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From technology enablers to circular economy: Data-driven understanding of the overview of servitization and product–service systems in Industry 4.0

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ABSTRACT

Product-based companies worldwide attempt to integrate services into their offerings, embarking on "servitization" as a key strategy. These days, the acceleration of technological innovation (i.e., Industry 4.0) has triggered an emerging IT-driven business paradigm called digital servitization or smart product-service system (PSS) that embeds Industry 4.0 technologies. As a result of these developments, related literature has expanded across different disciplines in recent years. However, understanding and describing literature is not easy considering its volume and variety. Establishing common ground for central concepts is essential for science. Thus, to clarify important topics and research issues on servitization and PSSs in Industry 4.0, we carry out a comprehensive literature review by performing text mining of 419 journal articles. A machine learning approach is applied to learn and identify the specific topics, and the suggested key references are manually reviewed to develop a state-of-the-art overview. A total of 10 key research topics are identified, and the enabler–engineering–goal framework is developed. This study contributes to clarifying a systematized view of dispersed studies of servitization and PSSs in Industry 4.0 across multiple disciplines and encourages further academic discussions and industrial transformation.

1. Introduction

Manufacturing companies encounter various challenges in their operations. For instance, competition among these companies in terms of cost and technology leadership has increased along with product commoditization, and global environmental regulations have become rigid. In response to these challenges, numerous companies have adopted a service-led competitive strategy, referred to as "servitization" (Baines et al., 2007), to distinguish themselves from their competitors. Essentially different from product, service contributes to innovation by fulfilling the unmet needs of customers, strengthening the relations between companies and customers, and increasing the freedom in developing environmentally benign offerings beyond the product itself (Tukker and Tischner, 2006). The service-led competitive strategy used by manufacturing companies has generated specific types of value propositions that integrate products and services into a single system (Lim et al., 2012). This strategy is described as a servitized value proposition "product–service system" (PSS) (Mont, 2002), which has been investigated as a means of innovating product-based offerings in an economically, environmentally, and socially sustainable manner (Tukker, 2015).

The recent emergence of the Fourth Industrial Revolution (Industry 4.0) technologies—including big data, artificial intelligence (AI), digital twin, Internet of Things (IoT), and cyber-physical systems (CPS)—has enhanced the connection among people, systems, services, products, and companies (Benitez et al., 2020; Lim and Maglio, 2018). Thus, new ways of doing business are introduced and can exert a particularly strong impact on manufacturing companies (Rymaszewska et al., 2017). These technologies trigger a digital transformation by allowing interactions among devices, machines, services, and products; thereby accelerating the adaptability of manufacturing companies to changes in their market. Such technological innovation benefits manufacturers by driving their adoption of innovative services (Frank et al., 2019a). Therefore, explorations have begun on which types of knowledge can aid in the use of Industry 4.0 technologies and facilitate the application of PSS and servitization, both of which play critical roles in achieving sustainability and improving customer experiences (Gaiardelli et al., 2021; Pirola et al., 2020).

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Despite its importance for servitization and PSS in Industry 4.0, reviewing relevant literature is not easy. What are the representative research topics and how are they related? The challenge in such review lies in the widespread scope and diverse perspectives toward servitization and PSS in Industry 4.0. As of October 12, 2022, searching for “servitization in Industry 4.0” and “product-service system in Industry 4.0” in Google Scholar respectively generated 7,860 and 30,100 results across different fields, including operations management, marketing, and industrial engineering. It is difficult for human researchers themselves to review these documents. While several scholars, including Paschou et al. (2020) and Zheng et al. (2019), have reviewed such literature to generate an overview of the topic, existing reviews are selective and limited in accommodating its volume and variety. To address this limitation, Pirola et al. (2020) used text mining for literature review, but considered only the concept of smart PSS. Although the concepts of servitization and PSS in Industry 4.0 (e.g., digital servitization, smart PSS, and AI-based PSS) are intrinsically related and integrated, no review has focused on the analysis of the related literature on both concepts at the same time which enhance the identification and synthesis of various aspects and related knowledge of both concepts. In addition, recent studies are not considered despite the rapid increase in associated publications over the past three years (2020–2022). Therefore, the above reviews are limited to suggest how companies can pursue servitization and PSS development by embedding and integrating Industry 4.0 technologies.

This study contributes to the current understanding of servitization and PSS in Industry 4.0 by applying text mining on related journal articles. Text mining is an effective technique to clarify representative topics of new concepts and to identify their relationships (Lee and Lim, 2021; Lim and Maglio, 2018). By using related keywords, we identified 419 published articles from the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Emerging Sources Citation Index databases in Web of Science and Scopus. By excluding other types of articles such as reviews and editorials, the machine learning focuses on specific topics and characteristics of the literature. To capture the essence of the text corpus, we incorporate several metrics into the proposed analytics method to measure the statistical and semantic significance of the corpus word-features and unsupervised machine learning algorithms, such as spectral clustering (Von Luxburg, 2007), Latent Dirichlet Allocation (LDA) (Blei et al., 2003), and Non-negative Matrix Factorization (NMF) (Lin, 2007). Spectral clustering is based on graph partitioning to identify clusters in a latent space, which are originally difficult to be separable in the sample space. LDA is a generative probabilistic model to identify topics from sets of words across documents. NMF is a matrix factorization method to extract latent factors from original features with nonnegativity constraints. Spectral clustering was utilized in this study to ascertain the key research topics in 419 articles, and the LDA and NMF were used to validate and interpret the clusters.

From the analysis of articles, important keywords, basic statistics, research topics, a framework, and implications of servitization and PSS in Industry 4.0 were derived. Specifically, 10 key research topics of the servitization and PSS in Industry 4.0 literature were identified. By combining these quantitatively derived findings with the qualitative review of the machine-suggested key references, we propose the enabler–engineering–goal framework for the servitization and PSS with Industry 4.0 technologies. This is a multi-level framework for servitization and PSS in Industry 4.0, which can be effectively used to identify, synthesize, and integrate various aspects and related knowledge from abstract to concrete concepts. Lastly, theoretical and managerial implications of the framework were identified from the findings, and therefore future research issues for servitization and PSS in Industry 4.0 are suggested accordingly.

Establishing a common ground for central concepts is essential in science (Fortunato et al., 2018). To integrate the perspectives and capabilities for servitization and PSS in Industry 4.0, we present a systematized view of dispersed knowledge by integrating it into a robust conceptualization and by identifying the commonality and diversity in related literature. The findings contribute to the academic discussion and industrial transformation toward a successful servitization and PSS development in Industry 4.0. This study is unique in the sense that, to gain a better understanding of our topic, a machine learning approach is applied, different from bibliometric and systematic literature reviews in terms of the quantity of articles analyzed and the process of knowledge discovery (i.e., automation with algorithms versus manual collection and reading). Such an approach enabled us to address the gap between existing research on technological development and servitization and PSS by incorporating various studies on servitization and PSS in Industry 4.0, ranging from technology and engineering to business. This is the distinct contribution of our paper among existing studies conducted on servitization and PSS in Industry 4.0 (e.g., Paschou et al., 2020; Zheng et al., 2019). The contribution of the machine-learning-based approach used in this study is provided in Fig. 1, which shows an overview of the research topics of servitization and PSS in Industry 4.0. In addition, our machine learning approach adds to, not subtracts or conflicts with, the traditional approach (i.e., literature review based on experts). Our method can then be used in other review studies in the future.

The rest of this paper is organized as follows. In Section 2, the literature review of servitization and PSS in Industry 4.0 as well as current machine-learning-based approaches to conduct a literature review are presented. In Section 3, the methodology, including data gathering, analysis, and interpretation, is elaborated. In Section 4, the findings that present a state-of-the-art overview of the literature are presented. In Section 5, the theoretical and managerial implications of the findings for future research are provided. Finally, in Section 6, conclusions are drawn.

2. Literature review

2.1. *Digital servitization and smart PSS*

The servitization and PSS embedding Industry 4.0 technologies—including AI, IoT, blockchains, cloud computing, big data, and CPS—have recently attracted scholarly attention (Gaiardelli et al., 2021; Pirola et al., 2020) given their high potential in improving the traditional states (Thoben et al., 2017). These technologies have also been referred to using different terms (Gaiardelli et al., 2021), including “digital servitization” and “smart PSS”, among others (Kowalkowski et al., 2017; Lerch and Gotsch, 2015; Zheng et al., 2018).

Industry 4.0 technologies facilitate the introduction of new service offerings and drive transformations in the features of existing services (Lim et al., 2018a), giving rise to the term “digital servitization” (Grubic, 2018). Industry practitioners have since then used digital servitization to improve firm performance, gain an advantage over competitors, build digital business models, generate knowledge from data, and devise new ways of value co-creation (Paschou et al., 2020). Given its utility, the types of knowledge necessary for digital servitization are explored, such as adopting front-end technologies (Frank et al., 2019a), analyzing the agenda and trends in related research (Paschou et al., 2020; Rha and Lee, 2022), defining digital servitization (Coreynen et al., 2017), exploring its role from the ecosystem network perspective (Schiavone et al., 2022), building a new paradigm of platform approach (Cenamor et al., 2017), and configuration of product-service-software offerings through modularity (Hsuan et al., 2021).

