Computers in Industry 142 (2022) 103730

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

# Context-awareness for the design of Smart-product service systems: Literature review

Angela Carrera-Rivera[a,*,1], Felix Larrinaga[a,2], Ganix Lasa[b,3]

[a] Mondragon Unibertsitatea, Faculty of Engineering, Loramendi 4, 20500 Arrasate, Spain
[b] Mondragon Unibertsitatea, Design Innovation Center (DBZ) - Faculty of Engineering Loramendi, 4, 20500, Arrasate

A R T I C L E I N F O

*Article history:*
Received 1 February 2022
Received in revised form 6 June 2022
Accepted 8 June 2022
Available online 27 June 2022

*Keywords:*
Smart-product service systems
Context-awareness
User-centred design
User experience

A B S T R A C T

Smart-Product Service Systems (S-PSS) emerge as a novel strategy to integrate smart products with advanced digital capabilities and their related e-services to satisfy user's needs in highly context-dependent environments. S-PSS has the potential to generate a transition towards more economically, ecologically and socially sustainable practices and business models due to its adaptive capacities. However, being able to exploit the digital capabilities of smart products and their services is still limited in design and even more to improve the user experience. For this reason, this study will focus on the Context-awareness capability that has been defined by multiple scholars as one of the most relevant properties that defines the smartness of a product. Following a systematic literature review approach, this work makes the following contributions: (1) it provides a bibliometric analysis using a cluster keyword map to analyze the most researched topics in S-PSS relevant to the design, user experience and analyze their connections; (2) an analysis of the case studies presented in the literature according to the life cycle of context-aware applications; and (3) establishes a research direction for the user experience and design of the S-PSS.



**Contents**



* Corresponding author.
*E-mail addresses:* aicarrera@mondragon.edu (A. Carrera-Rivera), flarrinaga@mondragon.edu (F. Larrinaga), glasa@mondragon.edu (G. Lasa).
[1] 0000–0001-8593–5961
[2] 0000–0003-1971–0048
[3] 0000–0002-2424–5526

https://doi.org/10.1016/j.compind.2022.103730
0166-3615/

## 1. Introduction

In the road to servitization, Product Service Systems (PSS) is a strategy to integrate products with specific related services that satisfy user's needs (Tukker, 2004). More companies are adopting PSS as a way to simultaneously maximize the value of the product and increase businesses' profits (Hallstedt et al., 2020). Furthermore, the COVID-19 pandemic accentuated the importance of servitization: the traditional manufacturing industry was affected and supply chains disrupted because of lockdowns in several geographic areas. Companies expected a high reduction in sales of products whereas a reduction in the sales of advanced services (e.g., remote condition monitoring, predictive maintenance, etc.) was comparably smaller (Rapaccini et al., 2020).

The term Smart Product-Service Systems (S-PSS) is relatively new, first being introduced by ValenciaCardona et al. (2014) as "smart products and its generated e-services into a single solution by embracing disruptive ICT." S-PSS are possible for the current advancement on digital technologies to transform business processes; this is also known as "digitalization" (Frank et al., 2019). Digital technologies can be used to deliver smart and interconnected services that can also interact with the physical world (IoT devices, sensors, etc.) and perform tasks involving data analytics, big data processing; and so forth.

S-PSS have been represented by several scholars as a "digital ecosystem" (Kuhlenkötter et al., 2017; Liu et al., 2018; Pirola et al., 2020) that integrates stakeholders, devices, and platforms and is characterized by its high complexity. Therefore, S-PSS require being able to capture the needs of multiple stakeholders in a collaborative process to create value (co-creation) (Zheng et al., 2019b). Must be able to react to multiple use environments with different contexts and be able to establish a *life-long partnership* (ValenciaCardona et al., 2014) between suppliers and customers through the services offered; where the User Experience(UX) can be a differentiator between competitors.

Context-awareness capability refers to the idea that devices or systems can react based on their environment, but also reason based on the user's current situation (Perera et al., 2013). ValenciaCardona et al. (2014) was one of the first to present the concept of S-PSS and point out the *"highly context-dependent"* nature of S-PSS design. In their study, the participants highlighted the importance of context to correctly define the value proposition and the aimed experience for the end-user. Similarly, Kammler et al. (2019) noted that the *smartness* from products came from *context-awareness* in multiple examined publications. Thus, the complexity of the multiple relationships involved in the S-PSS uses the context in interactions and operations as a factor to improve the performance and adaptability of the services provided.

The current paper aims to provide an insight into the current context-aware approaches focusing on several aspects of the design of S-PSS, including user-centred design (UCD) and UX as a cornerstone of user satisfaction and as relevant to the future of S-PSS scenarios (Dong et al., 2019). Furthermore, it sets the research agenda regarding context-awareness in the design of S-PSS by taking into account a review of case studies following the life cycle of context-aware applications.

The structure of the current work is as follows: Section 2 starts with the fundamental background related to S-PSS and its life cycle. Section 3 details the systematic literature review methodology, establishing the questions for this work and bibliometric analysis from the results. Section 4 explores the literature and presents UCD aspects in S-PSS including User Experience. Section 5 presents the literature related to Context Awareness in S-PSS while providing a general background. Section 6 gives a discussion answering the research question and establishing the connections of Context-Awareness in the design of S-PSS. Finally, Section 7 concludes this work.

## 2. Smart product-service systems

Smart Product-Service Systems(S-PSS) have been defined by several authors (see Table 1), who have established the key aspects of S-PSS, such as their relationships with multiple stakeholders, smart products, and related digital services. In this work, we take the definition from Zheng et al. (2019b) *"(S-PSS) is an IT-driven value co-creation business strategy consisting of various stakeholders as the players, intelligent systems as the infrastructure, smart, connected products as the media and tools, and their generated e-services as the key values delivered that continuously strives to meet individual customer needs in a sustainable manner".*

Therefore, S-PSS are established at the convergence between products with high levels of digitalization that serve customer-oriented business processes and related services. Thus, according to Zheng et al. (2019b), the digital capabilities are one of the clearest differentiators from traditional PSS, as seen in Fig. 1. Starting from intelligence capabilities, which denotes the ability to configure hardware elements to sense and capture information through the use of embedded systems and sensors integrated into products to capture data and react to their environment, this is the first step into digitalization. Then, the ubiquitous connectivity of smart products enabled for IoT technology and

**Table 1**
Definitions S-PSS.

| Definitions | References |
|---|---|
| "Smart products and its generated e-services into a single solution by embracing disruptive ICT." | (ValenciaCardona et al., 2014) |
| "A digital-based ecosystem of value creation characterized by high complexity, dynamics and interconnectedness among stakeholders." | (Kuhlenkötter et al., 2017) |
| "A platform service ecosystem, in which platform is made up of smart products and smart services, while multiple service systems constitute a service ecosystem." | (Liu et al., 2018) |
| "Digital-enabled business solution supplied within an ecosystem which provides economic and sustainable value to the customer by integrating into a unique offer intelligent products with data-enabled services allowed by physical and digital infrastructures" | (Pirola et al., 2020) |
| "Smart PSS could be regarded as cyber-physical products (CPP) which are described as a physical product that offers ICT-enabled services via either a built-in or an external network connecting device, allowing users to use the product functionality and communicate information during its use phase for acquiring complementary service support" | (Chou, 2021) |

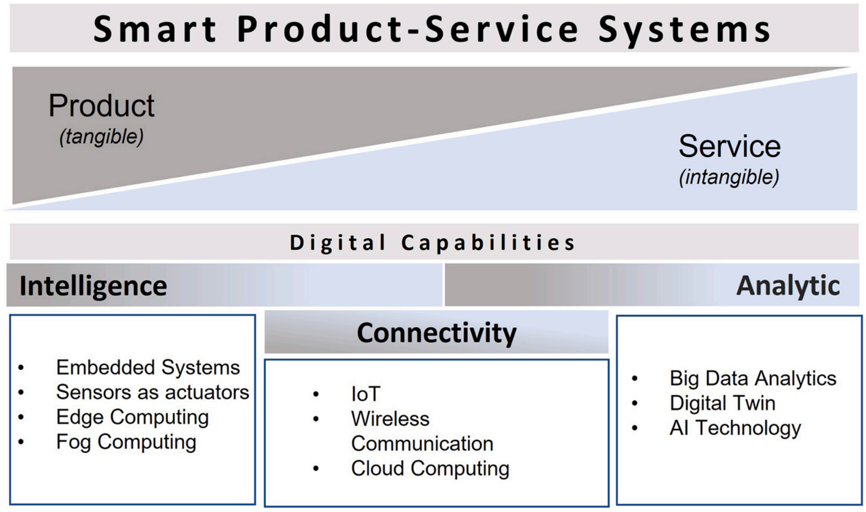


**Fig. 1.** Smart product service system graphic description.

wireless communications, which are fundamental for service providers to collect data and allows to improve the processing using cloud computing, furthermore, allows multiple devices to interact with each other. Finally, the analytic capability is responsible for converting the data from the deployed intelligent and connected products into valuable insights and actionable directions for businesses, which is enabled by technologies such as *big data analytics*, *Digital twins* and *Artificial Intelligence* (Lenka et al., 2017). However, S-PSS still shares the core business foundations of the traditional PSS, which can be classified into three main categories: Product-oriented, Result-oriented, and Use-oriented (Tukker, 2004).

### 2.1. S-PSS life cycle

It is possible to analyze S-PSS using the existing traditional product life cycle but here with certain important differences. The product life cycle is a sequence of phases that Kiritsis (2011) divided into three main epochs: the Beginning-of- Life (BoL), Middle-of-Life (MoL), and End-of-Life (EoL). The BoL starts with the designing stage, when a product is designed according to certain requirements and then manufactured. The MoL is related to the product's use, service, and repair. Finally, the EoL provides the approaches to reverse logistics, for instance, recycling, reusing, remanufacturing or disposal.

The design stage starts with the requirement elicitation process, in which customers' demands are identified, but in contrast with the traditional processes, designers can rely on data from user behaviour and demands that can be also obtained in the manufacturing and usage stages. Services can be classified as product-independent services (e-services) and digitalized services that depend on the smart capabilities of the physical product, such as monitoring, control, optimization, and autonomy. For digitalized services, digital twins or augmented reality can be a game-changer to make more accurate decisions (Zheng et al., 2019b).

The usage stage is very different from traditional PSS because of the smart capabilities of connected products and related services. Starting from smart operation and maintenance, being able to assess the performance of PSS and monitoring the operations. On the other hand, smart reconfiguration is the modification of a product to fulfil new requirements, here being able to react to new context.

Finally, the EoL is characterized by various scenarios such as reuse of the product with refurbishing or remanufacturing, recycling, or disposal. In traditional product sales, information loops are removed after the sale. S-PSS can reclaim the information, providing data to manufacturers and designers (Kiritsis, 2011). In Alcayaga et al. (2019), the term "smart-circular system" is introduced integrating the terms of Smart-PSS and circular economy. With new capabilities generated in Smart PSS, it is possible to improve the processes that lead to better use of resources at the EoL.

As described before, this new perspective on the product lifecycle does not necessarily change the application or interpretation of the phases, instead highlights the development of S-PSS as an incremental process. In contrast with the traditional product life cycle, where each phase is clearly divided, in S-PSS, it is necessary to use a holistic perspective where each phase is interconnected with the others (Wuest and Wellsandt, 2016).

