Giuditta Pezzotta · Roberto Sala · Xavier Boucher · Marco Bertoni · Fabiana Pirola *Editors*

Data-Driven Decision Making for Product Service Systems

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Preface

In recent decades, the manufacturing companies, traditionally focused on transactional-based relationships with the customers (e.g., lasting only for the product sale) and used to produce and sell vast amounts of standardized products, had to rethink their business offerings to cope with the increasing market competition driven by globalization and technological advancements. To distinguish themselves from competitors, they had to move toward a higher personalization of their offering, closer to customer requirements, especially through the use of service-based offerings. This process ended up in a transformation phenomenon known as servitization [1], where product-centric companies transformed their business model into service-based ones, built on top of customer characteristics and requests. Once on the market, service-based offerings are referred to as Product-Service System (PSS) [2], which are a combination of a mix of products and services used to create the offering [3]. According to [3], three main categories of PSS exist:

- Product-Oriented: the ownership of the product shifts from the supplier to the customer, who can buy the services from the supplier whenever necessary. The relationship between the stakeholders is transactional, with a low level of intimacy.
- Use-Oriented: the ownership of the product remains with the supplier, and the customer pays to use it. The use of the product is the leading transactional element, together with the services that add value to it. The relationship between the actors starts shifting from transactional to relational, with the customer interested in paying to use the product, and the level of intimacy increases.
- Result-Oriented: the product ownership remains to the supplier, and the customer pays for the result of using the product. The relationship between the actors is purely relational, and the level of intimacy is high.

The transformation from a product-centric approach to service-based offerings, highlights how companies adapt to changing market dynamics, customer demands, and the competitive landscape. This transformation allows businesses to cater to a broader spectrum of customer needs and preferences, ultimately fostering stronger and more lasting relationships with all the customers and users.

While PSS are offered in both B2B and B2C markets, the nature of the product may vary, passing from a simple product (e.g., a washing machine) in a B2C setting to equipment used for production in a B2B one. In the following, the term "asset" (or "industrial asset") will be used to refer to the physical components of the PSS offering as a reference to a tangible product that contributes to the value generation (e.g., produce a product) for the user.

The uptake of Product-Service Systems (PSS) business models in the manufacturing sector opens new opportunities for companies to create additional value and increase revenues. PSS offerings foster the creation of solid bonds between stakeholders, ensuring more stable cash flows. The recent trend toward digitization is fueling the companies' ability to gather unprecedented quantities of field data generated by the assets and by stakeholders (4), allowing the design on new, data-driven services and to improve the delivery of the existing ones.

However, this digital revolution poses challenges for PSS providers regarding the adoption of advanced technologies for the proper management of data collected from the field and its utilization in supporting decision-making throughout various phases of the solution lifecycle, namely in the design (i.e., Beginning of Life), use (i.e., Middle of Life) and decommissioning (i.e., End of Life) phases.

In the PSS literature, many authors focus their attention on decision-making support, data utilization and integration problems, aiming to provide frameworks, methods, and tools designed for supporting company decision-making in designing and providing profitable PSS solutions. As highlighted by the literature [5, 6], it is crucial in today's context to effectively manage information and leverage aggregated operational data to support strategical, tactical, and operational decisions, including:

- The design or re-design of assets and/or services, thereby affecting the PSS Beginning of Life.
- The assessment of the PSS solutions in the early design phase to verify their feasibility and expected benefits.
- The improvement of the daily operational decisions related to asset management with the goal of improving the PSS Middle of Life.
- The offering of new personalized services, thus opening new business opportunities in terms of revenues and the ability to prolong the PSS Middle of Life.
- The enhancement of the daily operational decisions related to service delivery and management, again, aimed at improving the PSS Middle of Life.
- The ability to foster product circularity through recycling, remanufacturing, refurbishing, and revamping decisions, thus affecting the PSS End of Life.

