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Human-centered design for advanced services: A multidimensional design methodology

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ABSTRACT

Advanced services have caught the attention of industries and academics as a way to exploit new customer value propositions. However, the existing design methodologies for advanced services are limited to partially addressing one or some key design elements, hence causing confusion in practice. Moreover, human factors are not often addressed, even though the design for advanced services requires human-centered thinking. Aiming to advance the body of research, the current study aims to conceptually propose a multidimensional design methodology called DIMAND that captures the key design elements and their relations in a single-view structure in accordance with a human-centric approach. Specifically, DIMAND encapsulates the (i) life-cycle service design interrelated with other key design elements—(ii) stakeholder networks, (iii) new service development methods, and (iv) design skills—that must be considered to develop effective advanced service design. Based on a hybrid research design, DIMAND was conceptually developed through systematic reviews and structured analysis of existing design methodologies, as well as an elicitation of expert knowledge in the domain through the analytical hierarchy process (AHP). For validation, the average usability score of DIMAND as evaluated by 26 practitioners was 72.2, which falls into "excellence" on the simplified system usability scale (SUS), hence confirming its potential utility. As a result, DIMAND offers a novel and holistic guideline for design practitioners and engineers to obtain coherence in all the life-cycle design processes by simultaneously taking these key design elements and their relations into account, making the design of advanced services more practical.

1. Introduction

There is a prominent tendency in industries and academics to design for new value propositions that enable companies to increase market share, competitiveness and customer satisfaction. This tendency requires new business models that ask manufacturing companies to extend services through product–service systems (PSSs) for value creation [88]. These PSSs integrate tangible products with immaterial services and then provide customers with a complete solution [53]. The idea is to offer not only a product (by ownership), but also its performance (e.g., pay-*per*-performance) and usage (e.g., pay-*per*-use) as a bundle of products and services [98], enabling companies' value chains to be extended. Specifically, extensive work has been done to classify PSSs into typical groups [59,83]: product-oriented groups (paying for buying pure products); use-oriented groups (paying for use); and result-oriented groups (paying for performance result). Lately, Baines and W. Lightfoot [6] provided a delineation of use- and result-oriented groups as advanced services, which are a special case of PSSs, that offer feature risk and revenue sharing agreements with customers over the life cycle of the service. Therefore, these advanced services reflect new ways of value creation in diverse aspects [11,44,55,63]: smart connected products and services (smart PSSs), commercial gains (e.g., revenue growth through hybrid offerings), and compelling sustainability (e.g., efficiency in material and energy usage). Digital and smart technologies, for example, machine learning [22], internet of things technology and big data analytics [99], are enablers of these advanced services, whose value proposition is shaped by the alignment among service–product–technology solutions and market development [18,98].

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To design for these advanced services, a structural methodology is required to reflect the life-cycle service design and enable effective service delivery [52,53]. The design methodology also requires human actors to be placed in the center of design work [49], allowing for capturing customer latent needs and understanding stakeholder requirements [75]. To realize this, human-centered design (HCD)—that is a set of design principles, methods and tools and also a philosophy—enables design practitioners to co-create value propositions with people (or stakeholders) across the life-cycle design process [24,56,79]. Nevertheless, previous reviews have revealed that human factors are not often addressed, even though the design for advanced services requires human-centered thinking [80,98]. Specifically, Nguyen, Lasa and Iriarte [60] reviewed 43 case studies in HCD and PSSs in Industry 4.0; only 12 % of these studies made an effort to validate and confirm the important inclusions of human factors—background, age, gender, education, cultural influences, and privacy management—in design. The human-centric approach in design was also recently emphasized by Piera et al. [66], who called for the digitalization of new smart services (e.g., artificial intelligent supporting services) by accommodating social-technical factors: ageing, disabilities, inexperience, conform and wellbeing. These human factors are particularly important for consideration in advanced service design related to socio-technical systems (e.g., pilot cockpit), in which the time-stamp added value of human-contributed cognitive activities is required. Above all, design for advanced services demands a new HCD methodology to design new value propositions [42,80]. This demand establishes the scope of the current research, conceptually shaping the development of a new design methodology oriented to HCD for advanced services.

In addition, even though researchers have conceptualized different design methodologies for advanced services, these methodologies are limited to partially addressing one or some key design elements, which need to be methodically addressed in a new design methodology to develop effective advanced service design. Specifically, one of the first key design elements is the life-cycle service design, which is often missed in existing design methodologies that have been limited to the concept development stage [3,98]. Second, other design approaches did not fully consider stakeholder networks and their roles, although they play a vital role in value co-creation as a key design element [60,71]. Third, a lack of new service development methods—to support value co-creation with stakeholders (e.g., scenarios, stakeholders map and mood board)—has been witnessed in other design methodologies that solely applied engineering methods (e.g., quality function deployment, Kansei engineering) [21]. In a recent publication, Nguyen, Lasa and Iriarte [60] called for a future research direction where a new HCD methodology is required to systematically address and connect these key design elements: the life-cycle service design, stakeholder networks, and new service development methods. Fourth, the design skills required for design teams to practice design activities have rarely been studied, even though these design skills affect their performance in the design for advanced services [46,71]. A lack of consideration of these key design elements could cause confusion in practice, resulting in an ineffective implementation leading to a “service paradox” [52,67]. Therefore, the design for advanced services poses requirements for a new design methodology that is not only oriented to HCD, but also encapsulates the must-have relationship among these key design elements: (1) the life-cycle service design; (2) stakeholder networks; (3) new service development methods; and (4) design skills.

Taking these requirements into the research scope, to develop effective advanced service design, this study aims to conceptually propose a multidimensional design methodology that captures the key design elements and their relations in a single-view structure in accordance with a human-centric approach. This methodology is named DIMAND, which is an acronym of the first letter of its life-cycle service design phases (diagnose, identify, measure, analyze, navigate, and deliver); this is further explained in Section 4. Based on ontology as a formal representation of all concepts and their relations [34,36], DIMAND is conceptually developed to formulate design knowledge that expresses the relations of key design elements within the domain of advanced service design. In particular, on the opposite end of existing intuitive approaches, DIMAND aims to encapsulate the (i) life-cycle service design and its relations with other key design elements—(ii) stakeholder networks, (iii) new service development methods, and (iv) design skills—that must be considered to develop effective advanced service design. As a structural design approach, DIMAND wants to help design teams govern the entire life-cycle service design by simultaneously considering these key design elements and their relations, hence making the design of advanced services more practical. This is realized by conceptually building DIMAND on a hybrid research design that takes advantage of (i) the body of knowledge in the literature through systematic reviews and *meta*-analyses, (ii) the elicitation of expert expertise through the analytical hierarchy process (AHP), and (iii) the usability assessment given by design practitioners and engineers through the simplified system usability scale (SUS).

The present work is organized as follows: Section 2 discusses the key design elements required for the design methodology. Section 3 presents the literature on the hybrid research design used to develop DIMAND. In Section 4, we present the new multidimensional design methodology for advanced services (DIMAND). Section 5 highlights the potential utility of DIMAND from the perspective of design practitioners. Section 6 provides the concluding remarks. Finally, these main sections are accompanied with the appendices (A and B) and research data [61] as supplementary information that enriches the transparency of the research results.

2. Framing key design elements required for advanced service design

According to the International Organization for Standardization [41], HCD incorporates human factors and ergonomics knowledge and techniques to make systems usable. This definition is broadened in the context of Industry 4.0 in which HCD offers a multidimensional (e.g., design artefacts, service solutions to ethical and legal issues) and transdisciplinary approach (e.g., physical, cognitive and social factors) in various design fields [60]: PSSs, user-centered design, human-in/on-the-loop, human–machine interface, and human-robot collaboration. These human-centric approaches are essential for exploring complex interdependencies of human and non-human actors (e.g., digital interfaces, smart devices and machines) in cyber-physical systems; hence, they can help in paving the way for understanding methodologically both functional and non-functional requirements [19,28]. Although functional requirements are technically evaluated or judged, non-functional requirements (e.g., service level agreement, user usability) are hardly defined without a human-centric approach [28,43]. The lack of consideration of these non-functional requirements could cause design problems: unexpected service behavior and even extensive redesign work. In the context of real-time supporting services, Kong et al. [48] called the design problems in using smart digital wearable systems (e.g., virtual and mixed reality) as user frustration or “key pain spots”. To alleviate design problems, HCD needs to be considered to help design practitioners in focusing on human factors and diversity to gain critical design requirements and feedback. These design requirements may range from human use and performance (e.g., postural comfort, physical ergonomics) [14,65] to human perception and cognition (e.g., mental stress, emotional stress, agreeableness, conscientiousness, neuroticism, openness) [70,92]. In the context of PSSs, Sierra-Pérez et al. [79] applied HCD to capture the stakeholder requirements in both functional requirements (e.g., scooter battery levels, scooter travel time) and non-functional requirements (e.g., trustworthiness, usefulness) for design. Similarly, Bu et al. [10] and Chang et al. [17] placed people (users and stakeholders) at the center of the requirements in their design approaches for user-centric smart PSSs. To confirm the role of HCD, Zheng et al. [98] systematically reviewed 97 studies and relevant works related to smart PSSs before coming to the conclusion that a human-centric approach must be addressed in a new design methodology. This conclusion shapes the scope of the current study, which aims to develop the new proposed multidimensional design methodology (DIMAND) oriented to HCD for advanced services.

In addition, the most recent literature reviews have revealed the key design elements that need to be addressed in a design methodology to develop effective advanced service design. Hence, the present study aims to conceptually develop DIMAND so that it is not only oriented to a human-centric approach, but also structured to systematically cover these key design elements. Based on ontological knowledge representation [36], Fig. 1 presents the formal representation of these key design elements and their relations, that is, what must be addressed in DIMAND.

First, Marilungo et al. [57] and Vasantha et al. [87] considered the life-cycle service design to be one of the key design elements. They analyzed different design approaches (e.g., design for PSSs, service engineering) in detail and then drew the conclusion that some design phases (e.g., planning and design) were well addressed; however, others (e.g., implementation, monitoring, feedbacks among phases) were vaguely defined. Agreeing with this conclusion, Agher et al. [3] and Song and Sakao [81] also carried out extensive review works before concluding that there is a lack of systematic methodical support covering the entire life-cycle service design. Recently, Carrera-Rivera et al. [15] systematically reviewed 53 studies in the context of smart PSSs and pointed out that those studies using a human-centric approach are very limited to the design phases instead of the life-cycle service design. Therefore, the design for effective advanced services requires life-cycle consideration encompassing all life-cycle phases in which design processes are defined to execute their corresponding phases [57,87,91]: planning and design, implementation and monitoring, product/service usage, and feedback loops between phases. Therefore, the first class of key design elements is the life-cycle service design, which needs to be expressed in DIMAND to cover the life-cycle design phases associated with design processes.

Second, in addition to the life-cycle service design, Richter et al. [71] analyzed 42 existing design methodologies for PSSs, concluding that these methodologies did not fully address the key design element: the actors and partners (stakeholders networks) and their engagement. Agreeing with this finding, Nguyen, Lasa and Iriarte [60] analyzed 43 existing design methodologies in HCD and PSSs in Industry 4.0, confirming the key design decisions (success factors) for effective design: (i) stakeholder networks and (ii) their involvements in each life-cycle design phase. The stakeholder networks are characterized by both internal stakeholders (e.g., design managers, manufacturing and maintenance staff) and external stakeholders (e.g., customers, third-party suppliers) whose diversity in interests and expectations needs to be respected and analyzed to comprehend the impact of stakeholder engagement at different life-cycle design phases. The engagement modes are defined by three levels of involvement: (i) an informative level, in which stakeholders only provide and receive design information; (ii) a consultative level, in which they comment on pre-define design scenarios; and (iii) a participative level, in which they make influencing decisions on a design process and outcome [60,77]. Thus, to develop effective advanced service design, DIMAND must cover this second class of key design elements: stakeholder networks that address both internal and external stakeholders, and their involvement in different life-cycle design phases. This relation between stakeholder networks and life-cycle service design is denoted as R1 in Fig. 1.