S-PSS have received increasing interest in the literature, especially in the design stage. Many approaches have been presented to capture stakeholder requirements by using different engineering methodologies (TRIZ, Quality Function Deployment (QFD), Kansei engineering (KE), Axiomatic Design (AD), Blueprint Design, adaptable design, etc.) (Cong et al., 2020b, 2020a; Chou, 2021), or by exploiting user data or opinions during the usage stage (Wang et al., 2020). On the other hand, UCD tries to understand and empathize with potential users from the conception of the S-PSS, to improve the UX by solving their needs early on. Because of the multiple elements involved in the design, it may be difficult to establish a research direction based on the gaps and current challenges. Furthermore, it is important to identify where the "context-aware" capability has been used in S-PSS and where it could be used in the future. To realize our objective, the following section presents the Systematic Literature Review (SLR) protocol, which allows for gathering a body of knowledge and further analysis.

## 3. Literature review methodology

An SLR is used to identify, evaluate and summarize the available research relevant to a particular group of research questions or identify any gaps in current research to suggest areas for further investigation (Kitchenham and Charters, 2007). Parsif.al[4] is an online tool that supports researchers in developing SLR, especially in the context of Software Engineering (Anon (2021), and it was used in the current review to plan and manage the several stages of the SLR (Planning, Study Selection, Quality Assessment and Data Extraction).

The goals of this review are as follows:

[4] https://parsif.al/

**Table 2**
PICO Criteria.

| | | |
|---|---|---|
| *Population* | Application area or Industry domain | Smart-Product Service Systems |
| *Intervention* | Methodology/tool/technology that addresses an specific issue | *Context-awareness* capability |
| *Comparison* | Methodology/tool/technology in which the intervention is being compared | –Not applicable– |
| *Outcome* | Outcomes relate to factors of importance to practitioners | User-Centric Design and UX of S-PSS |

1. Explore the state of the art in the design and UX of S-PSS
2. Explore the state of the art of *Context-Awareness* approaches for the design and UX of S-PSS

### 3.1. Research questions

Research questions set the focus for identifying the studies and the extraction of the data (Wohlin et al., 2012). The PICO (Population, Intervention, Comparison and Outcome) mnemonic was used to break down the goals of the review into searchable keywords and help in formulating the research questions (Petersen et al., 2015). PICO has been broadly used in medical and social sciences, to encourage the researchers to consider the components of the questions (Petticrew and Roberts, 2008). Kitchenham and Charters (2007) provided a detailed guide for SLR in the context of software engineering, establishing a correspondence of PICO elements in this context. Table 2 describes the elements and their use in this review.

Three questions are established based on the PICO criteria, the definition of S-PSS and the goals established. .

(1) What are the connections of UCD, UX and Context-Awareness for S-PSS?
(2) How has *context-awareness* capability been used in the design of S-PSS?
(3) What are the current gaps and challenges in the design of S-PSS to satisfy user needs and improve UX?

### 3.2. Search query string

Keywords and synonyms were chosen based on the PICO criteria, including the following main terms: *Smart Product-Service Systems*, *Context awareness*, *Service Design* and *User Experience*. Each set of searches was performed on the databases: Scopus and Web of Science, which were selected for their advanced search capabilities. Scopus and Web of Science deliver the broadest interdisciplinary content. The search strings used for each database can be found in Table 3, and have been used on all titles, abstracts and keys or metadata. Parsif.al was used in this stage to handle any duplicates found.

### 3.3. Study selection and quality assessment

For the study selection, articles from 2015 to December 2021 were collected, since the term, Smart-PSS was first presented in late 2014 by ValenciaCardona et al. (2014). Articles were excluded based on titles and abstracts, here following the exclusion criteria (Table 4). When in doubt, the document was skimmed and accepted or rejected according to these criteria.

Accepted papers were fully read and passed the quality assessment with the following questions: .

1. Is it related to Context Awareness in S-PSS or PSS?
2. Does the article propose a framework, tool or methodology?
3. Is it related to Service Design in S-PSS or PSS?
4. Is it related to UX, User-centric Design in S-PSS or PSS?
5. Is it related to industry (Industry 4.0)?
6. Do the researchers discuss any problems (limitations, threats) regarding the validity (reliability) of their results?
7. Is there a clear statement (definition) of the aims (goals, purposes, problems, motivations, objectives and questions) of the research?

Each paper can have a maximum score of 7 and the overall cutoff score was 4.5. Fig. 2 shows the process flow of the SLR adopted in the current paper.

### 3.4. Bibliometric analysis

This section consolidates the data from the bibliographic records of the 53 accepted papers. Analysis of the selected items can be summarised as follows:

1. *General distribution of the publications:* In total, the literature review includes 53 papers, which corresponds to 32 articles and 21 conference papers. Fig. 3a presents the journal and conferences distribution in descending order. *Advanced Engineering Informatics* and *Journal of Cleaner Production* have the highest number of contributions for journals, whereas *Procedia CIRP* and *Advances in Transdisciplinary Engineering* rank in the first places for

**Table 3**
Identified papers by database.

| Database | Query | Nº Results |
|---|---|---|
| *Scopus* | TITLE-ABS-KEY ( "SMART PRODUCT SERVICE*" OR "SMART SERVICE SYSTEM*" OR "PRODUCT SERVICE SYSTEM" ) AND PUBYEAR > 2015 AND ( TITLE-ABS-KEY ( "CONTEXT AWARE*" ) OR TITLE-ABS-KEY ( "SERVICE DESIGN" OR "USER EXPERIENCE" OR "USABILITY" OR "USER CENTRED DESIGN" ) ) AND ( LIMIT-TO ( DOCTYPE,"ar" ) OR LIMIT-TO ( DOCTYPE,"cp" ) ) AND ( LIMIT-TO ( LANGUAGE,"English" ) ) | 160 |
| WoS | (TS= ( "SMART PRODUCT SERVICE*" OR "SMART SERVICE SYSTEM*" OR "PRODUCT SERVICE SYSTEM" ) AND ( TS= ( "CONTEXT AWARE*" ) OR TS= ( "SERVICE DESIGN" OR "USER CENTRED DESIGN" OR "USER EXPERIENCE" OR "USABILITY" ) )) | 92 |

**Table 4**
Inclusion and Exclusion Criteria.

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| • Articles that include at least 2 of the keywords in title, abstract, or keywords<br>• Papers that address RQ1, RQ2 or RQ3 | • Articles published prior to 2015<br>• Articles that are not written in English<br>• The paper is a form of grey literature, e.g., technical report or dissertation.<br>• Article not relevant to at least 2 keywords |

conferences. Fig. 3b presents the distribution of article types, divided by both theoretical and empirical research. Theoretical research focuses on abstract ideas, concepts, and theories built on literature reviews (Marczyk et al., 2010). Theoretical articles account for 11 papers (around 21%), Review papers account for six papers, which include SLR papers (2 articles) and traditional literature review papers (4 articles). Empirical research (67% of the articles) uses scientific data or case studies for explorative, descriptive, explanatory, or measurable findings. The contributions of these works have been divided into five categories, where the largest contributions corresponds to frameworks (15 articles), followed by development or design approaches (12 articles). Frameworks provide a general and flexible structure to a system, whereas development or design approaches present a description of the steps for creating a specific prototype or software.

2. *Case Study Distribution:* From the empirical research, 31 case studies were found (Appendix A), and 15 case studies followed a *User-Centred Design* (UCD) approach. Fig. 4 presents the distribution of the industrial application sector in these case studies, which are divided into four sectors: development of e-health and welfare S-PSS(53%), smart home applications and devices (33%), vehicles with digital services (7%) and manufacturing that are related to S-PSS used on the shopfloor or devices used in manufacturing (i.e. 3D printers)(7%). Section 4 will discuss the findings. Fig. 5 presents the distribution of 20 case studies found in the literature that is related to “context-awareness” and do not necessarily follow a UCD approach. Similarly, there is manufacturing; e-health and welfare; smart city; educational devices and services related to products. Section 5.2 will describe the more representative case studies.
3. *Papers distribution by year:*Fig. 6 presents the distribution of papers per year and linear trend. This figure shows a consistent increase in the interest in S-PSS over the years, which is expected to keep increasing. The figures in Appendix A report the industrial application sector of case studies by year (Figure A.12a). The *E-health and welfare* sector presents an increase in the early years and consistency from 2020 and 2021 in case studies in this area. Similarly in context-awareness applications (Figure A.12c), followed by the *manufacturing* sector. Especially case studies following a UCD approach (Figure A.12b), demonstrate a major increase in the *E-health and welfare* sector in 2021, which indicates the relevance of understanding user needs for end-consumers of these S-PSS types (B2C).
4. *Keywords analysis:* The indexed and author keywords were extracted, the text was normalized (removing white spaces and symbols and converting to lowercase) using Python programming language. Following this, a cluster map was created from the author and indexed keywords that repeated three times or more, here using the VOSViewer software (Fig. 7). VOSViewer (Van Eck and Waltman, 2010) allows for developing cluster maps based on bibliographic data. Node size is representative of the number of papers related to the keyword, and lines represent the links among keyword terms that have a minimum strength of one (link with another term). The first recognizable cluster (blue) corresponds to terms like *product-service system*, *product design* and *service design*. However, product design has received more attention. The second cluster (red), corresponds to smart product service systems, where keywords like *user experience* and *user-centred design* are encountered, but also characteristics like *closed loop design* or *advance information*. The third cluster (green) corresponds to context awareness, which is related to terms like *artificial intelligence*, *cyber physical systems* but also to *sustainability* and *sustainable development*, which indicates the potential applications. In this cluster, there is not a relationship yet between *user experience* and *context awareness*. Finally, the fourth cluster represents *value co creation* (25% keyword occurrences), which is related to terms like *requirements elicitation*, *requirements engineering*, representing in joint 25% of the occurrences in the cluster. This is followed by *knowledge management* (12.5%) and *data driven design* (9.375%).

