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Cognitive Digital Twin Enabling Smart Product-Services Systems: A literature Review

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Abstract: Cognitive Digital Twin (CDT) has been taking considerable attention in several recent studies. CDT is considered as a promising evolution of Digital Twin bringing new smart and cognitive capabilities. Therefore, it is important to understand how companies can exploit this new technology and create new data-driven business models. Considering that context this article aims to identify Smart PSS business model based on Cognitive Digital Twin platforms. To reach this goal a literature review was conducted. As a principal contribution this study brings a set of new business models to offer Smart PSS based on cognitive digital twins. Moreover, the study presents several real cases of companies that are currently using the cognitive capabilities supplied by edge companies of the digital twin technologies.

Keywords: Cognitive Digital Twin, Business Model, Digital Services, Product-Services Systems

1 Introduction

Digital Twin is recognized as a key enabling technology of Industry 4.0 [1,2]. DT creates a virtual model of the physical entity of the production system, allowing the interaction and integration of physical world and information world, and collecting a big amount of data [3,4]. The DT have several manufacturing applications, such as product design, machine status monitoring, simulation, and visualization [5,6]. However, according to [5], the use of digital twins is frequently limited to be an exact replica of the physical assets, without any cognitive capability that could be bring new opportunities to the company.

Semantic technologies allows augmented cognitive capabilities to a DT [7]. According to [8], cognition requires modeling of, not only the physical characteristics, but also the behavior of production elements and processes. For this, it is necessary to develop data-oriented models through Data Analytics and Machine Learning techniques [8]. The growth of combination of DT with semantic models and data analytics tools emerged the concept of Cognitive Digital Twin (CDT) [1, 9].

Several authors (e.g., 1, 9, 10) state that CDT provide a more intelligent, comprehensive, and full lifecycle representation of complex systems, enabling to find data, and predict system behavior. The CDT can also enable the creation of higher service layers, which provide products with new intelligent behaviors and capabilities of communication. In that sense, companies can develop smart digital product-services

systems that could transform customer-supplier relationships and introduce new value propositions [11]. The Smart PSS business model comprises packages of products and services with smart digital capabilities, which can create, deliver, and capture value in real time [12]. These business models can focus on complementary digital services that support the most advanced servitized products or solutions that provide digital product personalization or the offer of Smart PSS of payment for use or payment for results [13].

In this sense, it is necessary to investigate how CDTs can be exploited to enable new Smart PSS business models, find new ways to (co)create value, as well as generate knowledge from data, improve the company's operational and environmental performance and get a competitive advantage [14]. Considering the context described above this study aims to propose new business models based on digital services enabled by Cognitive Digital Twin. To reach these aims a literature review was conducted.

The remaining sections are organized as follows. First, we start with the methodology section, where we present the methodological phases followed in the study. In Section 3 we describe and discuss the results. Finally, in Section 4 theoretical implications and managerial insights and future research suggestions directions based on the analysis and results presented.

2 Methodology

We follow three stages to conduct a literature based on the study of [15]: (i) research planning, (ii) research execution, and (iii) summary of results.

In the first phase, the research objective and data sources were defined. The goal defined in this stage was to identify the relation between CDT and PSS. For this, two databases were chosen to search: Scopus and ScienceDirect. Magazines and webpages that present practical application were also analyzed. The research questions that guided the study was: *How the cognitive capabilities provided by cognitive digital twins can be used to innovate in new Smart PSS business models?*

In the execution phase, the keywords were defined, and the definition of criteria for inclusion and exclusion of articles. The keywords defined for the search were: (cognitive digital twin OR Cognitive Twin) AND (services OR product-service system OR digital services OR servitization). The search was filtered by articles writing in English. Also, aiming to include relevant articles in the sample, the "Snowballing" technique was applied. Finally in the Summary of Results phase, was carried out on the content analysis of the articles and the main information was summarized according to the aim of the study.