The development of highly customized PSS and the enhancement of traditional models have been recently made possible by the emergence of Industry 4.0 technologies (Mourtzis et al., 2018). A smart PSS is simply one that integrates such technologies to provide new functionalities for networked smart products and service systems (Kuhlenkötter et al., 2017) and to satisfy individual customer needs in a sustainable way. Given these benefits, explorations have begun on the necessary knowledge, key challenges, and perspectives toward the future of using smart PSS, such as: five research agenda on tools for evaluating PSS

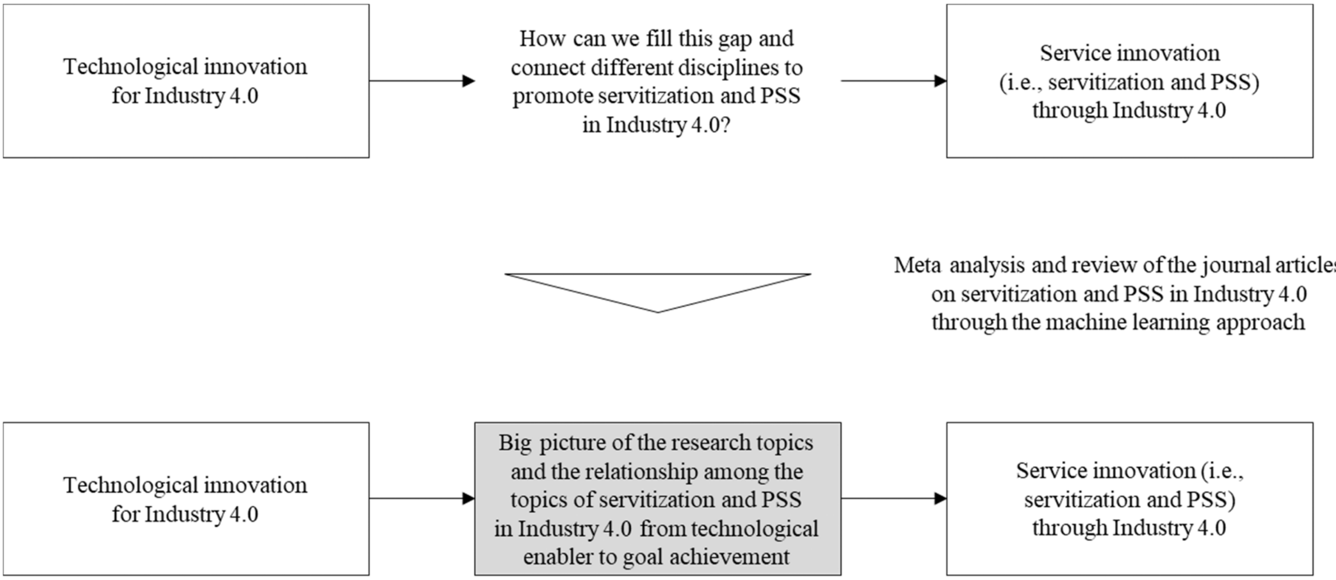

Fig. 1. Contribution of this work to bridge the gap between technological innovation and service innovation in Industry 4.0.

decisions, knowledge management along the lifecycle, PSS design, sustainability business models, and digital servitization (Pirola et al., 2020); four evolution dimensions of customer value experience, value creation mechanism, value offerings manifestations, and value creation interactions (Gaiardelli et al., 2021); and self-adaptiveness, sustainability, and use of advanced IT infrastructure (Zheng et al., 2019).

The increasing adoption of Industry 4.0 technologies has expanded the complexity of digital servitization and smart PSS since service offerings, processes, and network can be diversified, re-engineered, and extended, respectively (Eloranta et al., 2021). The expanded complexity poses significant challenges related to multiple aspects and levels of digital servitization and smart PSS, such as the identification of front- and back-end activities (Raja et al., 2018), structurization of capabilities (Benedettini, 2022), management of various products and services (Mourtzis et al., 2018), and configuration of digital technologies for PSS ecosystem (Kohtamäki et al., 2019). Addressing these challenges requires further research before servitization and PSS in Industry 4.0 can be applied in practice, given that the present knowledge on these topics remains less mature or practical than those on other innovation research topics. The existing knowledge for servitization and PSS in Industry 4.0 must be reviewed and integrated to offer highly concrete and useful knowledge for future research. Such integration is greatly warranted because the complexity of servitization and PSS innovation adjures various perspectives and knowledge.

A prerequisite to a successful servitization or PSS development using Industry 4.0 technologies is identifying and synthesizing various perspectives and knowledge to analyze and design multiple aspects and levels. Such identification also requires a guideline, and for this purpose, the literature on servitization and PSS in Industry 4.0 have recently been reviewed (e.g., Paschou et al., 2020). Available reviews offer crucial data and insights on servitization and PSS in Industry 4.0. However, as most are quite discerning in the sources they employ, these reviews are likely to have limited scope to accommodate the variety and volume of sources. In general, existing reviews focus on the application of Industry 4.0 technologies for servitization and PSS, and despite the value of understanding the entire spectrum of servitization and PSS in order to comprehend and promote it from technological development to service innovation, a complete outline of the research topics of servitization and PSS in Industry 4.0, from technological enabler to goal achievement of servitization and PSS, has yet to be presented. In addition, the existing review articles (e.g., Pirola et al., 2020) do not consider recent published articles despite the growing number of articles on the topic. Therefore, to allow human researchers to examine and integrate these documents at a large scale, this study takes a novel approach by applying text mining on a massive volume of related documents.

2.2. Framework for digital servitization process

Digital servitization is an extremely complex process, often involving conflicts between physical and digital service offerings, between product sale models and digital revenue, or between traditional supply chain relationships and new ecosystem partnerships (Kohtamäki et al., 2019; Sjödin et al., 2020). In the face of these conflicts, digital servitization is a constant challenge for service companies. Given that both servitization and digitalization are underpinned by complex business model changes (Kowalkowski et al., 2017; Hsuan et al., 2021), the convergence of these processes is obviously not going to be straightforward. Owing to this situation, calls for a systematic and holistic framework have been made by scholars such as Lenka et al. (2017) and Paschou et al. (2020) to improve the understanding of the challenges of such framework and support decision making.

In response to such call, several researchers have proposed frameworks for the process of digital servitization. For example, Chen et al. (2021) suggested a framework based on insights from a case study that illustrated how a traditional manufacturer instigates digital servitization through simultaneous business model expansion and digital technology adoption. The authors highlighted the characteristics of digital servitization which can be underpinned by a change in the architecture of the value creation, delivery, and capture mechanisms. Given these characteristics, the framework consists of three stages: (1) value proposition development, (2) value delivery system configuration, and (3) value capture mechanisms. Meanwhile, Struyf et al. (2021) proposed a three-tier analytical framework that uses the critical incident technique to help untangle and organize the digital servitization process. The authors highlighted a multilevel perspective that takes a holistic approach to interdependencies between the levels related to digital servitization. Their framework involves three levels: (1) network (e.g., partners), (2) organizational (e.g., resource configuration), and (3) micro-foundational (e.g., routines and capabilities for decision making). Based on the literature review, Kolagar et al. (2022) suggested an integrative four-layer framework for ecosystem transformation within the digital servitization field, including (1) ecosystem transformation triggers, (2) firm-level enablers, (3) different phases of ecosystem transformation, and (4) their effects. The proposed framework designs a progressive guideline for manufacturers to carry out ecosystem transformation and thus capitalize on the benefits of digital servitization. Finally, a framework for digital servitization value co-creation among multi-actors in AI services was proposed by Payne et al. (2021) on the basis of service-dominant logic. The framework comprises three dimensions: (1) AI-service exchange antecedents, (2) context of AI usage, and (3) consequences of digital servitization. It investigates how service ecosystems are reorganized and how the value co-creation process evolves when AI technologies for digital servitization are introduced.

The different stages of the digital servitization process for service companies have been outlined by the aforementioned studies and the resulting higher-order capability acknowledged as fundamental to managing the levels of their servitization journey. While numerous vital data and insights on the digital servitization process are obtained from these studies, none has yet presented a comprehensive summary of such process from technological development to service innovation. For instance, Chen et al. (2021), Struyf et al. (2021), Kolagar et al. (2022), and Payne et al. (2021) reported respectively on the transformation of business models, interdependencies of intrafirm and interfirm partners, ecosystem transformation, and value co-creation for AI services. The goal of the present study is to integrate knowledge about servitization and PSS in Industry 4.0 so as to comprehend their full scale and leverage them to shift from technological development to service innovation as well as identify blind spots of research issues of servitization and PSS in Industry 4.0.

2.3. *Text mining and machine learning approach to literature review*

The process of extracting new knowledge from a massive volume of textual data is called text mining. The applications of text mining techniques are varied and encompass different data types, including the utilization of scientific papers to characterize research fields (Lim and Maglio, 2018) and of patent data to evaluate technology trends (Yoon and Park, 2004). Undiscovered topics of a set of documents are unearthed through topic modeling algorithms like NMF and LDA, which are well-known algorithms for carrying out literature reviews. LDA, for instance, was applied by Pirola et al. (2020) to review literature on smart PSS. A network text analysis can be likewise used to test semantic relations among keywords through developing co-occurrence matrices and presenting a visual form of a network. In this regard, a keyword network was proposed that scrutinizes the betweenness centrality and degree of centrality to unearth research trends in digital transformation for service companies (Rha and Lee, 2022).