This suggests that implementing a structured process for collecting, processing, and managing operational data related to assets and services can open up new business opportunities for PSS providers. In particular, it is possible to affirm that companies still need to (i) design and implement processes for data collection and sharing, (ii) develop methods and tools to enhance decision-making, as well as (iii) improve skills related to data exploitation to improve decision consistency. In addition, it becomes clearer how operational data generated in the Middle of Life may contribute to decisions made in other phases of the PSS lifecycle if proper methods, tools, and processes are in place.

The book aims to provide an overview of the most recent developments related to decision-making in the PSS context in terms of data-driven processes, methods and tools to support the PSS lifecycle phases. The target audience includes researchers, practitioners and (Masters/Ph.D.) students.

This preface provides a general context and introduction for the book. The rest of the book is structured in four parts (Fig. 1), each one composed of three chapters:

- Data-Driven Decision-Making for PSS Design.
- Data-Driven Decision-Making for PSS Assessment.
- Data-Driven Decision-Making for Asset Design and Management in PSS Offerings.
- Data-Driven Decision-Making for Service Management and Delivery in PSS Offerings.

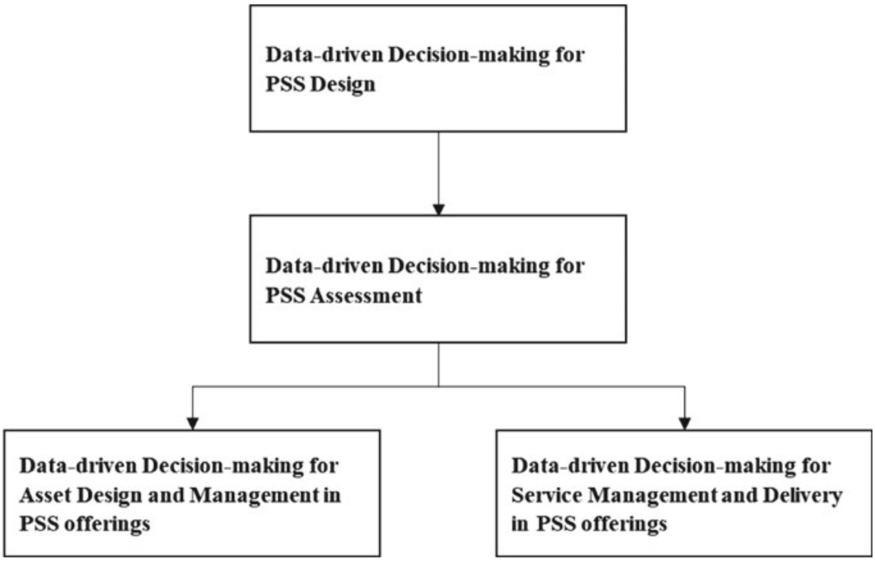

Fig. 1 Structure of the book

Data-Driven Decision-Making for PSS Design

This part of the book delves into key principles and approaches for improving Product-Service System (PSS) design, offering insights from the chapters on design thinking, leveraging digital technologies, and knowledge management. These chapters provide a comprehensive foundation for developing innovative and human-centric PSS solutions, harnessing the power of data-driven decision-making, and enhancing PSS lifecycle management.

Chapter "Design Thinking for Product-Service Systems Design" deals with the concept of design thinking, starting from the origins of this concept and exploring how it can be effectively applied to the PSS solution design. While providing an overview of the literature and discussing several examples in the PSS context, the chapter also provides a list of recommendations for the application of design thinking for each phase of the design thinking process.

Chapter "Challenges and Opportunities for the Design and Development of Intelligent, Sustainable and Resilient Personalized Product-Service Systems Towards Industry 5.0" explores how digital technologies can enhance PSS design within a human-centric resilient manufacturing framework. Through two applications of the proposed framework, the chapter aims at showing how various kinds of data (e.g., textual, numerical) can be used to support the PSS design. As such, data-driven analysis approaches are explored to inform decision-making and enhance PSS customization also considering sustainability.