The third class of key design elements represents new service development methods emphasized by Jing-chen Cong et al. [21]. The authors carried out a systematic review of the design approaches since the coining of the term PSSs to May 2020, highlighting limitations in studies focusing on adopting engineering methods—such as TRIZ as creative problem-solving techniques [53], quality function deployment [67] or Kansei engineering [17]—instead of new service development methods. Recently, Nguyen, Lasa and Iriarte [60] also highlighted the key role of these methods, including engineering and non-engineering methods, in transdisciplinary design (e.g., physical, cognitive and social factors) required for advanced services. For instance, non-engineering methods (e.g., participatory design, interviews) can help designers focus on human diversity to gain critical design requirements, while the engineering methods (e.g., Kano model) enrich the prioritization and segmentation of these design requirements. Accordingly,

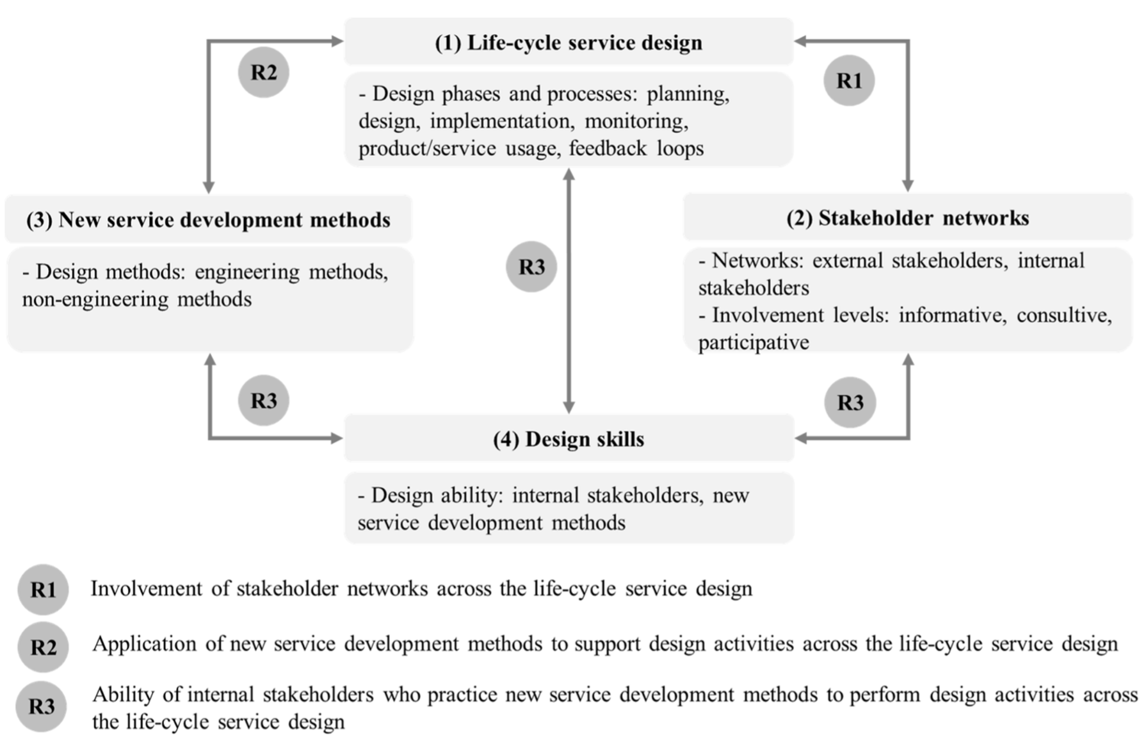

Fig. 1. Formalization of the key design elements and their relations for advanced service design.

DIMAND must take into account these new service development methods to support transdisciplinary design activities across different life-cycle design phases. This relationship between new service development methods and life-cycle service design is denoted as R2 in Fig. 1.

Finally, the fourth class of key design elements accounts for the actors' design skills: the ability of an actor who practices particular new service development methods to perform design activities (e.g., market research, design for agile prototyping). These design skills have rarely been addressed in the literature; this limitation was emphasized by Richter et al. [71]. The authors stated that the existing methodologies did not fully address the design skills required for design practitioners, who are typically internal stakeholders (e.g., designers, engineers, manufacturing and maintenance staff) and responsible for design activities and outcomes. The consideration of design skills in a design methodology is required, as indicated by Baines et al. [5] and Ingo Oswald Karpen et al. [46], who demonstrated that design skills are the key factors influencing key performance in advanced service design. Agreeing with this point, Spreitzer et al. [82] requested that company staff (internal stakeholders) need to be equipped with the proper skills to enable them understand how their work performance is carried out and developed. Thus, training on these proper skills helps companies enhance their sustainable development. This also means that the importance of anyone directly or indirectly involved in the making of products and/or services is embraced, hence developing a business culture on advanced service design instead of only market orientation [27,29]. Therefore, DIMAND also incorporates design skills—the ability of internal stakeholders who practice new service development methods to perform design activities across the life-cycle service design—to make the design of advanced services more practical. This relation among design skills, stakeholder networks (internal stakeholders), new service development methods and life-cycle service design is denoted as *R*3 in Fig. 1.

In summary, even though some studies have defined design methodologies, they only partially covered one or some key design elements for advanced services, which can cause confusion in practice. Hence, to develop effective advanced service design, the new multidimensional design methodology for advanced services (DIMAND) is conceptually proposed to capture the key design elements and their relations (Fig. 1) in a single-view structure, here in accordance with a human-centric approach. This structure aims to facilitate design practitioners and engineers to govern the entire life-cycle service design by simultaneously considering these key design elements and their relations, making the design of advanced services more practical. This is realized by utilizing a hybrid research design.

3. Research design

In the present study, the new multidimensional design methodology for advanced services (DIMAND) has been designed to encompass the interconnected key design elements (see Fig. 1). Fig. 2 shows two development stages of DIMAND, which are presented in the following subsections.

3.1. Snowballing literature review (stage 1)

First, we used logic to formulate design knowledge through a structured analysis of the different design methodologies in the literature [37]. The logic we followed was one of systematic reviews and *meta*-analyses conducted to identify and synthesize the relevant studies, which presents the design methodologies, frameworks or models oriented to a human-centric approach for advanced services. The analysis helped in identifying the patterns and synthesizing the key design elements (Fig. 1)— that were extracted from the identified studies—through the affinity method, which is known as the KJ method [4]; we could then structure them to form DIMAND. To realize this synthesis, we applied a snowballing literature review (SLR) so that the interrelated papers referenced and/or cited among them were systematically included [93]. Originating from evidence-based software engineering first coined by Kitchenham et al. [47], SLR has been accepted in engineering research, particularly for software engineering and advanced engineering informatics [1,97]. In addition, the implementation of a SLR can reduce the noise in searching for papers when compared with other systematic review methods, such as search strategies in databases [90]. Therefore, we executed the SLR procedure with the guidelines proposed by Wohlin [90] and presented in Fig. 3.

To conceptually propose a multidimensional design methodology (DIMAND) in accordance with a human-centric approach for advanced service design, the first step was to identify relevant papers whose research objective was to present a design methodology oriented to a human-centric approach for advanced services. Therefore, Therefore, there were three fundamental keywords: "human-centric", "methodology" and "advanced services"; however, scholars use disparate terms to

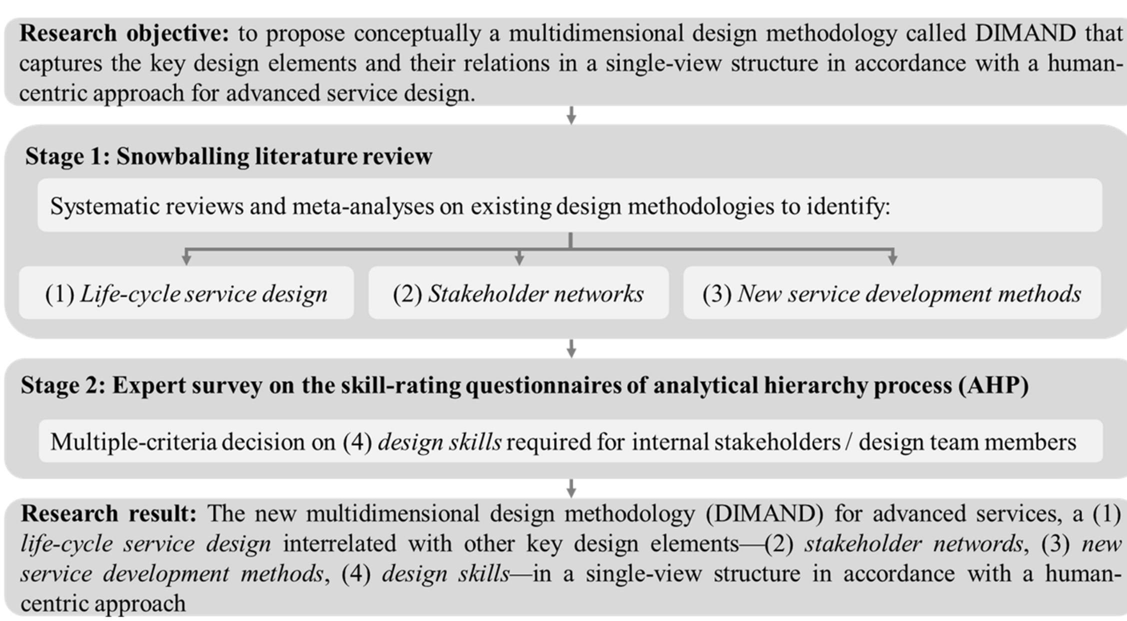

Fig. 2. Development stages of the new proposed multidimensional design methodology for advanced services (DIMAND).

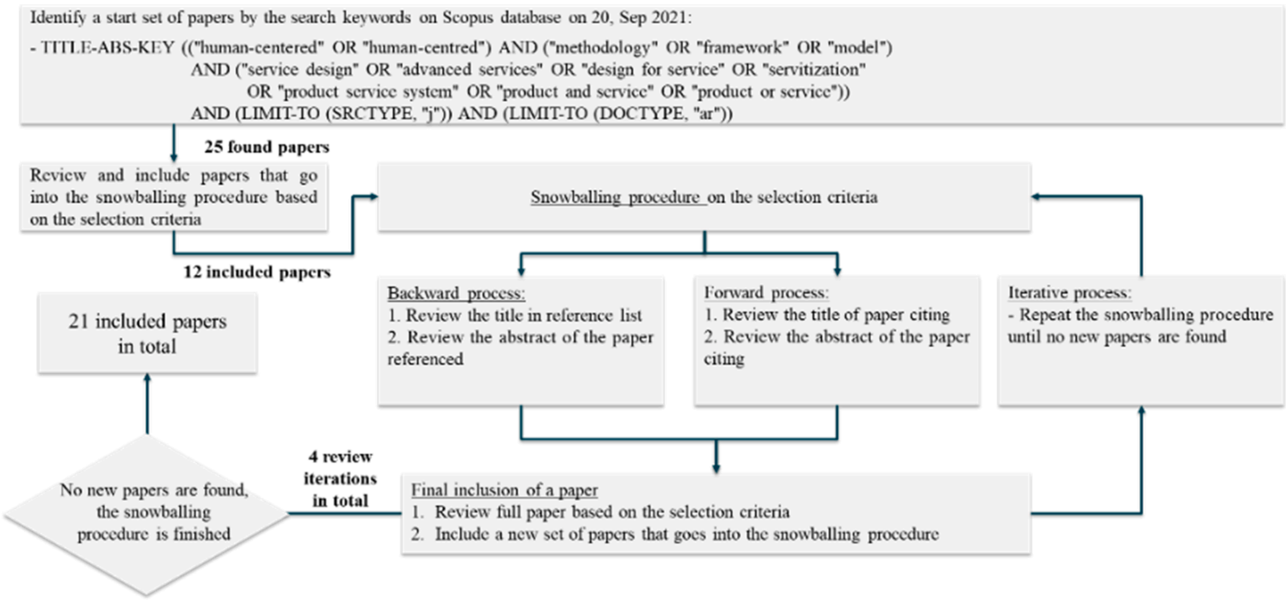

Fig. 3. A process flow of snowballing literature review.

describe these in the research community. First, the term "human-centric" has been well searched by the term "human-centered" to look for papers related to HCD in various contexts (e.g., human factors, person-centered solutions, human-centered manufacturing) [31,60,64]. Second, the term "methodology" has been frequently used together with "framework" or "model" in the context of PSSs [71]. Finally, papers related to "advanced services" can typically be found by using different but related terms, such as "product-service" and "servitization" [8,69], because the design for advanced services is a special case of PSSs [6]. As a result, the search string used to look for relevant papers was the connection of the terms associated with stemming: "human-centered", "methodology", "advanced services", "product-service", "servitization". In addition, SLR is less sensitive to search strings and/or keywords compared with using other systematic review methods (e.g., search strategies in databases); SLR mainly replies on the interrelated papers actually referenced and/or cited among them [90]. In conclusion, the search string is reasonable for use in accordance with the procedure of SLR (Fig. 3).