3 Results

As a result of the literature research, were obtained a total of 19 articles in Science Direct and Scopus. These articles are focused mainly on the concept or architecture of CDT, and on the use of CDT for manufacturing. Therefore, were incorporate other 5 articles about PSS business models. The number of articles found and the year of

publication, all in the last two years, shows that it is still an emerging topic, but with growing interest.

3.1 Cognitive Digital Twin Supporting Smart PSS

Cognitive Digital Twin is considering the next generation Digital Twins, which has a strong data-orientation [9,16]. The CDT, unlike the DT, offers new cognitive abilities [17]. Thus, a CDT can understand, detect early and predict the impact of different types of behavior observed [5]. According to [1] the CDT can be defined, as a digital representation of a physical system that includes a set of semantically interconnected digital models related to the different phases of the life cycle of the physical system, providing cognitive capabilities and supporting to perform autonomous activities.

CDT has applications during all phases of the product life cycle [18]. However, the majority of studies focus on the manufacturing phase [3, 8, 10] and had little explored the use of CDT to innovate in new services models. The addition of services in the after-sale phase can bring new competitive advantages for companies and extend the life cycle of the product [17]. A product/service system (PSS) is the incorporation of services into a product tangible traditionally offered by a manufacturing company, seeking to offer the customer a “complete package” combining goods, support services, self-service and knowledge [18-21].

One of the most used categories is the [19], who proposed three PSS categories: Base Services, Intermediate Services and Advanced Services. Table 1 presents the description of each PSS category.

Table 1. PSS Categories [21, 23]

PSS Category	Description	Extent of risk
Base	Focus on product provision. Services that facilitate the product sale or usage without significantly altering the product functionality	Low: The customer will take the major risk regarding the product
Intermediate	Services that expand the product functionality. Or services that help the customer to adapt to new products.	Medium: increased expose to the consequences of equipment faults
Advanced	Services that replace the purchase of a product, challenging the view that services are always complements to products	High: The company assume the major of product failures risks

PSS business models can be classified in two categories. A product-oriented PSS, mainly focused on to improve or boost product utilization, e.g. maintenance, spare parts, upgrades, project engineering. In other hand, the customer-oriented PSS, where the changes are more radical, and the PSS is mainly concerned with customer needs, and where the product is substituted by the services as a principal offer component [23, 24]. The Base and Intermediate Services are services that support the product selling. Companies that offer this kind of PSS have a business model oriented to a product.

Instead, companies that offer advanced services have a business model oriented to a customer [25, 13].

According to [26, 27] the advance of digital technologies such as Internet of Things (IoT), smart connected products (SCPs), artificial intelligence, among others, emerged a new concept of Smart Product Service System. The Smart PSS can be conceptualized as the development of new services and/or the improvement of existing ones using digital technologies [28]. These new Smart PSS transform customer-supplier relationships and introduce new value propositions [11]. In that way companies could take competitive advantage from these solutions, by (co)creating value with customers, and also by the generation of new knowledge from data, improving the firm's operational and environmental performance. In that sense, the cognitive digital twin can offer new opportunities to develop Smart PSS [29]. Companies can collect data by the implementation of CDT and develop machine learning models to monitor the health of a product, perform diagnosis and prognosis that can be offered as services [6]. The CDT allows collecting data from different products and generates information about product usages and product conditions. Using artificial intelligence, it is possible to analyze the data collected from the digital twin for diagnostics and preventive maintenance. Using AI methods, it is possible to identify under and over utilized products performance, identify patterns of anomalies, common faults, and insights in reducing operational costs. Besides, the company can generate detailed condition reports and share them by apps or digital platforms. Considering that context the following conceptual framework (**Fig 1**) was constructed.

