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A Holistic Relook at Engineering Design Methodologies for Smart Product-Service Systems Development

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Abstract

The rapid development and implementation of smart, connected products have triggered a promising manufacturing paradigm of servitization, i.e. smart product-service systems (Smart PSS). Unlike existing product development or service design process, Smart PSS owns the unique design characteristics of IT-driven value co-creation, closed-loop design, and context-awareness enabled by the advanced information and communication technologies. Nevertheless, to the best of authors' knowledge, there is scarcely any discussion on its design theories, which serves as the fundamental basis. To identify the limitations of current design approaches in supporting Smart PSS development and suggest some future research directions, this paper conducts a systematic literature review at existing engineering design methodologies to verify its appropriateness for the Smart PSS development. 9 typical design methods have been chosen based on the systematic review of 101 representative items published ever since the coin of PSS to date (04/05/2020) and 50 supplementary works. They are further compared and evaluated from three aspects, including "smart design" objects, enabling smart technologies and smart application fields. Not surprisingly, the investigation results indicate that none of the existing methodologies can fully meet the design characteristics of Smart PSS, while three research directions of Smart PSS design methodology are provided as the potential solution at last. It is hoped this paper can attract more open discussions and offer useful insights to both academics and industries in their development of Smart PSS.

Keywords: Smart product-service systems; engineering design; design methodologies; review

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Nomenclature

AD	Axiomatic Design
AR	Augmented Reality
B2B	Business to Business
B2C	Business to Customer
CAD	Computer-Aided Design
CPS	Cyber-Physical System
FBS	Function-Behavior-Structure
GDPR	General Data Privacy Regulation
GPS	Global Positioning System
ICT	Information and Communication Technologies
IoT	Internet-of-Things
KE	Kansei Engineering
LTC	Long-Term Care
MC	Mass Customization
PSS	Product-Service Systems
QFD	Quality Function Deployment
RFID	Radio-Frequency Identification
SCOAP	Smart, Connected Open Architecture Product
SCP	Smart, Connected Product
SSF	Systematic Search Flow
TRIZ	Teorija Rezhenija Izobretatelskih Zadach
UCD	User-Center Design
WoS	Web of Science
WSN	Wireless Sensor Network

1. Introduction

Nowadays, with increasing competition from economic globalization, more and more manufacturing companies are striving to maintain their competitive advantage by transforming their business models with integrated products and services (Qu et al., 2016). This value proposition paradigm was named product-service systems (PSS) (Tukker and Tischner, 2006), of which goal is to provide robust solutions to customers with bundles of “products” and “services”, while taking into account the requirements of various stakeholders at the same time (Mont, 2002). Since first coined in 1999 (Goedkoop et al., 1999), PSS has experienced fast development from Internet-based PSS (conventional PSS) (Lee, 2003), IoT-enabled PSS (Michael et al., 2010) to current Smart PSS, enabled by the prevailing information and communication technologies (ICT) (Valencia et al., 2015, 2014). Unlike the prior two paradigms, Smart PSS considers both the online smartness of cyberspace and offline smartness of the physical space with sustainability concerns (Zheng et al., 2019c), where Zheng et al. defined it as "*An IT-driven value co-creation business strategy consisting of various stakeholders as the players, intelligent systems as the infrastructure, smart, connected products (SCPs) as the media and tools, and their generated services as the key values delivered that continuously strives to meet individual customer needs in a sustainable manner.*" (Zheng et al., 2018a). In this context, SCPs are widely leveraged (Porter and Heppelmann, 2014) to realize the digital servitization of products and services enabled by the cyber-physical system (CPS) (Wiesner and Thoben, 2017) and Big Data technologies (Opresnik and Taisch, 2015). For example, the smart shared bike system provides users with smart riding services in a pay-per-use manner, where resource utilization efficiency can be elevated with sustainability (Tao et al., 2019).

However, to the best of authors' knowledge, most existing works have investigated Smart PSS development from either product or service aspect, respectively (Zheng et al., 2019c). From the product-oriented aspect, the existing body of research suggests that some features (e.g. self-awareness (Filho et al., 2017) and reconfigurable (Savarino et al., 2018)) frequently prescribe for designing SCPs. From the service-oriented aspect, several studies explore approaches based on IoT (Liu et al., 2019b) or data-driven techniques for developing smart e-services (Verdugo Cedeño et al., 2018), and many methods for advancing digitalized services (e.g. digital twin (Tao et al., 2017) and augmented reality (AR) (Gupta et al., 2018)). Although the design method for Smart PSS development has received much attention recently (Chen et al., 2020), scarcely any work provides a fundamental approach to realizing Smart PSS development by considering its unique design characteristics (i.e. IT-driven value co-creation, closed-loop design, context-awareness) in the digital servitization era (Liu et al., 2020b). Aiming to identify the limitations of current design approaches in supporting Smart PSS development and suggest some future research directions, this paper conducts a holistic review of the related publications ever since PSS first coined, and selected 101 highly related journal/conference papers to identify, summarize, and evaluate the valuable engineering design methodologies that can be adopted/adapted to support Smart PSS development process. The rest of this paper is organized as follows: Section 2 presents the unique design characteristics of Smart PSS. Section 3 gives a systematic literature review to select the most relevant publications. Based on the selection, a holistic relook of engineering design methodologies for "smart design" is elaborated in Section 4. Moreover, the main challenges of the selected ones and the trends of future research are highlighted in Section 5 and Section 6, respectively. The scientific contributions and limitations of this review are summarized at last.

2. The design characteristics and key elements of Smart PSS

Based on our previous work (Cong et al., 2020), three unique design characteristics of Smart PSS are outlined, including IT-driven value co-creation, closed-loop design, and context-awareness, in a data-driven manner. The interrelationship between design characteristics and key elements of Smart PSS is depicted in Figure 1. In this context, unlike the conventional design process starts from the very beginning of the lifecycle, Smart PSS design innovation can be regarded as a value generation process by considering the whole product-service lifecycle in a closed-loop manner with context-awareness. Nevertheless, a systematic design approach of Smart PSS following the proposed design characteristics remain unexplored.

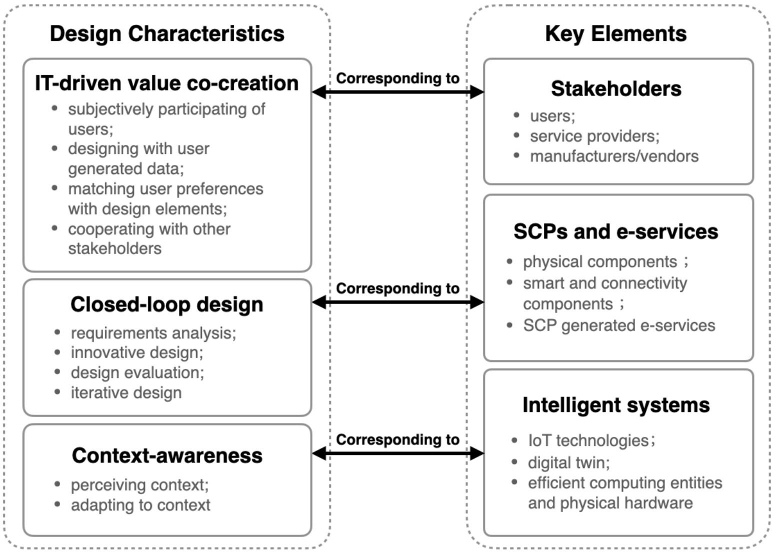


Figure 1. The interrelationship between design characteristics and elements.