As mentioned in Fig. 3, the first set of relevant papers (seeds) were searched using Scopus—through papers' titles, abstracts and keywords—because a single database is only required because a snowballing review depends on the referenced papers. These initial studies were evaluated and included by the following inclusion criteria: a full-text English and journal paper presenting a design methodology, framework or model oriented to a human-centric approach for advanced services. As a result, 25 papers were identified and evaluated against the inclusion criteria, resulting in 12 papers. These papers were selected for performing the snowballing procedure (the backward and forward process), in which their references and citing papers were reviewed against the selection criteria to identify new relevant papers. By following this approach, the completeness and replication of the SLR ensured the sufficient extraction of relevant studies, resulting in 21 included papers through four review iterations in total.

The design methodologies proposed by these 21 included papers were objectively analyzed to obtain the most information about the key design elements (Fig. 1) that were structured to form DIMAND. The detailed information extracted from each analyzed design methodology is recorded in Appendix A. Based on the analysis results, we captured three key design elements: (1) life-cycle service design, (2) stakeholder networks and (3) new service development methods. However, we found a prominent void in the literature where none of the analyzed papers addressed the last design element: (4) design skills. This motivated Nguyen, Lasa, Iriarte, Atxa, et al. [62] to conduct the below stage with an expert survey (Fig. 2) to fill this void.

3.2. *Expert survey on skill-rating questionnaires of AHP (stage 2)*

Knowledge representation (Fig. 1) related to design skills can be formulated into a rational question: "Who" (internal stakeholders or design teams, e.g., designers, manufacturing engineers) needs to practice "what" new service development methods (e.g., workshop techniques), here as design skills, to perform design activities (e.g., to understand customer nonfunctional requirements)? Based on expert elicitation as a methodological approach for formalization of knowledge [37], Nguyen, Lasa, Iriarte, Atxa, et al. [62] addressed this question by applying the AHP because the AHP elicits and aggregates expert responses to a question through an expert survey.

Fundamentally, based on the AHP, the expert survey contained skill-rating questionnaires in the form of pairwise comparison used to ask the experts to grade the importance weights of all design teams (elements or alternatives) on the acquisition of new service development methods. These design teams were independent, as required by Saaty [72]. Given

Table 1
Expert profile [62].

Identification	Expertise	Major fields	Working years
Expert #1	Academist	Industrial engineering, Industry 4.0, servitization	33
Expert #2	Practitioner	Innovation and technology	29
Expert #3	Academist	Human-centered strategy for innovation, Industry 4.0	22
Expert #4	Practitioner	Research and development, innovation and servitzation	20
Expert #5	Practitioner	Service engineering	19
Expert #6	Practitioner	Automation and digitalization in Industry 4.0, servitization	18
Expert #7	Academist	Sustainable product-service system, eco-innovation	14
Expert #8	Academist	Human-centered design, industrial design engineer	12
Expert #9	Practitioner	Digital manufacturing	10
Expert #10	Academist	Cyber physical systems, software engineering	7

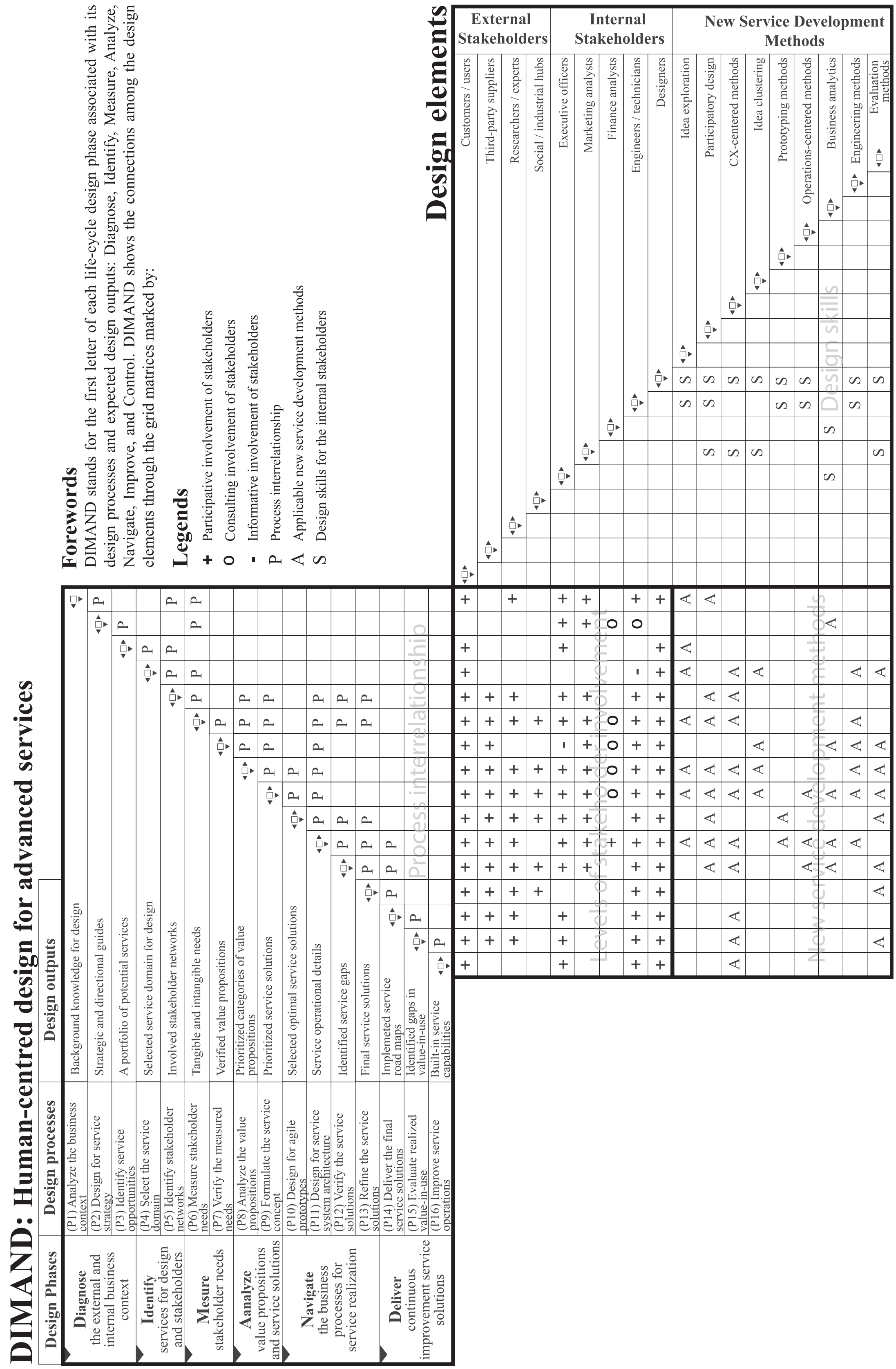

Fig. 4. A multidimensional design methodology for advanced services (DIMAND). The supplementary information (Appendix B) describes how DIMAND works in practice.

n design teams, that is, $D_1, \cdots, D_n$, the expert decides the relative importance r_{bd}—on a 9-point rating scale—indicating the importance of D_b relative to that of D_d to acquire a new service development method as a design skill. If these importance weights given by the expert are denoted as $w_1, \cdots, w_n$ corresponding to each design team member, then r_{bd} is the ratio of w_b/w_d. This formulates the reciprocal matrix of pairwise ratios:

$$D = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \ddots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \quad (1)$$

The experts who gave the importance weights through the expert survey were recruited based on their qualities rather than selecting a large and representative sample size to have a statistical inference (S. [54,68]. Thus, Nguyen, Lasa, Iriarte, Atxa, et al. [62] recruited 10 (industrial and academic) recognized experts, whose profiles are presented in Table 1; their disciplines were diverse, including HCD, industrial engineering and automation, servitization, business model and sustainable PSSs. As a result, the inputs for the expert survey were transdisciplinary. Through AHP algorithms, Nguyen, Lasa, Iriarte, Atxa, et al. [62] used the R language to compute all the reciprocal matrices of pairwise ratios whose data originated and were collected from the recruited experts responding to the expert survey. The AHP analysis results are presented in Section 4.4.

At the end of stage 2 (Fig. 2), we fully identified the first three key design elements—(1) life-cycle service design, (2) stakeholder networks and (3) new service development methods—from the SLR and then extracted the last one—(4) design skills—from the expert survey using the AHP [62]. These key design elements were then ready to be structured to form DIMAND, which can integrate and interlink these key design elements in a single-view structure in accordance with the human-centric approach.

4. Novel multidimensional design methodology for advanced services (DIMAND)

As mentioned in Section 2, the weakness was often addressed in the literature, where the existing methodologies did not fully comprehend—or just partially covered—the key design elements. One way to overcome this weakness is to formulate and map design knowledge through ontology (Fig. 1) that can present the relations among the key design elements within the domain of advanced services. This design knowledge can be detailed through a grid matrix—that has various applications, such as quality function deployment [26,40], to show correlation relationships among multiple elements—for its implementation in practice. Therefore, we customized this correlation matrix so that these design elements would be interconnected to form DIMAND as a single and multidimensional structure, as presented in Fig. 4. This structure can enable design practitioners and engineers to oversee the life-cycle service design (Section 4.1), which possesses the two-dimensional (back and forth) interrelationship among design elements: stakeholder networks (Section 4.2), new service development methods (Section 4.3) and design skills (Section 4.4). The following subsections present how DIMAND (Fig. 4) was formed through the two stages of the research design (Fig. 2) and how it works.

4.1. The life-cycle service design

As the first part of knowledge representation (Fig. 1), life-cycle service design must cover all life-cycle design phases and processes: planning and design, implementation and monitoring, product/service usage, feedback loops between phases. This requirement governs how the included studies were analyzed to synthesize the life-cycle service design. Based on the requirement and procedure of SLR presented in Section 3.1, we identified, analyzed and tabulated the 21 included studies, presenting their proposed HCD methodologies (see Appendix A). Based on this analysis, not all the analyzed design methodologies fully proposed life-cycle design phases and processes; the differences and omissions were very apparent among them. Specifically, Hartono [38] proposed a design methodology whose first design process was the "selection of the service domain"—to select airport service attributes (e.g., waiting rooms, staff friendliness) for service design—and subsequently "measurement of Kansei response"—to measure the feelings of customers about these service attributes. Instead of beginning with the "selection of the service domain", Camussi et al. [13] and Schiro et al. [76] proposed their own methodologies starting with "awareness-raising actions" in the context of public healthcare and "work system analysis" for healthcare information systems, respectively. Even though these design processes had different descriptions—"measurement of Kansei response", "awareness-raising actions", and "work system analysis"—and were applied in different contexts, their objective or outputs shared mutual facts: to "measure stakeholder needs" for design (e.g., understanding of customer needs and desires). By following this pattern of finding these mutual facts among the differences, the affinity analysis—known as the KJ method [4]—was applied to synthesize the analyzed design methodologies (Appendix A) in terms of design phases, design processes and outputs.

As a result, Table 2 shows the complete synthesis of the various research contexts of research (e.g., airport, media and healthcare) that appeared in almost all empirical studies (17 out of 21 studies). This formed the new HCD methodology, DIMAND, which stands for the first letters of six life-cycle service design phases: (i) *diagnose* the external and internal business context, to capture market opportunities and take the business capabilities (e.g., strategies, competitive advantage) into account; (ii) *identify* services for design and stakeholders, to select the service domain associated with its stakeholder networks; (iii) *measure* stakeholder needs, to capture tangible and intangible needs that are translated into value propositions; (iv) *analyze* value propositions and service solutions, to investigate the value propositions and translate them into service solutions; and (v) *navigate* the business processes for service realization, to direct the business resources and processes to design for these service solutions; (vi) *deliver* continuous improvement service solutions, to launch the service solutions with continuous-improvement service operations.