## 4. User-centred design in S-PSS

Based on the SLR process, this section outlines the key aspects of service design and UX in S-PSS, including the definitions, research objects and technical and application aspects. As an ecosystem, S-

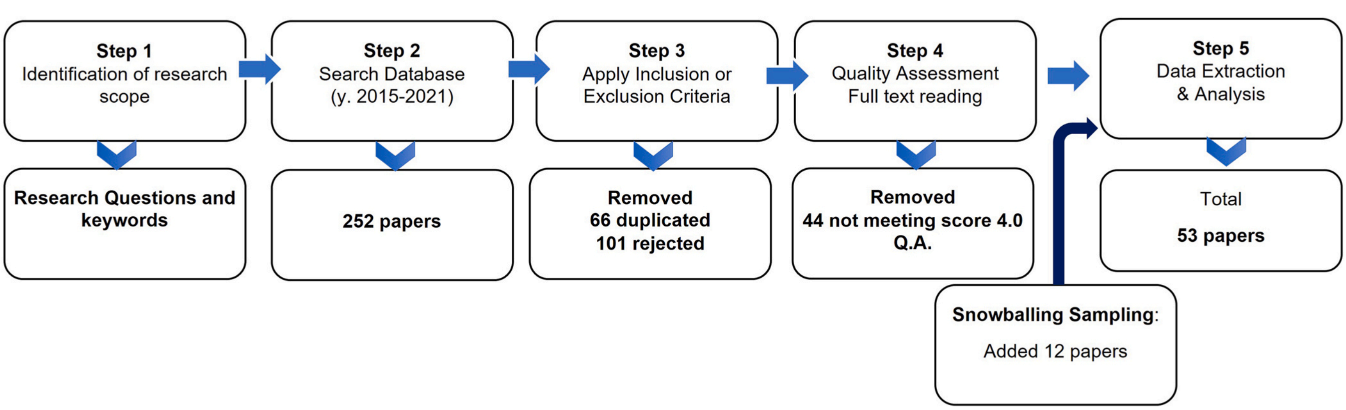


**Fig. 2.** SLR process.

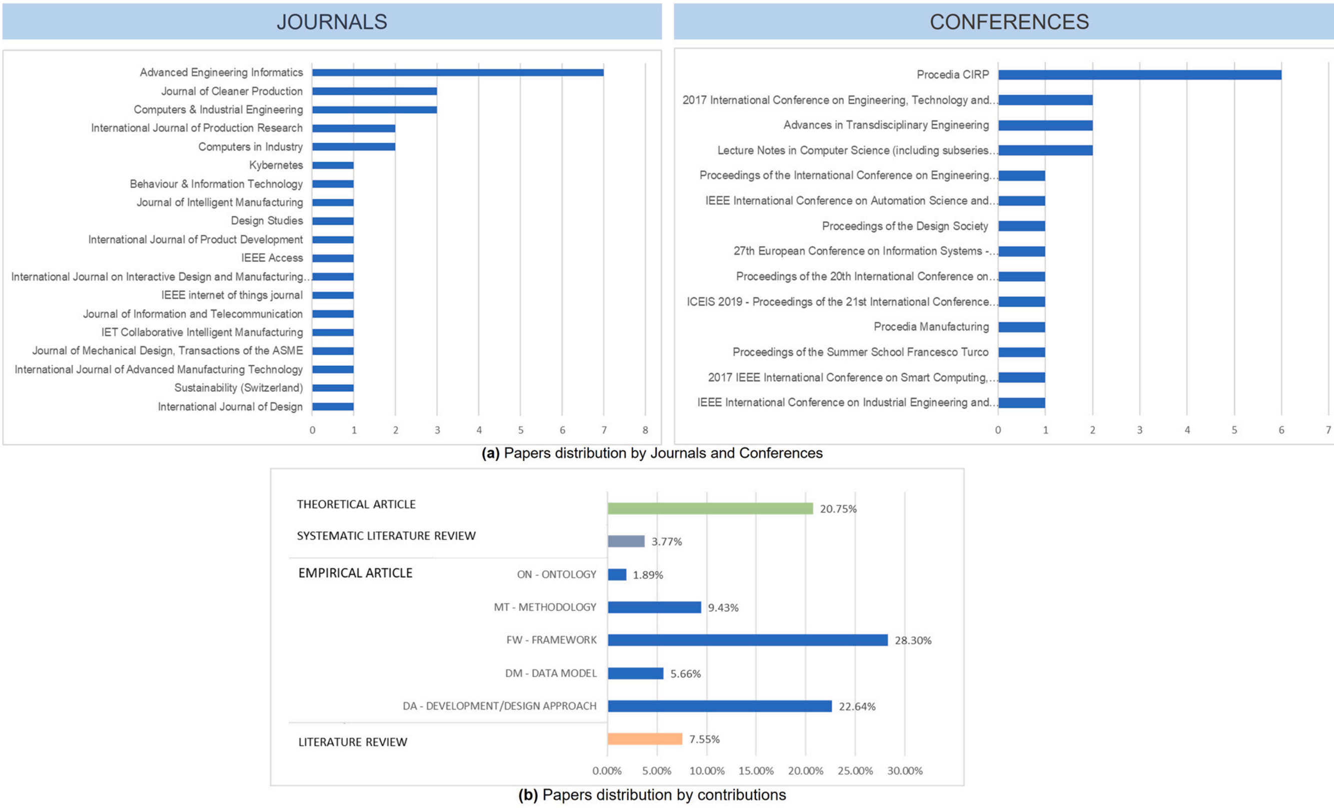


**Fig. 3.** Papers distribution.

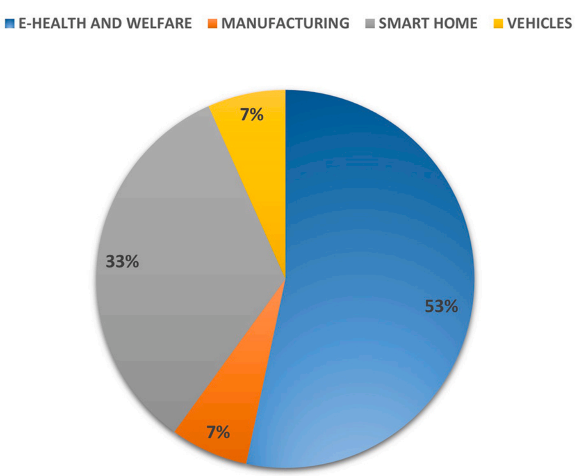


**Fig. 4.** Industrial Application Sector in UCD case studies.

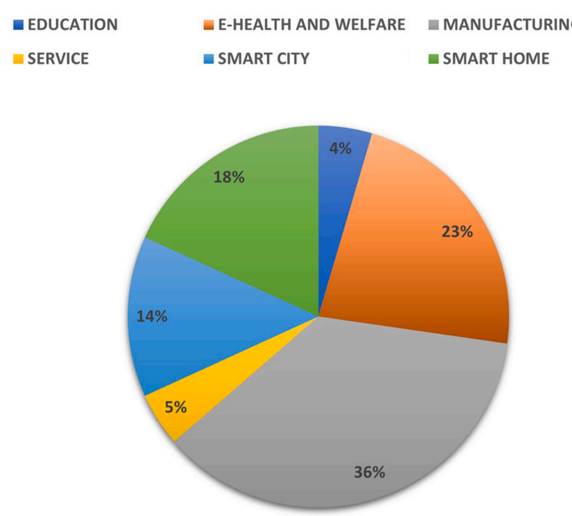


**Fig. 5.** Industrial Application Sector in Context-Awareness case studies.

PSS present the challenge of combining both product and service into one value proposition. From a product perspective, Smart Connected Products (SCPs) include self-X behaviours (self-awareness, self-reconfigurable, etc.), embeddedness and connectivity (Kammler et al., 2019). From a service perspective, S-PSS offers digital services that can be independent or dependent of the product and powered by technologies like digital twin or Augmented Reality (AR) (Zheng et al., 2019b). However overall, S-PSS should respond to the needs of multiple stakeholders to be sustainable (economically, socially and environmentally). The following subsections will describe the user-centred aspects of the design.

### 4.1. Service design and data-driven value co-creation

Service design is a multidisciplinary and human-centred methodology whose goal is to bring new services ideas to life by better understanding of the interactions among people, institutions, and technological systems (Costa et al., 2018). Zheng et al. (2019b) state

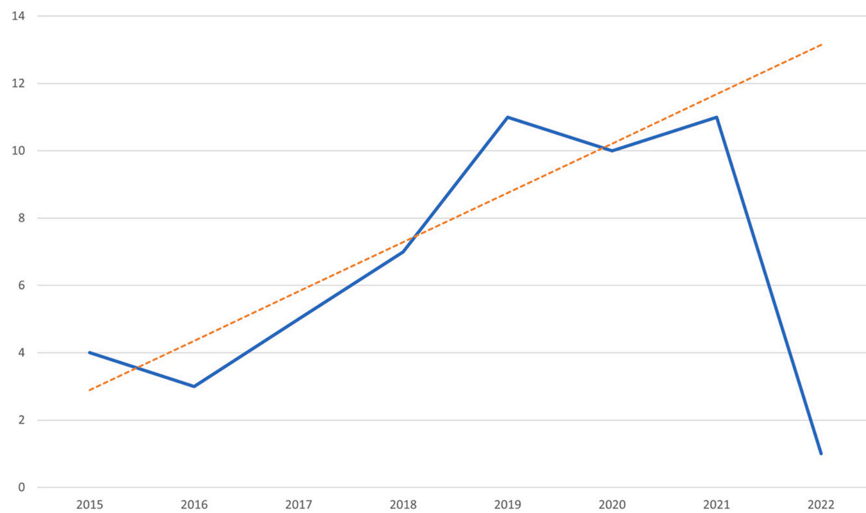


**Fig. 6.** Papers distribution by years.

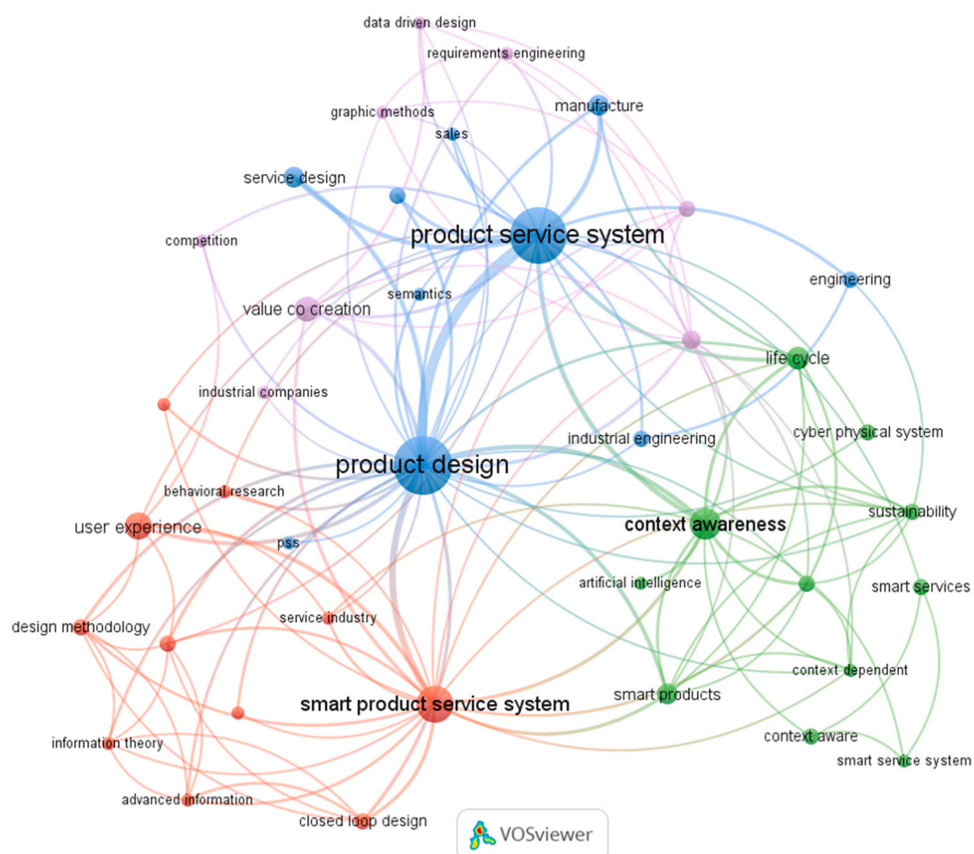


**Fig. 7.** Keywords cluster map.

that S-PSS follows the Service-Dominant (S-D) logic, a fundamental pillar of Service Design, that holds a "value co-creation" view indicating that user experiences, context and multistakeholder participation create innovative business value propositions (Wetter-Edman et al., 2014). In manufacturing industries, more companies are evolving towards servitization. Costa et al. (2018) stated that companies tend to overlook the customer experience and that the views of PSS are only coming from within the organization; the authors proposed an integrative approach towards PSS based on service design and S-D logic, here using qualitative research and several design artefacts spread out in four stages: exploration, creation, testing, and planning implementation. Similarly, Liu et al. (2018) proposed a value co-creation framework for S-PSS based on the principles of S-D logic highlighting the need for a personalized customer experience and creating value through the entire S-PSS life cycle. The framework includes four stages: co-exist, co-design, co-implement and co-evaluate. However, as Cong et al. (2020b) noted, data-driven value co-creation is a particular characteristic of S-PSS.

