underscoring the need for methods that facilitate coordination and cooperation throughout the development process. The literature also emphasizes the significance of flexibility and modularity in the development of smart PSS (Paliyenko et al., 2023b). Creating entirely new development processes is often not feasible in practice, so methods that allow for adaptation to specific situations and integration into existing structures are necessary.

The literature also highlights the inefficiency of separating product and service development processes in enterprises. Integrating these two strands of development is crucial for successful smart PSS development. For this integration, it is necessary to identify integration points in the processes and utilize key roles with interdisciplinary knowledge to bring together different disciplines (Lugnet et al., 2020). Investigating the design processes of enterprises engaging in smart PSS development can offer valuable insights into both the pioneering practices of industry leaders and the exploratory paths of newcomers.

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This inquiry could yield a deep understanding of the methodologies, strategies, and challenges involved in the transition towards smart PSS, providing a rich foundation for deriving theoretical frameworks and practical guidelines for successful smart PSS implementation.

For pioneers in smart PSS development, an in-depth examination could uncover the key factors contributing to their success, such as the adoption of agile and lean development methodologies, the integration of customer feedback loops, and the effective management of interdisciplinary teams. These insights could reveal how pioneering firms manage the inherent complexity of smart PSS. Additionally, studying pioneers could illuminate best practices in navigating regulatory environments, intellectual property challenges, and the cultivation of ecosystems that support innovation and value co-creation.

On the other hand, analyzing the journey of beginners in smart PSS development could offer a different set of insights, particularly regarding the organizational transformation required to shift from traditional product-centric models to service-oriented, customer-centric approaches. This investigation could highlight the barriers to entry for smart PSS development, such as skill gaps, resistance to cultural change, and the challenges of integrating new technologies into existing product lines. Moreover, it could shed light on the learning curves and change management strategies that facilitate the gradual adoption of smart PSS principles, including the development of new competencies, the restructuring of development processes, and the implementation of pilot projects to test and refine smart PSS concepts.

5. Conclusion and outlook

Developing smart PSS can be challenging, as enterprises need to integrate and synchronize development streams from multiple disciplines and consider elements from complex systems. Advancements in adjacent research areas can help accelerate and support the maturity of smart PSS development. This paper aims to explore and analyze existing methods from different research areas to support smart PSS design. It addresses research questions about the methods available for smart PSS development and the characteristic elements relevant to their development. The goal is to gain insights into different design approaches and derive characteristic elements for comprehensive understanding and the design of a consistent smart PSS development framework. The SLR identified 17 methods with various ICT-centered focus areas. The paper introduces these methods and examines their features, followed by a classification of methodological support along the product development cycle.

A major finding are the characteristic elements that contribute to a holistic smart PSS development framework. Customer involvement and user-centricity are crucial, allowing organizations to gather feedback and insights throughout the development process. Incremental development and testing enable quick adjustments based on user needs. Early business model design helps establish a solid foundation by considering key customers, partners, activities, and ICT requirements. Translating requirements into functions ensures alignment between customer needs and the functionality of the smart PSS. Service-oriented methods prioritize service delivery and customer involvement. Synchronized software development minimizes risks by integrating software early on. Leveraging data from various sources supports product development and optimization. Digital twin technology allows for virtual simulations and analysis, reducing the need for physical prototypes and enabling quick improvements. Integrating these elements into the development can enhance efficiency and lead to successful smart PSS outcomes.

The significance of the smart product-service systems (PSS) field is increasing, but there is a lack of systematic support for its development due to different interpretations and definitions of smart PSS across various disciplines. However, further research is necessary to tackle the unique challenges associated with smartness in PSS. In the future, research can concentrate on integrating the characteristic elements to establish a comprehensive framework for smart PSS design.

In specifically reviewing methods, this paper has not examined design processes and guidelines. Therefore, a subsequent study investigating such frameworks would be beneficial. Current methods for PSS development need to be reevaluated and adjusted to focus on integrating product and service design, promoting coordination and collaboration among stakeholders. Additionally, it is crucial to incorporate product and service development processes and identify points of integration, leveraging interdisciplinary knowledge to bridge different disciplines. While developing an integrated approach for smart PSS remains a research challenge, incorporating these elements and addressing the specific requirements of smart PSS can help overcome this challenge.

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