Chapter "Role of Ontology in Data-Driven PSS Engineering and Design and Lifecycle Management" discusses the topic of knowledge management to support data-driven PSS design. A semantic framework in the form of ontology representing generic PSS entities and their relations is presented. The potential for using the ontologies in data-driven PSS engineering and design is examined via two case studies, the first in design and building services in the machine industry and the second one in service configuration and operation in the logistics domain. Both cases address the application of ontologies for PSS lifecycle management as well.

Data-Driven Decision-Making for PSS Assessment

This part of the book deals with the topic of PSS assessment, first providing an overview of methods, tools, and techniques frequently adopted by researchers and practitioners during PSS design. Then, building on the use of data, the contribution that data-driven methods could provide to the early evaluation of PSS performance and, in turn, the feedback that could be provided while developing the PSS solution, allowing to select PSS alternatives that most fit the companies interests.

Chapter "Multi-Criteria Decision-Making for PSS Design" conducts a comprehensive literature review, shedding light on the subject of PSS assessment. The aim of the chapter is to review how Multi-Criteria Decision-Making (MCDM) is applied to guide design concept selection in the PSS context. The aim of these approaches is to augment the ability of the design team to identify, early in the process, the most valuable solution option(s). The chapter provides an overview of the most popular techniques used today, pointing out application cases across several industrial sectors.

Chapter "PSS Economic Model Simulation and Risk Assessment: Lessons from an Industrial Case Study" deals with Smart PSS offerings where data collection and processing play a pivotal role to create new PSS business models and enhance PSS design, assessment and delivery. This chapter presents a simulation approach to assess the economic risk of PSS alternatives to support decision-making when selecting among the various business models. The results show that, depending on the objectives, Smart PSS are not always as profitable as expected and that each actor may favor his proper business model.

Chapter "Simulation Applied in Product-Service System (PSS): System Dynamics Potentials of Supporting Sustainable PSS Development" focuses on investigating how simulation-based modeling can be exploited to support the development of sustainable PSS offerings. Specifically, using System Dynamics (SD) simulation approach, it is possible to support manufacturing managers in assessing different PSS solutions from economic and environmental perspectives. In the chapter, these have been used for the definition of a conceptual model leading to the development of a simulation model.

Data-Driven Decision-Making for Asset Design and Management in PSS Offerings

This part of the book focuses on the physical part of the PSS offering, the asset. In particular, the usefulness of data usage is demonstrated in the Beginning of Life (i.e., as a support for the product design) and Middle of Life phases, (i.e., to monitor the product health). The use of new technologies and the related benefits are highlighted.

Chapter "Using Operational Data to Represent Machine Components Health and Derive Data-Driven Services" discusses the possibility to extend the useful life of PSS product component(s) based on an assessment of their health condition and a prognosis of the remaining useful life. The approach presented intends to support companies in the identification and analysis of the required PSS data types and sources as well as the evaluation of the effort to obtain this data. The discussion is based on an example of a PSS aimed at the prognosis of the remaining useful life of a technical component.

Chapter "Data Driven Design for PSS (Product Re-design Based on Previous Knowledge)" presents a data-driven approach exploiting historical PSS operational data and computer-aided design (CAD) models to assess alternative design configurations. The approach encompasses the use of the design of experiment techniques and machine learning (ML) to create models for each PSS configuration. Two case studies run in collaboration with a tier-one aero-engine sub-system manufacturer and an original equipment manufacturer in the construction equipment field are presented.

Chapter "Data+ driven PSS Design in Collaborative Virtual Environments" deals with the topic of collaboration of multidisciplinary teams and knowledge sharing during the asset design in a PSS solution using Digital Twins. Through a case study, settled in a construction equipment manufacturing company, the authors present a framework to integrate different decision drivers, actors, and agents in the design of collaborative virtual environments for decision-making. Then, potential advantages and issues of the virtual environment, current challenges, and future developments are identified.