**Table 5**
Co-creation roles (Pezzotta et al., 2017).

| Co-Creation Role | Related Work |
| --- | --- |
| co-ideators: Users contribute new ideas | (Zheng et al., 2019a; Chou, 2021; Li et al., 2020a, 2021; Zhou et al., 2022) |
| co-design: User customization of a specific product or service | (Zheng et al., 2017) |
| co-innovators: Users can help with the development of new concepts | (Zheng et al., 2019a; Hribernik et al., 2017) |
| co-evaluators: Evaluation of ideas obtained through co-ideation process. | (Wang et al., 2021a; Mourtzis et al., 2018) |
| co-testers: Users test new offerings almost ready to be launched | (Seo et al., 2016; Bu et al., 2021) |
| customers as experience creators: Providers can generate richer experiences for customers using preferences and perceptions. | (Zheng et al., 2017; Zhou et al., 2022) |

The ability to capture user-generated data in real time should be an important part of the design process, and it is a way of identifying and evaluating customer needs. Customers may have different roles as co-creators in the different phases of the S-PSS lifecycle: co-ideators, co-innovators, co-evaluators, co-testers or customers as experience creators (Pezzotta et al., 2017).

Table 5 presents the description of each role and associated work according to the literature.

### 4.2. Closed-loop design

Closed-loop design has been described as a unique characteristic of S-PSS (Wang et al., 2019b; Cong et al., 2020b), because it is not limited to the design stage and can be extended to all phases of the lifecycle in a more holistic approach. Furthermore, as ValenciaCardona et al. (2014) stated, S-PSS developers should be prepared for life-long evolution. Cong et al. (2020b) depicted four phases of "closed-loop design". In each phase, the opportunities for value co-creation by users and customers, here with a data-driven perspective, were identified, as seen in Fig. 8:

(1) Requirements analysis phase: User requirements need to be identified, collected and identified. In this phase, customers may have the role of co-ideators. In service design, studies have alluded to the role of co-ideators through the automatic identification of requirements. For instance, this has been done by processing the descriptions of user experiences made in natural language (Li et al., 2020a, 2021). It is also possible for users to participate as experience creators if behaviour and cognitive factors are included in the analysis.
(2) Innovative design phase: Through the use of innovative prototypes, it is possible to later analyze the fulfilment of requirements and customer needs.
(3) Design evaluation: This evaluation should consider different perspectives, the sustainability aspects, value proposition and customer value. Customers can participate as co-evaluators. Here, Wang et al. (2020) proposed an approach for the concept evaluation of service bundles using sentiment analysis of customer opinions. An evaluation of usability and user experience is also necessary, and users take the role of co-testers, in which the

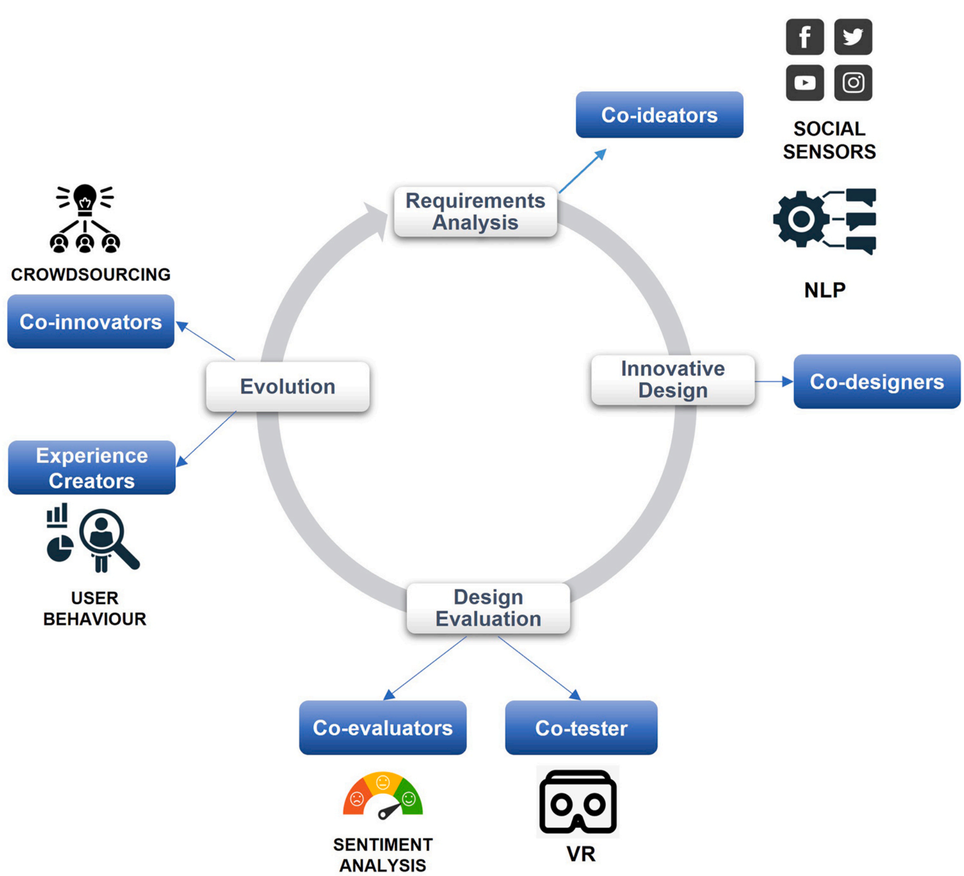


**Fig. 8.** Co-creation roles and Closed-loop design.

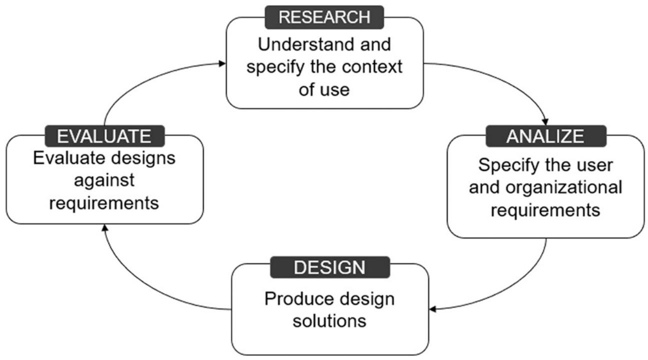


**Fig. 9.** UCD process as depicted by ISO 9241–210.

use of virtual reality or augmented reality can produce immersive and more realistic experiences.

(4) Evolution phase: This phase represents the iterative and self-adaptive aspect of S-PSS, where service models or product adjustments can be triggered by the specific context (Cong et al., 2020b). In this phase, users can take the role of co-innovators. Zheng et al. (2019a) proposed a hybrid crowdsensing approach using user-generated and product-sensed information to predict design actions and incentives for users of smart-water dispensers. The role of experience creator in a data-driven manner highlights the use of data behaviours for S-PSS customization.

### 4.3. UX in S-PSS

Functional requirements should be accompanied with cognitive and emotional requirements concurrently (Zheng et al., 2017). Whereas service design is more related to the strategic aspect of value creation, UX, as defined by ISO 9241–210, is the result of *"a person's perceptions and responses from the use and/or anticipated use of a product, system, or service"* (Iso, 2010). UX is a result of the internal state of the user, the characteristics of the designed entity and the context features where the interaction occurs (Hassenzahl and Tractinsky, 2006). A user's internal state is represented by aspects such as predispositions, expectations, needs and mood, which makes the user experience unique. The characteristics of the designed entity refer to the purpose, usability and functionality, where the general usability criteria from the ISO 9241–210 standard are considered a baseline (Iso, 2010). From an industrial perspective, it is necessary to address that UX for the workplace can lead to different UX goals. Kaasinen et al. (2015) defined UX at work as *"The way a person feels about using a product, service, or system in a work context, and how this shapes the image of oneself as a professional"*.

In the S-PSS, the user experience is characterized by feelings of *customer empowerment*, *the individualization of services*, *the sense of ownership*, and an *individual and shared experience* (Valencia et al., 2015). As *experience creators*, customers and users can be involved in the solution conceptualization, hence supporting better customization (Pezzotta et al., 2017).

### 4.4. User-centred development approaches in S-PSS

User-centred development approaches take users' needs and participation as the centre of the co-designing development process to improve user acceptance (Ngoc et al., 2021). As a principle, UCD tries to address and improve the entire user experience, provides a competitive advantage and contributes towards sustainability objectives (Iso, 2010). According to ISO 9241–210 (Iso, 2010), UCD consists of four stages: understand and specify the context of use, specify user requirements, produce design solutions that meet these requirements and evaluate; the general process has an iterative nature that is repeated until the expected results have been obtained (see Fig. 9).

Chang et al. (2019) presented a case study for a smart pillbox directed at the elderly; using behavioural analysis and the interviews, they performed a user analysis not only to capture their specific requirements but also to understand the physiological, cognitive, and behavioural dimensions. Similarly, Jia et al. (2021) used behavioural analysis and experience maps for the development of a smart rehabilitation assisting device. In both cases, current users' problems, popularly denominated 'pain points' usually highlight service opportunities. Here, cloud-based services were developed according to the found needs. Non-engineering approaches and qualitative tools (i.e., observation, interviews, experience maps, etc.) are broadly used by UX designers at the very early stage of design for user research, to understand the context of use and users involved.