Therefore, the left pillar of DIMAND (Fig. 4) addresses HCD for advanced services, including the consecutive and interlinked design phases associated with design processes and outputs, forming the life-cycle service design, whose detailed description is presented in the supplementary information (Appendix B). This life-cycle service design includes from the *diagnose* and *identify* phase (planning), the *measure* and *analyze* phase (design), the *navigate* phase (implementation and monitoring), and the *delivery* phase (product/service usage). Moreover, the interrelationship of all design processes—here reflecting the feedback loops among them—is also displayed by the grid matrix, whose cells are marked by "P"; otherwise, there is no relationship addressed among them by the reviewed papers. Specifically, Acklin [2] and Iriarte et al. [42] paid attention to the *diagnose* and *identify* phase. First, Acklin [2] proposed a design methodology whose the first design process was to "analyze the business context" for the acquisition of "background knowledge for design": to understand what a company has learned so far and its business ecosystem (e.g., markets, customer trends). This understanding can enable the company to "design for service strategy" (e.g., communication and brand strategies). Second, Iriarte et al. [42] highlighted their design methodology whose starting design process was to "analyze the business context" by taking a snapshot of a detailed investigation of the business: competitive advantages and potential value propositions for advanced services in the machinery industry. According to the authors, this investigation can help the company properly "identify stakeholder networks": key customer staff responsible for the purchase of the solution on offer (e.g., top managers, technicians, and operations personnel), and internal stakeholders (e.g., quality manager, operations manager, product manager, technicians). Instead

Table 2
The synthesis of the life-cycle service design, as extracted from Appendix A.

Author(s)	Year	Research type	Context	DIMAND methodology[a]															
				Diagnose the external and internal business context			Identify services for design and stakeholders		Measure stakeholder needs		Analyze value propositions and service solutions		Navigate the business processes for service realization				Deliver continuous improvement service solutions		
				Analyze the business context	Design for service strategy	Identify service opportunities	Select the service domain	Identify stakeholder networks	Measure stakeholder needs	Verify the measured needs	Analyze the value propositions	Formulate the service concept	Design for agile prototypes	Design for service system architecture	Verify the service solutions	Refine the service solutions	Deliver the final service solutions	Evaluate realized value-in-use	Improve service operations
Hartono [38]	2020	Empirical	Airport services				X		X	X	X	X			X				
Camussi et al. [13]	2020	Empirical	Public healthcare						X		X	X	X						
Schiro et al. [76]	2020	Empirical	Health information systems						X		X	X	X	X	X		X		
Papazoglou et al. [64]	2020	Empirical	Laser and sheet metal machinery						X	X	X	X		X	X	X			
Grenha Teixeira et al. [33]	2019	Empirical	Health information systems						X		X			X	X	X			
Yu & Sangiorgi [96]	2018	Empirical	Digital services						X		X	X	X	X			X	X	X
Yu [95]	2018	Empirical	Library services						X		X								
Iriarte et al. [42]	2018	Empirical	Railways and sheet metal machinery	X				X	X		X	X	X	X	X				
Costa et al. [25]	2018	Empirical	Laboratory equipment					X	X		X	X	X	X	X	X	X		
Ueda et al. [86]	2018	Conceptual	ICT services and products						X		X	X	X		X				
Grenha Teixeira et al. [32]	2017	Empirical	Media and healthcare						X			X	X	X	X				
Salgado et al. [73,74]	2017a 2017b	Empirical	Public healthcare	X					X		X	X	X		X	X	X	X	
Cha et al. [16]	2017	Empirical	ICT car services						X		X	X	X	X	X	X			
Chew [18]	2016	Conceptual	Commercial services		X				X	X	X	X		X					
Kumar & Maskara [50]	2015	Empirical	Health information systems						X		X	X	X						
Kumar et al. [51]	2014	Empirical	Public healthcare						X		X	X	X						
Ueda [84,85]	2013 2009	Conceptual	ICT services			X	X		X		X	X	X	X	X				
Acklin [2]	2010	Conceptual	Undefined	X	X	X		X						X			X	X	X
Johnson et al. [45]	2005	Empirical	Health information systems				X		X		X	X	X		X	X			

[a] DIMAND is the acronym of the first letter of life-cycle service design phases: diagnose, identify, measure, analyze, navigate, and deliver. Appendix B presents each design phase in detail.

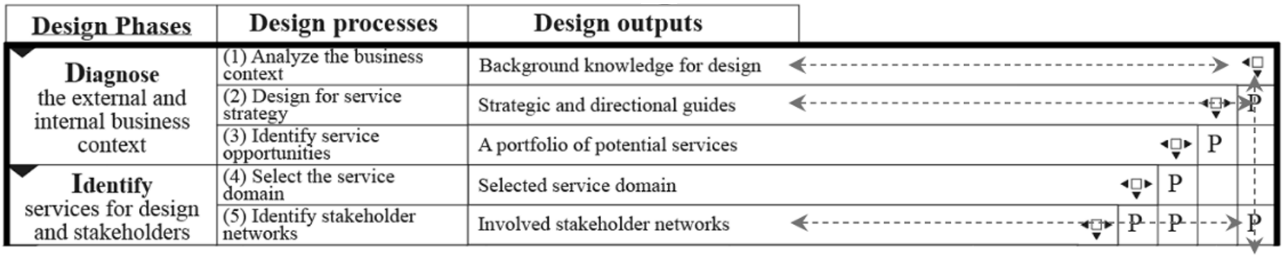

Fig. 5. An illustration of process interdependency. A cutting plane of DIMAND (Fig. 4) that exemplifies how the design processes are a two-dimensional interrelationship through the grid matrices, which can be seen by reading the path of the two-directional dotted arrows as an example. This reading pattern is applicable to the rest of the connections among the design elements in DIMAND.

Fig. 6. The synthesis of stakeholder networks, extracted from Appendix A. Each stakeholder can take or exchange among the participatory roles, consulting roles or information roles in the different stages of life-cycle service design.

of focusing on the *diagnose* and *identify* phase, Yu [95] focused only on the *measure* and *analyze* phase (design). The author proposed a HCD methodology whose the starting design task was to "measure stakeholder needs" in both functional and non-functional requirements of students in terms of a library service (e.g., experiences, opinions, user perception). Subsequently, the measured requirements were the design inputs used to "analyze the value propositions" according to user contexts, such as physical conditions, technical capabilities, and cognitive links among product attributes, consequences, and goals.

Process interdependencies (feedback loops) among these design processes is symbolized by "P" through the grid matrix in DIMAND; this is exemplified in Fig. 5, which shows the feedback loops among the design processes: "analyze the business context", "design for service strategy", and "identify stakeholder networks".

These interdependencies or feedback loops among design processes have not been commonly addressed in the literature; however, they support the practitioners to cross track the design outcome among these design processes because the outcome of a design process may affect that of another design process. Above all, DIMAND addresses the life-cycle service design and interconnection among the design processes ("P"), facilitating design practitioners to keep the life-cycle perspective in mind and take process dependency and contingency planning into their design decisions.

4.2. Stakeholder networks

For the second part of knowledge representation (Fig. 1), stakeholder networks must consider both internal and external stakeholder networks, and their involvement levels—an informative level, a consultative level, a participative level—across the life-cycle service design. This consideration governs how the included studies were analyzed to synthesize the stakeholder networks. Similar to the synthesis of the life-cycle service design, the design element of the stakeholder networks has been built by extracting and synthesizing the "Stakeholders" across the design processes, here as addressed by the analyzed design methodologies (Appendix A). Fig. 6 shows the synthesis of the stakeholder networks, revealing broad participation of both internal and external stakeholders. Moreover, we classified the stakeholder roles into three levels of involvement—informative ("-"), consultative ("o"), and participative ("+")—across life-cycle design processes. Specifically, the informative stakeholders can take passive roles in the provision and receipt of design information, while consultative stakeholders consult design actions and solutions. The participative stakeholders co-create and engage with their decisions on the design process.

The top of the right pillar of DIMAND (Fig. 4) embeds the stakeholder networks. These stakeholder networks are connected with the life-cycle service design (the left pillar) through the same grid matrices of DIMAND, hence realizing the relation between them (R1 in Fig. 1). By doing this, two design decisions related to the involvement of stakeholders can be made: (i) who will be involved in which specific design process and/or which design process asks for the participation of whom and (ii) what the level of involvement for each stakeholder in the according design process. The answer to these two questions is given by the grid matrices, whose cells are marked by the symbols of "+" (participative), "o" (consulting) and "-" (informative); otherwise, there is no relationship addressed among them by the reviewed papers.

In the analyzed papers, the role of finance analysts was not addressed across the life-cycle service design, except for the work of Chew [18] who highlighted the importance of finance analysts whose consulting roles ("o") were to cooperate with other design teams (e.g., market analysts and IT technicians). This cooperation was intended to "design for service strategy" (e.g., business and market models)—and "measure stakeholder needs", "verify the measured needs", "analyze the value propositions" and "formulate the service concept". Moreover, Chew [18] also appreciated the participative role ("+") of "finance analysts" required to "design for service system architecture" in terms of the monetization process linked to the business strategy. Although Iriarte et al. [42] did not discuss the role of finance analysts in the design team, they explicitly highlighted the participative involvement ("+") of "executive officers" across departments (e.g., business managers, project managers, sales managers) to "analyze the business context" in the very first design phase. They also underlined the participative roles ("+") of "researchers" who offered their design knowledge to facilitate their case company to "analyze the business context" and other design processes. Instead of highlighting an individual role, cooperation among design teams has also been noted as essential, as emphasized by Papazoglou et al. [64]. Specifically, marketing analysts, designers and engineers—who are responsible for manufacturing and maintenance—work participatively together with external stakeholders (e.g., customers, third-party suppliers) to verify whether or not customer needs can be fulfilled with the company capability (e.g., product-service design, production scheduling and capability, commissioning).

Table 3
New service development methods, as extracted from Appendix A.

Method group	Analysis objective	Design methods
Idea exploration	To seek design ideas through the exploration of both primary and secondary data about customer needs and wishes as well as market requirements in general.	Interview techniques: narrative interviews, in-depth interviews, contextual interviews, and open-ended interviews. Survey techniques: face-to-face survey and closed-ended email surveys. Observation techniques: ethnographic and empathic research, daily probes, contextual design, field notes and investigations, market observation and analysis, scenario observation, and laboratory visits. Secondary research: desk research, literature review, trend and experiential research, and technological studies. Focus-group techniques: brainstorming techniques, and Delphi method.
Participatory design	To allow stakeholders to have the active involvement in the co-creation design process of value proportions that ensures design solutions meet their needs and are usable.	Workshop techniques: Gender-Café debate, Generative labs, Barcamps, creative co-design workshops, experience sharing workshops, open dialogue approach, and future sessions. Participatory innovation methods: service design labs, Ideathon, Hackathon. Role-playing techniques: service role-playing, voting and mutual consensus.
Customer experience-centered methods (CX-centered methods)	To offer systematic approaches for the analysis of requirements and experiences of customers and then looking for design solutions, enhancing customer experiences at all touchpoints.	Service design visualizations: customer value constellation, extended customer experience modelling, and constellation map for PSSs. Service mapping techniques: empathy map, interaction map, actor network map, customer journey map, user experience journey visualization, organizational network map for PSSs, stakeholder motivation matrix, stakeholder system map, mind mapping, service road map of channel experiences and operational requirements. Personas and storytelling techniques: storyboards, photo-essay and photo-diary method, and persona method. Value proposition canvas, multisided value proposition canvas. Human-factors and ergonomics. Color, material and finish design (CMF design).
Idea clustering	To classify and rank unstructured data and organize them into homogeneous groups.	Affinity diagram (KJ method). Kano model. Idea ranking.
Prototyping methods	To enable design teams to convert design ideas into tangible forms that can be tested and evaluated.	Ideation: sketched images, UX/wireframe sketches, paper prototyping. Concept validation: wireframes. Refinement and usability: physical prototypes and equipment, software mock-ups, GUI design, 3D modelling.
Operations-centered methods	To design and map outbound service operations with inbound service operations.	Service operational mapping: value matrix for PSSs, navigation map for PSSs, service system navigation, service encounter and experience design, service blueprints.
Business analytics	To gain business insights and drive business planning that manages the development process of service toward sustainability.	Business model canvas. Service lifecycle management. Game theory. Contingency theory. Profit formula.
Engineering methods	To engineer the service development process toward efficiency (e.g., removal of non-valued activities during the service design) and effectiveness (e.g., usable designs that meet accurately customer requirements in first place without reworks).	Service quality model: SERVQUAL model. Statistical model: linear regression model. Improvement techniques: TRIZ (creative problem-solving techniques), Lean, benchmarking, hierarchical task analysis. Manufacturing blueprints: unified modelling language diagrams (UMLD), decision trees, 3D interactive visual platform for product-oriented configuration language, ontology web language, supply chain operational reference processes, business process model and notation, modularity principles.
Evaluation methods	To evaluate the outcome (efficiency and effectiveness) of a design process using both quantitative and qualitative manners.	Statistical validity: hypothesis testing *(analysis of variance)* on usability, *t*-test, chi-square test. Usability testing: interviews, workshops, surveys, field notes and observations, SUS questionnaire, computer system usability questionnaire, heuristic evaluation, think-aloud protocol. Ergonomics evaluation methods: task analysis. Key performance indicators (KPIs).