Data-Driven Decision-Making for Service Management and Delivery in PSS Offerings

This part of the book focuses on the intangible part of the PSS offering, the service. The themes of data usage as well as the importance of knowledge management are discussed with examples related to smart service design and improvement. Additionally, through the case studies, the contribution that data usage can provide to decision-making at the operational, tactical, and strategical levels in the service context is demonstrated.

Chapter "Defining the Smartness of Data-Driven PSS in Decision-Making" lists and discusses the characteristics (enabling technologies, ecosystem view, value-in-context, customization, future orientation, and digital communication) that Smart PSSs should have to be effective in delivering value to customers. The chapter explores, with the help of two case studies, what are the purposes and beneficiaries of service-oriented data-driven decisions in the Smart PSS context. The similarities and differences between the two are then highlighted.

Chapter "Re-engineering the Way Maintenance Data Are Collected and Analysed: The Service Report" deals with data collection for knowledge extraction in the context of maintenance-based PSS offerings. If not well organized and structured, maintenance intervention data might result to be unusable, or difficult to process, limiting the possibility to extract useful information for improvement purposes, such as the improvement of the service (e.g., re-engineering of the maintenance delivery process to reduce errors) or asset-related management policies (e.g., definition of preventive maintenance calendar). Through a case study, the chapter discusses how data collection can be improved to favor the analysis, and, thus, the improvement of maintenance service management and delivery.

Chapter "Knowledge-Driven Action Within Complex Product-Service Systems" deals with the problem of data and knowledge availability and usage. Service and PSS decision-making is often a challenge because of the complexity of multi-level systems, requiring the use of professional experience, personal knowledge, together with the data generated from the technical, operational, and business levels within operational, tactical, and strategic timeframes. Using industrial cases, the chapter describes how data, contextual information, and tacit knowledge could be used to make informed decision-making.

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Marco Bertoni owns a Ph.D. from Politecnico di Milano and boasts over 15 years of academic expertise in product development, design thinking, system engineering, and knowledge management. Currently serving as Professor in Mechanical Engineering at Blekinge Institute of Technology, he co-chairs the "Design of Product-Service Systems" SIG within the Design Society, while conducting research on the application of modeling and simulation to facilitate cross-functional decision-making in the initial phases of PSS design. Marco describes himself as an ambidextrous thinker that loves to observe situations and people's behaviors, making sense of them to explore opportunities for innovation across boundaries and disciplines. Marco lives in the Swedish city of Karlskrona with his family, and in his spare time he is an active footballer and a passionate cyclist.

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Data-Driven Decision Making for PSS Design

Design Thinking for Product-Service Systems Design

Marco Bertoni and Christian Johansson Askling

Abstract Human-centred approaches to problem-solving have gained significant popularity in recent years. Among them, Design Thinking (DT) has received widespread attention, particularly through the work of design firms like IDEO and the Stanford d.school. Needfinding, idea generation, and prototyping techniques have often been applied to design Product-Service Systems (PSS) 'experiences', where tangible products and intangible services are integrated to design value-adding solutions for customers and users. Yet, the literature does not fully explain how the DT body of knowledge can effectively be applied to intentionally design PSS in different contexts. This chapter reviews existing literature on the usage of the DT method and tools in PSS design, presenting a list of recommendations that emerged from applying DT in co-production mode with companies in the Swedish manufacturing sector.

Keywords Design Thinking · Product-Service Systems · Beginning-of-Life · Innovation engineering · Value innovation

1 Introduction

One of the many challenges industrial manufacturers face today is creating value for their customers by delivering experiences instead of just selling a product. This new goal requires a far-reaching integration of different knowledge domains from different stakeholders, already from the earliest design stages [1]. This transforms the output of the innovation process from a simple artefact to a fully-fledged solution (integrating software and services) that emphasises value creation for all involved

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parties. Such solutions are often instantiated as so-called Product-Service Systems (PSS), which, in the same way as a product, software, or service, need to be 'intentionally designed' [2, 3], necessitating a designerly approach to make them value-adding [4].