Validation of the user experience is a crucial step in which surveys and observations are an easy way to obtain feedback to measure usability and UX. Jia et al. (2021) evaluated the usability based on three aspects: functionality, perceived usability and appearance. However, questionnaires, interviews and observation can also be subjective or limited to participants' perceptions or personalities. Methods to avoid the subjectivity include eye-tracking which is broadly used by designers for its ease of use; physiological measurement data, such as electrocardiogram (ECG), electroencephalography (EEG) or fNIRS which help designers understand the cognitive process; virtual reality (VR) which can provide a more realistic environment, reducing the physical constraints for

**Table 6**
Methods and tools in UCD approaches.

| Needs | Methods | User-Centric Design Phases | | | |
|---|---|---|---|---|---|
| | | Research | Analyze | Design | Evaluate |
| Realistic Environment. Reduce physical constraints | • Virtual Reality (Seo et al., 2016; Bu et al., 2021; Dong and Liu, 2018)<br>• Augmented Reality (Seo et al., 2016) | | | X | X |
| Ease of Use | • Lo-fi prototype (Jia et al., 2021; Chang et al., 2019; Dong and Liu, 2018)<br>• Hi-fi prototype (Jia et al., 2021; Chang et al., 2019; Li et al., 2020a) | | | X | X |
| Quantitative Analysis | • Surveys (Chang et al., 2019; Jia et al., 2021; Zheng et al., 2017) | X | X | | X |
| Qualitative Analysis | • Interviews (Chang et al., 2019; Jia et al., 2021; Li et al., 2020a)<br>• Observation (Chang et al., 2019; Jia et al., 2021) | X | X | | X |
| Understand behaviour | • User Mental Model (Dou and Qin, 2017)<br>• User Journey Map (Chang et al., 2019; Jia et al., 2021; Lim and Kim, 2017; Zhou et al., 2022) | X | X | | X |
| Cognitive Analysis | • Brain Activity - Functional near-infrared Spectroscopy (fNIRS), Electroencephalography (EEG) (Bu et al., 2021)<br>• Eye tracking (Dou and Qin, 2017; Zheng et al., 2017) | X | X | | X |
| Physiological Analysis | • Electroencephalography (EEG)<br>• Electrocardiogram (ECG) (Dou and Qin, 2017) | X | X | | X |

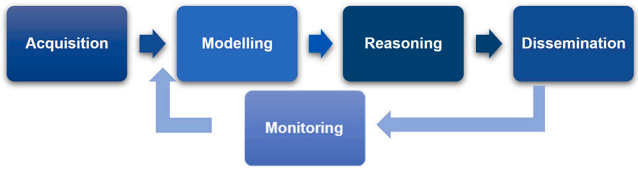


**Fig. 10.** Context Life Cycle.
Adopted from Perera et al. (2013).

understanding user behaviour (Dou and Qin, 2017. For instance, Bu et al. (2021) developed a VR S-PSS for a rowing machine; using VR and fNIRS, they captured the information generated by the devices and the brain signals of the participants, which were then measured through a metric specially chosen for the evaluated task. Seo et al. (2016) proposed a hybrid evaluation method for smart home services based on VR and AR prototypes; both prototypes were evaluated for possible consumers and have similar efficiency, ease of use and perceived usefulness. In the study, participants stated that AR provided a more natural experience of the smart home, but VR was more immersive, even though it was also more physically and mentally stressful. Dou and Qin (2017) obtained physiological data from several sensors including ECG and EMG from elderly people combined with environmental information, to build a user mental model to better understand the experience of a smart TV S-PSS. User mental models also help designers to build new products and services.

Dong et al. (2019) emphasized that the existing research is mostly focused on evaluating the UX and proposed an information model that captures and represents the elements intervening in the UX of S-PSS, such as users, scenarios that are the sources of context, tangible products, intangible services and the sequence of interactive actions; the model was tested using a graph database that helped designers to organize information more systematically. Context-Based activity modelling is another tool for modelling the activity, the intervening actor and the context where services are used or needs occur (Lim and Kim, 2017; Kim and Hong, 2019).

Table 6 summarizes the different methods and tools found on user-centred approaches for S-PSS and the needs they covered.

## 5. Context awareness

The term "context-aware" was first used by Schilit and Theimer (Schilit and Theimer, 1994) in 1994 as the "ability to discover and react to changes in the environment". Since then, it has solidified as a core feature of ubiquitous computing. Context was defined by Abowd et al. (1999) as "any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves".

In general, a context-aware system uses context to deliver information and/or services relevant to a user's task (Abowd et al., 1999). Thus, a context-aware system does not necessarily imply automatization or real-time processing, instead, it refers to the ability to respond to context. There are three main features that a context-aware application can support: .

- Presentation: Context can be used to resolve what services or information need to be presented to the user.
- Execution: Automatically execute services based on a context evaluation
- Tagging: The data of multiple sensors and sources need to be fused for further analysis and interpretation.

### 5.1. Context life cycle

Perera et al. (2013) defined four general steps in the context life cycle as a way to describe the process of developing context-aware applications. Fig. 10 presents the context life cycle but includes the *Monitoring* phase to support continuous evolution of the application. The first step is *Context Acquisition*, which refers to data that needs to be acquired from different sources (i.e. sensors, cps, databases, etc). In Context Modelling, the collected data needs to be represented in a meaningful way. Then, in Context Reasoning, data are processed to provide useful information and insights (context). The Context Dissemination phase distributes context to consumers, which can be end-users or other applications. Finally, Context Monitoring is a stage not broadly represented and should be considered after dissemination because context may change at some point. Systems or applications have to be able to identify changes and update the models accordingly.

Table 7 summarizes each step of the context lifecycle with the associated techniques (Perera et al., 2013).

**Table 7**
Context life cycle.

| Phase | Techniques |
|---|---|
| Acquisition: Getting data from sensors | • Event based<br>• By type of sensors: physical, logical, virtual<br>• By Acquisition process. |
| Modelling: representing data into meaningful units | • Key-Value pairs<br>• Object Based<br>• Ontology Based<br>• Graph Based |
| Reasoning: Deducting new information from multiple data sources. | • Supervised Learning<br>• Unsupervised Learning<br>• Ontology Based<br>• Fuzzy Logic<br>• Neural Networks |
| Dissemination: Distribution of new information or services to entities | • Query Based<br>• Publish and subscribe |
| Monitoring: Identify changes and update models accordingly | • Clustering Analysis<br>• Time-series analysis<br>• Reinforcement Learning |

### 5.2. Context-awareness in S-PSS

"Context-aware" applications have been used in the different phases of the S-PSS life cycle. Service providers are expected to create applications capable of reacting in varying usage scenarios. However, there are challenges; the data are heterogeneous, with different data formats and multi-sourced, data can come from user behaviour (actions and values collected using the products or IT platforms) (Wutzler et al., 2017). For example, sensor data are collected directly from the products (Zheng et al., 2019a), but also with the increase of social media awareness from individuals and organizations, it is possible to capture the opinions and comments of customers as user-generated content.

A common approach to measuring the concept evaluation of PSS is through key performance indicators (KPIs) from different perspectives such as customer, sustainability, or risks. Mourtzis et al. (2018) presented a context-aware framework to evaluate a PSS based on lean methodology. The sources of information were the feedback received from shop floor experts and business customers through social media platforms. They also considered the information from machines and manufacturing execution systems to obtain the KPI values. Using Natural Language Processing (NLP) techniques, they analyzed the comments and feedback. The information was delivered to users through a web application. Wang et al. (2020) proposed evaluating S-PSS based on the user experience and usage scenarios.

Aligned with the life cycle of context-aware applications, they modelled the context sources, features, and types using key/value pairs. A set of scenarios were identified with context features and predetermined values, for instance, “printing speed”, “print frequency”, and so forth. Each scenario represented a Product Service Bundle (PSB), to evaluate these, the authors performed sentiment analysis on comments relevant to the user experience. Several perceptual indicators were analyzed and ranked, allowing for identifying those PSB that outperform the rest (Wang et al., 2021a).

Another characteristic of S-PSS is their constant evolution. Some studies have concluded the need of taking advantage of the large amounts of data generated in the usage phase, to fully capture the implicit requirements that users have (Zheng et al., 2019b). For instance, Wang et al. (2019a), (2021b) proposed a graph-based context-aware framework for the requirement elicitation process in a data-driven manner. The framework consists of three layers: the bottom layer includes the identification of physical resources and data resources. The knowledge management layer uses domain ontologies to model the product’s components, services, and context. The top layer is the requirement elicitation layer, which is modelled through a requirements graph. Using a boilerplate presented by Arora et al. (2014), a requirement can be represented as ‘under what context, system component(s) shall/should/will do process’. Each node in the graph represents the context, product, and service. The graph-based process aims to predict the most relevant product and services based on the usage context obtained through analysis of users’ comments. The similarity of the context node with the product and service node is ranked. Elements are listed from high to low to easily identify which requirements are more relevant to users. Similarly, using a hypergraph framework and usage scenarios it was also possible to create configurable S-PSS (Wang et al., 2021c).

In the usage phase, Ren et al. (2021) presented an approach for fault-diagnosis in smart production machines, here considering the needs of service providers in use-oriented PSS. Moreover, the paper highlighted the need for big data analytics to fully potentiate the S-PSS, considering the amount of data generated for multiple customers and different products and operations. In the study, the data from smart machines were modelled into tuples to form data cubes and further analyzed using Deep Neural Networks. Athanasopoulou et al. (2020) also used neural networks for path planning in a smart mobility platform. Data from cameras and geolocalization were used as context sources. The project can be seen as pay-per-service unit in result-oriented PSS.

Maleki et al. (2018) proposed an ontology-based framework that can support the smart services in industrial machinery PSS. The study noted the highly customized environment of industrial S-PSS and how it can be tackled with a generic design composed of a collection of ‘solution-ready’ components that can be ‘mixed and match’ and can be later used in several PSS. Each service can be modelled into a pattern that relates the product, service and required information, using the modular structure of SSN ontology (Compton et al., 2011) and integrating it with context-specific classes and relationships. The framework was developed with the Apache Jena framework which is used for building semantic web applications.

Li et al. (2020b) proposed a context-aware framework for S-PSS development, that considers all phases of the S-PSS lifecycle to fulfil a sustainable solution. The framework has four main steps, requirement elicitation, solution recommendation, solution evaluation and knowledge evolvement to support the decision making and optimization of the system. At the core, context-awareness aims to model the multiple scenarios in immense user-generated data and product- sensed data in the S-PSS (Li et al., 2021). Table 8 summarizes each stage of the context awareness life-cycle applied to S-PSS case studies found in the literature. The following section will analyze and answer the research questions established in section 3.1.

## 6. Discussion and opportunities for research

To answer the questions carefully and comprehensively, analysis has been built on the significant aspects that should be considered when examining context awareness capability in S-PSS focusing on the design and user experience. Based on relevant literature, these aspects, along with the findings, have been explored in previous sections.

*RQ1: What are the connections of UCD, UX and Context-Awareness for S-PSS?*

The context is any type of information helping to identify the current situation of an entity, be it a person, place or object. Several researchers have highlighted the importance of the context in S-PSS (Cong et al., 2020b; ValenciaCardona et al., 2014; Zheng et al., 2019b) because it helps ensure that services and products can adapt in multiple scenarios and to various stakeholders. Section 4 further explored UCD, considering service design and UX. Fig. 11 shows how these different concepts, which are interrelated in the design of S-PSS use *context*. In the case of S-D logic as part of service design focuses more on the creation of value for the customer, stating that it is a co-creation process and a great part of the value is in the context, implying that the process must be capable of understanding the beneficiary’s environment and the associated resources (Wetter-Edman et al., 2014). UX concentrates on the part of user design that will be the mode of interaction with the S-PSS, whose sources of context are a combination of users, resources and factors of the use environment, all of which affect the experience. It is understandable then why the context-awareness capability is important in the S-PSS and the importance of capturing context for customers and for users.

*RQ2: How has context awareness capability been used in the design of S-PSS?*

Section 5.2 explored the case studies found in the literature whose contribution is reflected in frameworks and development approaches. Table 8 shows that the case studies were not limited to the previously established design stages, but rather extended to the maintenance of smart products. To answer the question, it is necessary to analyze the important aspects of the stages involved in the development of context-aware applications to finally highlight the uses in the UCD and user experience. .