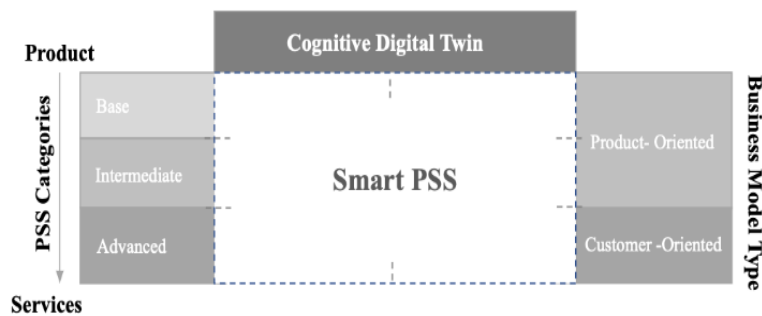


Fig 1. Conceptual Model

In the case of base services, the capabilities supplied by the CDT will be focused on monitoring product conditions to provide the necessary replacement parts at the right time, to avoid warranty issues. In the case of intermediary services, the CDT can be used to support services to guarantee the state and condition of equipment. Finally for advanced services, the CDT allows firms to offer services focused on the result, bringing to the manufacturing company the major responsibility for the product. [28,29]. Furthermore, these solutions can be integrated into a Cognitive Digital Twin platform. Platform approach enable the implementation of advanced service in a easier way [14, 30].

In the market, there are a few DT platforms which have been evolving with the inclusion of applications for data analysis, however some companies refer to these

solutions as Cognitive Digital Twin. Some of the most representative companies in the sector of CDT technologies are IBM, Siemens, Bosch, Ansys and General Electric. Next, several case studies of companies that offer products-services based on CDT platforms are presented. These cases were identified through the success stories reported by the suppliers of the CDT platforms.

3.2 Digital Cognitive Twin Platform for Product-Services Systems: Use Cases

IBM has a group of applications related to cognitive digital twins. For example, IBM Watson™ IoT Platform is a cloud-hosted service that makes it simple to derive value from Internet of Things (IoT) devices, through several artificial intelligence applications. In addition, the Maximo Asset Health Insights application, monitoring of asset health and optimize preventive maintenance by combining asset record information and sensor data so that businesses are better able to plan capital improvement. The company also launched the IBM Digital Twin Exchange, which is a marketplace that connects organizations that are looking to buy digital twins with members of IBM's partner ecosystem, who can sell them fault codes, maintenance plans, 3D models, and other data related to physical assets. After buying the digital twin using IBM Digital Twin Exchange, companies could use AI and IoT solutions to fully capitalize on the value of digital twins, using IBM Watson or IBM Maximo enterprise asset management. A success case reported is KONE, a leading manufacturer of elevators delivering a “‘people flow’ system for small and large buildings with full risk contractual services”. For this it uses the IBM Watson IoT platform and its cognitive capabilities in many ways e.g., KONE E-Link™, a facility management tool that allows asset monitoring, provides elevator performance, traffic analysis, and helps to predict the condition of the elevator [30]. This Smart PSS can be classified as *advanced services* because the company guarantees the availability of the system through full risk contracts.

Siemens is one of the most advanced companies in the field of digital twins. The company developed several technologies to implement digital twins such as: MindSphere, and Siemens Digital Enterprise Suite, that include Siemens Product Life Cycles System (PLM), Manufacturing Operation Management System (MOM), among others. A reported example of a company using Siemens digital twin technologies is Saildrone. This company designs, manufactures and operates a fleet of unmanned surface vehicles (USVs) for maritime security, ocean mapping and ocean data collection. The company uses Siemens Digital Twin technologies, such as the MindSphere IoT platform, which allows the collection of data on sea conditions. The company moved from a business model based on selling the product to a business model based on selling data collected by the USVs. Business customers can rent a drone a day to collect ocean data about specific oceans or regions. Then Saildrone provides customers with the requested data and handles the entire collection process. The USVs utilize machine learning models that run onboard GPU compute processors to provide real-time visual detection of targets that are otherwise not broadcasting their position. Since the company has completely changed its value offering, replacing products with drone rental, data collection and processing services, it can be classified as *advanced services* [32].