To this end, DIMAND has been equipped with the complete piece of information about stakeholder involvement, offering a complete guideline on how to oversee and plan "who will do what" across the life-cycle service design. Beyond the external stakeholders (e.g., customers, third parties), DIMAND encourages design practitioners to take the (direct and indirect) involvement and understanding of the internal actors (e.g., executive officers, marketers, engineers in manufacturing and maintenance and product engineering) into the design decisions, fostering value co-creation capabilities on advanced service design.

4.3. New service development methods

For the third part of knowledge representation (Fig. 1), the new service development methods must be both non-engineering (e.g., participatory design, interviews) and engineering methods (e.g., quality function deployment, statistics). This requirement shapes the way new service development methods were synthesized. In particular, this synthesis was realized by categorizing the "design methods" of the analyzed papers extracted from Appendix A. Table 3 shows the homogeneous categories of these methods and now they share mutual objectives. Specifically, when it comes to "measure stakeholder needs", Hartono [38] carried out the design methods of a "face-to-face survey" and "interview" to explore the experiences of customers (e.g., happy, satisfied) within service design. Similarly, Camussi et al. [13] captured the service ideas specified from customers through "ethnographic observations" and "narrative interviews". Although these methods are different regarding their execution techniques and usage contexts, they share mutual objectives: to seek human ideas for service design.

As a result, the bottom of the right pillar (design elements) of DIMAND (Fig. 4) integrates these new service development methods, as presented in Table 3. This integration interlinks with the life-cycle service design through the grid matrices, whose cells are marked by "A" in DIMAND; otherwise, there is no relationship addressed among them as seen by the analyzed papers. Thus, the integration realizes the relation between them (R2 in Fig. 1). Specifically, Hartono [38] replied on the method group "idea exploration" (e.g., face-to-face surveys, interviews) to "measure stakeholder needs" (e.g., the quality perception of clients about airport services); this relationship is symbolized by "A" in DIMAND. Similarly, Camussi et al. [13] also applied the same method of "idea exploration" (e.g., ethnographic observations, narrative interviews) to "measure stakeholder needs" by capturing the stories, needs and desires of customers in the healthcare system. Alternatively, Kumar and Maskara [50] applied the both method groups: "idea exploration" (e.g., ethnography, observation and interview) and "participatory design" (e.g., workshop techniques). These human-centric design methods allowed the authors to "measure stakeholder needs" regarding functional and non-functional requirements in design for healthcare software, such as technology adoption, painful areas in usability and human factors (e.g., values, beliefs, attitudes, user experience and clinician preferences).

By realizing the interconnection between the new service development methods and the life-cycle service design, one can seek what the design method can be used for, hence enabling the execution of the specific design processes. In the reverse direction, one can also answer the following inquiry: What design methods can a design process apply? For example, the design methods for 'idea clustering' (e.g., affinity diagram, Kano model) may be used by four design processes—"select the service domain", "verify the measured needs", "analyze the value propositions", and "formulate the service concept"—in the life-cycle service design, which is symbolized by "A" in DIMAND. In the reverse direction, to "analyze the business context", one may want to apply-one or more design methods of "idea exploration" (e.g., field research, desk research) and "participatory design" (e.g., workshops, Barcamps) to acquire the design output: "background knowledge for design". A design practitioner can also apply "engineering methods", such as hierarchical task analysis, to "measure stakeholder needs" in terms of user physical tasks and goals. For some advanced services related to social-technical systems (e.g., digital dashboard for decision making), other engineering methods, such as the functional resonance analysis method [66], may be required to measure the time-stamp information between cognitive workload and technical resources embedded in such advanced services.

As a result, DIMAND is not only the life-cycle service design, but it also shows how the design phases and processes can be supported and implemented by the sets of new service development methods (Table 3) that are viable and have been proven in the literature to work. This allows design practitioners and engineers to be aware of a wide range of both service- and engineering-specific methods that supports the

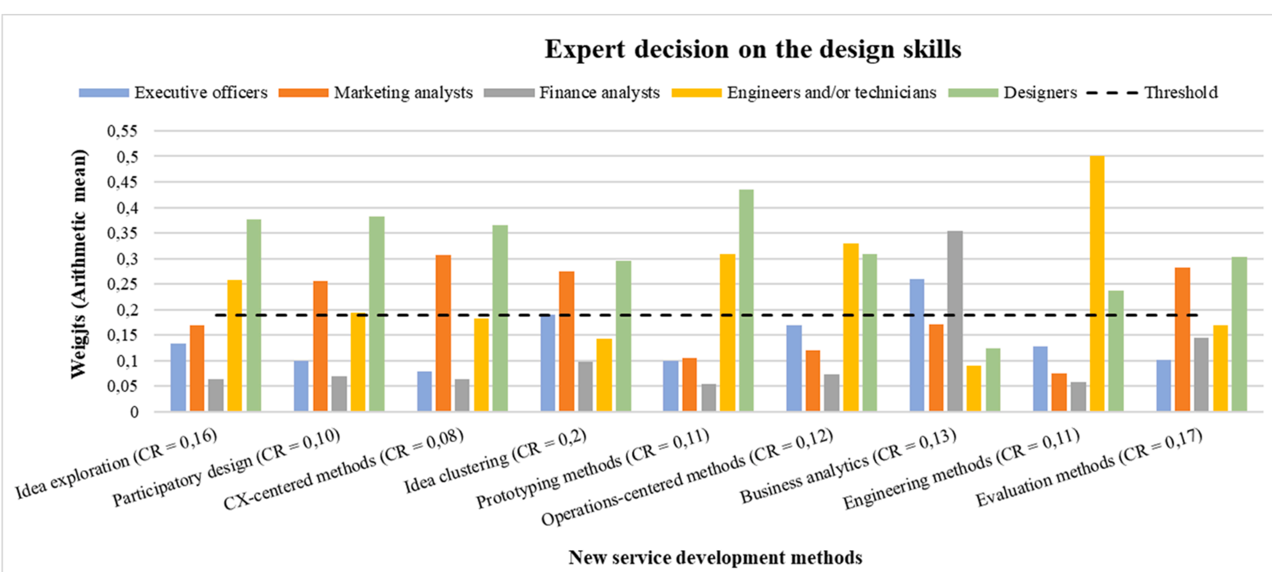

Fig. 7. Expert decision on the design skills. This result is extracted and visualized from the dataset [61], including: the expert survey, its dataset (expert responses) and the R codes for the AHP analysis. Based on the importance weights in the arithmetic mean, the expert responses are tolerably consistent in the conclusion that two or three groups of the design teams—whose importance weight values are higher than 0,19 (threshold), hence dominating that of the other groups—should master a group of new service development methods as their skill set.

transdisciplinary approach required for advanced service design.

4.4. Design skills

For the fourth part of knowledge representation (Fig. 1), design skills represent the ability of internal stakeholders (design teams), who practice new service development methods to perform design activities across the life-cycle service design. Therefore, as mentioned in Section 3.2, Nguyen, Lasa, Iriarte, Atxa, et al. [62] designed the expert survey containing skill-rating questionnaires in the form of a pairwise comparison. These pairwise questionnaires capture the importance weights of all design teams on the acquisition of the new service development methods, as design skills, from the experts (Table 1). Specifically, based on the Table 3, there are nine groups of new service development methods used to form nine corresponding skill-rating questionnaires in the form of pairwise comparison matrices (the reciprocal matrix of Equation (1)) among five groups of design teams (Fig. 6). The dataset [61] provides fully the expert survey, its dataset (expert responses) and code availability (R language) for the AHP analysis. The detailed description of the dataset [62] offers complete instructions on how to analyze the dataset in accordance with the AHP procedure.

To summarize the result, Fig. 7 visualizes the importance weights of the design teams on the need to acquire new service development methods as design skills. Because all values of consistency ratio (CR) are no more than 0,2 [54,78], the expert responses are tolerably consistent in the conclusion that two or three groups of design teams should be prioritized to master a group of new service development methods as their skill set.

According to the experts, the "designers" and "engineers and/or technicians" should be more preferred to master the skill set of "idea exploration"—which supports them in acquiring design ideas through the exploration of customer requirements and/or markets—than the other groups of design teams. Similarly, the "executive officers" and "finance analysts" are more preferred to equip the skill set of "business analytics" to be competent in gaining business insights and driving business planning that can manage the service development process towards sustainability. The same reasoning is applicable to the rest of the design teams.

As a result, the right pillar of DIMAND (Fig. 4)—which connects the internal stakeholders (design teams) with the new service development methods—also integrates these prioritized design skills, here in line with Fig. 7 whose bar values of importance weights are higher than 0,19 (threshold). This connection realizes the relation between them (*R*3 in Fig. 1). As can be seen by the "S" symbols integrated into DIMAND, this reveals the transdisciplinary design team, in which two or three job roles (design teams) should practice a specific group of service development methods; this also shows how a company should make decisions about the training priority among its design teams. By building the transdisciplinary design team, the skills and mindset from different fields (e.g., service, engineering and industrial design) can function as an accelerator for the design of advanced services to the market by combining technological design and HCD [2]. Among the design teams, except for the skill set of "business analytics" (e.g., game theory, contingency theory), "designers" are required to practice all skill sets. In line with this result, Calabretta, G. and De Lille [12] suggested a much broader role for design professionals in the company to enable the transition process towards the effective design of advanced services. In addition to designers, the roles of "engineers and/or technicians" and "marketing analysts" were also emphasized. The engineers—who may come from different departments, such as research and development, manufacturing and maintenance, and quality assurance—should not only be qualified in technical skills, including "prototyping methods", "operations-centered methods", and "engineering methods". But they should also understand what customers want in both the functional (e.g., technical problems, service quality reports) and non-functional requirements (e.g., user perception, cognitive and work domain).

Table 4
Participation of 26 design practitioners and engineers in the SUS survey.

Job role	Sector	Job role	Sector
#01 Design for engineering	Consumer goods	#14 Design for UX/UI	Governmental organization
#02 Design for engineering	Equipment goods	#15 Design for UX/UI in industry	Equipment goods
#03 Design for industry	Component manufacturer	#16 Innovation management	Telco
#04 Design for product and service	Finance	#17 Innovation management, advanced product quality planning (APQP)	Component manufacturer
#05 Design for product and service	Telco	#18 Maintenance management and operations research	Equipment goods
#06 Design for product and service	Equipment goods	#19 Maintenance, quality, strategy and operations consulting	Equipment goods
#07 Design for product and service	Component manufacturer	#20 Manufacturing development for digitalization	Equipment goods
#08 Design for product and service	Innovation consultancy	#21 Manufacturing process engineering	Software development
#09 Design for service	Design consultancy	#22 Mechanical and automation design	Research center
#10 Design for service and industry	Research center	#23 Mechanical design, design for product	Innovation consultancy
#11 Design for service and industry	Innovation consultancy	#24 Mechanical design, project management	Equipment Goods
#12 Design for strategies	Household appliances	#25 Mechanics and industrial production	Consumer goods
#13 Design for strategies	Consumer goods	#26 Mechanics and industrial production	Research center

Comprehending customer requirements can be more effective by training the skill sets of "idea exploration" (e.g., focus-group and interview techniques) and "participatory design" (e.g., service design labs and workshops) for both engineers and marketing analysts. Coreynen et al. [23] also stated that front-office staff need to master service skill sets beyond their professional skills to support in upscaling or in the successful adoption for the design of advanced services.

To this end, DIMAND aids practitioners in developing the internal service capability ("who needs to know what") and makes the decision on the training priority among cross-functional design teams through these skill sets (the "S" symbols). This capability building helps the company develop and nurture the transdisciplinary design team, in which the skills and mindsets from different fields can function as an accelerator for the design of advanced services.

In summary, the final structure of DIMAND encompasses all interconnected key design elements in a single-view structure (Fig. 4) in accordance with the human-centric approach. As a result, DIMAND guides design practitioners and engineers so that they can obtain coherence in the life-cycle service design and simultaneously take the relations among the key design elements into consideration in their design decisions, making the design of advanced services more practical. Finally, we ensured the potential utility of DIMAND by quantitatively measuring its usability through SUS.