- *Acquiring and Modelling context*

A model allows for abstracting the specifications of concern in S-PSS. The data acquisition from heterogeneous sources makes data models a common necessity in the studies reviewed and a fundamental step in context-aware applications. For the design aspect of S-PSS, not only is it necessary to consider physical sensor data from smart products, but also social sensor data, and user data. However, there is a static component to S-PSS that represents the structure of the smart product and related services (i.e. bundles), which are usually defined before usage. According to Maleki et al. (2018) in an S-PSS architecture, the domain knowledge models function in an intermediary role to integrate the S-PSS services with the cyber-physical components. One approach is the use of domain ontologies. Ontologies are a means to formally model concepts from a particular domain into a detailed specification of entities with properties and relations. Domain ontologies define the vocabulary related to a particular domain (Gruber, 1993; Guarino et al., 2009). Some studies started with the development of new ontologies (LeDinh et al., 2021; Wang et al., 2019a). Hajimohammadi et al. (2017) proposed a generic ontology for PSS development that includes all the life cycle phases of products and services. Instead, others have adapted known

**Table 8**
Context Aware case studies found in the literature.

| Case Study | Acquisition | Modelling | Reasoning | Dissemination | Lifecycle Stage |
|---|---|---|---|---|---|
| • (Wang et al., 2021a) 3D Printer<br>• use-oriented<br>• B2C | 3Dhub.com user-comments and Experts | Key/Value pairs | • Supervised Machine Learning (SVM)<br>• NLP | Not specified | • Smart Design-Usage<br>• Concept Validation (co-evaluators) |
| • (Mourtzis et al., 2018)<br>• Mold-die making industry<br>• product-oriented<br>• B2B | Comments on issues and maintenance and manufacturing data from sensors | Relational Database | • Supervised Machine Learning<br>• NLP | Web Application | • Smart Design-Usage<br>• Concept Validation (co-evaluators) |
| • (Wang et al., 2019a, 2021b)<br>• Framework evaluation using open data to simulate a<br>• use-oriented bicycle PSS<br>• B2C | Reviews and comments and sensor data | Domain Ontology, Context Ontology Graph-database (Neo4j) | • Graph Algorithms | Not specified | • Smart Design-Usage<br>• Requirement elicitation (co-ideators) |
| • (Li et al., 2020b)<br>• Illustrative example of 3D Printer<br>• use-oriented PSS<br>• B2C | 3Dhub.com user-comments Sensed data from 3D printer | Key/ Value Pairs, Domain Ontology | • Supervised Machine Learning (Random Forest) | Not specified | • Smart Design-Usage<br>• Smart End of Life |
| • (Ren et al., 2021)<br>• Smart Production Machines<br>• use-oriented PSS<br>• B2B | Data collected by sensors. Records from MES. | Data Warehouse | • Deep Neural Networks | Not specified | • Smart Maintenance<br>• Fault Prognosis |
| • (Athanasopoulou et al., 2020)<br>• Smart Mobility Platform<br>• result-oriented PSS<br>• B2C | Camera data. Sensor location information. | Not specified | • Neural Networks | Not specified | • Smart Usage |
| • (Maleki et al., 2018)<br>• Machine health monitoring<br>• product-oriented PSS<br>• B2B | Sensors in laser cutting machines. | PSS Ontology and SSN Ontology | • Rule Based reasoning and semantic reasoning | web application | • Smart Maintenance |
| • (Seo et al., 2016)<br>• Smart home<br>• product-oriented PSS<br>• B2C | VR devices and AR app interactions | UX ontology for smart home services | • Semantic reasoning (Jean inference) | mobile app | • Smart Design<br>• Smart prototyping (co-testers) |
| • (Le et al., 2020)<br>• Smart bot for Customer Support<br>• product-oriented PSS<br>• B2C | Forums related to product (extracting questions and answers) | Context-aware knowledge Ontology | • NLP based on RASA NLU Open Source | web application | • Smart Usage |

ontologies in their core of their solutions. Li et al. (2020a) used the Function-Behaviour-Structure (FBS) ontology to model the prototype of a smart product and exploited user-generated data collected from Wiki pages and e-commerce platforms as sources of context to create a knowledge graph using Neo4j, which could provide innovative concepts and probable relations when solving unusual requirements for S-PSS. On the other hand, the context acquired from social sensors can come from multiple sources (i.e. social networks, e-mails, e-commerce reviews); here, it is the modeling and reasoning process that allows for obtaining the context of, for example, usage scenarios, type of user, place or time. .

- *Reasoning context*

Most of the studies presented in Table 8 have used supervised machine learning techniques to address the reasoning phase and NLP which is a subfield of machine learning and it is mainly used in raw and unstructured text. Machine learning takes advantage of the large amount of data generated by smart devices, social sensors and data from users. However, some of these studies also point to a lack of data as a challenge in the early phases of S-PSS (Wang et al., 2020), where the selection of hybrid methods that combine one or more techniques can address this situation. Considering the use of ontologies in the modelling stage, semantic reasoning could take advantage of this to infer new knowledge based on established relationships in ontologies using frameworks, such as Jena, an open source Java framework for building semantic web applications. Graph databases can also import ontologies, allowing for the use of graph algorithms to infer new information. For instance, Neo4j is a graph data platform that includes a database and data analysis suite, and it has been used in some of the works presented in this review (Seo et al., 2016; Maleki et al., 2018).

- *Dissemination and Monitoring*

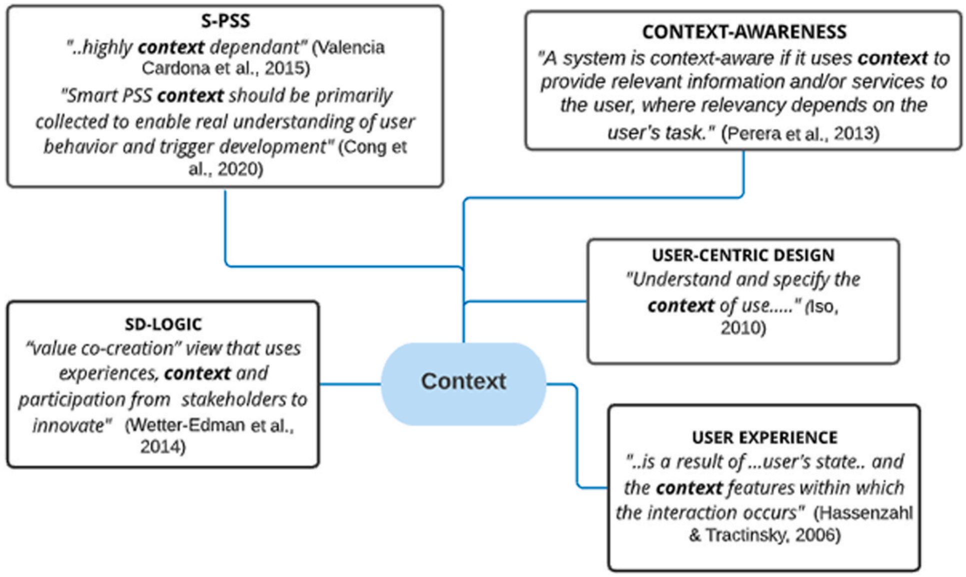


**Fig. 11.** Context relationship on S-PSS ecosystem based on: (Valencia et al., 2015; Cong et al., 2020b; Perera et al., 2013; Iso, 2010; Hassenzahl and Tractinsky, 2006; Wetter-Edman et al., 2014).

The dissemination of 'context' to end-users and its application in the *usage* stage of the S-PSS, as well as to which users the solutions were oriented, it was generally not discussed in the papers selected. This aspect is very close to the user experience and user interaction, since it is relevant on how new information or services are delivered to the user. This might be a part that needs more attention to understand more perspectives, for example, from designers, providers and end-users. Furthermore, the process of context monitoring represents the evolution of the design. It is important to monitor user feedback regarding the decisions made by the application. Feedback from users can come through integrated surveys, but also from user behaviour. For instance, if a user is not happy with the service or information that the application is offering, it is likely they will return to an old state of the application, or do not interact with the information. This can be taken as negative feedback. Reinforcement learning aims to maximize some notion of reward, for instance, end-user satisfaction by optimizing the recommendations, information or services provided to the user (Nurmi and Floréen, 2004). There is no evidence in the literature of methods to address the evolution of a context-aware application used in S-PSS .

- *Context-Awareness in user-centred design*

In the design, a great part of the efforts in the context-aware applications for S-PSS have been observed in the concept evaluation of product-service bundles, and requirement elicitation and analysis for capturing implicit requirements; for which it has been exploded external sources to smart products such as social sensors. Several case studies coincide in the analysis of user comments related to their experiences, obtained through social networks or other means of communication using NLP techniques, and the evaluation using sentiment analysis to quantify the positive or negative feelings from text (Mourtzis et al., 2018; Wang et al., 2021a; Le et al., 2020; Li et al., 2020a; Lin et al., 2016). Hence, the requirements arise based on opinions of product-service bundles. Here, context-aware applications are passive, they present the new or updated context to an interested user or they make the context persistent for the user to retrieve later (Liu et al., 2011). Overall, the role of users as co-ideators has been largely explored in the literature; requirement analysis and the concept evaluations are tools for internal stakeholders to make decisions, but there is no evidence in the literature of an evaluation and the use of the results from part of companies; a more industrialized view is necessary. There is still room in other areas to present more studies, for instance, in the areas of *innovative design* and *evolution*.

In these areas, there is a need to further integrate real-time sensor data from smart products and take advantage of that as a source of context, the use of context, in general, should provide adaptive applications according to use. Furthermore, there is a lack of research that use data from user behaviour and preferences in the usage stage of S-PSS to provide active context-awareness applications that automatically adapt to discover context through changing the application's behaviour (Liu et al., 2011).

Regarding the user experience, context awareness has been used to create more realistic prototypes that can adapt to use, hence obtaining a realistic opinion of the product (Seo et al., 2016) before fabrication. Another use is the creation of mental models from users as they test smart products, here capturing data from a variety of sensors devices specially designed to obtain physiological and psychological information from users (Dou and Qin, 2017). Therefore, the context-aware applications presented in the literature try to capture or perceive the context to bring new information, but they do not present methods to adapt the S-PSS to the context. .

- *Current Challenges*

For context-aware applications, there is a lack of research focusing on the architectural patterns that support the modularity, interoperability and scalability of the systems in the context of S-PSS, whose operations foresee a large number of simultaneous users. Thus, the volume of the data and the velocity where data occurs, along with the variety of sources are important to consider in big data analysis and architecture to respond to the real-time needs of multiple users. The process of filtering and validating the relevant contextual information within the time limits specified by the respective applications is a difficult process. This motivates an investigation of real-time and context-aware big data processing techniques for the handling of contextual information of any business entity instantly, including internal and external sources of context (Dinh et al., 2020).

*RQ3: What are the current gaps and challenges in the design of S-PSS to satisfy user needs and improve UX?*

Most engineering methodologies for design are oriented at smart products rather than smart services (Cong et al., 2020b). Therefore, there is still a need to create more frameworks or methodologies to support the *smart service* aspect of S-PSS. Other important aspects to consider are the following: .