IT-driven value co-creation is carried out by *stakeholders* who are mainly classified into three species, i.e., users, service providers, and manufacturers/vendors (Zheng et al., 2019b). Creating common values with IT is an expedient manner for Smart PSS design. Lenka et al. (2017) proposed a framework for digitalization capabilities that enabled value co-creation, which consists of the customer sphere, joint sphere, and provider sphere. The joint sphere is expanded by perceptive mechanisms and responsive mechanisms. Based on the above framework, the critical elements of IT-driven value co-creation are summarized in four aspects below. (1) For the customer sphere, customers should participate in the development process of Smart PSS subjectively through some appropriate approaches and technologies (Liu et al., 2018). Smart PSS should adopt a design methodology that can assist users in creating value independently by leveraging ICT. (2) For the perceptive joint sphere, user-generated data should be utilized in Smart PSS design. Precepting users' preferences through collecting and processing real-time data are the most crucial part of the design process, for the reason that ensuring the real-time interaction between users and developers in the context is fundamental to the development of Smart PSS (Lenka et al., 2017). (3) For the responsive joint sphere, user preferences should be matched with the design elements of Smart PSS in specific usage contexts. To respond to the collected users' preference, developers should construct some models to connect preferences (e.g. affective responses, desired impressions, and user types) to related design elements (e.g. product form features, patterns, and attributes) by leveraging artificial intelligence (Li et al., 2018). (4) For the provider sphere, an IT-driven cooperation way for the stakeholders except for users (e.g., providers, manufacturers, vendors, suppliers, and decision-makers) should be concerned about in Smart PSS development (Li and Found, 2017). Scientific cooperation between these stakeholders in the context can effectively improve the development efficiency of Smart PSS.

Closed-loop design is conducted among *SCPs and e-services*, which are composed by three parts (Zheng et al., 2018a), i.e. physical components (Porter and Heppelmann, 2014), smart and connectivity components (Zheng et al., 2018b), and SCP generated e-services (Wang et al., 2018). Relevant information can be collected and utilized by SCPs and e-services for providing sustainable value to stakeholders through the system lifecycle, especially during the usage stage. Liu et al. (2018) proposed four phases of the Smart PSS creation, including (1) determining the stakeholders and their requirements, (2) inviting users involves the innovative design, (3) implementing the interactive value by the providers and users, (4) evaluating Smart PSS to improve it. Nevertheless, the closed-loop design of Smart PSS emphasizes that interactive value could be realized in the usage stage. It highlights the integration of innovative design and iterative design processes into the development. Thereby, a design methodology of Smart PSS should assist the stakeholders in completing not only the creation from scratch but also the real-time upgrade/modifications of product/service in the usage stage. Therefore, based on the four phases proposed by Liu et al. (2018), the four phases of Smart PSS closed-loop design are summarized below. (1) Requirements analysis phase. The user requirements, which deserve to be further addressed in Smart PSS, should be identified, collected, and analyzed in this phase (Hou and Jiao, 2019). (2) Innovative design phase. At this stage, the generation of new prototypes gets more attention. Some design methods can be used to output the innovative solutions which fulfill user requirements (Zheng et al., 2018b). (3) Design evaluation phase. The evaluation of Smart PSS could be conducted through three perspectives, including the customer value perspective (Qu et al., 2016), sustainability perspective (Liu et al., 2020a), and value propositions perspective (Liu et al., 2019c). (4) Iterative design phase. Smart PSS should quickly and automatically iterate its design plan to adapt to a new context when customers are using it. Some reasonable manners, such as changing/upgrading modules or controlling parameters, can become critical instruments in the iteration of SCPs and e-services to extend the lifespan of Smart PSS. The dynamically adapting plans of the system make appropriate responses to the changes in user requirements to meet individual customer requirements with sustainability concerns (Gu et al., 2004).

Context-awareness is based on those *intelligent systems* (Wang et al., 2018), and defined as a wide range of technologies ensuring a high degree of connectivity and intelligence, such as IoT technologies (Rymaszewska et al., 2017), digital twin (Schleich et al., 2017), efficient computing entities and physical hardware (Monostori et al., 2016). Wang et al. (2019) proposed that product-sensed data and user-generated data in the Smart PSS context should be primarily collected to enable real understanding of user behavior and trigger development. Based on the above statement, the main focus of Smart PSS context-awareness lies in two perspectives: (1) perceiving context; (2) adapting to context. For the prior one, intelligent systems help Smart PSS determining the present context with the hardware sensors which provide product-sensed information or the social sensors (Xu et al., 2018) which provide user-generated information on a social network. For the latter one, Smart PSS should update design solutions according to the contexts automatically or by the development team getting involved. Especially in the usage stage, the design approach driven by massive user-generated data in the smart, connected environment should provide tools for changing/upgrading the product/service predictively to adapt to the specific context (Zheng et al., 2019c).

3. Systematic literature review process

Systematic literature review as an essential part of any research work (Kamble et al., 2018) should be performed by using a methodological procedure. Ferenhof and Fernandes (2016) prescribed a literature review methodology (i.e. SSF method) based on the analysis of several works that deal with literature review and their result. This paper adopted the four phases of the SSF method, as presented in Figure 2.

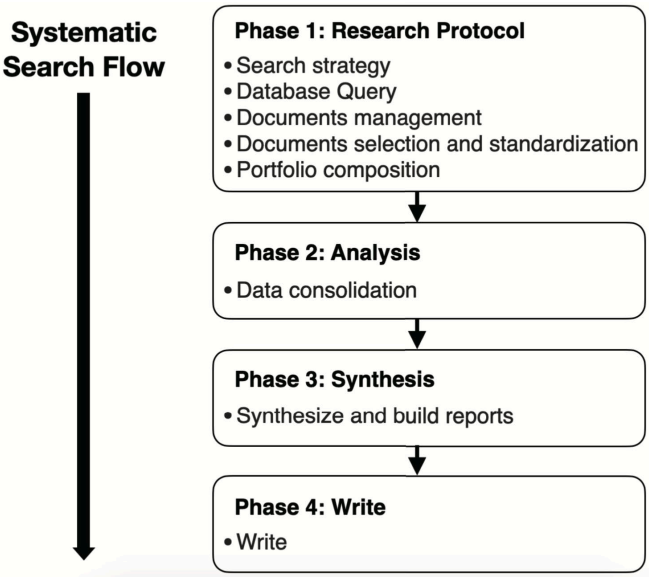


Figure 2. Systematic review flow diagram (derived from Ferenhof and Fernandes (2016)).

3.1 Research protocol

Research protocol (i.e. Phase 1) is devoted to the research protocol definition, covering the elaboration of a set of rules and parameters to configure the research process, determining the characteristics according to research need (Ferenhof and Fernandes, 2016). This phase is composed of five activities below.

(1) *Search strategy.* A set of procedures define the way to retrieve information from the databases (Ferenhof and Fernandes, 2016). In order to search literature from the databases, a concept of “smart design” (Zheng et al., 2019c) is coined to distinguish the design methods for Smart PSS development from conventional ones, as shown in Figure 3. It is defined as the ones: (1) the research objects are smart products, smart services or Smart PSS, (2) by using smart or digital technologies (e.g. artificial intelli-

gence and IoT), and/or (3) adopted in smart areas (e.g. smart home). Motivated by this, several engineering design methodologies (i.e. TRIZ, QFD, KE, UCD, AD, Blueprint design, Adaptable design, MC, and FBS), which have been adopted in PSS development and have been researched on "smart design" before, were further identified. Meanwhile, search terms such as "smart" and "digital" were also used in the search strategy to make search results more relevant. The language was defined as English, and the type of document was defined as "article". The search space is article title or abstract or keywords. In addition, the holistic review of "smart design" methodologies is carried out among the existing methodologies for PSS development. PSS was first coined in 1999, hence the time range was set from 1999 to 2020 (accessed on 04/05/2020).

The search string is written as: Topics=(TRIZ OR QFD OR (quality-function-deployment) OR (Kansei engineering) OR (User-center-design) OR (Axiomatic design) OR (Adaptable design) OR (Mass Customization) OR (Function-behavior-structure) OR FBS) AND Topics = ((PSS design) OR (product-service design) OR (product design) OR (service design)) AND Topics = (smart OR digital) AND Language = English AND Timespan = 1999-2020 AND Document types = Article.