Machine learning algorithms (e.g., clustering and classification) to analyze text data can be used for literature review discovering previously unknown knowledge from the data. For example, Weißer et al. (2020) suggested a clustering approach to literature review using k-means clustering, meanwhile, Popoff et al. (2020) used support vector machines, naïve Bayes, and decision tree for classifying data of systematic literature reviews which were converted into bag-of-words. In addition, visualization techniques are key to interpretation of text data analysis results because most of the text mining cases involve numerous features and require semantic interpretation (Lim and Maglio, 2018). For example, a visualization of the network between keywords is1 useful to effectively catalog the keywords and detect the key links between them (Yoon and Park, 2004).

Prior research implemented embedding methods to convert text data into real-valued vectors in lower-dimensional space in order to apply machine learning and text mining algorithms. Term frequency–inverse document frequency (TF–IDF) and bag of words are two examples of these methods. However, despite the advantages of these embedding methods for performing review literature, inconsequential features limit their applications as they can only generate too specific, nongranular, or unrelated research topics. The existing studies likewise encounter challenges when setting parameters for the use of machine learning and text mining algorithms. The same is true when the literature review results are evaluated because of the limited scope and subjective description of the review. To address these limitations, the identification of important word-features describing literature, the clustering analyses, only the parameter setting and analysis result interpretation should be conducted by humans with data analysis results for decision making. Thus, in the present study, machine learning models and text mining techniques are combined to probe in detail into the areas of servitization and PSS in Industry 4.0, an endeavor that may be challenging to accomplish by humans alone.

3. Methodology

Developing a unified conceptualization of servitization and PSS in Industry 4.0 is not easy given the variety and volume of related studies. Therefore, we applied on text mining techniques and machine learning models to develop our understanding of servitization and PSS in Industry 4.0. A comprehensive set of 419 journal articles is collected and analyzed in this study (Fig. 2).

Journal papers related to servitization and PSS in Industry 4.0 were identified and downloaded from the Web of Science Core Collection and Scopus databases of SCIE (1945–), SSCI (1987–), and Emerging Sources Citation Index (2015–) by using the keywords related to servitization and PSS in Industry 4.0 (Step 1). The following search query was selected for the study: "Topic = ("servitization" OR "servitisation" OR "servicification" OR "servicization" OR "servicisation" OR "service-driven manufacturing" OR "product-service system" OR "product service system") AND Topic = ("big data" OR "bigdata" OR "data-driven" OR "data driven" OR "digitization" OR "digitalization" OR "digital transformation" OR "iot" OR "internet of things" OR "internet-of-things" OR "A.I." OR "AI" OR "artificial intelligence" OR "CPS" OR "cyber-physical system" OR "cyber physical system" OR "digital twin" OR "digital-twin" OR "smart factory" OR "smart manufacturing" OR "industry 4.0" OR "fourth industrial revolution")." The aforementioned databases provide high-quality peer-reviewed papers that included discussions related to this study. Only research articles were collected for this review because other types of papers—such as reviews, editorials, and conference proceedings—may be too broad and tend to generate noise when learning specific topics and characteristics of literature. Unlike previous reviews, this study collected and analyzed full population data from the databases in a semi-automatic manner. The

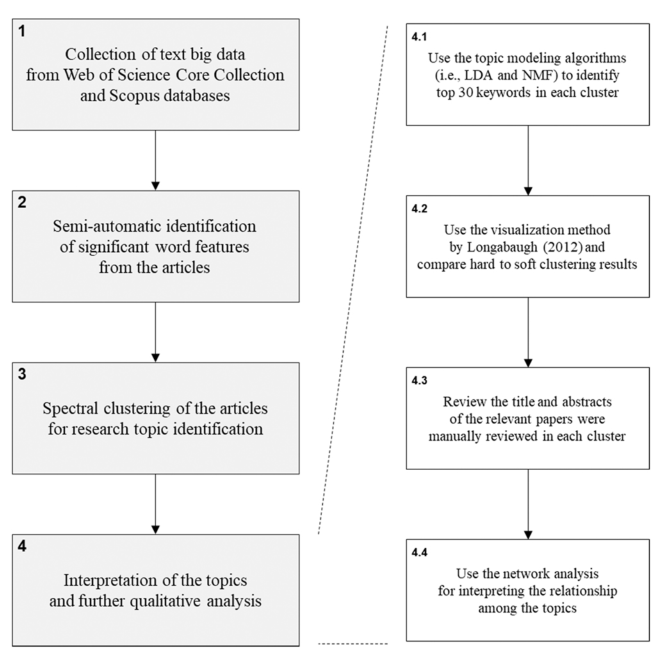

Fig. 2. Text mining of the literature on servitization and PSS in Industry 4.0.

identification initially yielded 661 articles (Web of Science Core Collection: 343; Scopus: 318), of which 242 were removed due to duplicated, missing, or outlier data, thereby leaving a text corpus of 419 articles. Following related studies (Noh et al., 2015), we use the text data (including the titles, abstracts, and keywords) to reduce noise, increase signal strength, maximize efficiency, and overcome the problem related to the limited accessibility of the full texts.

The text corpus, which is 419 documents with 5418-word features matrix (i.e., document-term matrix), was then prepared for subsequent analysis via text preprocessing (Step 2). This step aimed to the removal of potential sources of noise. For this, we eliminated letters not found on the alphabet and stop words (e.g., "and," "for," and "it"). The entire text was also transformed to lowercase (e.g., "Service" to "service"), customized rules were applied (e.g., non-contextual words that are commonly used in journal articles, such as "result" and "paper," were eliminated), and all words were lemmatized (e.g., "processes" to "process").

A document-term matrix embedded with TF–IDF was then created for the word-feature selection because many text mining-based studies employ a TF–IDF measure instead of simple frequency. The words in the text corpus were categorized into Type 1 (developed by specific companies or the article authors, including application names and acronyms), Type 2 (contextual and relevant to the topic being investigated, such as "business," "sustainable," or "system"), and Type 3 (frequently used in English documents, such as "over" and "within," and in scientific publications, such as "approach" and "method"). In the word-feature selection, only those falling under the Type 2 words were considered, and those under the words in other types were excluded. Type 2 words tend to have high TF–IDF values as they appear frequently in numerous articles. Type 1 words are normally marked with very high TF–IDF values as they appear frequently in one article but are absent in others, meanwhile Type 3 words generally have low values for the opposite reason. Two parameters are considered when detecting Type 2 words. For Parameter 1, important keywords from each article are detected via TF–IDF to eliminate general words (i.e., Type 3 words). For Parameter 2, keywords ranked as a top word several times (Parameter 2) in the articles are pinpointed to eliminate case-sensitive words (i.e., Type 1 words). In the present study, five and two were set as the corresponding optimal values of Parameters 1 and 2 following the algorithm and word significance metrices proposed by Lim and Maglio (2018). Briefly, words that appeared a minimum of two times across all articles from the combination of the five words that most frequently occurred in each article. Hence, Types 1 and 3 words were removed from the original data set, and Type 2 words representing the servitization and PSS in Industry 4.0 were established. Finally, among the initial 5418-word features, only 294 were retained for further analysis.

Spectral clustering was then carried out using the Laplacian matrix and graph partitioning to identify the key topics that represent servitization and PSS in Industry 4.0 literature (Step 3). Following the recommendations of pilot studies that evaluated the performance of various clustering algorithms (e.g., k-means clustering, density-based spatial clustering of application with noise, and affinity propagation clustering), we selected graph partitioning, an NP-hard problem that requires the application of a heuristic algorithm. Specifically, each run returns a different set of clustering results and an optimal number of clusters cannot be easily identified. The silhouette coefficient values (Rousseeuw, 1987) of the data were then averaged to quantify the clusters included in the text corpus. For each set of 20 cases, the average of 100 iterations was computed. The precise number of clusters from 1 to 20 was tested based on the finding that the value of the mean silhouette coefficient decreases monotonously from the cluster number 12. Next, the data of each cluster were manually evaluated, that is, the cluster results were verified and the top articles in each cluster examined. Two clusters that focused on the same topics as the other clusters were integrated into the latter. Ultimately, 10 clusters were chosen as the ideal number.

Cluster interpretation undergoes four sub-processes (Step 4). (1) The top 30 representative keywords for each cluster are detected using topic modeling algorithms like NMF and LDA. (2) Clusters were clarified using the visualization proposed by Longabaugh (2012). In the binary adjacency matrix, individual clusters are represented by yellow squares, and the density and size of the clusters respectively specify the homogeneity (i.e., text similarity) and amount of data. The two topic modeling algorithms (i.e., soft clustering) previously used were applied to confirm the spectral clustering (i.e., hard clustering) results for each scenario with varying topic numbers. This sub-step proved the analysis did not overlook any topic. The results indicate that every topic was considered. (3) For each cluster, the title and abstracts of the relevant articles were evaluated by humans, and the contents of both the top and bottom data were assessed. This was because the contents were detected on the basis of the cosine similarity between each article and the centroid of each cluster. (4) Network analysis was performed on the clustering results. Specifically, the centroids (i.e., those of the TF–IDF-embedded document vectors) in every cluster were distinguished and cosine similarities between them were calculated. In general, the similarity scores were high and all clusters (nodes) were connected as they were all highly related. Accordingly, for each cluster, only the top three most closely related clusters were singled out and connected to examine the most important relationships between research topics. The results reveal that nodes in the center are connected to many others and thus have strong relationship values. By contrast, nodes in the boundaries are connected through nodes in the center and thus have weak relationship values. Overall, nodes in the center embody the concepts that connect those in the periphery. Meanwhile, to improve the depth of the findings and pinpoint direction for further research, qualitative analysis is conducted by examining the outcomes of text mining and the literature gathered. The interpretation results are elaborated in Sections 4.2 and 4.3 below.