5. Usability assessment

Nguyen, Lasa and Iriarte [60], and Haber and Fargnoli [35] pointed out that design methodologies in the literature lacked evaluations of their utility. This encouraged us to overcome this limitation by evaluating DIMAND for the sake of enriching our research contribution; this validation ensured that the knowledge representation of DIMAND matched the design purpose within the domain of advanced services

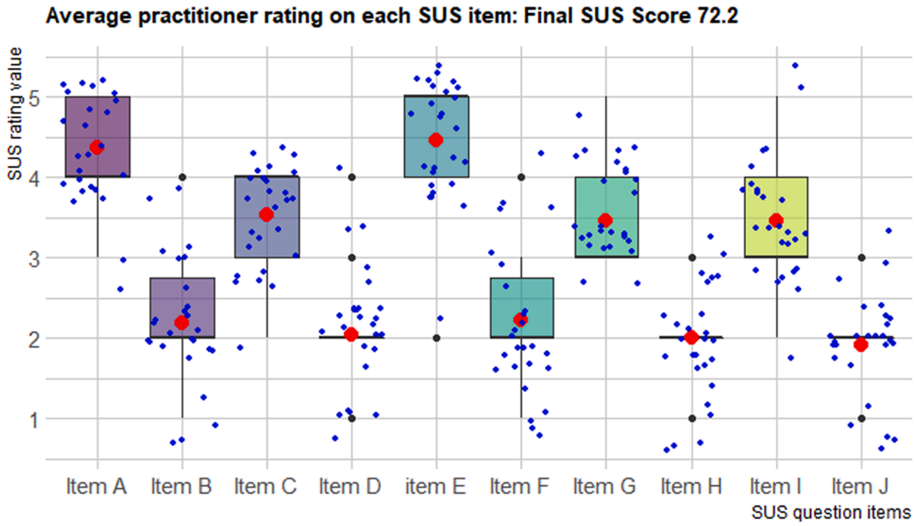

Fig. 8. Practitioner assessment of DIMAND's usability through the SUS questionnaire. Items A to J represent the corresponding SUS question items proposed by Holden [39] (e.g., "I would use DIMAND", "DIMAND was too complex for me", "DIMAND was easy to use"). The red/big dot on each boxplot (SUS question item) is the average rating value given by the 26 practitioners. The green/small dots are the practitioner individual rating values, with a small amount of random variation to their original locations as a mean to avoid overlaps among them [89]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[37]. Therefore, we used a simplified version of the SUS: a 10-item questionnaire measuring the usability perception applied on a 5-point Likert response options (strongly disagree to strongly agree). This SUS was improved by Holden [39] in terms of the wording from its original version proposed by Brooke [9]. SUS can robustly be used across many domains, such as engineering design [30], software engineering [94] or smart PSSs [17]; SUS is also robust with a small number of participants and is easily understood by participants with diverse disciplines [58]. These characteristics make SUS applicable for measuring the perceived usability of DIMAND from the perspectives of practitioners who bridge the gap between academic knowledge and implementation in practice.

Subsequently, based on Cohen [20], we determined the proper sample size as having a medium effect size of 0.5 and power of 80 % for the one-sample *t*-test. As a result, we recruited a total of 26 design practitioners (see Table 4) who have worked between two and more than five years as designers (e.g., user interface and user experience design (UX/UI), product and service design) and engineers (e.g., mechanics, industrial production, maintenance) to join the assessment. Table 4 shows their diverse disciplines in different industries (e.g., equipment manufacturers, consulting and research centers), ensuring the usability of DIMAND is well perceived by a wide range of design teams' profiles. Before the assessment, we ensured that these practitioners understood how DIMAND worked by communicating the same explanation presented in Section 4.

Fig. 8 presents the average rating given by these practitioners on each SUS item. The final SUS score of the DIMAND structure (Fig. 4) is 72.2 out of 100 from a practitioner perspective. Based on the adjective range of SUS scores reported by Bangor et al. [7], DIMAND's usability falls into the "excellence" rating.

By taking a detailed look at Fig. 8, the odd-ordered SUS items have the average rating values of more than 3, showing a positive usability assessment for DIMAND. Two of them, including item A ("I would use DIMAND") and item E ("The various parts of DIMAND were well integrated"), possess the higher average rating values at around 4,5 (between agree and strongly agree). This shows that the practitioners appreciated DIMAND as a multidimensional design methodology for compressing design knowledge by integrating the key design elements (Fig. 1) in a single-view structure in accordance with the human-centric approach. On the other hand, the even-ordered SUS items have average rating values around 2 (disagree), indicating the potential utility of DIMAND in practice under the central perspective of the practitioners. Specifically, the usability issues in DIMAND reflected by, for instance, item B ("DIMAND was too complex for me") and item D ("I really need help from someone to use DIMAND") were not a concern of the practitioners.

Above all, these SUS results validate that the knowledge representation of DIMAND (Fig. 4) matches the design purpose within the domain of advanced services: the (1) life-cycle service design interrelated with (2) stakeholder networks; (3) new service development methods; and (4) design skills in a single-view structure (its practice is presented in the supplementary information Appendix B).

6. Discussion and conclusion

Design for advanced services has caught the attention of industries and academics as a way to exploit new customer value propositions, hence enabling companies to create new revenue streams, competitiveness and customer satisfaction; however, doing so requires substantial efforts in an in-depth and overarching view of human actors in design [60,80]. This is because human-centered thinking allows value cocreation with customers and stakeholders and manages their expectations, opportunities and risks [49,75]. Nevertheless, the existing design methodologies for advanced services do not often address human-centered thinking; a lack of consideration of human actors could cause design problems: unexpected service behavior, user frustration and even extensive redesign work [28,48]. Moreover, the existing design methodologies have been limited to partially addressing one or some key design elements, causing confusion in practice and even leading to a service paradox [52,67]. Therefore, to make a contribution to the literature, we conceptually proposed a multidimensional design methodology called DIMAND (Fig. 4). On the opposite of existing intuitive approaches, DIMAND addresses (1) the life-cycle service design interrelated with other key design elements—(2) stakeholder networks, (3) new service development methods, (4) design skills—to orchestrate design activities in a single-view structure with the human-centric approach. We developed DIMAND through a hybrid research design (Fig. 2) that can take advantage of the body of knowledge in the literature through SLR and *meta*-analyses (Section 3.1). We also elicited 10 experts' expertise through the AHP analysis (Section 3.2) accompanied with the dataset to enhance the present research transparency [61]. Subsequently, based on the SUS (Section 5), we invited 26 design practitioners and engineers (Table 4) to evaluate the usability of DIMAND and confirm its potential utility.

In particular, the current study contributes to the literature on advanced service design in four ways. First, in response to the requests from Marilungo et al. [57] and Vasantha et al. [87], we built DIMAND to address the life-cycle service design, spanning from the *diagnose* phase to the *delivery* phase (Section 4.1). Even though life-cycle perspectives have been highlighted as being essential for advanced service design, fine-grained insights have been lacking [52]. Specifically, although Yu

[95] focused solely on measuring and analyzing customer requirements, Iriarte et al. [42] and Costa et al. [25] also paid attention to analyzing the business context and then identifying proper stakeholders. Thus, our study has addressed the call by Agher et al. [3] and Song and Sakao [81] by providing DIMAND as a systematic methodology that can cover the entire life cycle service design, starting from planning and design to product/service usage with feedback loops.

Second, responding to the work of Zheng et al. [98] and Carrera-Rivera et al. [15], we have incorporated an in-depth and overarching view of human actors (stakeholder networks) across the life-cycle service design into DIMAND (Section 4.2), fostering human-center thinking in design. We have demonstrated that DIMAND expresses the visibility of collaborative and collective opportunities for both internal and external stakeholders to co-design for advanced services across design processes. Thus, DIMAND has fulfilled the requirements posed by Richter et al. [71] and Nguyen, Lasa and Iriarte [60], embracing stakeholder involvement across the life-cycle service design.

Third, the current study has demonstrated how the life-cycle service design can be conducted with a wide range of new service development methods (Section 4.3), including both engineering and non-engineering design methods. Rather than replying only to engineering methods, we embedded the new service development methods across the life-cycle service design into DIMAND, as proposed by Jing-chen Cong et al. [21] and Nguyen, Lasa and Iriarte [60]. This has allowed for transdisciplinary design (e.g., physical ergonomics, cognitive and social factors), which is required for advanced services.

Fourth, we have responded to the call by Richter et al. [71] by integrating the design skills required for advanced service design into DIMAND (Section 4.4). This has contributed to the literature related to internal service capability (“who needs to know what”) and decision making on the training priority among cross-functional design teams through skill sets (the “S” symbols), as called for by Baines et al. [5] and Ingo Oswald Karpen et al. [46]. Through design skills, DIMAND encourages the mindset of building transdisciplinary design teams that are cross-functional (e.g., design, marketing, finance, manufacturing and maintenance) and involved in the making of advanced services. This mindset fosters a business culture perspective, in addition to market focus, as called for by Fernandes et al. (2019) and Gilles and Christine [29].

Finally, in relation to the practical implications for design practitioners and engineers, DIMAND (Fig. 4) offers systematic methodical support that can enable them to obtain coherence in all life-cycle design processes by simultaneously taking other key design elements—-stakeholder networks, new service development methods and design skills—and their relations into account. This holistic approach allows for the design of advanced services that are more practical in four ways. First, DIMAND addresses the life-cycle of service design, enabling design practitioners to keep the life cycle perspective in mind, utilize process dependency and contingency planning and be aware of the feedback loops among design processes in their design decisions. This allows for holistic life-cycle planning so that extensive redesign work, unexpected service behavior and even the effect of the service paradox can be avoided. Second, DIMAND is equipped with the complete piece of information of stakeholder involvement, offering design practitioners a complete guideline on how to start overseeing and planning the stakeholders’ roles across the life-cycle of service design. For external stakeholders, DIMAND helps design practitioners in understanding the partnerships among them so that they can plan how to leverage several parts of the ecosystem and not only rely on one, as proposed by Fernandes et al. [27]. DIMAND also encourages design practitioners to take the (direct and indirect) involvement of internal stakeholders into collaborative and collective design activities, working towards the development of value cocreation capabilities. Third, DIMAND instructs design practitioners how to implement design processes by using sets of new service development methods that are viable and have been proven in the literature. Thus, DIMAND allows design practitioners and engineers to be aware of a wide range of both service- and engineering-specific methods that can support a transdisciplinary approach, ranging from understanding customer requirements to prototyping methods. Fourth, DIMAND facilitates design practitioners in building up transdisciplinary design teams and training agendas for cross-functional teams by providing new service development methods. The training agenda can be prioritized for a particular job role, as illustrated by “S” in DIMAND (Fig. 4), to ensure the development of a transdisciplinary design team. As a result, DIMAND encourages design practitioners to balance the design skill sets among their cross-functional teams to develop their own internal service capabilities.

Despite the rigor of this hybrid research design, we acknowledge that some relevant research papers could have been missed during the SLR because of the selection of search terms and journal papers. The interpretation of the result was also influenced by our knowledge in the field; the substantial knowledge in this research was shaped by the body of knowledge in the literature, and the recruited experts and practitioners’ experience. Finally, we acknowledge that a limitation remains the conceptual methodology of DIMAND; we alleviated this limitation by presenting Appendix B, which offers the implementation instructions of DIMAND for practice. In addition, future research should aim to overcome this limitation by field implementations of DIMAND with selected multiple company cases. This field implementation can help deploy and adapt DIMAND to fit the business context of company cases, in which internal actors cooperate with researchers to design for advanced services. Through practice learning and experience during the field implementation, DIMAND will be subject to further refinement through reflection-in-action in each design process, resulting in innovation practices for company cases in particular and lessons learned for DIMAND in general.

Research data

Data transparency and code availability can be found online in Mendeley Data: Nguyen, N. H., Lasa, G., Iriarte, I., Atxa, A.;, Unamuno, G., & Galfarsoro, G. (2022a). Expert evaluation: Datasets of skill-rating questionnaires for advanced service design through Analytical Hierarchy Process. Mendeley Data. https://doi.org/10.17632/7brkgztjdx.3.

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.