Another platform is Bosch IoT hub, which offers tools for digital twin management. The platform is constituted by three modules: (i) IoT device management that manage, update, control, and service your IoT devices throughout their entire life cycle, (ii) IoT data management & analytics that allows to collect, process, store, assess, and use your IoT data to the maximum and (iii) IoT edge and analytics Empower the intelligent edge and enable your devices for AIoT [33]. As a success case, Bosch reports the company HOLMER which has developed a remote diagnostics and maintenance package for its machines called EasyHelp 4.0 using the Bosch IoT hub. Service technicians use it to extract IoT data and learn more about the condition of farm equipment. In this way, the customer benefits from the possibility of remote diagnosis and maintenance and faster service. EasyHelp 4.0 is also connected to the *agrorouter*, the universal data exchange platform for farmers and contractors. This is claimed to allow relevant data to be conveniently transmitted online from the vehicle to a wide variety of endpoints. We consider that this solution can be classified as *intermediary services*, as the company's value proposition is focused not only on offering products and spare parts, but also offering remote maintenance services [33]. Another case reported by Bosch is the company Mann+Hummel. This company uses the Bosh platform to offer device fleet management services. By connecting an entire fleet of devices, fleet managers can remotely check the status of devices or compare the performance of individual devices and machines. It also allows for easy benchmarking across the entire fleet to identify best practices and machines with good/poor performance [33]. This service can be classified as *basic services* because it focuses on device connectivity and information sharing.

Ansys also developed a Twin Builder, which is a digital twin platform that incorporates machine learning capabilities. Ansys reports the company Electronic Cooling Solutions using the Twin Builder for thermal management of lithium batteries for electric cars. With this solution, Electronic Cooling Solutions optimized the product design and increased and shortened the product launch time. In addition, the company began to provide its customers with preventive maintenance services, and recommendations for a high-performance product designed. This service can be classified as a *basic service* because it aims to promote the sale of the product and the major risk is in the customer side [34]

General Electric Company also developed a Digital Twin that integrates analytic models that measure asset health, wear and performance. This company in partnership with Teledyne Controls, create a strategic to transform aircraft engine health monitoring by using the Predix platform and Teledyne's GroundLink® technology to apply data and analytics on continuous flight data to provide customers with more effective engine maintenance operations. Teledyne has three types of service packages: (i) Flight data analysis for maintenance and engineering, (ii) Flight data analysis for flight safety and risk management. Each of these services includes remote monitoring, trouble alarm message, report sharing. The company also provides access to thousands of data points owned by airlines collected every minute by onboard wireless fast access recorders (QARs), such as Teledyne's GroundLink Comm+, which can help equipment manufacturers improve analytics. and processes. In addition, the service enables the export of Fullflight data to third-party services [35]. This Smart PSS can be classified as *intermediate service* because the company offer condition monitoring services and advance data analysis.

Table 2 summarizes the examples discussed earlier according to PSS types and business models.

Table 2. Example of PSS

Smart PSS Category	Examples	Business Model
Base	<ul style="list-style-type: none"> - Thermal management solution using Asys Digital Twin technologies - Mann+Hummel- Fleet Management Service 	Product-Oriented
Intermediate	<ul style="list-style-type: none"> - HOLMER remote diagnosis and maintenance package using Bosch IoT hub. - Teledyne Controls uses GE digital twin to collect data and provided information 	
Advanced	<ul style="list-style-type: none"> - Saildrone used Siemens Digital Twin Technologies to change its business model from product center to data provider - Kone uses IBM digital technologies to supply a flow people management system. 	Customer-Oriented

Summarizing the principal PSS identify through the cases are: (i) Asset Remote monitoring (trouble alarm message, report sharing), (ii) Remote diagnosis and maintenance package, (iii) Risk Management (Failure Causes Analysis), (iv) Predict the product condition, (v) Fleet Management (remotely check the status of devices (eg location, health, usage) or compare the performance of individual devices and machines, (vi) Spare Parts Management, (vii) Provides access to external data, (viii) Allow connection to an universal data exchange platform that include data of different actors of the ecosystem.