4. Findings

4.1. Statistics of the servitization and PSS in Industry 4.0 literature

Table 1 shows the basic statistics of the 419 collected scientific

Table 1
Top 20 journals and countries with articles on servitization and PSS in Industry 4.0.

Journal	Frequency	Country	Frequency
Sustainability	26	China	60
Industrial Marketing Management	26	Sweden	44
Journal of Cleaner Production	18	Germany	39
Advanced Engineering Informatics	15	Italy	37
Technological Forecasting and Social Change	15	United Kingdom	24
International Journal of Production Economics	13	Finland	18
International Journal of Production Research	11	Brazil	18
Journal of Business and Industrial Marketing	11	France	16
Journal of Business Research	11	Spain	14
Computers in Industry	10	United States	14
Production Planning and Control	8	South Korea	11
International Journal of Business Environment	7	Taiwan	11
Research-technology Management	6	Switzerland	10
International Journal of Operations and Production Management	6	Singapore	9
Journal of Manufacturing Technology Management	5	Denmark	8
Journal of Service Management	5	Norway	8
Service Business	5	Netherlands	7
Electronic Markets	5	Portugal	6
Strategic Change	5	Hungary	5
Applied Science	5	Netherland	4

articles, including their journal, year, and country of publication. *Industrial Marketing Management* and *Sustainability* have published numerous articles related to servitization and PSS in Industry 4.0. Many related papers have also been published in other journals, including *Journal of Cleaner Production, International Journal of Production Economics,* and *Journal of Business Research*. Meanwhile, several papers on the characteristics of Industry 4.0 technologies have been published in technology-related journals, such as *Computers in Industry, Advanced Engineering Informatics,* and *Technological Forecasting and Social Change*. Traditional manufacturing powerhouses—such as China, Sweden, Germany, Italy, the United Kingdom, and Finland—have the highest number of published articles on servitization and PSS in Industry 4.0. These statistics also highlight the efforts of Scandinavian countries and Brazil in using Industry 4.0 technologies to achieve sustainable production and consumption.

Fig. 3 plots the number of articles published in each year and highlights the rapid growth of the servitization and PSS in Industry 4.0 literature and the relevance of the present review. This number is also expected to continue increasing in the future.

4.2. Key topics (10) in the servitization and PSS in Industry 4.0 literature

Fig. 4 shows the 10 topics explored in the servitization and PSS in Industry 4.0 literature and represent 10 clusters of data. Fig. 4 shows the topic interpretation and naming outcomes. Enclosed in parentheses are the numbers of scientific articles that discuss each topic.

The identified topics are as follows: three ("technology enabler," "digitalization," and "capability") addressed the roles of Industry 4.0 technologies as enablers of servitization and PSS; five ("design and development," "business planning," "platformization," "customization," and "monitoring and maintenance") addressed the engineering aspects (i.e., how the technologies can be used to enable servitization and PSS provision); and the remaining two ("innovation" and "circular economy") underscored the goals of servitization and PSS provision using these technologies. The articles for each cluster were reviewed from the top 10 representative items of the corresponding cluster determined based on the mean cosine similarity of an item to the others.

The three topics on the enablers of servitization and PSS provision are as follows. Topic 1 Technology Enabler addresses the application of Industry 4.0 technologies—including big data analytics, cloud computing, digital twin, blockchains, and CPS—for servitization and PSS provision in manufacturing industries (Charro and Schaefer, 2018; Flores-García et al., 2022; He et al., 2020; Taleb et al., 2019; Wiesner et al., 2017; Zhang et al., 2020). This topic also identifies the opportunities and patterns of using such technologies (Bellandi et al., 2020; Frank et al., 2019b; Oliveira et al., 2020) and the direction of future research (Culot et al., 2020; Jardim-Goncalves et al., 2017). Topic 2 Digitalization addresses the digital transformation of product-oriented firms toward servitization and PSS provision using IoT. The special focus is on "digital servitization" (Frank et al., 2019a; Pirola et al., 2020), covering its effects on business excellence at the organizational level (Simonsson and Agarwal, 2021), the benefits and challenges in its usage (Loonam et al., 2018; Vendrell-Herrero et al., 2017a), and case studies on its applications across various industries (Cimini et al., 2021; de la Calle et al., 2021). In addition, this topic explores the application of digital twins in creating an environment that enables the examination of business concepts and PSS value propositions through feasibility experiments (Karagiannis et al., 2022) and data integration throughout the entire PSS lifecycle using the environment of digital twin (Woitsch et al., 2022). Topic 3 Capability investigates the technological capabilities, including digitalization, data analytics, IoT, and AI (Chen et al., 2022; Karttunen et al., 2021; Lenka et al., 2017; Sjödin et al., 2021), and the managerial and organizational capabilities (Benedettini, 2022; Gauthier et al., 2018) for servitization.

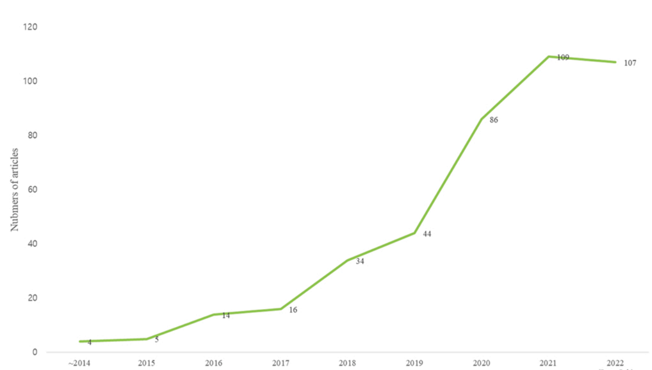

Fig. 3. Publication year trend of the servitization and PSS in Industry 4.0 literature.

The five topics on engineering aspects are as follows. Topic 4 Design and Development covers the design of a methodology or framework for PSS development. The special focus is on smart PSS (Cong et al., 2020), covering data-driven approaches for its design (Cong et al., 2022; Kuo et al., 2021; Li et al., 2021; Wang et al., 2019), evaluation methods (Chen et al., 2020; Wang et al., 2021), reference models for development (Tseng et al., 2021), the application of digital twins for PSS design and development, including the function-oriented PSS optimizing approach from the perspective of digital twins which enhances the ideality degree of smart PSS solutions (Wu et al., 2021) and the framework for PSS digital twins that comprise the super-system ecosystem, lifecycle processes, and hardware twins (Bertoni and Bertoni, 2022). Topic 5 Business Planning covers the understanding and categorization of various business models for manufacturing firms, such as for knowledge-intensive services, IoT services, data-driven services, AI services, digital twin application services, and smart PSS (Kuula et al., 2018; Niu and Qin, 2021; Rapaccini and Adrodegari, 2022; Turunen et al., 2018). Similarly discussed are the pricing and revenue models for digital servitization and IoT services (Linde et al., 2021; Marttoner-Arola et al., 2019), structure or configuration of business models and value creation networks (Raddats et al., 2022; Reim et al., 2019), and the importance of business model development for small- and medium-sized enterprises (SMEs) in the manufacturing industry (Coreynen et al., 2017; von Joerg and Carlos, 2022). Topic 6 Platformization covers the adoption of an IoT platform approach for servitization (Fu et al., 2022; Zhou et al., 2021), transformation of an ecosystem (Benitez et al., 2020; Kohtamäki et al., 2019; Sjödin et al., 2022; Sklyar et al., 2019), identification of patterns in IoT platform advancement (Markfort et al., 2021), architecture of cloud-based platforms (Rasouli, 2020), and the use of digital technologies for leveraging platforms in traditional industries (Tian et al., 2021). Topic 7 Customization covers the identification of customer orientations and requirements for PSS (Liu et al., 2020; Shimomura et al., 2018) and the development of a methodology or framework for personalization (Esheiba et al., 2022; Maleki et al., 2018; Ng et al., 2021). Topic 8 Monitoring and Maintenance covers the development of PSS for operations monitoring and preventive maintenance by implementing Industry 4.0 technologies, including CPS, augmented reality, big data, and deep learning (Ding et al., 2021; Pardo et al., 2022; Ren et al., 2022; Wang et al., 2020).