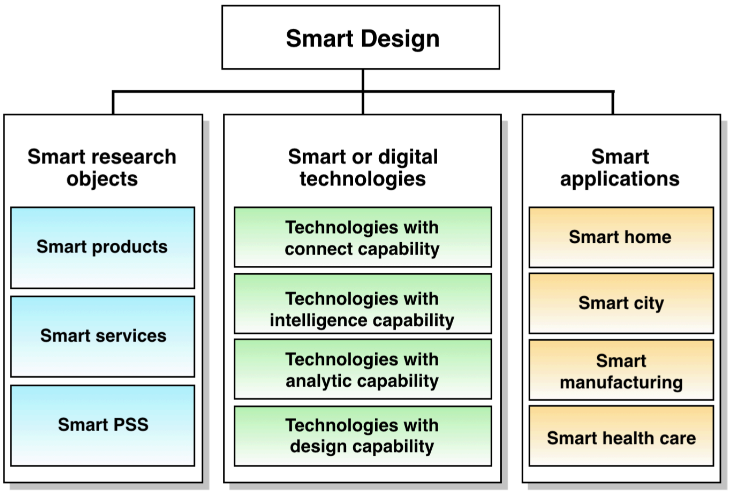


Figure 3. The interrelationship between design characteristics and elements.

(2) *Database query*. The researcher should execute the search by using a computational interface (Ferenhof and Fernandes, 2016). The authors carried out the basic search by using the WoS and Scopus, owing to their wide coverage of all the high quality and major peer-reviewed articles in academia. The search strategy initially resulted in 243 matches in WoS (all databases) and 179 matches in Scopus. This activity produced 293 articles ultimately after removing the duplicate items.

(3) Documents management. This activity aims at documenting the bibliographies through references-organizing software (Ferenhof and Fernandes, 2016). Zotero and Mendeley were used in this paper to simplify the storage and statistics process.

(4) Documents selection and standardization. The selected filters are applied to the process of this activity. The titles, abstracts, and keywords of each document were read to select the documents that are aligned with the search theme (Ferenhof and Fernandes, 2016). In this paper, a selection was conducted to exclude the paper, not within the engineering design field (e.g., medicine and computer science), by reading the titles and abstracts in detail. In this stage, 189 relevant items were extracted.

(5) *Portfolio composition.* This activity requires thoroughly reading documents to understand the subject researched and executing another filter to exclude documents that do not demonstrate adherence to the subject (Ferenhof and Fernandes, 2016). After more in-depth reading of the items, 129 articles were excluded because they did not discuss about "smart design" methods (e.g. applying design methodologies to advance some technologies). Meanwhile, through reading references of the chosen items, 19 relevant articles that focus on "smart design" methods and 22 representative papers that propose the nine methodologies were supplemented. Through the above steps, a total of 101 representative items were finalized as the foundation of this systematic literature review.

3.2 Analysis

Analysis (i.e. Phase 2) is devoted to consolidating the data. In this phase of the SSF method, some analyses (e.g., the growth in citations over the period and the distribution of the articles in a specific field) can be completed by using bibliometrics (Ferenhof and Fernandes, 2016). The analysis of the selected items in this paper can be summarized in 6 points below:

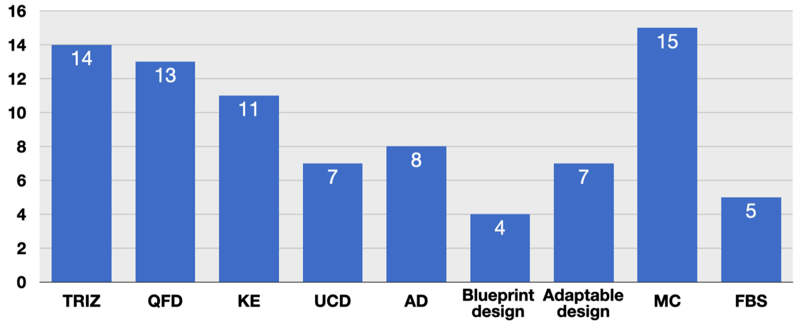
(1) *Distribution of publications as per design methodologies.* Figure 4(a) counts the number of articles that focus on "smart design" (excluding articles that only proposed methodologies) by each methodology. It is worth noting that the number of articles about MC (15 items) is the most, which reasonably depicts the increasing demand for providing personalized solutions in the smart context. In addition, four articles integrated two or three methods, two of them combined TRIZ and blueprint, one of them involved TRIZ and QFD, and one of them integrated TRIZ, blueprint, and QFD. One can find that TRIZ is combined with other methodologies in the field of "smart design" repeatedly.

(2) *Contributions from journals.* People's perception of the publications has been impacted by the credibility and reputation of publishing journals (Kamble et al., 2018). The Excel tool is used to extract the journal classification. As shown in Figure 4(b), Computers and Industrial Engineering ranks first with six publications, which is followed by Industrial Computers, International Production Research Journals, and Intelligent Manufacturing Journals with five articles, respectively.

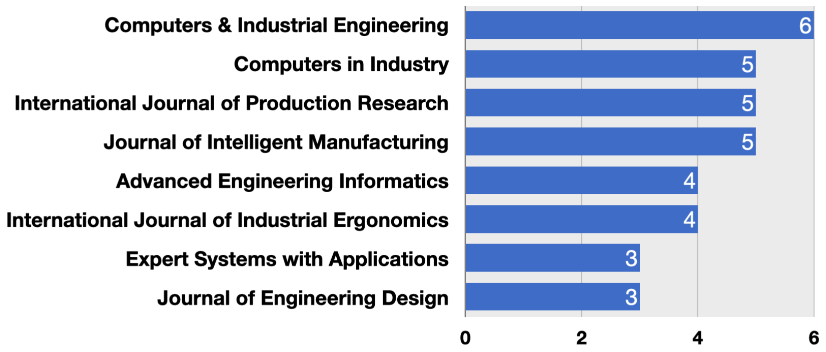
(3) *Article distribution across the reviewed timeframe.* In the past 22 years, an upward trend is visible regarding papers published in the field of “smart design” (see Figure 4(c)). It is observed that 34 out of 79 articles that focus on “smart design” were published in the year 2017–2020, which shows the researchers' strong interest in “smart design”.

(4) *Frequently used keywords.* The most commonly used keywords in all selected papers were extracted by using the Excel tool. Apart from the words of design methodology name (e.g. TRIZ and QFD) and the words which describe the field (e.g. service design， product development), the most frequently used keywords were “open architecture product”, “CPS” and “CAD”, showing the significance of these concepts and technologies for “smart design” (see Figure 4(d)).

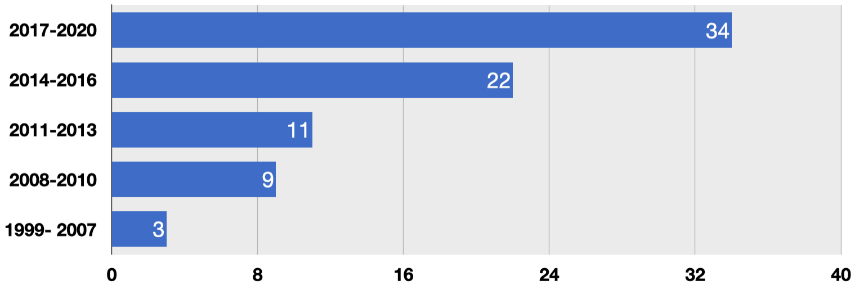
(5) *Distribution of publications as per research categories.* The selected papers about “smart design” were categorized into three research categories, as shown in Figure 4(e). The distribution of categories indicates that more attention has been paid to smart or digital technologies. In particular, technologies with analytical capabilities have received more research. The descriptive analysis of each subelement of “smart design” three categories is conducted in detail in Section 4.