- *Evolutionary design in S-PSS*

The 'closed-loop design' characteristic highlights the constant evolution of an S-PSS, but how to manage feedback and behaviour from users is still not well addressed; here, requirement management and elicitation have received more attention (Pirola et al., 2020). Studies on UX in S-PSS are especially scarce and they only focus on the evaluation of user experience in the design stage. Thus, they do not follow the holistic perspective of the S-PSS life cycle. Considering the design characteristics established in section 4, most of the works do not address how to exploit the data generated from devices and users to provide 'customized experiences' and 'self-adaptable design' capable of reacting to different sources of context (i.e. device context, user context and environment context). Cong et al. (2020b) highlighted that user preferences should be associated with different design elements of Smart PSS in specific usage contexts. However, the studies in this research area are still limited to some user-specific preferences in the usage stage of Smart PSS. For instance, digital service platforms accessible through mobile apps or web applications are a big part of S-PSS offer, the use of adaptive user interfaces (UI) in this context has the potential to adapt to user interaction patterns, hence, achieve a more personalised UX that can lead to greater user satisfaction in S-PSS. The role of users as "experience creators" and "co-designers" can be further exploited to provide S-PSS customization using a data-driven approach. .

- *Data Privacy*

Data-driven and evolutionary design will require the user's personal and behavioural information, which could vary depending on S-PSS' application domains. The services created must help users make informed decisions about their privacy. Similarly, users must have control over their personal information (van Ooijen and Vrabec, 2019). Privacy regulations should be followed (i.e. General Data Privacy Regulation GDPR) and ensure users' consent and awareness of the data collected (Zheng et al., 2019a). Furthermore, considering the use of several machine learning approaches reviewed in this paper, it is necessary to define "how much data", "what data" and "why" .

- *Holistic UCD view and Multi-business perspective*

UCD is very relevant for capturing the needs of the stakeholders and guaranteeing a better user experience. However, studies using this approach are very limited to the *design* stage of S-PSS; how to continually evolve smart products and services while maintaining a user-centric approach is challenging. Moreover, 53% of the reviewed case studies that used the UCD approach were related to *e-health and welfare* S-PSS, followed by 33% in Smart Home applications. It seems that this type of industry, which is characterized by a Business-to-Consumer (B2C) business model, is more interested in understanding end consumers, since they represent a large part of the market to which their products and services are directed. Whereas, for instance, the *manufacturing* area has a lower number of case of studies following UCD approach, especially characterized by a Business-to Business (B2B) model that is more about selling industrial products based on materials and parts, capital items, supplies, etc; an area where the users are always not so evident or not considered (He and Zhang, 2022).

In Table 8, seven (7) out of the ten (10) case studies reviewed are focused on B2C. Three case studies are directed at B2B. Basic design and UX principles are shared between both approaches (i.e. functionality, intuitiveness, attractiveness, etc.). However, the goals of the UX change; end-consumers are strongly motivated by emotions, in contrast with B2B models, which are more motivated for professionalism, customization of services and establish loyal relationships (Ritter and Winterbottom, 2017). For instance, obtaining opinions from B2B from social sensors will be difficult. There will be a need of more integrative ways to gather feedback within the S-PSS.

## 7. Conclusions

As a business strategy that combines smart services and connected products into one solution, S-PSS have gained more attention among academics. The current review followed an SLR approach and presented some limitations because of the breadth of the topics covered, which made it difficult when classifying the selected works. However, the review accomplished its goal to provide the reader with a general overview of concepts while presenting current studies described in the literature, gaps and challenges. Furthermore, the current study has answered the three research questions and synthesized the relationships among UCD, UX and context-awareness in S-PSS.

Other contributions of this work are as follows:

- *A bibliometric analysis of the SLR* in the field of S-PSS design with a user-centred approach. This includes the description of both empirical and theoretical research. Furthermore, an analysis of industrial sectors in cases of studies following context-aware and UCD approaches. Finally, a keyword cluster analysis that provides a visual and quick overview of the subjects that the studies have focused on and how they are interrelated.
- *An analysis of design aspects of S-PSS with a user perspective* The present paper examined the aspects and internal characteristics of the design of S-PSS as related to different roles that users can have in design in the various stages of the S-PSS life cycle, enhancing the digital capabilities of S-PSS that allow "data-driven value co-creation" within a "closed-loop design approach". The review has presented works following UCD, which have been utilized only in the design stage. This is true, especially in the very early stages of S-PSS development, where the lack of data can hinder a data-driven design. The authors emphasize that the personalization of services based on context could allow the design to be extended to the usage phase of S-PSS and provide a smart user experience.
- *A context-aware lifecycle analysis of case studies* Following the lifecycle of context-aware applications, this work have described each stage and the multiple case studies found in the literature have been synthesized.

After examining the relationships of many components of the design of S-PSS and context information, future work will follow the context-aware lifecycle approach, to provide a smart user experience in S-PSS. Considering as a basis a User-centric design and the data-driven co-creation characteristic of S-PSS.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie Grant No. 814078.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.compind.2022.103730.

## References


Abowd, G.D., Dey, A.K., Brown, P.J., Davies, N., Smith, M., Steggles, P., 1999, Towards a better understanding of context and context-awareness.In: International symposium on handheld and ubiquitous computing.Springer, pp.304–307.

Alcayaga, A., Wiener, M., Hansen, E.G., 2019. Towards a framework of smart-circular systems: An integrative literature review. J. Clean. Prod. 221, 622–634 (publisher: Elsevier).

AnonSimple Complex, 2021. Parsif.al.⟨https://parsif.al/⟩.

Arora, C., Sabetzadeh, M., Briand, L.C., Zimmer, F., 2014, Requirement boilerplates: Transition from manually-enforced to automatically-verifiable natural language patterns.In: 2014 IEEE 4th International Workshop on Requirements Patterns (RePa).IEEE, pp.1–8.

Athanasopoulou, L., Papacharalampopoulos, A., Stavropoulos, P., 2020. Context awareness system in the use phase of a smart mobility platform: A vision system for a light-weight approach. Procedia CIRP 88, 560–564 (publisher: Elsevier).

Bu, L., Chen, C.-H., Ng, K.K., Zheng, P., Dong, G., Liu, H., 2021. A user-centric design approach for smart product-service systems using virtual reality: a case study. J. Clean. Prod. 280, 124413 (publisher: Elsevier).

Chang, D., Gu, Z., Li, F., Jiang, R., 2019. A user-centric smart product-service system development approach: A case study on medication management for the elderly. Adv. Eng. Inform. 42, 100979. ⟨https://www.sciencedirect.com/science/article/pii/S147403461930552X⟩.

Chou, J.-R., 2021. TRIZ-based product-service design approach for developing innovative products. Comput. Ind. Eng. 161, 107608 (publisher: Elsevier).

Compton, M., Barnaghi, P., Bermudez, L., Castro, R., Corcho, O., Cox, S., Graybeal, J., Hauswirth, M., Henson, C., Herzog, A., et al., 2011. The ssn ontology of the semantic sensor networks incubator group. J. Web Semant.: Sci. 1570–8268 (Services and Agents on the World Wide Web, ISSN).

Cong, J., Chen, C.-H., Zheng, P., 2020a. Design entropy theory: A new design methodology for smart pss development. Adv. Eng. Inform. 45, 101124.

Cong, J.-c., Chen, C.-H., Zheng, P., Li, X., Wang, Z., 2020b. A holistic relook at engineering design methodologies for smart product-service systems development (Nov.). J. Clean. Prod. 272, 122737. https://doi.org/10.1016/j.jclepro.2020.122737

Costa, N., Patrício, L., Morelli, N., Magee, C.L., 2018. Bringing service design to manufacturing companies: integrating PSS and service design approaches. Des. Stud. 55, 112–145 (publisher: Elsevier).

Dinh, L.T.N., Karmakar, G., Kamruzzaman, J., 2020. A survey on context awareness in big data analytics for business applications. Knowl. Inf. Syst. 62 (9), 3387–3415.

Dong, Y., Liu, W., 2018. Research on UX evaluation method of design concept under multi-modal experience scenario in the earlier design stages. Int. J. Interact. Des. Manuf. (IJIDeM) 12 (2), 505–515 (publisher: Springer).

Dong, Y., Zhu, R., Tian, Q., Liu, W., Peng, W., 2019. A Scenario Interaction-centered Conceptual Information Model for UX Design of User-oriented Product-service System. Procedia CIRP 83, 335–338 (publisher: Elsevier).

Dou, J., Qin, J., 2017, Research on User Mental Model Acquisition Based on Multidimensional Data Collaborative Analysis in Product Service System Innovation Process.In: International Conference on Engineering Psychology and Cognitive Ergonomics.Springer, pp.35–44.

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. Technol. Forecast. Soc. Change 141, 341–351.

Gruber, T., 1993, What is an Ontology.

Guarino, N., Oberle, D., Staab, S., 2009. What is an ontology? Handbook on Ontologies. Springer, pp. 1–17 (pp).

Hajimohammadi, A., Cavalcante, J., Gzara, L., 2017. Ontology for the PSS lifecycle management. Procedia CIRP 64, 151–156 (publisher: Elsevier).

Hallstedt, S.I., Isaksson, O., ÖhrwallRÖnnbÄck, A., 2020. The need for new product development capabilities from digitalization, sustainability, and servitization trends. Sustainability 12 (23), 10222.

Hassenzahl, M., Tractinsky, N., 2006. User experience-a research agenda. Behav. Inf. Technol. 25 (2), 91–97 publisher: Taylor & Francis.

He, J., Zhang, S., 2022. How digitalized interactive platforms create new value for customers by integrating b2b and b2c models? an empirical study in china. J. Bus. Res. 142, 694–706.

Hribernik, K., Franke, M., Klein, P., Thoben, K.-D., Coscia, E., 2017, Jun, Towards a platform for integrating product usage information into innovative product-service design.In: 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC). pp.1407–1413.10.1109/ICE.2017.8280047.

Iso, D., 2010. 9241–210: 2010: ergonomics of human-system interaction—part 210: human-centred design for interactive systems (formerly known as 13407). International Standards Organization, Switzerland.

Jia, G., Zhang, G., Yuan, X., Gu, X., Liu, H., Fan, Z., Bu, L., 2021. A synthetical development approach for rehabilitation assistive smart product–service systems: A case study. Adv. Eng. Inform. 48, 101310 (publisher: Elsevier).

Kaasinen, E., Roto, V., Hakulinen, J., Heimonen, T., Jokinen, J.P., Karvonen, H., Keskinen, T., Koskinen, H., Lu, Y., Saariluoma, P., others, 2015, Defining user experience goals to guide the design of industrial systems.Behaviour & Information Technology 34(10), 976–991, publisher: Taylor & Francis.

Kammler, F., Kemmerich, H., Brinker, J., Thomas, O., 2019, Scrutinizing the design specifications of smart products: a practical evaluation in yachting.

Kim, Y.S., Hong, Y., 2019. A systematic method to design product-service systems using personalisation services based on experience evaluations. Int. J. Prod. Dev. 23 (4), 353–386 (publisher: Inderscience Publishers (IEL)).

Kiritsis, D., 2011. Closed-loop PLM for intelligent products in the era of the Internet of things. Comput. -Aided Des. 43 (5), 479–501 (publisher: Elsevier).