Two topics focus on the goals of servitization and PSS provision using Industry 4.0 technologies. Topic 9 Innovation covers the following: organizational innovations for supply chain management, operational efficiency achievement, and resource allocation improvement (Irfan et al., 2022; Mosch et al., 2021; Vendrell-Herrero et al., 2017b); impact of Industry 4.0 technologies on the financial company performance (Abou-Foul et al., 2021; Bortoluzzi et al., 2022; Favoretto et al., 2022; Kohtamäki et al., 2020; Martín-Peña et al., 2019) and the practices, opportunities, and challenges in digitalization and servitization (Frishammar et al., 2019). Topic 10 Circular Economy covers the framework or linkage of digital technologies (Ingemarsdotter et al., 2019; Liu et al., 2022; Neligan et al., 2022), technology adoption barriers and challenges

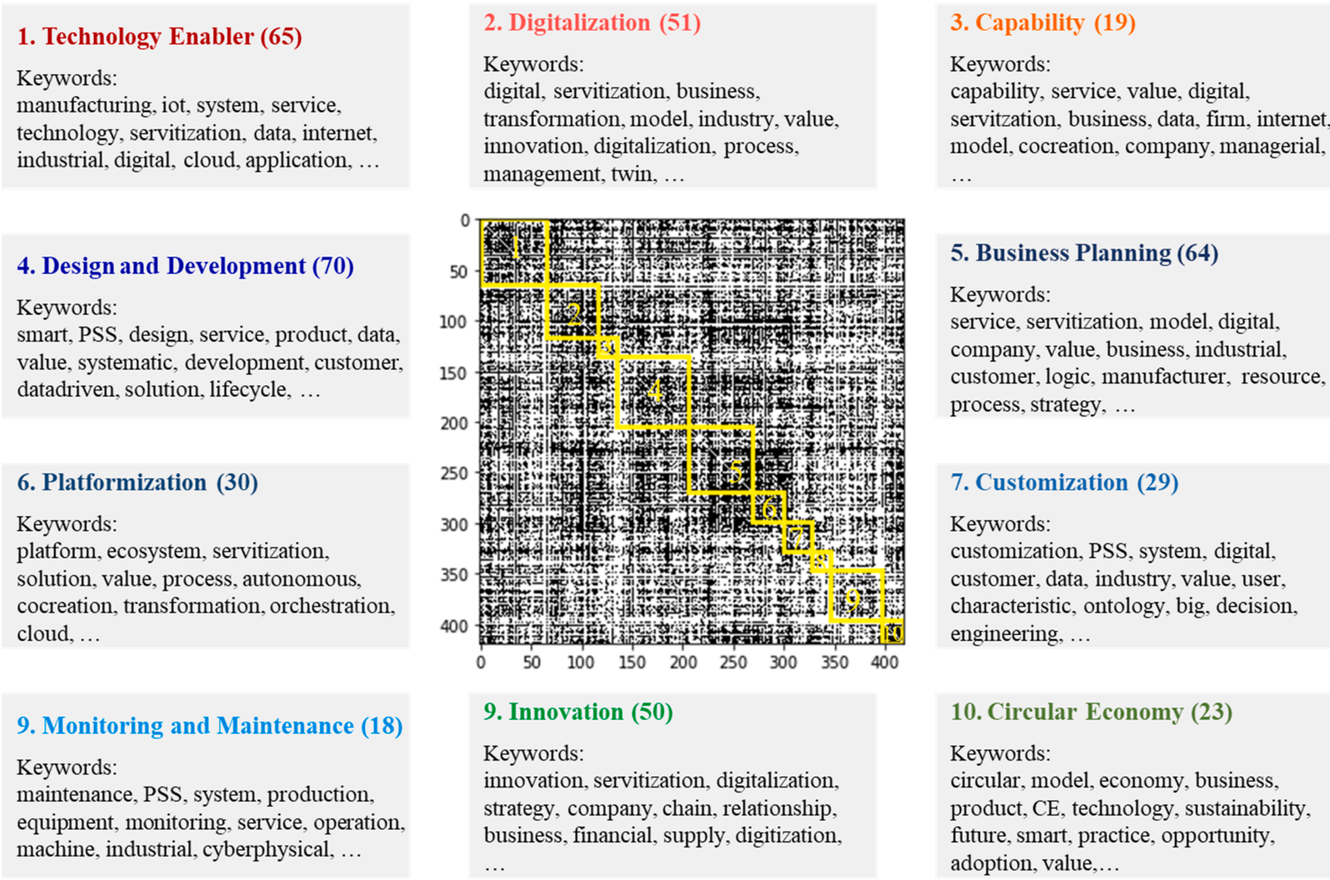

Fig. 4. 10 key topics in the servitization and PSS in Industry 4.0 literature.

(Hidalgo-Carvajal et al., 2021; Ingemarsdotter et al., 2020; Ingemarsdotter et al., 2021), and the business models that enable a circular economy through digital technologies (Bressanelli et al., 2018; Han et al., 2020).

4.3. Enabler–engineering–goal framework

This section presents an overview of the literature on servitization and PSS in Industry 4.0 by integrating the abovementioned findings. The mechanisms and outcomes of product-service innovation systems in

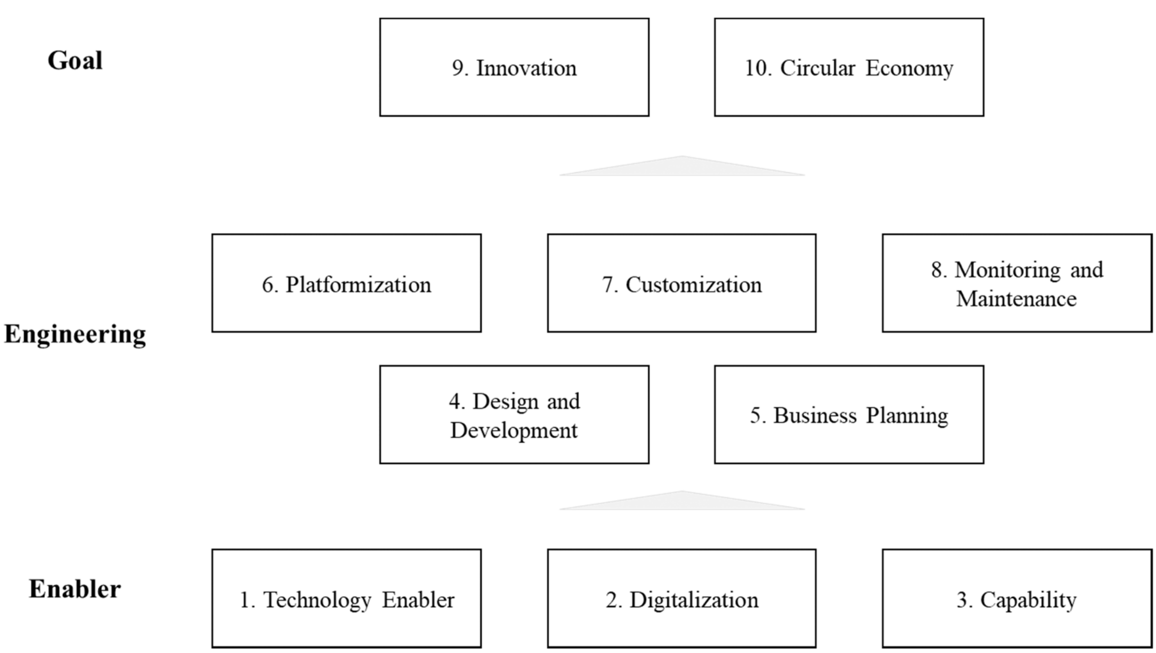

Fig. 5. Enabler–engineering–goal framework for servitization and PSS.

terms of management practices (Visnjic et al., 2018) have been questioned. Fig. 5 shows such mechanisms as captured in literature. Product-based companies are motivated to adopt servitization and PSS provision enabled by technology-driven digitalization movement and capability enhancement. They also have internal needs to advance the manufacturing itself and the supply chain using technology enablers, such as AI, CPS, and digital twin. For servitization and PSS provision, these companies may develop various plans for business models with new technologies and use them for platform transformation, customization, and adaptive and preventive maintenance to attain profit efficiency or enhance customer experience. Specific methods for PSS design, analysis, evaluation, and development have thus been developed for such companies. In addition, through servitization and PSS provision, companies aim to achieve innovation and contribute to the circular economy.

The enabler–engineering–goal framework can be used to interpret the existing definition of digital servitization and smart PSS. In literature, digital servitization is defined as "the transformation in processes, capabilities, and offerings within industrial firms and their associate ecosystems to progressively create, deliver, and capture increased service value arising from a broad range of digital technologies such as IoT, big data, AI, and cloud computing" (Sjödin et al., 2020, p. 478). In the perspective of the enabler–engineering–goal framework, the transformation, service values, and the digital technologies relate to the engineering methods (Topics 4–8), goals (Topics 9–10), and the enablers (Topics 1–3) of digital servitization, respectively. Zheng et al. (2018) defined a smart PSS as an IT-driven value co-creation business strategy (Topics 4–5) consisting of various stakeholders as the players (Topic 6), intelligent systems as the infrastructure (Topics 7–8), smart and connected products as the media and tools (Topics 1–3), and their generated e-services as the key values delivered that continuously strive to meet individual customer needs in a sustainable manner (Topics 9–10).