3.3 Business Model Canvas for Smart PSS

To understand how companies transit from a product center business model to a services center business model an overview of its changes to different aspects of its business dimensions is needed. In that sense, Business Canvas Model (BMC) allows to simplify and systematize the business dimensions that explains how firms create, deliver and capture value [36].

Several authors have proposed the design of a business model to implement PSS, using BMC [37-42]. Based on these studies and the examples described above were identified changes associated to each of the business models dimensions for each type of Smart PSS BM (Table 3).

Table 3. Business Model Configuration for Smart PSS.

Business Model Dimensions	Product -Oriented	Customer-Oriented
Value proposition	Product Performance information sharing The customer continues being the main product responsible. Lower cost of product maintenance	Product Performance Guarantee Lower responsibility of product Lower cost of product maintenance
Customer segment	B2C or B2B	B2C or B2B New customer segments
Key activities	Human Resource training focus on services and digital technologies Some data processing capacity Definition of new process and reasonability for services area Improve of sharing information and customer support area	Human Resource training focus on services and digital technologies Organizational culture manage change Higher understanding of the customer behavior Higher data processing capacity Definition of new process and responsibilities
Key Resources	IoT infrastructure Cloud services CDT platform Human Resources with digital and analytics skills	IoT infrastructure Cloud services CDT platform Human Resources with digital and analytics skills AI technologies investment
Customer Relationship	Long-term relationships Sharing information and knowledge Value co-creation Interaction improvement	Risk Sharing Contracts Sharing information, knowledge Value co-creation Closer relationship with customers
Distribution Channels	Marketing campaigns Retail and sales training (service oriented) Non-physical channels (Remote Support, digital platform)	Marketing campaigns Retail and sales training (service oriented) Non-physical channels (Remote Support, digital platform)
Partem Network	IT-partern for infrastructure IT-parter for development Finantial Partners	IT-partern for infrastructure IT-parter for development Services provider (data analysis) Finantial Partners
Revenue Stream	Payment is based on a monthly or yearly fixed rate	Pay per use, pay per result, pay per service unit, pay per performance, availability, subscription.
Cost Structure	Initial investment on digital technologies and human resources Operational and Maintenance Cost	Higher initial investment Operational and Maintenance Cost

To implement product-oriented business model, the company would have to make changes in three principal dimensions of the business model: key resources, key

activities, and customer relationships (Fig.2) [37].