Design Thinking (DT) [5] is often described as a major value-centred approach to support the activities related to the conceptualisation, assessment and prototyping of innovative PSS. DT is defined as "*a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.*" [6]. The methodology is built on the idea of 'fail often, fail early'. This is all about learning how to generate and validate successful ideas and concepts through rapid divergent/convergent cycles along three perspectives [7] in a way to boost the design team's capabilities to integrate tangible products and intangible services.

DT is a widespread tool for human-centred design [8], yet its application in the PSS realm is not as widely discussed. Even though several cases are presented in the literature, ranging from manufacturing [9] to healthcare [10] to maritime logistics [11], DT is today considered a support—and not a replacement—to the PSS design process [9]. DT is acknowledged for helping organisations nurture creativity, imagination, and innovation [12] and being more systematic when creating user-friendly, efficient, and effective PSS offerings [4]. Yet, the lack of technology-related activities, partial support for overall market analysis and limitations on sustainability issues hold back its application in the PSS realm [9].

This chapter follows up on these observations, with the objective of reviewing the knowledge domain at the intersection between DT and PSS design. The research work has been conducted in a co-production mode with several company partners in the Swedish manufacturing industry, to investigate the following research question: "*How can DT effectively be applied to intentionally design PSS in different contexts?*". The corollary question: '*What are the key factors influencing the success of PSS designs developed using DT?*' was further explored to summarise the findings concerning the application of the method for different PSS types, including data-driven and smart PSS.

The chapter kicks off by illustrating how the DT processes have been formalised and interpreted through the years since its conception. It further delves into examining how DT concepts and tools have been introduced in the PSS design process, discussing the main challenges and opportunities from an academic standpoint. Emerging from the analysis of multiple cases in the Swedish manufacturing sector, the authors propose a generic framework for DT-supported PSS design, including recommendations, tools and lessons learned at each process step. The chapter further offers suggestions aimed at facilitating and educating teams in utilising DT to design PSS.

2 An Introduction to the Design Thinking Process

Auernhammer and Roth [13] trace the origins of DT to the 1959 summer program in Creative Engineering at Stanford University by psychologist and engineer John E. Arnold, designer Robert McKim, psychologists Abraham Maslow, Robert Hartman, and J.P. Guilford. The program emphasised a design philosophy focused on invention, creativity, and the interconnectedness of cognitive processes and environmental interactions, highlighting the importance of creating tangible solutions that go beyond individual components. The approach peaked in the 80s when it introduced a new discourse on problem-solving, leveraging concepts of ambidextrous thinking and design as a social process. Larry Leifer's design axioms [14], including 'design is a social activity', 'designers must preserve ambiguity', and 'all design is redesign', further shaped this discourse.

Around 1999, IDEO, a global design firm, popularised the term 'Design Thinking' through their approach showcased in ABC's Nightline News documentary "The Deep Dive", where IDEO's interdisciplinary team redesigned a shopping cart in five days using a DT-influenced approach. The book "The Art of Innovation" by Kelley and Littman [15] is acknowledged as another milestone in the evolution of DT. In 2005, the Hasso Plattner Institute of Design (d.school) was created at Stanford University, coinciding with the emergence of DT discourse in the innovation management literature [13].

2.1 Stages in the DT Process

Modern DT was not 'invented' at a specific time but has rather evolved over the years through the collaborative efforts of faculty, students, and practitioners. As shown in Fig. 1, DT—as well as Service Design Thinking [16]—is described as a multiple-step process which can include between 3 and 9 steps, with sub-stages. Noticeably, the process is not only highly iterative [17], but the steps are often run concurrently and out of order.