Table 2 shows the results of comparison between our framework and existing frameworks for digital servitization process introduced in Section 2.2. Chen et al. (2021) proposed three stages for the business model expansion of digital servitization in which value proposition and value delivery system stages relate to all topics in engineering methods (Topics 4–8). These stages consider various business models through Industry 4.0 technologies. The value capture mechanism stage relates to digital servitization goals (Topics 9 and 10). However, this framework does not consider the enablers of digital servitization in our framework. Struyf et al. (2021) introduced three levels to describe the interdependencies of intrafirm and interfirm partners for digital servitization where its micro-foundational level is associated with the capability in enablers (Topic 3). Meanwhile, network and organizational levels relate to three topics in engineering methods (Topics 4–6). Kolagar et al. (2022) presented four layers of ecosystem transformation for digital servitization; here, the firm-level enabler layer relates to digitalization (Topic 2), relational capability (Topic 3), design and development (Topic 4), and business model planning (Topic 5). The ecosystem trigger layer relates to customization (Topic 7) because it identifies novel customer demand and readiness. The ecosystem transformation layer reports the platformization process (Topic 6), whereas the effect layer relates to digital servitization innovation (Topic 9). Payne et al. (2021) proposed three dimensions in which AI service exchange antecedent and AI usage context dimensions relate to digital servitization enablers (Topics 1–3). Digital servitization consequence dimension indicates digital servitization innovation (Topic 9). As described in Section 2.2, existing studies do not provide a full-range overview of the digital servitization process from technological development to service innovation. Nevertheless, our framework covers the whole spectrum of servitization and PSS in Industry 4.0 as a basis for promoting it from technological development to service innovation. Our framework can also provide useful guidance for practitioners to identify blind spots of the research statuses of servitization and PSS in Industry 4.0.

Fig. 6 presents the network of relationships among the 10 key topics. The size of a node indicates the percentage of articles covering each topic relative to all articles. The number in arc indicates the cosine similarities between the topics. Digitalization (Topic 2) is the key enabler of servitization and PSS provision, which connects business planning (Topic 5) and platformization (Topic 6) to achieve innovation (Topic 9) and circular economy (Topic 10). Business planning (Topic 5) is essential for the engineering of servitization and PSS provision to achieve innovation (Topic 9) and circular economy (Topic 10) with all enabler-related topics (Topics 1–3).

The relationship among the key topics in Fig. 6 can be interpreted considering the types of Industry 4.0 technologies. For smart PSS, Zheng et al. (2019) classified the types into three categories, including connection (e.g., IoT, 5 G networks RFID, and GPS), intelligence (e.g., cloud computing, embedded system, and edge computing), and analytic (e.g., big data analytics, CPS, and AI) technologies. Digitalization (Topic 2) and capability (Topic 3) are related to connection technologies that facilitate the establishment of a technological foundation for servitization and PSS provision, such as construction of data management and IT support systems as well as an ecosystem of various stakeholders. In other words, connection technologies enhance business planning for system construction (Topic 5) and platformization for ecosystems (Topic 6). Meanwhile, technology enabler (Topic 1) is related to intelligence and analytic technologies that enhance the creation of specific values of servitization and PSS provision. For example, AI is used for active monitoring and predictive maintenance to manage specific PSS (Ren et al., 2022) while big data is used for identifying customer needs and then customizing PSS (Ng et al., 2021). Recently, many companies have attempted to differentiate PSS through these technologies that facilitate engineering-related topics, including design and development (Topic 4), business planning (Topic 5), customization (Topic 7), and monitoring

Table 2
Comparison between our framework and existing studies on the digital servitization process.

Framework	Topic	Chen et al. (2021)	Struyf et al. (2021)	Kolagar et al. (2022)	Payne et al. (2021)
Enabler	1. Technology Enabler	X	X	X	
	2. Digitalization			Firm-level Enabler (Topics 2–5)	AI-service Exchange Antecedent & Context of AI usage (Topics 1–3)
	3. Capability		Micro-foundational (Topic 3)		
Engineering	4. Design and Development	Value Proproposition & Value Delivery System (Topics 4–8)	Network & Organizational (Topics 4–6)		X
	5. Business Planning				
	6. Platformization			Ecosystem Transformation Phase (Topic 6)	
	7. Customization		X	Ecosystem Trigger (Topic 7)	
	8. Monitoring and Maintenance			X	
Goal	9. Innovation	Value Capture Mechanism (Topics 9–10)		Effect (Topic 9)	Digital Servitization Consequence (Topic 9)
	10. Circular Economy			X	X

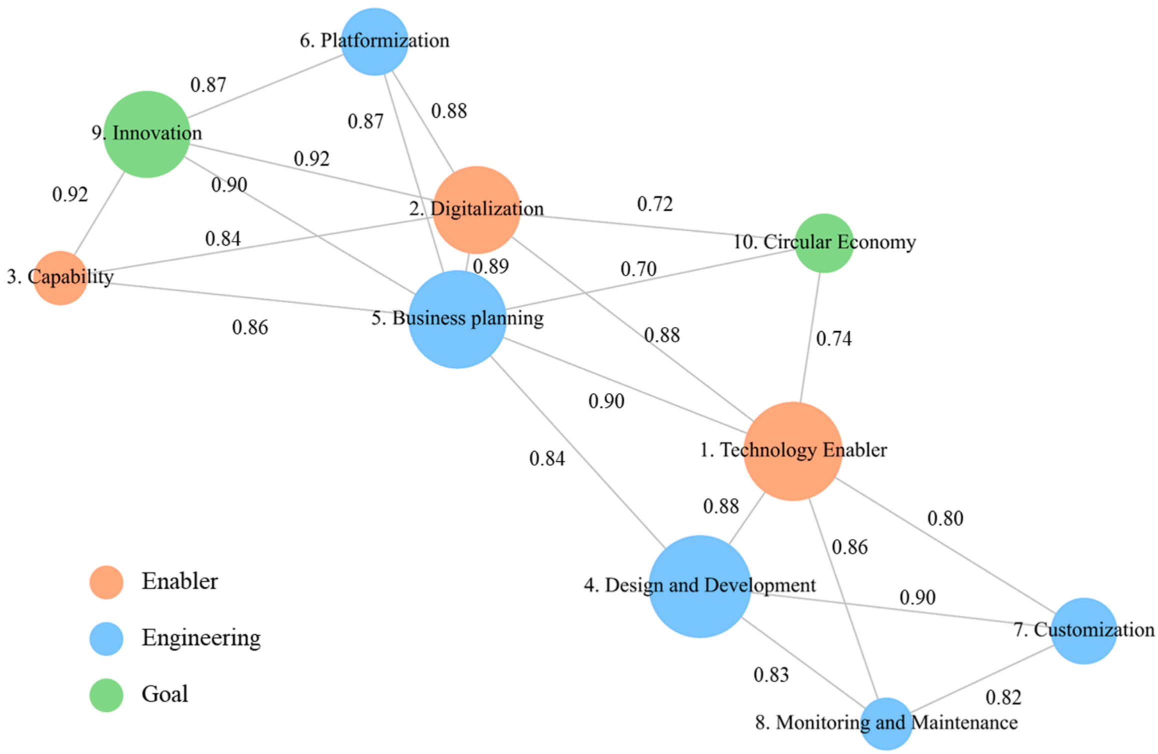

Fig. 6. Relationship among the 10 key topics.

and maintenance (Topic 8).

5. Discussion

This section discusses the theoretical and managerial implications of each framework component (Sections 5.1–5.3). Future research issues regarding servitization and PSS in Industry 4.0 are explored by supplementing quantitative results with additional in-depth qualitative reviews of selected articles (Section 5.4).

5.1. Enablers of the framework

Literature has explored the strategic choices underlying product-service innovation systems in Industry 4.0 (Gaiardelli et al., 2021). Digitalization (Topic 2) plays a particularly relevant role in this investigation as an enabler of servitization and PSS. Results of the review show that adopting digitalization as a strategy can facilitate servitization and PSS provision (Frank et al., 2019a; Paiola et al., 2020). Specifically, organizations can benefit from digitalization when addressing customer-facing front-end issues and solving back-end challenges (Kryvinska et al., 2020); the former relates to improving relationships and interactions with customers whereas the latter relates to improving operational efficiency by modifying the organizational structure (Coreynen et al., 2017). In our database, several articles explore the use of digitalization for organizational innovation (e.g., Simonsson and Agarwal, 2021; Vilkas et al., 2022). However, articles on the use of digitalization for managing customer relationships are scarce despite its importance. Therefore, further studies are needed to help manufacturers improve their relationships with customers via digitalization or digital servitization.

Ulaga and Reinartz (2011) identified “product usage and process data derived from the firm’s installed base of physical goods” as a critical resource for the design and implementation of servitization. Meanwhile, Kohtamäki et al. (2019, p. 390) defined digital servitization as “the transition toward smart product-service-software systems that enable value creation and capture through monitoring, control, optimization, and autonomous function.” Apart from introducing many service opportunities for organizations, digital technologies also help manufacturers maintain their intensive interactions with their customers and retrieve large amounts of process data while using their products (Opresnik and Taisch, 2015). Although the retrieved articles have highlighted the role of digitalization for servitization, a guideline for servitization and PSS provision is yet to be developed. For innovation with servitization and PSS in Industry 4.0, the question is how to use the data collected from their customers. A guideline for manufacturers to use digital technologies is necessary to influence their customers’ value creation and to embed themselves in such processes during the product use phase. In our database, Lim et al. (2018b) showed a related industrial project where an automobile manufacturer enables digitalization-enabled servitization by using data from customer processes (Lim et al., 2019a). The findings may be used as references for digitalization-enabled servitization and PSS.