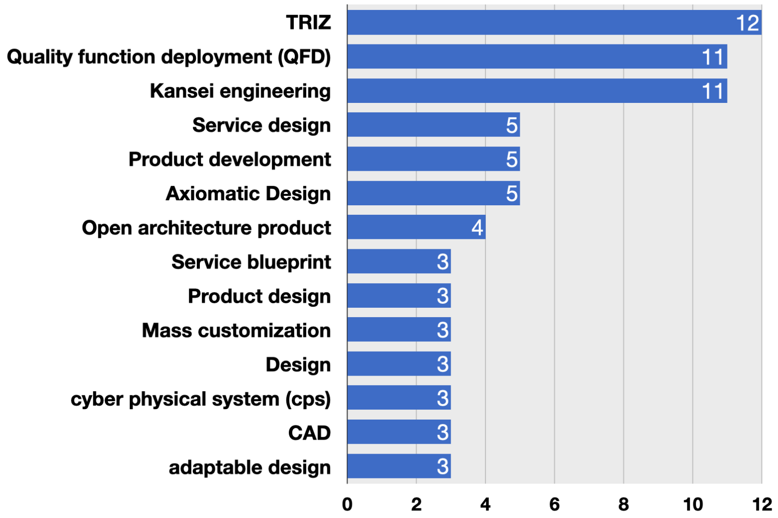
(a) Number of papers per each methodology.



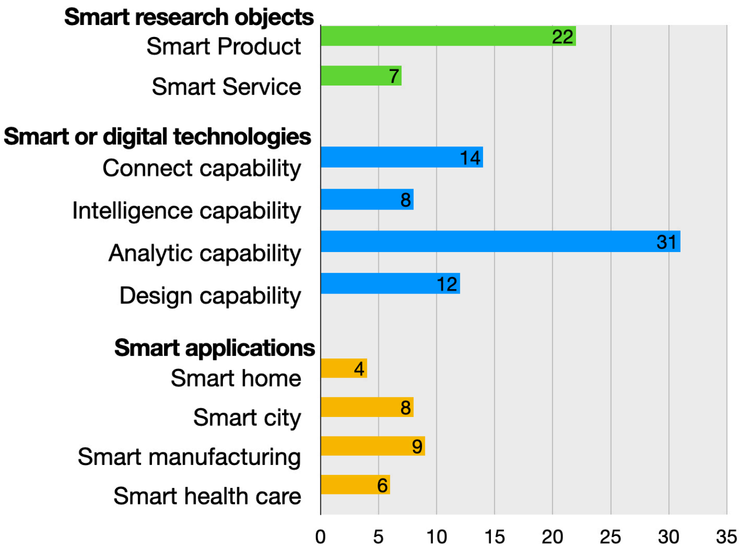
(b) Top contributing journals (≥three papers).



(c) Number of papers per three year of publication.



(d) Frequently used keywords (count ≥3).



(e) Distribution of research categories.

Figure 4. Distribution of selected papers.

3.3 Synthesis and Writing

Synthesis (i.e. Phase 3) and *Writing (i.e. Phase 4)* aim to construct the lessons about the theme and consolidate the results through scientific writing (Ferenhof and Fernandes, 2016). Based on the definition of "smart design" method, key aspects of the selected items can be further classified into two parts, i.e. methodologies and applications, as shown in Figure 5. Methodologies part introduces the fundamentals of "smart design" methods, including the definitions and research objects (Section 4.1), and their enabling technologies (Section 4.2). Applications part depicts their real-life applications (Section 4.3). Based on that, existing challenges (Section 5) and future research perspectives (Section 6) can be derived as research outcomes of this comprehensive review.

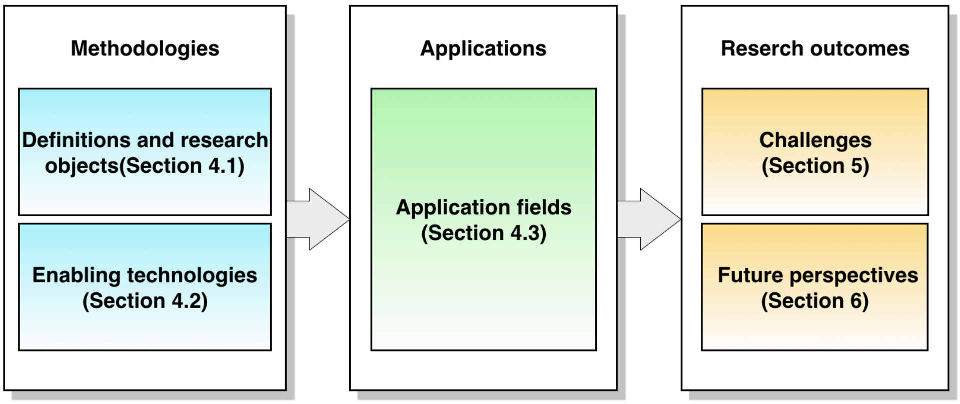


Figure 5. The overall structure of the review.

4. Engineering design methodologies for “smart design”

Based on the systematic literature review process, this section outlines the key aspects of engineering methodologies about “smart design”, including the definitions and research objects, technical aspects, and application aspects.

4.1 Definitions and research objects

Among existing literature, the major definitions of design methodologies are listed in Table 1. It also summarizes the “smart design” objects from the selected items, including smart products and smart services. Most engineering methodologies were initially proposed for smart products (22 items), rather than smart services (7 items). The major findings can be summarized into two aspects below.

From smart product-oriented aspect, some previous studies focus on the design of the physical components. To realize the real-time hardware optimization, the physical product can be divided into three types of modules (i.e. common physical modules, configurable physical modules, and user-generated physical modules). The user-generated physical modules as add-on modules can be designed by users individually through an adaptable interface (Zheng et al., 2018b). In the Smart PSS development process, the openness of physical components should be concerned to achieve the adaptable change of modules according to users' feedback. When updating the product, the stakeholders can reconfigure product modules rather than remanufacturing the entire product.

From smart service-oriented aspect, Smart PSS highlights a servitized value proposition with less environmental impact for a circular economy (Zheng et al., 2019c). Nevertheless, only a few reviewed paper has discussed how to increase resource efficiency through smart design methods. Fargnoli et al. (2018) presented an approach to enhance sustainability and explained its benefits in the development of sustainable PSS solutions. Moreover, there is still a lack of holistic design method, taking both software-based e-services and digitalized services into an overall consideration. The related literature all focuses on e-services, which are independent with the physical products (Wang et al., 2018). Lee et al. (2019a) treated Smart PSS as a research object and combined TRIZ and service blueprint for proposing a structural service innovation approach. However, the primary concern of this method is from service engineering with little SCP consideration. The studies of digitalized services (e.g. the remote maintenance services based on the digital twin of a machine tool) still need to be explored more deeply with higher self-adaptability or context-awareness in order to adapt to the challenges of Smart PSS.

Table 1. Definitions and research objects.