The first step in the process usually involves framing the question or problem [18, 19], then reaching out to discover user needs through needfinding and observations (e.g., [20]), aiming for an empathic understanding [21] of the addressed problem [22]. Empathy is crucial in human-centred design as it enables insight into users and their needs, setting aside assumptions [23]. This step requires further analysis, asking the team to synthesise observations and field data to define core problems as problem statements. What follows is an exploration of alternative perspectives on the problem to identify innovative solutions, facilitating a process where the design team can 'think outside the box' to generate original, value-adding ideas to be later turned into solution concepts. A defining feature of the DT process is 'prototyping'. In an early stage, it involves producing so-called prEtotypes [24], which are inexpensive scaled-down versions or specific solution features. These are aimed at finding the

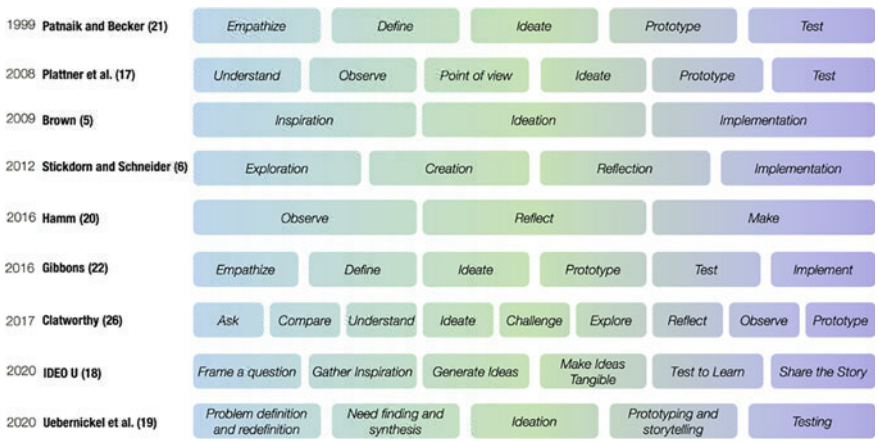

Fig. 1 Comparison between major Design Thinking frameworks

'right' solution for each problem [25], answering the question about 'what' to design rather than 'how' to design it. At each iteration, these initial 'rough' artefacts are developed into more mature prototypes, demonstrated in increasingly representative test scenarios to relevant stakeholders, often customers or their representatives. The core message is: concluding a DT loop with more questions than those at the start is a success, not a failure. DT is purposely iterative; hence, its process is largely aimed at redefining one or more problems—by returning to previous stages to make further iterations, alterations, and refinements—to find or rule out alternative solutions.

Service Design Thinking [10], a concept related to Service Design, explores similar themes but uses a different terminology (with phases often termed Exploration, Creation, Reflection, and Implementation). It shares a common logic and mindset with DT, including iterative and concurrent divergence-convergence processes. What sets them apart are varying values and perspectives, along with using specific tools that highlight the concepts of 'touchpoints' and 'value-in-use' [26], borrowing from the service design literature.

2.2 *DT Macro- and Micro-cycles*

The iterative nature of the DT process is captured by two complementary mechanisms, which are macro- and micro-cycles [27]; here an overarching macro 'iteration' is intertwined with more micro 'loops' that create prerequisites for iterative ideation (see Fig. 2).

The macro-cycle involves iterating towards divergence, transitioning to the so-called 'groan zone' to converge later. Its goal is to understand the problem and concretise the solution's vision. Conversely, a micro-cycle consists of six phases. The first step involves understanding the actual needs of one or more target groups through