5.2. Engineering of the framework

Previous studies have attempted to identify which product–service innovation system configurations using Industry 4.0 technologies enable manufacturers to design various services for value creation (Björkdahl, 2020; Frank et al., 2019a). Concerning the application of engineering methods for digital servitization and smart PSS development, this question is particularly relevant to design and development (Topic 4), platformization (Topic 6), and customization (Topic 8). One way to devise various services is to consider service modules for design and development, platfomization, and customization, and how these can be configured together with product and software modules (Hsuan et al., 2021).

When designing service modules, a set of reusable and easily interchangeable core elements must be established (Baldwin and Woodard, 2009; Lim et al., 2018c). To this end, the service architecture is divided into several modules by a service platform. Modular service architectures are especially useful in measuring the uniqueness of modules, which is crucial in dissuading competitors from imitating, customizing, or replicating a service across different families and rapidly developing new services based on existing ones (Voss and Hsuan, 2009). In this case, resource management can be improved in servitization by dividing the available service offerings into modules. Manufacturers may also benefit from adopting a platform approach based on a modular architecture when aiming for operational efficiency and customization in PSS provision (Cenamor et al., 2017).

Organizations need to evaluate both their internal (e.g., knowledge, data management systems, and people) and external (e.g., supplier network) resources when configuring their service modules to ensure that the value proposition they deliver actually matches the cost, time, and quality demands of their customers (Heikka and Nätti, 2018). Industry 4.0 technologies can be leveraged to identify various service modules, enable their automatic configuration, and to maximize the opportunities and address the challenges involved. In our database, several articles identify service modules and design concepts using AI and big data analytics (e.g., Schiavone et al., 2022; Wang et al., 2021). However, articles on the use of Industry 4.0 technologies for automatic configuration of service modules and their use in platform transformation are scarce despite their applicability to digital servitization and smart PSS.

Among the selected articles, Cong et al. (2022) developed a machine-learning-based iterative design method that extends the usage life of smart PSS through rapid replacement and positioning of unsatisfied service modules. Almeida et al. (2019) built a framework that helps in the achievement of IoT business goals and allows flexible configurations by using both standard and optional modules. The findings from such articles may be used as references for methodology development for automatic configuration of service modules.

By investigating the data management practices in an organization, Li et al. (2016) found that the efficient utilization and management of big data greatly depend on available data modules in a cloud service platform. Apart from defining the success of servitization for managers, Cenamor et al. (2017) revealed that the information module at the core of the platform architecture can also enhance the builder and configuration roles of front- and back-end units, respectively, by leveraging value. Hsuan et al. (2021) proposed a conceptual framework for digital servitization considering product–service–software systems, architectures, and modules. Data, information, and software modules may be used for developing a methodology for platform transformation.

5.3. Goal of the framework

In a rapidly changing market environment, the servitization or PSS models for SMEs are generally more effective than their larger counterparts (Loebbecke and Picot, 2015). Whether the servitization and PSS development in Industry 4.0 actually stimulate and offer more opportunities to manufacturing SMEs is also questioned (Overwhelm, 2015). While the literature highlighted the crucial role of technologies in digital servitization and smart PSS, the SMEs' perspective has thus far received limited coverage (Kohtamäki et al., 2020; Kolagar et al., 2021). The two topics at the goal level are highly relevant to answering this question. The servitization and PSS goals address factors that are related to innovation and circular economy. Such goal varies in scope and scale and is related to the size and age of an organization.

Several studies have explored servitization in SMEs. In terms of innovation (Topic 9), Clegg et al. (2017) found that enterprization and servitization transformations are highly interdependent and co-implementable with a focus on information technology and systems. How SMEs can grow into components of a multi-organization enterprise that delivers product-service solutions are discussed. In a survey of 224 SMEs (firms with fewer than 250 employees) in the Finnish software industry, Valtakoski and Witell (2018) found that front-office (FO) service capability enhances SME performance, whereas back-office (BO) service capability generates the opposite effect. Young SMEs benefit from having strong FO service capability, and as they mature, the importance of their BO service capability increases. Lachiewicz et al. (2018) explored the servitization implementation stages in the company development management of a Polish SME that designs office furniture and equipment. The development of servitization is classified into four stages of maturity, starting from peripheral services with limited customer interactions and mainly based on transactions to ending with the proposal of comprehensive product and service solutions that are co-designed by the service provider and customers.

From the perspective of the circular economy (Topic 10), Rizos et al. (2016) identified eight barriers and seven enablers faced by SMEs when implementing circular economy business models. Similarly, Pacheco et al. (2019) identified 17 main barriers involved in the transition toward a sustainable PSS in manufacturing SMEs and proposed as solutions. From the decision support perspective, Chalal et al. (2015) developed a modeling and simulation approach as a decision support system for servitization in industrial SMEs and then tested this method in a French SME engaged in remanufacturing wastes and electrical and electronic equipment.

5.4. Future research issues for servitization and PSS in Industry 4.0

This section focuses on the challenges identified from quantitative learning (i.e., text mining, machine learning, and network analysis) and qualitative learning (i.e., manual literature review) outcomes. Table 3 illustrates an overview of servitization and PSS challenges in Industry 4.0 that should be addressed in future research.

In our framework enablers (Topics 1–3), we find multiple studies that highlight the importance of big data for digital servitization and smart PSS (e.g., Ardolino et al., 2018; Lim et al., 2018b) among various digital technologies (Topic 1). Big data usage offers great potential to enable novel product–service offerings based on data transformation into information and knowledge (e.g., Kim and Trimi, 2023). However, many of these works have only paid attention to the roles and possibilities of big data for digital servitization and smart PSS. For digital servitization to succeed, identifying data-related activities during service lifecycles (e.g., data collection, analysis, delivery, security, and privacy) and managing them effectively through technology-based infrastructures are imperative. In addition, structuring or configurating ecosystems for data-related stakeholders should be conducted to lead for data-driven transparency among stakeholders and to operate services efficiently. In the digitalization topic (Topic 2), few studies have attempted to develop guidelines for data-driven digital servitization, even though the significance of such concepts has already been established (e.g., Kim et al., 2018; Lim et al., 2018b). Further research is thus needed to develop systematic guidelines for data-driven digital servitization that are already mentioned in Section 5.1. In the capability topic (Topic 3), various studies have identified managerial and organizational capabilities for digital servitization, such as production/delivery operations management, valuable and sustainable offering development, relationship management, and incentive identification (e.g., Benedettini, 2022; Marcon et al., 2022). However, most of these studies are limited to describing how data-driven perspectives can be reflected to managerial and organizational capabilities. Data-driven capability exploitation is one of the key research directions in digital servitization because it contributes to knowledge development and leveraging in new, effective, and comprehensive ways (e.g., Agarwal et al., 2022; Chirumalla et al., 2023). Further studies are needed to develop methodologies for fostering a mindset about data-driven decision making across all employee levels in service companies to provide data-driven solutions to customers; digital servitization implementation requires changes in organizational culture and mindset (e.g., Töytäri et al., 2018).

In our framework engineering (Topics 4–8), we find multiple studies that emphasize the ecosystem perspective examining digital servitization through a holistic and multi-actor lens as influenced by interactions with internal organizational actors and actors from outside firm

Table 3
Future research issues of servitization and PSS in Industry 4.0.

Framework	Topic	Subtopic (Section 4.2)	Research agenda
Enabler	Technology Enabler	• Digital technology application for digital servitization and smart PSS (e.g.,Taleb et al., 2019)	• Using digital technologies for managing data-related activities • Developing methodologies for structuring or configurating ecosystems for data-related stakeholders
	Digitalization	• Digital servitization patterns (e.g.,Frank et al., 2019a) • Digitalization benefits and challenges (e.g.,Loonam et al., 2018)	• Developing systematic guidelines for data-driven digital servitization
	Capability	• Managerial and organizational capabilities (e.g.,Benedettini, 2022) • Skill education for digital technologies (e.g.,Calle et al., 2020)	• Reflecting data-driven perspectives to managerial and organizational capabilities • Fostering the mindset about data-driven decision making across all employee levels
Engineering	Design and Development	• Methodologies and reference models for design, analysis, and evaluation (e.g.,Chen et al., 2020;Tseng et al., 2021) • Use of digital twin for PSS design and development (e.g.,Wu et al., 2021)	• Developing methodologies to organize design or evaluation processes from multi-actor perspective • Developing representation models to use digital twin for PSS design and development
	Business Planning	• Technology-driven business models (e.g.,Niu and Qin, 2021) • Quality, performance, risk, and revenue evaluations (e.g.,Linde et al., 2021)	• Defining new forms of value-creation interactions among various actors • Developing risk-and-revenue-sharing models for considering value-creation and delivery mechanisms among various actors
	Platformization	• Platform transformation (e.g.,Fu et al., 2022) • Ecosystem transformation (e.g.,Benitez et al., 2020)	• Conducting platform transformation considering servitization and PSS value creation • Developing methodologies to the automatic configuration of service modules and their use in platform transformation
	Customization	• Customer orientation/need/requirement identification (e.g., Liu et al., 2020) • Methodologies or frameworks for personalization (e.g.,Ng et al., 2021)	• Developing methodologies to identify changing customer needs/patterns in real time • Designing customer value experience to tailor customer needs and patterns
	Monitoring and Maintenance	• Operations monitoring and preventive maintenance (e.g.,Ding et al., 2021) • Stakeholder activity monitoring (e.g.,Pardo et al., 2022)	• Developing tools to monitor real-time activities of supporting decision making considering multiple constraints and actors • Developing data collection strategies
Goal	Innovation	• Supply chain management (e.g.,Irfan et al., 2022) • Resource allocation improvement (e.g.,Mosch et al., 2021) • Performance improvement (e.g.,Bortoluzzi et al., 2022) • Cultural innovation (e.g.,Favoretto et al., 2022)	• Developing guidelines to change the organizational culture of manufacturing companies for digital servitization • Examining the effect of organizational culture on company performance
	Circular Economy	• Technology adoption for circular economy (e.g.,Ingemarsdotter et al., 2020) • Circular system development (e.g.,Liu et al., 2022) • Waste and pollution management (e.g.,Neligan et al., 2022) • Policy development for circular economy (e.g.,Umeda et al., 2020)	• Identifying circular economy elements for successful digital servitization • Developing process models for alignment among these elements • Developing methodologies to evaluate the performances of business models that can be applied in various industries