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Appendices. Supplementary material

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References

[1] M.A. Abdelmegid, V.A. González, M. O’Sullivan, C.G. Walker, M. Poshdar, F. Ying, The roles of conceptual modelling in improving construction simulation studies: A comprehensive review, Adv. Eng. Inf. 46 (2020), 101175, https://doi.org/10.1016/j.aei.2020.101175.
[2] C. Acklin, Design-Driven Innovation Process Model, Design Management Journal 5 (1) (2010) 50–60, https://doi.org/10.1111/j.1948-7177.2010.00013.x.
[3] J.-R. Agher, P. Dubois, A. Aoussat, A Bibliometric Analysis of Product-Service Systems’ Design Methodologies: Potential Root-Cause Identification of PSS’ Failures, Sustainability 13 (11) (2021) 6237, https://doi.org/10.3390/su13116237.

[4] A. Awasthi, S.S. Chauhan, A hybrid approach integrating Affinity Diagram, AHP and fuzzy TOPSIS for sustainable city logistics planning, Appl. Math. Model. 36 (2) (2012) 573–584, https://doi.org/10.1016/j.apm.2011.07.033.

[5] T. Baines, H. Lightfoot, P. Smart, S. Fletcher, Servitization of manufacture: Exploring the deployment and skills of people critical to the delivery of advanced services, Journal of Manufacturing Technology Management 24 (4) (2013) 637–646, https://doi.org/10.1108/17410381311327431.

[6] T. Baines, W.H. Lightfoot, Servitization of the manufacturing firm, International Journal of Operations & Production Management 34 (1) (2013) 2–35, https://doi.org/10.1108/IJOPM-02-2012-0086.

[7] A. Bangor, T. Staff, P. Kortum, J. Miller, T. Staff, Determining what individual SUS scores mean: adding an adjective rating scale, Journal of Usability Studies 4 (3) (2009) 114–123.

[8] F.H. Beuren, T.T. Sousa-Zomer, P.A. Cauchick-Miguel, Proposal of a framework for product-service systems characterization, Production 27 (2017), https://doi.org/10.1590/0103-6513.20170052.

[9] J. Brooke, SUS: A "Quick and Dirty" Usability Scale, in: P.W. Jordan, B. Thomas, I. L. McClelland, B. Weerdmeester (Eds.), Usability Evaluation In Industry, CRC Press, 1996, p. (p. 6)., https://doi.org/10.1201/9781498710411.

[10] L. Bu, C.-H. Chen, K.K.H. Ng, P. Zheng, G. Dong, H. Liu, A user-centric design approach for smart product-service systems using virtual reality: A case study, J. Cleaner Prod. 280 (2021), 124413, https://doi.org/10.1016/j.jclepro.2020.124413.

[11] A. Calabrese, R. Costa, N.L. Ghiron, L. Tiburzi, E.R.G. Pedersen, How sustainable-orientated service innovation strategies are contributing to the sustainable development goals, Technol. Forecast. Soc. Chang. 169 (2021), 120816, https://doi.org/10.1016/j.techfore.2021.120816.

[12] G. Calabretta, C.S.H. De Lille, Service Design for Effective Servitization and New Service Implementation, Fifth Service Design and Innovation Conference (2016) 91–104.

[13] E. Camussi, C. Sassi, E. Zulato, C. Annovazzi, M.C. Ginevra, Hacking women's health: A new methodology, Journal of Prevention & Intervention in the Community 48 (2) (2020) 174–188, https://doi.org/10.1080/10852352.2019.1624356.

[14] F. Caputo, A. Greco, M. Fera, R. Macchiaroli, Workplace design ergonomic validation based on multiple human factors assessment methods and simulation, Production and Manufacturing Research 7 (1) (2019) 195–222, https://doi.org/10.1080/21693277.2019.1616631.

[15] A. Carrera-Rivera, F. Larrinaga, G. Lasa, Context-awareness for the design of Smart-product service systems: Literature review, Comput. Ind. 142 (2022), 103730, https://doi.org/10.1016/j.compind.2022.103730.

[16] Y. Cha, J. Kim, B. Park, Y. Park, S.-D. Kim, Development of an ICT Car Service Applying a Human-Centered Design, KSII Trans. Internet Inf. Syst. 11 (6) (2017) 3071–3085, https://doi.org/10.3837/tiis.2017.06.015.

[17] D. Chang, Z. Gu, F. Li, R. Jiang, A user-centric smart product-service system development approach: A case study on medication management for the elderly, Adv. Eng. Inf. 42 (2019), 100979, https://doi.org/10.1016/j.aei.2019.100979.

[18] E.K. Chew, iSIM: An integrated design method for commercializing service innovation, Information Systems Frontiers 18 (3) (2016) 457–478, https://doi.org/10.1007/s10796-015-9605-y.

[19] C. Cimini, F. Pirola, R. Pinto, S. Cavalieri, A human-in-the-loop manufacturing control architecture for the next generation of production systems, J. Manuf. Syst. 54 (2020) 258–271, https://doi.org/10.1016/j.jmsy.2020.01.002.

[20] J. Cohen, Statistical power analysis for the behavioral sciences, 2nd ed., Routledge Member of the Taylor and Francis Group, New York, 1988.

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

[22] J. Cong, P. Zheng, Y. Bian, C.-H. Chen, J. Li, X. Li, A machine learning-based iterative design approach to automate user satisfaction degree prediction in smart product-service system, Comput. Ind. Eng. 165 (2022), 107939, https://doi.org/10.1016/j.cie.2022.107939.

[23] W. Coreynen, P. Matthyssens, R. De Rijck, I. Dewit, Internal levers for servitization: How product-oriented manufacturers can upscale product-service systems, Int. J. Prod. Res. 56 (6) (2018) 2184–2198, https://doi.org/10.1080/00207543.2017.1343504.

[24] N. Costa, L. Patrício, N. Morelli, Revisiting PSS and service design in the light of the SD-logic. ServDes16, June. (2016).

[25] N. Costa, L. Patrício, N. Morelli, C.L. Magee, Bringing Service Design to manufacturing companies: Integrating PSS and Service Design approaches, Des. Stud. 55 (2018) 112–145, https://doi.org/10.1016/j.destud.2017.09.002.

[26] J. Fan, S. Yu, J. Chu, D. Chen, M. Yu, T. Wu, J. Chen, F. Cheng, C. Zhao, Research on multi-objective decision-making under cloud platform based on quality function deployment and uncertain linguistic variables, Adv. Eng. Inf. 42 (2019), 100932, https://doi.org/10.1016/j.aei.2019.100932.

[27] S. da Costa Fernandes, L.D. Martins, H. Rozenfeld, Who are the Stakeholders Mentioned in Cases of Product-Service System (PSS) Design? Proc. Int. Conf. Eng. Des. 1 (1) (2019) 3131–3140.

[28] S. Fukuzumi, N. Noda, Y. Tanikawa, How to Apply Human-Centered Design Process (HCDP) to Software Development Process?, 2017 IEEE/ACM 1st International Workshop on Design and Innovation in Software Engineering (DISE), (2017) 13–16. https://doi.org/10.1109/DISE.2017.10.

[29] N. Gilles, L.-C. Christine, The Sustainable Value Proposition of PSSs: The Case of ECOBEL "Shower Head", Procedia CIRP 47 (2016) 12–17, https://doi.org/10.1016/j.procir.2016.03.043.

[30] J.A. Gopsill, H.C. McAlpine, B.J. Hicks, Supporting engineering design communication using a custom-built social media tool – PartBook, Adv. Eng. Inf. 29 (3) (2015) 523–548, https://doi.org/10.1016/j.aei.2015.04.008.

[31] I. Göttgens, S. Oertelt-Prigione, The Application of Human-Centered Design Approaches in Health Research and Innovation: A Narrative Review of Current Practices, JMIR MHealth and UHealth 9 (12) (2021), e28102, https://doi.org/10.2196/28102.

[32] J. Grenha Teixeira, L. Patrício, K.-H. Huang, R.P. Fisk, L. Nóbrega, L. Constantine, The MINDS Method: Integrating Management and Interaction Design Perspectives for Service Design, Journal of Service Research 20 (3) (2017) 240–258, https://doi.org/10.1177/1094670516680033.

[33] J. Grenha Teixeira, N.F. de Pinho, L. Patrício, Bringing service design to the development of health information systems: The case of the Portuguese national electronic health record, Int. J. Med. Inf. 132 (2019), 103942, https://doi.org/10.1016/j.ijmedinf.2019.08.002.

[34] T.R. Gruber, A translation approach to portable ontology specifications, Knowledge Acquisition 5 (2) (1993) 199–220, https://doi.org/10.1006/knac.1993.1008.

[35] N. Haber, M. Fargnoli, Prioritizing customer requirements in a product-service system (PSS) context, TQM Journal 31 (2) (2019) 257–273, https://doi.org/10.1108/TQM-08-2018-0113.

[36] T. Hartmann, R. Amor, E.W. East, Information Model Purposes in Building and Facility Design, J. Comput. Civil Eng. 31 (6) (2017) 04017054, https://doi.org/10.1061/(ASCE)CP.1943-5487.0000706.

[37] T. Hartmann, A. Trappey, Advanced Engineering Informatics - Philosophical and methodological foundations with examples from civil and construction engineering, Developments in the Built Environment 4 (2020), 100020, https://doi.org/10.1016/j.dibe.2020.100020.

[38] M. Hartono, The modified Kansei Engineering-based application for sustainable service design, Int. J. Ind. Ergon. 79 (2020), 102985, https://doi.org/10.1016/j.ergon.2020.102985.

[39] R.J. Holden, A Simplified System Usability Scale (SUS) for Cognitively Impaired and Older Adults, Proceedings of the International Symposium on Human Factors and Ergonomics in Health Care 9 (1) (2020) 180–182, https://doi.org/10.1177/2327857920091021.

[40] G. Horvat, D. Zagar, J. Vlaovic, Evaluation of quality of service provisioning in large-scale pervasive and smart collaborative wireless sensor and actor networks, Adv. Eng. Inf. 33 (2017) 258–273, https://doi.org/10.1016/j.aei.2016.10.003.

[41] International Organization for Standardization. Ergonomics of Human-System Interaction—Part 210: Human-Centred Design for Interactive Systems (ISO Standard No. 9241-210:2019) (2nd ed.). (2019). https://www.iso.org/standard/77520.html.

[42] I. Iriarte, M. Hoveskog, D. Justel, E. Val, F. Halila, Service design visualization tools for supporting servitization in a machine tool manufacturer, Ind. Mark. Manage. 71 (2018) 189–202, https://doi.org/10.1016/j.indmarman.2018.01.003.

[43] S. Izukura, S. Hosono, H. Sakaki, E. Numata, K. Kimita, Y. Shimomura, Bridging Non-functional Requirements and IT Service Design, Procedia CIRP 30 (2015) 24–29, https://doi.org/10.1016/j.procir.2015.02.104.

[44] G. Jia, G. Zhang, X. Yuan, X. Gu, H. Liu, Z. Fan, L. Bu, A synthetical development approach for rehabilitation assistive smart product–service systems: A case study, Adv. Eng. Inf. 48 (2021), 101310, https://doi.org/10.1016/j.aei.2021.101310.

[45] C.M. Johnson, T.R. Johnson, J. Zhang, A user-centered framework for redesigning health care interfaces, J. Biomed. Inform. 38 (1) (2005) 75–87, https://doi.org/10.1016/j.jbi.2004.11.005.

[46] I.O. Karpen, G. Gemser, G. Calabretta, A multilevel consideration of service design conditions: Towards a portfolio of organisational capabilities, interactive practices and individual abilities, Journal of Service Theory and Practice 27 (2) (2017) 384–407, https://doi.org/10.1108/JSTP-05-2015-0121.

[47] B.A. Kitchenham, T. Dyba, M. Jorgensen, Evidence-based software engineering, in: Proceedings. 26th International Conference on Software Engineering (2004) 273–281. https://doi.org/10.1109/ICSE.2004.1317449.

[48] X.T.R. Kong, H. Luo, G.Q. Huang, X. Yang, Industrial wearable system: the human-centric empowering technology in Industry 4.0, J. Intell. Manuf. 30 (8) (2019) 2853–2869, https://doi.org/10.1007/s10845-018-1416-9.

[49] A.K. Korper, L. Patrício, S. Holmlid, L. Witell, Service design as an innovation approach in technology startups: a longitudinal multiple case study, Creativity and Innovation Management 29 (2) (2020) 303–323, https://doi.org/10.1111/caim.12383.