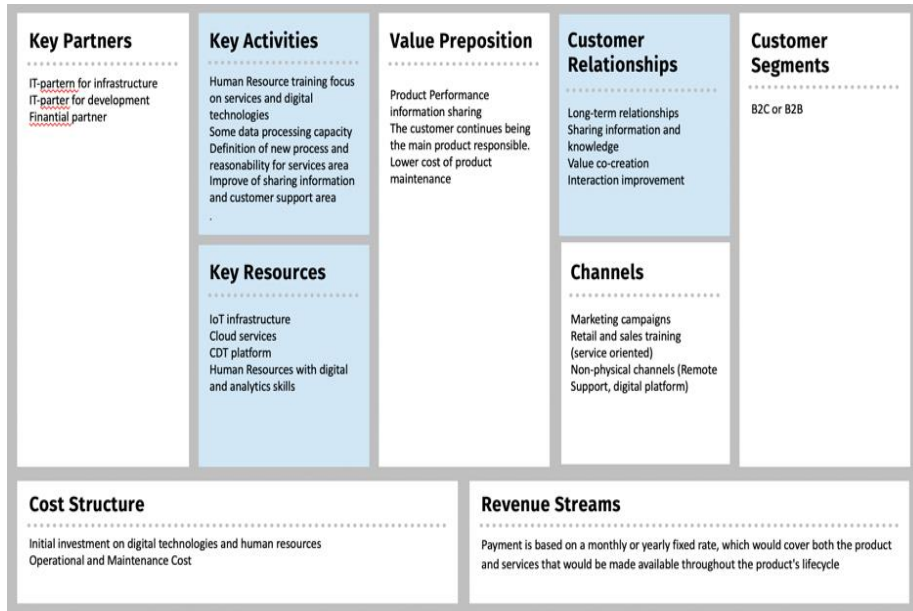


Fig 2. Canvas for Product-Center BM

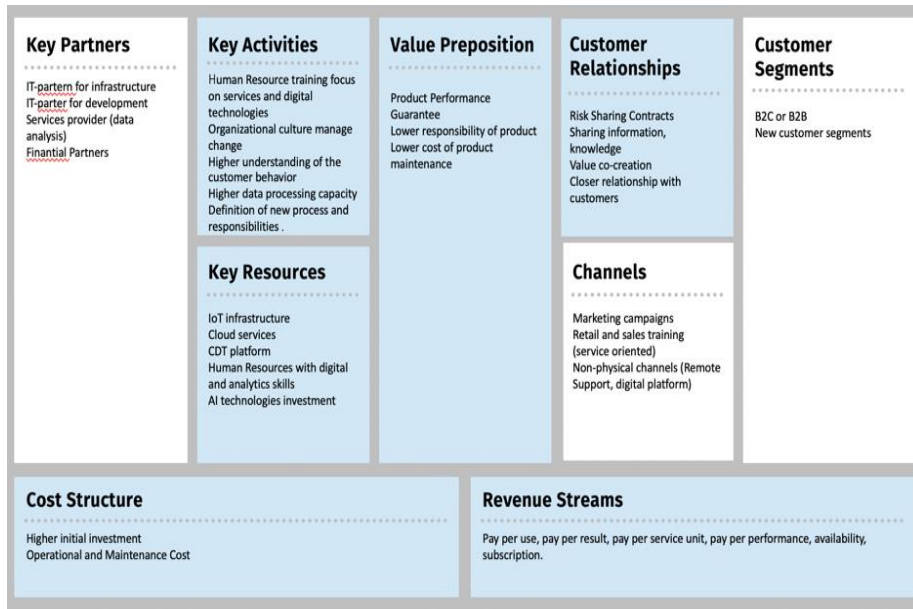


Fig 3. Canvas for Customer-Center BM

Moreover, in the case of Customer Business Model (Fig.3), companies will need to do major changes, principally in the dimensions of key activities, key resources, value proposition, cost structure, revenue streams and customer relationships [37].

4 Conclusions

The study proposed a theoretical model that aims to relate the different dimensions of the Smart PSS, with the capabilities provided by the cognitive digital twin. The model considers three different dimensions of Smart PSS (based, intermediate and advanced services) that will be enabled by the CDT. In addition, the model also contemplates two categories of business models, Product-Oriented and Customer Oriented. The business model orientation depends on several aspects such as the value proposition, the relationship with customers and the payment methods, among others. We also presented some digital twin platforms that are already in the market, and how companies are using these platforms to offer Smart PSS.

Another important conclusion that arises from the cases is the importance of collaborating with other partners to develop solutions., with several examples in this study considering more than one technology supplier to reach the company goal. In addition, it is possible to observe how several companies collect external data to integrate into the product's digital twin to improve analysis and service delivery. To do that companies use digital platforms where several ecosystem actors share data to improve their analysis.

Finally, in future research will be important to conduct qualitative studies to understand the mechanism that companies use to develop smart PSS based on CDT, focusing on the business model dimensions. Also, exploratory research could be developed to study the transformation path for companies to move from a product-center business model to a data-driven service-focused business model.