Design methodologies	Research objects		Definitions	
	Smart Product	Smart Service	Specification	Ref.
TRIZ	(Moehrle, 2010) (Koswatte et al., 2015) (Wang, 2015a) (Wang, 2017)	(Lee et al., 2015) (Wang et al., 2017b) (Lee et al., 2019a)	TRIZ (from the Russian phrase "Teorija Rezhenija Izobretatelskih Zadach") proposed by Russian researcher is a creative problem-solving theory, which was developed as a knowledge-based innovative approach for solving conflicts in technical systems by some techniques.	(Savransky, 2000) (Ilevbare et al., 2013)
QFD	(Li et al., 2014) (Choi et al., 2015) (Wang et al., 2015) (Wang, 2017) (Kim et al., 2018)	(Sohn et al., 2013)	Quality Function Deployment (QFD) as a product development methodology driven by customer requirements is to decompose the implementation process of customer demands into different stages of product development, and evaluate the product performance according to the customer satisfaction.	(Zairi and Youssef, 1995) (Köksal and Eğitman, 1998) (Govers, 2001)
KE	(Wang and Chin, 2017) (Li et al., 2018)	/	Kansei Engineering (KE) was developed initially in Japan as a consumer-oriented product design technology. Through studying the emotional response of users to the product systematically, and transforming the emotion of customers into measurable physical design parameters by ergonomics and computer science.	(Nagamachi, 1995) (Jindo and Hirasago, 1997) (Nagamachi and Imada, 1995)
UCD	/	(Augusto et al., 2017)	The term 'User-Centred Design (UCD)' originally came from Donald Norman's research laboratory, emphasizing the core role of user information during each phase of the design process and proposes that early user engagement can facilitate the design process effectively.	(Anderson et al., 1988) (Karat and Watson, 1996) (Kraft, 2012)
AD	(Rauch et al., 2016) (Riel et al., 2018)	/	Axiomatic Design (AD) was first proposed by Suh. AD theory submits two essential axioms, include the Independence Axiom which maintains the uncoupled of functional requirements and the Information Axiom which minimizes product information content, that can eliminate the possibility of making mistakes in the product development process.	(Suh, 1998) (Suh, 2007)
Blueprint design	/	(Lee et al., 2015) (Lee et al., 2019a) (Xu, 2020)	Service Blueprint proposed by Shostack (1982) is an analysis approach by integrating service content and information structure on a clear map to help designers investigate organizational service processes based on customer behavior.	(Lynn Shostack, 1982) (Chou et al., 2012)
Adaptable design	(Peng et al., 2013) (Zhang et al., 2015) (Hu et al., 2015) (Zheng et al., 2017a) (Zheng et al., 2018b) (Zheng et al., 2019a)	/	Adaptable design was first presented by Gu to adapt new requirements through design adaptability or product adaptability with replacing or adding certain modules through pre-defined adaptive interfaces when the conditions change.	(Gu et al., 2004) (Gu et al., 2016)
MC	(Li et al., 2013)	(Chiu and Chiou, 2016)	Mass Customization (MC) maintains a balance between product differentiation and standardization by leveraging manufacturing flexibility and mass production efficiency.	(Kotha, 1994) (Eastwood, 1996) (Davis, 1997)
FBS	(Liu et al., 2019a) (Qin et al., 2019)	/	Functional-Behavior-Structure (FBS) framework was proposed by Gero (1990) to represent the design process as the translation between function, behavior, and structure. The design flow of the FBS framework was presented as eight steps.	(Gero, 1990) (Gero and Kannengiesser, 2004)

4.2. Enabling technologies

Table 2 shows the enabling technologies to realize "smart design". From a technical perspective, to clarify the enabling technologies, the category of digitalization capabilities which proposed by Zheng et al. (2019) is adopted and improved in this paper. As shown in Figure 6, the digitalization capabilities have been classified into four categories, i.e. connect capability, intelligence capability, analytic capability (Zheng et al., 2019c) and design capability. Design capability which is added in this paper stands for the ability to inspire design ideas, realize design concepts, or complete iterations through digital tools. The main focus of these categories is depicted below:

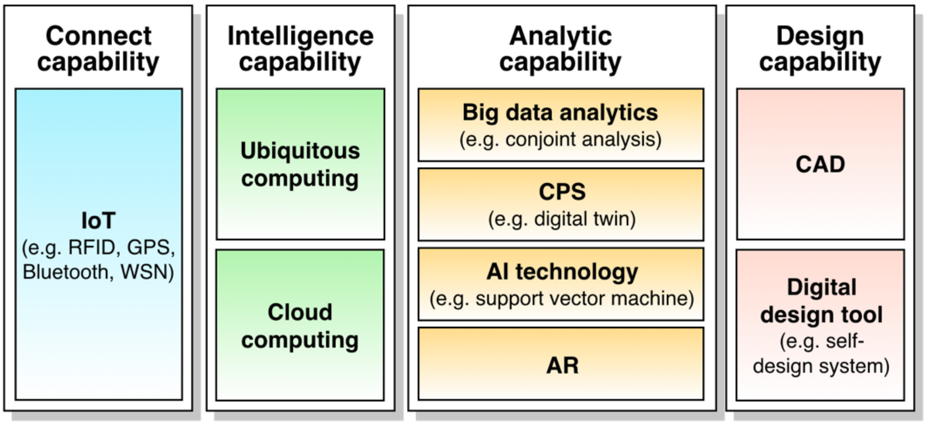


Figure 6. Enabling technologies of "smart design".

The enabling technologies with connect capability, as the fundamental technologies of smart products/services, were discussed by most engineering methodologies. There is little research on using these technologies as a reasonable means to improve design methodologies that assist systems in collecting user behaviors' data and offer related design iterations to respond to the operation data. Meanwhile, most of the studies mention the connection technologies in specific cases (e.g. smartwatches (Li et al., 2018) and smart parking (Lee et al., 2015)), it still lacks a common engineering approach to explain how to choose an appropriate connection technology for various Smart PSS during the development stage.

The enabling technologies with intelligence capability have only been mentioned in 7 of the reviewed articles. One can find that less of the reviewed papers pay deserved attention on design methodologies improvement from an information perspective. The articles, which mention the technologies with intelligence capability, lack in-depth discussions on the way to capture information from real-time product-sensed data, and they just utilize cloud computing or ubiquitous computing as a foundation without some detail researches (Zhang et al., 2017). Take long-term care (LTC) cloud system as an example, Chang et al. (2017) proposed that LTC cloud system takes advantages of cloud computing. However, the integrated design methodology, which was provided to resolve LTC problems, had little discussions on how to collect and process massive information from user-generated data intelligently with cloud computing.

The enabling technologies with analytic capability can transform the data/information available at hand into visible design elements and valuable plans for the developers. Therefore, in reviewed papers, massive researches utilized these technologies, especially machine learning algorithms and statistics analysis methods. Machine learning algorithms were utilized to solve the design mapping problems between the users' responses and the design features to make the design plans matching the requirements of target users better. Nevertheless, there is still little research on which algorithms are more suitable in specific unique design scenarios and the comparison of the efficiency and success rate of these algorithms. Meanwhile, statistical analysis methods were applied to identify some vital goals in product development. Zabotto et al. (2019) proposed a Kansei engineering system to create mood boards with the information given by users via a rough set probability analysis. Nevertheless, there is a lack of consensus on which statistics analysis method has capabilities such as accurateness and generalization to fit different development goals. Besides, fuzzy logic always be used by integrating with other methods for the prioritization of some items (e.g. alternative customer suggestions (Soroor et al., 2012), importance of performance measures (Hu et al., 2015), and importance degrees of customer requirements (Lin et al., 2008)), for the reason that multiple items are often preferred rather than a single item to avoid any possible bias and to minimize the partiality in the design process.

The enabling technologies with design capability focus on how to assist developers with different professional levels currently, but there is little research on finishing real-time iterations automatically with less human intervention. Nowadays, the computer-aided design (CAD) system was used to help stakeholders finishing the design work more accessible (Lo et al., 2010). Sharif Ullah et al. (2016) discussed the integration of CAD, TRIZ, and user requirements and introduced the way to create a questionnaire by combining the TRIZ-CAD outcomes. Kaiser et al. (2017) presented a virtual development framework by using advanced CAD and simulation solutions. Meanwhile, some digital tools (e.g. delight design platform (Yanagisawa et al., 2016) and digital human modeling (Högberg, 2009)) were adopted to make the development process more naturally and efficiently. Shangguan et al. (2015) developed a rapid design system for the generation of complex gearboxes, which is supported by the knowledge database and the AD-based inference engine. Arrighi et al. (2016) proposed a novel modular digital toolbox by combining a mixed reality hardware/software system and KE techniques.

Table 2. Technologies for “smart design” methods.