boundaries (e.g., Sklyar et al., 2019). Gaiardelli et al. (2021) argued that the transition toward the ecosystem perspective implies moving from a single sequential discipline to a parallel multidisciplinary design and evaluation; here, all decisions, usually made on an individual basis, are now jointly evaluated and merged in a decision environment. Therefore, in the design and development topic (Topic 4), future research is needed to develop methodologies that organize design or evaluation processes for integrating the multi-actor perspective of digital servitization and smart PSS. Lim et al. (2019b) suggested a multifactor service design method for considering the multifactor nature of service in the service design process. The method may be used as a reference for developing methodologies considering the multi-actor perspective. A representation model for PSS design and development can also be useful for considering the multi-actor perspective. With the recent emergence of digital twins for PSS design and development, the importance of models representing the relationship between virtual and physical entities has increased (Rasheed et al., 2020). The success of PSS utilizing digital twins relies on the ability to represent the physical-to-virtual (P2V) or virtual-to-physical (V2P) connections that allow continuous optimization cycle and prediction of physical states in the virtual environment (Karagiannis et al., 2022; Wu et al., 2021). Thus, a representation model for PSS design and development that considers P2P and V2P connection would be useful in practice. From the business planning perspective (Topic 5), many studies have indicated complex networks among various digital servitization actors affects value-creation interactions (e.g., Gaiardelli et al., 2021). Further research on how to define the new forms of value-creation interactions among various actors, how to reshape the traditional business model fit for these forms, and how to develop risk-and-revenue-sharing models for considering value creation and delivery mechanisms can enhance such interactions.

Through the interpretation of Fig. 6, future research issues can be identified to facilitate servitization and PSS in Industry 4.0. First, most studies on platformization (Topic 6) focus on ecosystem construction and data collection system based on digitalization and capability (i.e., connection technologies). Further research on products and services that consider various activities related to servitization and PSS value creation in Industry 4.0, such as data analysis, information creation using data, and information delivery from the platform perspective, is a requirement for the transformation of more innovative platforms. Information and software modules (mentioned in Section 5.2) can be useful for applying the platform transformation of data-related activities. Second, many works on customization (Topic 7) and monitoring and maintenance (Topic 8) have highlighted data usage activities for servitization and PSS provision based on technology enablers (i.e., intelligence and analytic technologies). Specifically, these studies show how to analyze data, design information using data, and deliver such information to customers for servitization and PSS provision. These activities can be enhanced with further research related to data collection activities before use in servitization and PSS provision. Specifically, data types to be collected for servitization and PSS provision (i.e., data type), how to collect them (i.e., data source), how to preprocess them (i.e., data preprocessing), and how to share them with other actors in companies (i.e., data standard) must be identified.

In our framework goal (Topics 9–10), we find multiple studies arguing that organizational culture plays a critical role in firm digital servitization success or failure (e.g., Kohtamäki et al., 2019; Tronvoll et al., 2020). Specifically, a need for an agile mindset and way of working is found more imperative for digital servitization than for traditional servitization (Sjödin et al., 2020). Moreover, the agile culture has recently attracted scholarly attention in manufacturing SMEs (Kolagar et al., 2021). Despite the importance of organizational culture, few studies have identified how to change organizational culture and how to evaluate this change for digital servitization success. Therefore, in the innovation topic (Topic 9), further research explains guidelines to change the organizational culture of manufacturing companies for digital servitization and identifies the profound effect of the organizational culture on company performance. In the circular economy topic (Topic 10), many studies have emphasized that incorporating circularity principles into business models requires manufacturing processes to be reconfigured through digital technologies, such as AI and data mining (e.g., Chauhan et al., 2022). This reconfiguration can be achieved using circular business models, including retain product ownership, product life extension, and design for recycling strategies (Atasu et al., 2021). Such business models can be developed with further research on identifying circular economy elements, developing process models for alignment among these elements for designing business models, and developing methodologies to evaluate business model performance; these models can be applied in various industries.

6. Conclusion, limitations, and future research

Servitization and PSS development for manufacturing firms by using Industry 4.0 technologies have recently received considerable research and policy attention. However, no integrated and conceptual review focus on various concepts related to servitization and PSS in Industry 4.0. To understand the overview of this topic, we applied text mining on related journal articles. Based on the analysis, we identified 10 key research topics and suggested a multi-level framework (i.e., enabler–engineering–goal framework). In addition, we discussed the theoretical and managerial implications of the findings for future research, which can benefit the applications of Industry 4.0 technologies for servitization and PSS in practice.

Having conducted the study, we identify its theoretical contribution in the servitization and PSS literature. Despite the importance of servitization and PSS in Industry 4.0, only a few attempts have been made to analyze the related literature on both concepts at the same time. This study maps the knowledge scattered across the literature in order to achieve a more cohesive and systematized conceptualization, thereby furthering current insights on servitization and PSS in Industry 4.0. A total of 10 key research topics related to servitization and PSS in Industry 4.0 are identified here, from the issues on technological development to service innovation. A framework is proposed that clarifies the overview of the literature on servitization and PSS in Industry 4.0, and future research agenda for servitization and PSS in Industry 4.0 are presented for applying the proposed framework. The framework conceptualizes different aspects and levels of servitization and PSS in Industry 4.0, which previous studies do not consider all aspects of servitization and PSS in Industry 4.0. In addition, we provide details on three activities associated with each phase – activation, navigation, and consolidation. The impact of this study is based on its contribution to the intensive discussions regarding the significance of Industry 4.0 technologies for servitization and PSS in industry and society. In addition, it offers clarifications and an underpinning for further discussions.

From a methodology perspective, our study provides a successful example of the collection, analysis, and interpretation of large text databases for examining broad studies on servitization and PSS in Industry 4.0 and developing a high-level concept of the entire literature. Our study is unique since we aim to minimize the subjectivity of experts as well as increase inclusiveness in processing and aggregating text about servitization and PSS in Industry 4.0. When compared with information drawn from prior research, the empirical findings of the present study are in agreement, suggesting that the outcomes of the semi-automated analysis of textual big data are reasonable and evidently reveal the framework of extant literature. Researchers can utilize the proposed data-driven research method to examine the evolution of a research outline and identify its peripheries. With these future applications in mind, we urge other scholars to conduct reviews using the machine-learning-based approach as a new review technique for interdisciplinary fields. Future research can use the proposed approach to gain insights on other interdisciplinary topics in engineering, science, sociology, and the humanities.

This study has several limitations that can be addressed in future research. First, the findings are data dependent, that is, the results may change if the data source or time frame of data collection is modified. All available scientific data from the Web of Science Core Collection and Scopus databases were considered in this study, and future studies may either expand or reduce the scope and source to other databases or specific domains (e.g., innovation studies or operations management journals) to suit their purpose. Other search keywords may also be used to collect news data and patent data can be analyzed to further understand the technological aspects of servitization and PSS in Industry 4.0. Second, our approach per se cannot provide detailed information on each research topic, such as digital servitization in manufacturing SMEs, because the approach focuses on the identification and categorization of relevant topics across different articles rather than interpreting the detailed information in each article. As such, a systematic literature review for a specific topic is needed to describe a particular aspect of digital servitization and smart PSS in more detail. Third, the findings obtained from text mining must be integrated with real research and development projects related to servitization and PSS through empirical studies. Our research team has already collaborated on such projects with the industry and government (e.g., big data analytics for quality control service development for a chemical product manufacturer). Integrating this study with such project cases can further facilitate an in-depth understanding and promotion of servitization and PSS in the current digital economy.

CRediT authorship contribution statement

Minjun Kim: Writing – original draft preparation/conceptualization, Investigation. **Chiehyeon Lim**: Methodology, Supervision, Writing – review & editing. **Juliana Hsuan**: Writing – review & editing, Supervision.

Declaration of Competing Interest

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Data availability

Data will be made available on request.

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