References

1. Zheng, X., Lu, J., & Kiritsis, D. (2021). The emergence of cognitive digital twin: vision, challenges and opportunities. *International Journal of Production Research*, 1-23.
2. Hyre, A., Harris, G., Osho, J., Pantelidakis, M., Mykoniatis, K., & Liu, J. (2022). Digital twins: representation, replication, reality, and relational (4Rs). *Manufacturing Letters*, 31.
3. Al Faruque, M. A., Muthirayan, D., Yu, S. Y., & Khargonekar, P. P. (2021). Cognitive Digital Twin for Manufacturing Systems. In *2021 Design, Automation & Test in Europe Conference & Exhibition* (pp. 440-445).
4. Li, H., Wang, G., Lu, J., & Kiritsis, D. (2022). Cognitive twin construction for system of systems operation based on semantic integration and high-level architecture. *Integrated Computer-Aided Engineering*, (Preprint), 1-19.
5. Ali, Muhammad Intizar, Pankesh Patel, John G. Breslin, Ramy Harik, and Amit Sheth. 2021. "Cognitive Digital Twins for Smart Manufacturing." *IEEE Intelligent Systems*, 36 (2): 96–100.
6. Semeraro, C., Lezoche, M., Panetto, H., & Dassisti, M. (2021). Digital twin paradigm: A systematic literature review. *Computers in Industry*, 130, 103469.

7. Zhou, G., Zhang, C., Li, Z., Ding, K., & Wang, C. (2020). Knowledge-driven digital twin manufacturing cell towards intelligent manufacturing. *International Journal of Production Research*, 58(4), 1034-1051.
8. Eirinakis, P., Lounis, S., Plitsos, S., Arampatzis, G., Kalaboukas, K., Kenda, K., Stojanovic, N. (2022). Cognitive Digital Twins for Resilience in Production: A Conceptual Framework. *Information*, 13(1), 33.
9. Rožanec, J. M., Lu, J., Rupnik, J., Škrjanc, M., Mladenčić, D., Fortuna, B., ... & Kiritsis, D. (2022). Actionable cognitive twins for decision making in manufacturing. *International Journal of Production Research*, 60(2), 452-478.
10. Abburu, S., Berre, A. J., Jacoby, M., Roman, D., Stojanovic, L., & Stojanovic, N. (2020, June). COGNITWIN–Hybrid and cognitive digital twins for the process industry. In 2020 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC). IEEE.
11. Pagoropoulos, A., Maier, A., & McAloone, T. C. (2017). Assessing transformational change from institutionalising digital capabilities on implementation and development of product-service systems: Learnings from the maritime industry. *Journal of Cleaner Production*, 166, 369–380.
12. Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of production economics*, 204, 383-394.
13. Frank, A. G., Mendes, G. H., Ayala, N. F., & Ghezzi, A. (2019). Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective. *Technological Forecasting and Social Change*, 141, 341-351.
14. Silva, H., & Soares, A. L. (2021). Digital Platforms as Enablers of Smart Product-Service Systems. In *Working Conference on Virtual Enterprises* (pp. 506-513). Springer, Cham.
15. Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British journal of management*, 14(3), 207-222.
16. Yitmen, I., Alizadehsalehi, S., Akner, I., & Akner, M. E. (2021). An Adapted Model of Cognitive Digital Twins for Building Lifecycle Management. *Applied Sciences*, 11(9), 4276.
17. Lu, J., Zheng, X., Schweiger, L., & Kiritsis, D. (2021). A Cognitive Approach to Manage the Complexity of Digital Twin Systems. In *Smart Services Summit*. Springer, Cham.
18. Vandermerwe, S., Rada, J., 1988. Servitization of Business: Adding Value by Adding Services. *European Management Journal* 6, 314–324.
19. Tukker, A., 2004. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment*, 13, 246–260.
20. Baines, T., Lightfoot, H., Smart, P., & Fletcher, S. (2013). Servitization of manufacture: Exploring the deployment and skills of people critical to the delivery of advanced services. *Journal of Manufacturing Technology Management*.
21. Cusumano, M. A., Kahl, S. J., & Suarez, F. F. (2015). Services, industry evolution, and the competitive strategies of product firms. *Strategic management journal*, 36(4), 559-575.
22. Matthyssens, P., & Vandenbempt, K. (2010). Service addition as business market strategy: identification of transition trajectories. *Journal of service management*.
23. Ayala, N. F., Paslauskis, C. A., Ghezzi, A., & Frank, A. G. (2017). Knowledge sharing dynamics in service suppliers' involvement for servitization of manufacturing companies. *International Journal of Production Economics*, 193, 538-553.
24. Lerch, C., & Gotsch, M. (2015). Digitalized product-service systems in manufacturing firms: A case study analysis. *Research-technology management*, 58(5), 45-52.
25. Abdel-Basst, M., Mohamed, R., & Elhoseny, M. (2020). A novel framework to evaluate innovation value proposition for smart product–service systems. *Environmental Technology & Innovation*, 20, 101036.