Design methodologies	Connect capability		Intelligence capability		Analytic capability		Design capability	
	Technologies	Ref.	Technologies	Ref.	Technologies	Ref.	Technologies	Ref.
TRIZ	IoT; RFID	(Lee et al., 2015) (Lee et al., 2019a)	Cloud computing	(Chang et al., 2017)	Association rule mining; Conjoint analysis; AR; CPS; Analytical hierarchy process	(Wang, 2015a) (Lee et al., 2019a)	CAD	(Wang et al., 2017b) (Sharif Ullah et al., 2016)
QFD	RFID; GPS	(Lee et al., 2013)	/		Genetic algorithm; Fuzzy adaptive resonance theory network; Association rules mining; Latent semantic indexing; Grey relational analysis; Analytical hierarchy process	(Lin et al., 2008) (Erkarslan and Yilmaz, 2011) (Soroor et al., 2012) (Li et al., 2014) (Wang et al., 2015) (Chen et al., 2015)	Computer-aided conceptual design system;	(Lo et al., 2010)
KE	Bluetooth; GPS	(Wang, 2015b) (Wang and Chin, 2017) (Li et al., 2018)	/		Support vector machine; Factor analysis; Procrustes analysis; Neural network; Support vector regression; Ridge regression; Classification and regression tree; Multi-layer perceptron; Rough set theory; Conjoint analysis; Grey relational analysis; Correspondence analysis; Genetic algorithm; Back propagation neural network; Classification syllogism	(Li et al., 2008) (Yang, 2011) (Guo et al., 2014) (Wang and Yeh, 2015) (Wang, 2015b) (Wang and Chin, 2017) (Misaka and Aoyama, 2018) (Li et al., 2018) (Zabotto et al., 2019)	Delight design platform; Modular digital toolbox	(Yanagisawa et al., 2016) (Arrighi et al., 2016)
UCD	IoT; WSNs	(Augusto et al., 2017) (Cavallo et al., 2018)	Ubiquitous computing	(Obal and Stojmenova, 2013) (Augusto et al., 2017)	/		Self-design greeting card system; Digital human modelling	(Yang and Yang, 2016) (Högberg, 2009)
AD	IoT; WSNs; RFID	(Riel et al., 2018) (Viriyasitavat et al., 2019)	/		Computer simulation; CPS	(Espadinha-Cruz et al., 2015) (Riel et al., 2018)	Rapid design system	(Shangguan et al., 2015)
Blueprint design	IoT; RFID	(Lee et al., 2015) (Lee et al., 2019a)	/		CPS; AR	(Lee et al., 2019a)	/	
Adaptable design	IoT	(Zheng et al., 2018b) (Zheng et al., 2019a)	Cloud computing	(Zheng et al., 2017b) (Zheng et al., 2018b) (Zheng et al., 2019a)	CPS; Digital twin	(Zheng et al., 2018b) (Zheng et al., 2019a)	/	/

MC	RFID; Bluetooth; GPS	(Li et al., 2013) (Ramadan et al., 2017)	Ubiquitous computing	(Yew et al., 2016)	Association rule mining; tree structure; Fuzzy multiple attribute decision making; CPS; AR	(Zhu et al., 2008) (Dean et al., 2009) (Li et al., 2013) (Yew et al., 2016) (Karaköse and Yetiş, 2017) (Huang et al., 2020)	Web-based collaborative visualization technologies; Virtual development; CAD; Three-dimensional laser scanning; Genetic algorithms	(Chen and Feng, 2003) (Chu et al., 2006) (Tuck et al., 2008) (Kaiser et al., 2017)
FBS	/		Ubiquitous computing	(Liu et al., 2019a)	Case-based reasoning technique; Knowledge representation; Digital twin	(Christophe et al., 2010) (Hu et al., 2017) (Liu et al., 2019a) (Qin, 2019)	/	

4.3 Application field

Table 3 summarizes the typical application scenarios. It is interesting to find that although most of the applications are still within the smart (intelligent) manufacturing sector (e.g. additive manufacturing (Kang et al., 2018)), they are gradually moving to other sectors such as smart home (e.g. smart kitchen (Obal and Stojmenova, 2013)), smart city (e.g. smart airports (Sohn et al., 2013)) and smart healthcare (e.g. long-term care cloud system (Chang et al., 2017)). The core findings in these application fields can be summarized as:

1) Smart home. The new capabilities for online and offline service innovations of the smart appliance/smart living can be provided by Smart PSS (Zheng et al., 2019c), but only two reviewed methodologies have been studied in this sector currently, which mainly showed how to develop smart products or systems in different home scenarios. For examples, Qin et al. (2019) proposed the CMR+FBS model to analyze the conversion relationship between the functions and contents, and Cavallo et al. (2018) adopted a UCD-based design approach for designing, developing, and testing the personal robotic system.

2) Smart city. Some approaches view application to the smart city as a significant work, most reviewed papers still lack a comprehensive research of smart mobility, which also are the main dimensions of smart city. Nowadays the design methods of smart city have been discussed on some city components, and the integrated roadmap framework to support strategic planning for smart city development (Lee et al., 2013).

3) *Smart manufacturing*. Although articles about smart manufacturing account for a large amount, it still lacks some concerns about developing Smart PSS for improving performance and decreasing cost in different industries by some digital technologies.

4) *Smart healthcare*. Smart PSS can provide the necessary database of user physical and behavior data, and the smart technologies (e.g. image remote transmission and data calculating). However, the current reviewed articles still lack some conceptual and empirical discussion on applying Smart PSS in smart hospital or smart family health development.

Table 3. Applications of "smart design" methods.

Design methodologies	Smart home		Smart city		Smart manufacturing		Smart health care	
	Scenarios	Ref.	Scenarios	Ref.	Scenarios	Ref.	Scenarios	Ref.
TRIZ	/		Smart collaborative systems in fast food restaurant; Smart interoperable menu systems; Smart shopping service; Intelligent parking	(Lee et al., 2015) (Wang et al., 2017a) (Wang et al., 2017b) (Lee et al., 2019b)	Factory of the Future (FoF)	(Negny et al., 2017)	Mobile health; Long-Term Care; Smart rollators for the elderly or disabled users	(Miao et al., 2017) (Chang et al., 2017) (Zhang et al., 2019)
QFD	/		A smart city development project in Korea; Smart interoperable menu systems; Smart Airports	(Lee et al., 2013) (Wang et al., 2017a) (Sohn et al., 2013)	/		Mobile health; Health information exchange; Smart rollators for the elderly or disabled users	(Chen et al., 2015) (Miao et al., 2017) (Zhang et al., 2019)
KE	/		/		/		/	
UCD	Smart-home system; Smart kitchen; Personal robot system	(Kühnel et al., 2011) (Obal and Stojmenova, 2013) (Cavallo et al., 2018)	/		/		Consumer Health Technologies; Helping people with Down's Syndrome	(LeRouge et al., 2013) (Augusto et al., 2017)
AD	/		Mobile logistics tools	(Büyüközkan et al., 2012)	Real-time capable production planning; Performance of manufacturing cells	(Rauch et al., 2018) (Chen et al., 2001)	/	
Blueprint design	/		Intelligent parking; Smart interoperable menu systems	(Lee et al., 2015) (Wang et al., 2017a)	/		/	
Adaptable design	/		/		Cloud manufacturing	(Zheng et al., 2017b)	/	
MC	/		Smart trade	(Karaköse and Yetiş, 2017)	Digital manufacturing; Smart manufacturing; Smart factory	(Dean et al., 2009) (Purohit et al., 2016)	/	

						(Kang et al., 2018) (Huang et al., 2020) (Kim et al., 2020)		
FBS	Family smart products	(Qin et al., 2019)	/		/		/	

5. Challenges

In the previous sections, engineering design methodologies associated with “smart design” have been discussed in three aspects. As shown in Table 4 (Cong et al., 2020), these works are categorized from three design characteristics of Smart PSS. Despite the achievements listed, one can find that none of the existing design methodologies can meet all the three characteristics. Smart PSS still faces several challenges in its development process, which are outlined as three aspects below.

5.1 IT-driven value co-creation aspect

Smart PSS emphasizes the IT-driven co-creation value proposition in two ways, including users’ active engagement and stakeholders’ (e.g. service providers and manufacturers/suppliers) communications with each other. For the prior one, there are three challenges elaborated below.

1) *Subjectively participating of users.* Other than some conventional methods (e.g. focus group and individual interviews), Smart PSS should well-utilize the fundamental technologies (e.g. digital twin and AR) to stimulate inspirations of users and create some new ways for users to participate in the system iteration during usage stage. Nevertheless, the reviewed papers currently focus on the ones: (1) users can express their thoughts through some traditional methods (e.g. questionnaire, brainstorming and field interviews (Lin et al., 2008)) and (2) users can co-design with the developers in the design stage (e.g. the end-users can configure individual parts of a 3D assembly in a regular browser (Lo et al., 2010)). It still lacks research to help users participating in the iterative design by utilizing enabling technologies of Smart PSS.