Kitchenham, B., Charters, S., 2007, Guidelines for performing systematic literature reviews in software engineering. Tech. rep., Technical report, EBSE Technical Report EBSE-2007–01.⟨https://www.cs.auckland.ac.nz/~norsaremah/2007%20Guidelines%20for%20performing%20SLR%20in%20SE%20v2.3.pdf⟩.

Kuhlenkötter, B., Wilkens, U., Bender, B., Abramovici, M., Süße, T., Göbel, J., Herzog, M., Hypki, A., Lenkenhoff, K., 2017. New perspectives for generating smart PSS solutions–life cycle, methodologies and transformation. Procedia CIRP 64, 217–222 (publisher: Elsevier).

Le, D.T., Thi, T.T.P., Pham-Nguyen, C., Nam, L.N.H., 2020, Towards a context-aware knowledge model for smart service systems.In: International Conference on Computational Collective Intelligence.Springer, pp.767–778.

LeDinh, T., Pham, Thi, Pham-Nguyen, T.T., Nam,L.N.H, C., 2021. A knowledge-based model for context-aware smart service systems. J. Inf. Telecommun. 1–22 Publisher: Taylor & Francis.

Lenka, S., Parida, V., Wincent, J., 2017. Digitalization capabilities as enablers of value co-creation in servitizing firms. Psychol. Mark. 34 (1), 92–100 (publisher: Wiley Online Library).

Li, X., Wang, Z., Zheng, P., Peng, T., Chen, C.-H., Aug., 2020b, A Closed-Loop Context-Aware Framework for Sustainable Smart PSS Development.In: 2020 IEEE 16th International Conference on Automation Science and Engineering (CASE). IEEE.10.1109/2Fcase48305.2020.9217030.

Li, X., Chen, C.-H., Zheng, P., Wang, Z., Jiang, Z., Jiang, Z., 2020a. A knowledge graph-aided concept–knowledge approach for evolutionary smart product–service system development. J. Mech. Des. 142 (10), 101403 (publisher: American Society of Mechanical Engineers).

Li, X., Wang, Z., Chen, C.-H., Zheng, P., 2021. A data-driven reversible framework for achieving Sustainable Smart product-service systems (Jan.). J. Clean. Prod. 279, 123618. https://doi.org/10.1016/j.jclepro.2020.123618

Lim, M.J., Kim, Y.S., others, 2017, Service design for people with disabilities using context-based activity modelling and international classification of functioning, disability and health.In: DS 87–3 Proceedings of the 21st International Conference on Engineering Design (ICED 17) Vol 3: Product, Services and Systems Design, Vancouver, Canada, 21–25.08. 2017. pp.231–240.

Lin, K.-Y., Chien, C.-F., Kerh, R., 2016. Unison framework of data-driven innovation for extracting user experience of product design of wearable devices. Comput. Ind. Eng. 99, 487–502.

Liu, W., Li, X., Huang, D., 2011, A survey on context awareness.In: 2011 International Conference on Computer Science and Service System (CSSS).IEEE, pp.144–147.

Liu, Z., Ming, X., Song, W., Qiu, S., Qu, Y., 2018. A perspective on value co-creation-oriented framework for smart product-service system. Procedia Cirp 73, 155–160 (publisher: Elsevier).

Maleki, E., Belkadi, F., Boli, N., Van Der Zwaag, B.J., Alexopoulos, K., Koukas, S., Marin-Perianu, M., Bernard, A., Mourtzis, D., 2018. Ontology-based framework enabling smart product-service systems: application of sensing systems for machine health monitoring. IEEE Internet things J. 5 (6), 4496–4505 (publisher: IEEE).

Marczyk, G.R., DeMatteo, D., Festinger, D., 2010. Essentials of Research Design and Methodology. vol. 2 John Wiley & Sons,.

Mourtzis, D., Fotia, S., Vlachou, E., Koutoupes, A., 2018. A Lean PSS design and evaluation framework supported by KPI monitoring and context sensitivity tools. Int. J. Adv. Manuf. Technol. 94 (5–8), 1623–1637 (publisher: Springer Nature BV).

Ngoc, H.N., Lasa, G., Iriarte, I., 2021. Human-centred design in industry 4.0: case study review and opportunities for future research. J. Intell. Manuf. 1–42 (Publisher: Springer).

Nurmi, P., Floréen, P., 2004, Reasoning in context-aware systems. Helsinki Institute for Information Technology, Position paper.Citeseer.

Perera, C., Zaslavsky, A., Christen, P., Georgakopoulos, D., 2013. Context aware computing for the internet of things: A survey. IEEE Commun. Surv. Tutor. 16 (1), 414–454 (publisher: Ieee).

Petersen, K., Vakkalanka, S., Kuzniarz, L., 2015. Guidelines for conducting systematic mapping studies in software engineering: An update. Inf. Softw. Technol. 64, 1–18.

Petticrew, M., Roberts, H., 2008. Systematic Reviews in the Social Sciences: A Practical Guide. John Wiley & Sons,.

Pezzotta, G., Cavalieri, S., Romero, D., 2017, Collaborative product-service systems engineering: Towards an active role of customers and stakeholders in value co-creation.In: 2017 International Conference on Engineering, Technology and Innovation (ICE/ITMC).IEEE, pp.1247–1254.

Pirola, F., Boucher, X., Wiesner, S., Pezzotta, G., 2020. Digital technologies in product-service systems: a literature review and a research agenda. Comput. Ind. 123, 103301. ⟨https://www.sciencedirect.com/science/article/pii/S0166361520305352⟩.
Rapaccini, M., Saccani, N., Kowalkowski, C., Paiola, M., Adrodegari, F., 2020. Navigating disruptive crises through service-led growth: The impact of COVID-19 on Italian manufacturing firms. Ind. Mark. Manag. 88, 225–237 (publisher: Elsevier).
Ren, S., Zhang, Y., Sakao, T., Liu, Y., Cai, R., 2021, An Advanced Operation Mode with Product-Service System Using Lifecycle Big Data and Deep Learning.International Journal of Precision Engineering and Manufacturing-Green Technology, 1–17 Publisher: Springer.
Ritter, M., Winterbottom, C., 2017. UX for the Web: Build Websites for User Experience and Usability. Packt Publishing Ltd,.
Schilit, B.N., Theimer, M.M., 1994. Disseminating active map information to mobile hosts. IEEE Netw. 8 (5), 22–32.
Seo, D.W., Kim, H., Kim, J.S., Lee, J.Y., 2016. Hybrid reality-based user experience and evaluation of a context-aware smart home. Comput. Ind. 76, 11–23 (publisher: Elsevier).
Tukker, A., 2004. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus. Strategy Environ. 13, 246–260.
Valencia, A., Mugge, R., Schoormans, J., Schifferstein, H., 2015. The design of smart product-service systems (PSSs): An exploration of design characteristics. Int. J. Des. 9, 1.
ValenciaCardona, A., Mugge, R., Schoormans, J.P., Schifferstein, H.N., 2014, Challenges in the design of smart product-service systems (PSSs): Experiences from practitioners.In: Proceedings of the 19th DMI: Academic Design Management Conference. Design Management in an Era of Disruption, London, UK, September 2–4, 2014. Design Management Institute.
Van Eck, N.J., Waltman, L., 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84 (2), 523–538 (publisher: Springer).
van Ooijen, I., Vrabec, H.U., 2019. Does the gdpr enhance consumers' control over personal data? an analysis from a behavioural perspective. J. Consum. Policy 42 (1), 91–107.
Wang, Z., Zheng, P., Chen, C.-H., Khoo, L.P., 2019b, A survey of requirements management in smart product-service systems.In: Transdisciplinary Engineering for Complex Socio-technical Systems.IOS Press pp.613–622.
Wang, Z., Chen, C.-H., Zheng, P., Li, X., Khoo, L.P., 2019a. A novel data-driven graph-based requirement elicitation framework in the smart product-service system context. Adv. Eng. Inform. 42, 100983 (publisher: Elsevier).
Wang, Z., Li, X., Chen, C.-H., Khoo, L.-P., Sep., 2020, Evaluating Smart PSS Solutions with Context-Awareness in Usage Phase.In: Transdisciplinary Engineering for Complex Socio-technical Systems – Real-life Applications. Vol. 12 of Advances in Transdisciplinary Engineering. IOS Press, pp. 333–342, iSSN: 2352751X, 23527528.10.3233/ATDE200092.
Wang, Z., Chen, C.-H., Li, X., Zheng, P., Khoo, L.P., 2021a. A context-aware concept evaluation approach based on user experiences for smart product-service systems design iteration. Adv. Eng. Inform. 50, 101394 (publisher: Elsevier).
Wang, Z., Chen, C.-H., Zheng, P., Li, X., Khoo, L.P., 2021b. A graph-based context-aware requirement elicitation approach in smart product-service systems. Int. J. Prod. Res. 59 (2), 635–651.
Wang, Z., Chen, C.-H., Zheng, P., Li, X., Song, W., 2021c. A hypergraph-based approach for context-aware smart product-service system configuration. Comput. Ind. Eng., 107816.
Wetter-Edman, K., Sangiorgi, D., Edvardsson, B., Holmlid, S., Grönroos, C., Mattelmäki, T., 2014. Design for value co-creation: Exploring synergies between design for service and service logic. Serv. Sci. 6 (2), 106–121 (publisher: INFORMS).
Wohlin, C., Runeson, P., Höst, M., Ohlsson, M.C., Regnell, B., Wesslén, A., 2012. Systematic Literature Reviews. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 45–54. https://doi.org/10.1007/978-3-642-29044-2_4. (pp).
Wuest, T., Wellsandt, S., 2016. Design and Development of Product Service Systems (PSS)-Impact on Product Lifecycle Perspective. Procedia Technol. 26, 152–161 (publisher: Elsevier).
Wutzler, M., Weissbach, M., Springer, T., 2017, Role-based models for building adaptable collaborative smart service systems.In: 2017 IEEE International Conference on Smart Computing (SMARTCOMP).IEEE, pp.1–6.
Zheng, P., Yu, S., Wang, Y., Zhong, R.Y., Xu, X., 2017. User-experience based product development for mass personalization: a case study. Procedia CIRP 63, 2–7 (publisher: Elsevier).
Zheng, P., Liu, Y., Tao, F., Wang, Z., Chen, C.-H., 2019a. Smart product-service systems solution design via hybrid crowd sensing approach. IEEE Access 7, 128463–128473.
Zheng, P., Wang, Z., Chen, C.-H., Khoo, L.P., 2019b. A survey of smart product-service systems: Key aspects, challenges and future perspectives. Adv. Eng. Inform. 42, 100973 (publisher: Elsevier).
Zhou, T., Chen, Z., Cao, Y., Miao, R., Ming, X., 2022. An integrated framework of user experience-oriented smart service requirement analysis for smart product service system development. Adv. Eng. Inform. 51, 101458.

Angela Carrera Rivera [MSc] is currently a doctoral student at the Mondragon Unibersitatea computer science department on the subject of context-awareness in the design of Smart Product-Service Systems and part of the DiManD project, a Innovative Training Network (ITN) in the area of Industry 4.0.

She obtained her Bachelor's degree in Information Systems (2008) at the Escuela Superior Politécnica del Litoral (Ecuador), she obtained her Master's degree in Information Technology (2016) at the University of Melbourne (Australia). She has worked on business management software (ERP) development projects and banking management software for Latin America.