26. Zinke-Wehlmann, C., Frericks, S., & Kluge, A. (2021, November). Simulating Impact of Smart Product-Service Systems. In Working Conference on Virtual Enterprises (pp. 289-297). Springer, Cham.
27. Paschou, T., Rapaccini, M., Adrodegari, F., & Saccani, N. (2020). Digital servitization in manufacturing: A systematic literature review and research agenda. *Industrial Marketing Management*, 89, 278-292.
28. Marcon, É., Marcon, A., Ayala, N. F., Frank, A. G., Story, V., Burton, J., ... & Zolkiewski, J. (2022). Capabilities supporting digital servitization: A multi-actor perspective. *Industrial Marketing Management*, 103, 97-116.
29. Cenamor, J., Sjödin, D. R., & Parida, V. (2017). Adopting a platform approach in servitization: Leveraging the value of digitalization. *International Journal of Production Economics*, 192, 54-65.
30. Ardolino, M., Rapaccini, M., Saccani, N., Gaiardelli, P., Crespi, G., & Ruggeri, C. (2018). The role of digital technologies for the service transformation of industrial companies. *International Journal of Production Research*, 56(6), 2116-2132.
31. Greenfield, David. (2022). Digital Twin Applications by Small Companies. *Automation World*. <https://www.automationworld.com/factory/iiot/article/22171994/siemens-cloudbased-digital-twin-used-by-saildrone-and-nemos-garden>.
32. Jung, S., Ferber, S., Cramer, I., Bronner, W., & Wortmann, F. (2021). Bosch IoT Suite: Exploiting the Potential of Smart Connected Products. In *Connected Business*. Springer, Cham.
33. <https://www.ansys.com/products/digital-twin>
34. General Electric. (2016). GE Expands Predix Platform to Advance Industrial Internet Opportunities for Customers
35. Osterwalder, A., and Pigneur, Y. (2010). *Business model generation: a handbook for visionaries, game changers, and challengers*, John Wiley & Sons, Hoboken, New Jersey.
36. Barquet, A. P. B., de Oliveira, M. G., Amigo, C. R., Cunha, V. P., & Rozenfeld, H. (2013). Employing the business model concept to support the adoption of product-service systems (PSS). *Industrial Marketing Management*, 42(5), 693-704.
37. Orellano, M., Neubert, G., Gzara, L., & Le-Dain, M. A. (2017). Business Model configuration for PSS: An explorative study. *Procedia CIRP*, 64, 97-102.
38. Poepelbuss, J., & Durst, C. (2019). Smart Service Canvas—A tool for analyzing and designing smart product-service systems. *Procedia CIRP*, 83, 324-329.
39. Khan, M. A., & Wuest, T. (2019). Upgradable product-service systems: implications for business model components. *Procedia CIRP*, 80, 768-773.
40. Michalik, A., Möller, F., Henke, M., & Otto, B. (2018). Towards utilizing customer data for business model innovation: The case of a German manufacturer. *Procedia CIRP*, 73, 310-316.
41. Johansson, C., Elfsberg, J., Larsson, T. C., Frank, M., Leifer, L. J., Nilsson, N., & Söderberg, V. (2016). Urban Mining as a Case for PSS. *Procedia CIRP*, 47, 460-465.