2) *Designing with user-generated data.* A challenging question urgently needed to be addressed the way to collect and process real-time user behavior data. It is also a valuable research direction regarding what kinds of data should be sensed from diverse Smart PSS in-use situations (Hou and Jiao, 2019). For example, when designing a smart electric bicycle service system, the usage data of speed increments, time of changing speed, the cadence (steps/min) and the frequency of ringing the bell should be utilized

and combined with surrounding environmental data to extract useful information, which can guide the design iteration of the bicycle. However, the existing researches were mainly focused on the customer data from the questionnaire (Erkarslan and Yilmaz, 2011), the online reviews data in social media and anthropometric data. For example, Kim et al. (2018) extracted web data from Internet-based social network service and used smart QDF to originate the correlation between extracted web data and functions, and Högberg (2009) applied an anthropometric database incorporated in RAMSIS in the study. User behavior data in Smart PSS design is not discussed in most of the methodologies.

3) *Matching user preferences with design elements.* User preferences should be associated with different design elements of Smart PSS in specific usage contexts, so that the relationship models based on context become a challenging issue. Previous studies constructed some specific models for the connection between some user preferences and design elements. Misaka and Aoyama (2018) combined KE and neural network for correlating the KANSEI of users with the parameters of the crack patterns. Little in-depth research has been done to concern the changed of association relationship in the different usage contexts, which genuinely meets the user-specific preferences in the usage stage of Smart PSS.

For the latter, the cooperation of stakeholders faces a significant challenge that, co-creation of the service provider, who ensure users obtaining the near-optimal service, need to be discussed in design methodologies as well. Nowadays, some studies proposed methods for the integration of all the stakeholders into a whole design process (Obal and Stojmenova, 2013), but the main stakeholders in the reviewed papers only refer to product suppliers (Soroor et al., 2012), operators (e.g. caregivers and therapists) (Augusto et al., 2017), product and service developers (Obal and Stojmenova, 2013). Service provider, as a vital stakeholder of Smart PSS, still lacks sufficient studies.

5.2 Closed-loop design aspect

The closed-loop design of Smart PSS emphasizes the iteration of entire design/redesign process to extend the lifespan, of which the key challenges of each phase are summarized below.

1）*Requirements analysis phase.* There are some challenges and research opportunities on the customer requirements identifying, collecting and analyzing. Wang et al. (2015) proposed a method to help different types of customers assessing requirements in their preferred. However, a significant challenge of this method is how to integrate requirements extracted from user behavior data with subjective user description (Hou and Jiao, 2019). Chen et al. (2015) presented an approach to extract useful customers voices from social media and transform the voices into requirements. Nevertheless, transforming customers voices to requirements with less misinterpretation of the voices is a great challenge. Wang (2015a) showed a TRIZ based framework to identify critical features that formulate customer dissatisfaction. However, this study performed market segmentation in advance. An automated user grouping approach deserves to be further addressed to achieve better product development without human intervention. Sharif Ullah et al. (2016) proposed an approach to integrate CAD and TRIZ within the framework of the user requirements assessment process. However, this method cannot work well when the focus issues in the questionnaire fail to related to CAD modeling and TRIZ parameters. Liu et al. (2020) developed a framework to analyze system requirements of Smart PSS toward customer needs. The framework, which is only based on B2C-type Smart PSS, needs to be extended to B2B-type.

2） *Innovative design phase.* Some challenges remain not well-solved at the moment. Wang et al. (2017b) described a conceptual service design framework to apply in different problem contexts. One challenging problem is how to reduce the necessary demand of the designers' labor in a service CAD environment. Hu et al. (2017) developed an intelligent, creative conceptual design system for designers based on knowledge reasoning. However, the way of summary and reuse professional knowledge in different types of Smart PSS, which can help various Smart PSS make design decisions more effectively, is a significant challenge. Pan et al. (2019) examined how to design Smart PSS for service-oriented, intelligent interoperable logistics. Nevertheless, the little in-depth discussion focused on the potential ability of the proposed paradigm to address the sustainability issues.

3)*Design evaluation phase.* Smart PSS still faces several challenges in its design evaluation process. Arrighi et al. (2016) evaluated users’ satisfaction for the entire product, through questionnaires and psychophysiological measurements accurately. However, a significant challenge for Smart PSS is to build a feedback mechanism which can accurately evaluate some small design modifications without human operation, for the reason that Smart PSS should be iteratively optimized accord with the quality evaluation of design modifications to obtain the near-optimal design plan. Yanagisawa et al. (2016) aimed to develop a model-based design environment that can simulate a customer’s affective responses toward digital design models. It is deemed to be a great challenge to automatically determine which affective indexes should be measured in different types of Smart PSS. Cavallo et al. (2018) proposed a methodology based on the simultaneous evaluation of dependability and acceptability for the robotic systems in a

smart environment. In fact, it is a practical challenge to finish the evaluation in the practical usage context, rather than the environment with an experimental infrastructure.

4）*Iterative design phase.* Real-time requirements and evaluations collection leads to extensive design iterations, creating challenges for the self-adaptable capability of Smart PSS, which needs a design method to adjust its product or service modules in a manner triggered by the specific context (Zheng et al., 2019c). Peng et al. (2013) achieved different adaptabilities of product to meet the requirements in specific environments. However, the way to feedback the context information to developers for product iteration is still not well-addressed now (Patil et al., 2019). Zheng et al. (2018b) presented that users can utilize their tangible experience of the product to change the physical modules. Nonetheless, the way to integrate user-generated quantitative data with real-time qualitative user experience data for the iterative design is still a potential challenge.

5.3 Context-awareness aspect

Smart PSS needs to determine the current context through hardware sensors and social sensors, and adaptively update the design solutions in real-time. Nevertheless, there is currently little relative research on this aspect in the existing methodologies. Two challenges remain not well-solved at the moment.

1) *From a perceiving context perspective*, the main challenge is how to distinguish context from big data via hardware and social sensors, including environmental data, system/user physical status data and social data. Importantly, social data here is different from "the reviews data in social media", which is mentioned in Section 5.1. The social data here emphasizes not only the user reviews of Smart PSS but also the records on their social network, daily lifestyles, consumption level, pleasure way, aesthetic preferences, etc. These data can describe users' features and build a better-personalized usage context. However, the existing design methodologies lack some relevant research. Meanwhile, it is noteworthy that data privacy and protection are significant to users. The development of Smart PSS should follow the data privacy regulations (e.g. GDPR) to ensure users' awareness and approval to the data collected.

2) *From an adaptability perspective,* a challenging question that needs to be solved is how to enable Smart PSS, making design-level adaptive changes according to the specific context. Two ways which still lack sufficient study in the existing papers are proposed below. Firstly, the system responds to the context automatically in real-time during the usage phase, such as replacing the modules and adjusting

parameters. Secondly, the development team should predict the possible contexts and corresponding solutions during the development phase, and continuously optimize the design solutions according to user feedback in the use phase.

Table 4. Comparison of reviewed design methodologies for Smart PSS（derived from Cong et al. (2020)）.