[50] A. Kumar, S. Maskara, Revealing clinicians' experiences towards healthcare software usability using human-centred design approach, J. of Design Research 13 (1) (2015) 36, https://doi.org/10.1504/JDR.2015.067229.

[51] A. Kumar, S. Maskara, I.-J. Chiang, Building a prototype using Human-Centered Design to engage older adults in healthcare decision-making, Work 49 (4) (2014) 653–661, https://doi.org/10.3233/WOR-131695.

[52] H. Kwon, B.-H. Baek, Y.-S. Jeon, Y.-L. Kim, H.-B. Jung, Key factors of service design methodology for manufacturing servitization, Cogent Business & Management 8 (1) (2021) 1883220, https://doi.org/10.1080/23311975.2021.1883220.

[53] C.-H. Lee, C.-H. Chen, A.J.C. Trappey, A structural service innovation approach for designing smart product service systems: Case study of smart beauty service, Adv. Eng. Inf. 40 (2019) 154–167, https://doi.org/10.1016/j.aei.2019.04.006.

[54] S. Lee, S.D. Ross, Sport sponsorship decision making in a global market, Sport, Business and Management: An International Journal 2 (2) (2012) 156–168, https://doi.org/10.1108/20426781211243999.

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

[56] V. Lofthouse, S. Prendeville, Human-Centred Design of Products And Services for the Circular Economy – A Review, The Design Journal 21 (4) (2018) 451–476, https://doi.org/10.1080/14606925.2018.1468169.
[57] E. Marilungo, M. Peruzzini, M. Germani, Review of Product-Service System Design Methods (2016) (pp. 271–279). https://doi.org/10.1007/978-3-319-33111-9_25.
[58] A.I. Martins, A.F. Rosa, A. Queirós, A. Silva, N.P. Rocha, European Portuguese Validation of the System Usability Scale (SUS), Procedia Comput. Sci. 67 (2015) 293–300, https://doi.org/10.1016/j.procs.2015.09.273.
[59] V. Mathieu, Product services: from a service supporting the product to a service supporting the client, Journal of Business & Industrial Marketing 16 (1) (2001) 39–61, https://doi.org/10.1108/08858620110364873.
[60] N.H. Nguyen, G. Lasa, I. Iriarte, Human-centred design in industry 4.0: case study review and opportunities for future research, J. Intell. Manuf. 33 (1) (2022) 35–76, https://doi.org/10.1007/s10845-021-01796-x.
[61] N.H. Nguyen, G. Lasa, I. Iriarte, A. Atxa, G. Unamuno, G. Galfarsoro, Expert evaluation: Datasets of skill-rating questionnaires for advanced service design through Analytical Hierarchy Process, Mendeley Data. (2022), https://doi.org/10.17632/7brkgztjdx.3.
[62] N.H. Nguyen, G. Lasa, I. Iriarte, A. Atxa, G. Unamuno, G. Galfarsoro, Datasets of skills-rating questionnaires for advanced service design through expert knowledge elicitation, Sci. Data 9 (1) (2022) 321, https://doi.org/10.1038/s41597-022-01421-3.
[63] N.H. Nguyen, G. Lasa, I. Iriarte, G. Unamuno, An overview of Industry 4.0 Applications for Advanced Maintenance Services, Procedia Comput. Sci. 200 (2022) 803–810, https://doi.org/10.1016/j.procs.2022.01.277.
[64] M.P. Papazoglou, A. Elgammal, B.J. Krämer, Collaborative on-demand Product-Service Systems customization lifecycle, CIRP J. Manuf. Sci. Technol. 29 (2020) 205–219, https://doi.org/10.1016/j.cirpj.2018.08.003.
[65] M. Peruzzini, M. Pellicciari, F. Grandi, A.O. Andrisano, A multimodal virtual reality set-up for human-centered design of industrial workstations, Dyna (Spain) 94 (2) (2019) 182–188, https://doi.org/10.6036/8889.
[66] M.A. Piera, J.L. Munoz, D. Gil, G. Martin, J. Manzano, A Socio-Technical Simulation Model for the Design of the Future Single Pilot Cockpit: An Opportunity to Improve Pilot Performance, IEEE Access 10 (2022) 22330–22343, https://doi.org/10.1109/ACCESS.2022.3153490.
[67] Y.-J. Ping, R. Liu, W. Lin, H.-C. Liu, A new integrated approach for engineering characteristic prioritization in quality function deployment, Adv. Eng. Inf. 45 (2020), 101099, https://doi.org/10.1016/j.aei.2020.101099.
[68] C. Powell, The Delphi technique: myths and realities, J. Adv. Nurs. 41 (4) (2003) 376–382, https://doi.org/10.1046/j.1365-2648.2003.02537.x.
[69] M. Qu, S. Yu, D. Chen, J. Chu, B. Tian, State-of-the-art of design, evaluation, and operation methodologies in product service systems, Comput. Ind. 77 (2016) 1–14, https://doi.org/10.1016/j.compind.2015.12.004.
[70] A. Richert, S. Müller, S. Schröder, S. Jeschke, Anthropomorphism in social robotics: empirical results on human–robot interaction in hybrid production workplaces, AI & Soc. 33 (3) (2018) 413–424, https://doi.org/10.1007/s00146-017-0756-x.
[71] A. Richter, P. Glaser, B. Kölmel, L. Waidelich, R. Bulander, A Review of Product-service System Design Methodologies, in: Proceedings of the 16th International Joint Conference on E-Business and Telecommunications, 2019, 115–126. https://doi.org/10.5220/0007917201150126.
[72] T.L. Saaty, The Analytic Hierarchy Process, McGraw Hill, New York, 1980.
[73] M. Salgado, M. Wendland, D. Rodriguez, M.A. Bohren, O.T. Oladapo, O.A. Ojelade, K. Mugerwa, B. Fawole, A service concept and tools to improve maternal and newborn health in Nigeria and Uganda, International Journal of Gynecology & Obstetrics 139 (S1) (2017) 67–73, https://doi.org/10.1002/ijgo.12382.
[74] M. Salgado, M. Wendland, D. Rodriguez, M.A. Bohren, O.T. Oladapo, O.A. Ojelade, A.A. Olalere, R. Luwangula, K. Mugerwa, B. Fawole, Using a service design model to develop the "Passport to Safer Birth" in Nigeria and Uganda, International Journal of Gynecology & Obstetrics 139 (S1) (2017) 56–66, https://doi.org/10.1002/ijgo.12381.
[75] R. dos Santos, E.V. Bueno, H.T. Kato, R.O. Corrêa, Design management as dynamic capabilities: a historiographical analysis, European Business Review 30 (6) (2018) 707–719, https://doi.org/10.1108/EBR-11-2016-0147.
[76] J. Schiro, S. Pelayo, A. Martinot, F. Dubos, M.-C. Beuscart-Zéphir, R. Marcilly, Applying a Human-Centered Design to Develop a Patient Prioritization Tool for a Pediatric Emergency Department: Detailed Case Study of First Iterations, JMIR Human Factors 7 (3) (2020), e18427, https://doi.org/10.2196/18427.
[77] H. Schulze, H. Brau, S. Haasis, M. Weyrich, T. Rhatje, Human-centered design of engineering applications: Success factors from a case study in the automotive industry, Human Factors and Ergonomics In Manufacturing 15 (4) (2005) 421–443, https://doi.org/10.1002/hfm.20036.
[78] S. Sharma, R. Pratap, a Case Study of Risks Optimization Using Ahp Method, International Journal of Scientific and Research Publications 3 (10) (2013) 2250–3153, www.ijsrp.org.
[79] J. Sierra-Pérez, J.G. Teixeira, C. Romero-Piqueras, L. Patrício, Designing sustainable services with the ECO-Service design method: Bridging user experience with environmental performance, J. Cleaner Prod. 305 (2021), 127228, https://doi.org/10.1016/j.jclepro.2021.127228.
[80] B.A.A. Solem, M. Kohtamäki, V. Parida, T. Brekke, Untangling service design routines for digital servitization: empirical insights of smart PSS in maritime industry, Journal of Manufacturing Technology Management 33 (4) (2022) 717–740.
[81] W. Song, T. Sakao, A customization-oriented framework for design of sustainable product/service system, J. Cleaner Prod. 140 (2017) 1672–1685, https://doi.org/10.1016/j.jclepro.2016.09.111.
[82] G. Spreitzer, C.L. Porath, C.B. Gibson, Toward human sustainability: How to enable more thriving at work, Organizational Dynamics 41 (2) (2012) 155–162, https://doi.org/10.1016/j.orgdyn.2012.01.009.
[83] A. Tukker, Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet, Business Strategy and the Environment 13 (4) (2004) 246–260, https://doi.org/10.1002/bse.414.
[84] Y. Ueda, Proposal for Service-Oriented design processes, Fujitsu Sci. Tech. J. 45 (2) (2009) 171–178.
[85] Y. Ueda, Research trend of HCD in Fujitsu and prospects for innovation design, Fujitsu Sci. Tech. J. 49 (4) (2013) 376–382.
[86] Y. Ueda, K. Matsumoto, H. Zempo, User experience design in Fujitsu, Fujitsu Sci. Tech. J. 54 (1) (2018) 3–8.
[87] G.V.A. Vasantha, R. Roy, A. Lelah, D. Brissaud, A review of product–service systems design methodologies, J. Eng. Des. 23 (9) (2012) 635–659, https://doi.org/10.1080/09544828.2011.639712.
[88] J. Wang, R. Li, G. Ding, S. Qin, Z. Cai, Product-service system engineering characteristics design for life cycle cost based on constraint satisfaction problem and Bayesian network, Adv. Eng. Inf. 52 (2022), 101573, https://doi.org/10.1016/j.aei.2022.101573.
[89] H. Wickham, ggplot2: Elegant Graphics for Data Analysis, Springer-Verlag, New York, 2016 https://ggplot2.tidyverse.org.
[90] C. Wohlin, Guidelines for snowballing in systematic literature studies and a replication in software engineering, in: Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering - EASE '14, 2014, 1–10. https://doi.org/10.1145/2601248.2601268.
[91] R. Woitsch, A. Sumereder, D. Falcioni, Model-based data integration along the product and service life cycle supported by digital twinning, Comput. Ind. 140 (2022), 103648, https://doi.org/10.1016/j.compind.2022.103648.
[92] L. Wu, Z. Zhu, H. Cao, B. Li, Influence of information overload on operator's user experience of human–machine interface in LED manufacturing systems, Cogn. Technol. Work 18 (1) (2016) 161–173, https://doi.org/10.1007/s10111-015-0352-0.
[93] F. Xue, L. Wu, W. Lu, Semantic enrichment of building and city information models: A ten-year review, Adv. Eng. Inf. 47 (2021), 101245, https://doi.org/10.1016/j.aei.2020.101245.
[94] N. Ya-feng, L. Jin, C. Jia-qi, Y. Wen-jun, Z. Hong-rui, H. Jia-xin, X. Lang, W. Jia-hao, M. Guo-rui, H. Zi-jian, X. Cheng-qi, Z. Xiao-zhou, J. Tao, Research on visual representation of icon colour in eye-controlled systems, Adv. Eng. Inf. 52 (2022), 101570, https://doi.org/10.1016/j.aei.2022.101570.
[95] E. Yu, Designing for Value: Insights from the Emotional Appraisal Approach to Understanding User Value, The Design Journal 21 (2) (2018) 185–207, https://doi.org/10.1080/14606925.2018.1407540.
[96] E. Yu, D. Sangiorgi, Service Design as an Approach to Implement the Value Cocreation Perspective in New Service Development, Journal of Service Research 21 (1) (2018) 40–58, https://doi.org/10.1177/1094670517709356.
[97] A. Zabin, V.A. González, Y. Zou, R. Amor, Applications of machine learning to BIM: A systematic literature review, Adv. Eng. Inf. 51 (2022), 101474, https://doi.org/10.1016/j.aei.2021.101474.
[98] P. Zheng, Z. Wang, C.-H. Chen, L. Pheng Khoo, A survey of smart product-service systems: Key aspects, challenges and future perspectives, Adv. Eng. Inf. 42 (2019), 100973, https://doi.org/10.1016/j.aei.2019.100973.
[99] T. Zhou, Z. Chen, Y. Cao, R. Miao, X. Ming, An integrated framework of user experience-oriented smart service requirement analysis for smart product service system development, Adv. Eng. Inf. 51 (2022), 101458, https://doi.org/10.1016/j.aei.2021.101458.