		TRIZ	QFD	KE	UCD	AD	Blue-print design	Adaptable design	MC	FBS
IT-driven Value co-creation	Subjectively participating of users	/	(Wang et al., 2015) (Lin et al., 2008)	(Li et al., 2018) (Arrighi et al., 2016) (Guo et al., 2014)	(Yang and Yang, 2016) (Cavallo et al., 2018)	/	/	(Zheng et al., 2017a) (Peng et al., 2013) (Zheng et al., 2017b	(Chu et al., 2006) (Dean et al., 2009) (Zhu et al., 2008)	/
	Designing with user-generated data	(Wang, 2015a)	(Lo et al., 2010) (Erkarslan and Yilmaz, 2011) (Chen et al., 2015) (Kim et al., 2018)	(Zabotto et al., 2019)	(Högberg, 2009)	/	/	(Zheng et al., 2018b) (Zheng et al., 2019a)	(Li et al., 2013) (Kaiser et al., 2017)	/
	Matching user preferences with design elements	(Wang, 2015a)	/	(Li et al., 2008) (Guo et al., 2014) (Wang and Yeh, 2015) (Wang and Chin, 2017) (Li et al., 2018) (Misaka and Aoyama, 2018) (Zabotto et al., 2019)	/	/	/	(Zheng et al., 2017a)	(Li et al., 2013)	/
	Cooperation of other stakeholders	/	(Soroor et al., 2012)	/	(Obal and Stojmenova , 2013) (Augusto et al., 2017)	/	/	/	(Chu et al., 2006)	/
Closed-loop design	Requirements analysis	(Wang, 2015a) (Sharif Ullah et al., 2016)	(Wang, 2017) (Wang et al., 2015) (Lin et al., 2008) (Sohn et al., 2013)	/	/	/	/	/	(Zhu et al., 2008) (Chu et al., 2006)	(Liu et al., 2019a)

				(Chen et al., 2015) (Kim et al., 2018)							
	Innovative design		(Wang, 2015a) (Moehrle, 2010) (Lee et al., 2015) (Wang et al., 2017b) (Wang et al., 2017a) (Lee et al., 2019a)	(Lo et al., 2010) (Kim et al., 2018)	/	(Högberg, 2009) (Augusto et al., 2017)	(Riel et al., 2018)	(Lee et al., 2019a)	/	/	(Liu et al., 2019a) (Christophe et al., 2010) (Hu et al., 2017)
	Design evaluation		(Wang, 2015a) (Wang et al., 2017b)	(Wang et al., 2017a) (Lin et al., 2008) (Kim et al., 2018)	(Arrighi et al., 2016) (Yanagisawa et al., 2016)	(Cavallo et al., 2018)	/	(Lee et al., 2015) (Wang et al., 2017a)	(Peng et al., 2013) (Zhang et al., 2015)	(Chu et al., 2006)	(Hu et al., 2017) (Liu et al., 2019a)
	Iterative design		/	/	/	(Karat and Watson, 1996)	/	/	(Peng et al., 2013) (Zheng et al., 2018b) (Zheng et al., 2019a) (Gu et al., 2004)	(Chu et al., 2006)	
Context-awareness	Perceiving context	Via hardware sensors	/	/	/	(Cavallo et al., 2018)	/	/	(Zheng et al., 2018b) (Zheng et al., 2019a)	/	(Liu et al., 2019a)
		Via social sensors	/	/	/	/	/	/	/	/	/
	Adapting to context	Development team involvement	/	/	/	/	/	/	/	/	/
		Automatically	/	/	/	/	/	/	/	/	/

6. Future perspectives

To overcome the challenges listed in Section 5, potential approaches and future research directions are highlighted below to welcome more open discussion and in-depth research in the near future.

6.1 Information design with IT-driven value co-creation

To fulfil the challenge of *IT-driven value co-creation*, Smart PSS design can take the process of information extraction, transmission, summary, and share into an overall consideration. Due to the intelligentization, digitization and servitization characteristics of Smart PSS, it can make information in the context as the research objective, instead of physical substance. The information in smart PSS can be input by designers, engineers, and other stakeholders directly. Meanwhile, it also can be extracted from the context data collected by SCP sensors, the behavior data generated by customers in using period, and the online data of social networks. We advise developing a method to focus on the information collecting, storing and transmitting of Smart PSS and how to deliver information accurately to every stakeholder through the SCPs and smart services (Cong et al., 2020). It may cover: 1) how to use information as a value (Lim et al., 2015), mining it from different kind of data in the specific context and expressing it precisely to users who need it (Lim et al., 2018), and 2) how to accessibly and intelligently share the information generated by stakeholders to the interdisciplinary team (includes users) (McMahon, 2015) during the conceptual design stage (Wodehouse and Ion, 2010).

6.2 Information-centric modular design

To ensure *closed-loop designing*, the Smart PSS design methods should comprehensively observe all design phases from a holistic perspective, especially the iterative design phase. Smart PSS should finish its iteration more intelligently, automatically and individually for a different context. To extend lifecycle with less manufacturing process and human intervention, the novel design method for Smart PSS can be based on modularization design (Fargnoli et al., 2019), which may cover (1) the concept of information modules can be proposed and used as a core module in self-adaptable platforms to replace the product and service modules (Cenamor et al., 2017), and (2) an information system can be established to record and update the input and output information of each module under different contexts for completing and selecting the solutions more accurately (Aurich et al., 2006).

6.3 Self-adaptable design for Smart PSS development

Last but not least, self-adaptable design can be proposed to solve the challenges of *context-awareness aspect*. Figure 7 described the self-adaptable design process of Smart PSS (Cong et al., 2020). In the innovative design phase, developers should create a new Smart PSS and output the overall design plan. In usage stage, new information (e.g. customer reviews information, user behavior information, and component status information) will be collected to perceive the context. And then, in order to self-adapt to the context, Smart PSS should process the information in real-time, and adjust the modules or modify the design plan according to the information automatically (Cong et al., 2020).

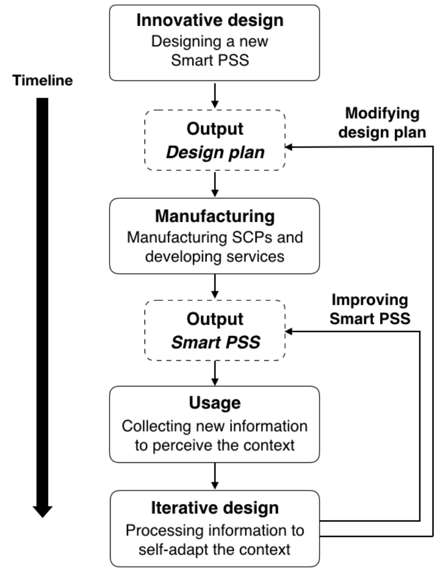


Figure 7. Self-adaptable design process of Smart PSS（derived from Cong et al. (2020)）.

7. Conclusions

Smart PSS, as an emerging IT-driven value co-creation business strategy coined in 2014, has attracted ever-increasing attention among academics recently. Nevertheless, there still lacks a fundamental design methodology for Smart PSS development. To identify the limitations of current design approaches in supporting Smart PSS development and suggest some future research directions, this paper conducted a holistic relook at the existing engineering design methodologies and selected 101 representative items relevant to the Smart PSS development. The main scientific contributions of this work can be summarized in three aspects below:

1) *Provided a holistic relook of the related publications on engineering design methodologies for Smart PSS development*. To our best knowledge, only a few works conducted the investigation of Smart PSS, let alone a review on engineering methodologies to support Smart PSS development process. This study can serve as the baseline to attract more open discussions in the Smart PSS design methodologies.

2) *Proposed "smart design" from three aspects (i.e. smart research objects, smart enabling technologies and smart application scenarios) to effectively find the valuable methodologies that can be adopted/adapted in Smart PSS development process*. Nowadays, Smart PSS has been delivered to the market widely to satisfy the needs of individual consumers in various application scenarios (e.g. smart

city and smart office). However, specific design methods for Smart PSS were rarely discussed in literature to assist companies in obtaining adequate design resources within a low-cost budget. The achievements and limitations of the 9 engineering methodologies in “smart design” can better facilitate companies to understand of the pros and cons of adapting them in Smart PSS design, and to improve their design efficiency and survive in today’s competitive market.

3) *Illustrated the current design challenges of Smart PSS and introduced three promising research directions for Smart PSS design methodology.* Promising research directions of Smart PSS design methodology were recommended from an information perspective to achieve better social, economical and environmental sustainability in a circular economy.

Apart from these achievements, as a holistic relook, some limitations still exist. First, “smart design” was defined from three aspects, which may not be comprehensive/generic enough. Second, owing to the existing scope of Smart PSS, this research only selected papers from the engineering methodologies and future works can be done in the investigation of non-engineering methodologies (e.g. scenarios, stakeholders map and mood board) as well. Nevertheless, it is hoped that this holistic review will provide useful insights and serve as the fundamental basis to motivate more in-depth research in the Smart PSS development field in the near future.

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