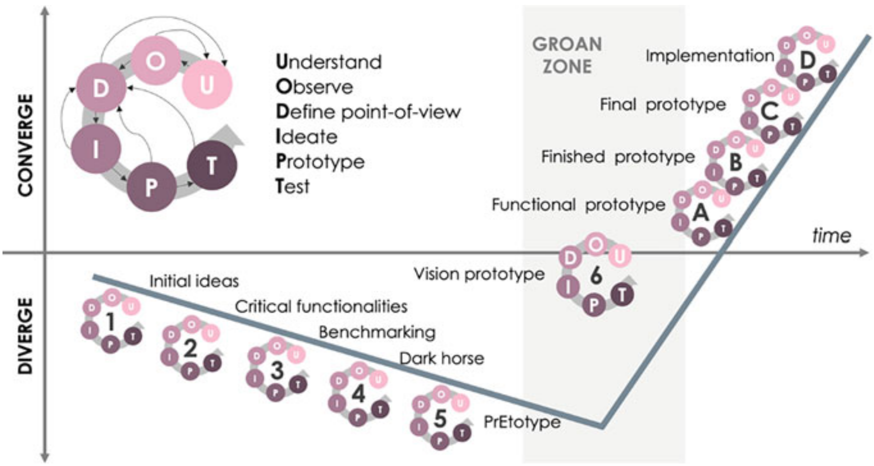

Fig. 2 Micro- and macro-cycle in DT problem solving (adapted from [27])

insightful questions (e.g., the six why-questions: who, why, what, when, where, and how). The second step focuses on observing real situations where the problem manifests itself. The third step is about defining a point of view to establish a common knowledge base. The fourth step is dedicated to developing new concepts, ideas, and solutions to create value. The fifth step brings these ideas to life through prototypes, making them tangible. The sixth step entails testing the prototypes to gain insight into their accomplishments and challenges. Reflections after each micro-cycle are essential for gaining insights from decision-making and creating a knowledge base for future iterations.

3 DT Methods and Tools

3.1 Framing the Design Problem

Design criteria are important in DT for evaluating and refining ideas, ensuring that the end solution meets user needs and achieves desired outcomes. The *Desirability-Feasibility-Viability* (DFV) framework [28] is a major construct that pinpoints the key factors needed to evaluate the potential success of a design concept. *Desirability* captures the human perspective and refers to the level to which a solution appeals to its users or stakeholders. It involves understanding human needs and preferences, assessing the solution's potential to meet those needs and creating a positive user experience. *Feasibility* is aimed at assessing whether a solution is technically possible and whether it can be developed within available resources, timeframe, budget, and technical requirements. Eventually, *Viability* captures the solution's potential for business or financial success and its ability to generate revenue, create value, and achieve long-term sustainability.

By considering these three categories of factors, designers can identify barriers or challenges and prioritise their efforts on those concepts that are most likely to succeed. User testing, prototyping, and stakeholder feedback are common methods to elaborate on the ability of a proposed solution to meet the DFV criteria.

3.2 Understanding, Observing, and Defining the Point of View

Needfinding [21] is a vital technique in DT for collecting user insights that inform designers about unmet needs, pain points, and opportunities for innovation. Effective needfinding involves careful planning, execution, and empathy. It is conducted iteratively through, for instance, observation, interviews, and surveys, often in the users' natural environment.

The design work at this stage follows an 'analogue' approach. One example is using Affinity diagrams for clustering and analysing observations and ideas. Generating such diagrams involves writing data and facts on sticky notes, grouping related notes into clusters, and creating connections between the latter. The outcome is a foundation for further investigation and, ultimately, ideation. *Personas* are another popular item in the DT specialist toolbox. These fictional characters' cards include demographic information, personality traits, behaviours, motivations, and goals. Each card is synthesised from data collected about real people and represents a user 'type'. Persona descriptions are critical to gaining insight into the user's perspective when aiming for intuitive, engaging, and effective proposals. *Empathy maps* detail how potential users will experience a proposed solution. They are based on a four-quadrant diagram, each one representing different aspects of the user's experience: what they see (the physical environment, including objects, people, and events they interact with), what they hear (auditory experience, what they hear and how they interpret it), what they say and do (behaviours and actions, including verbal and nonverbal communication), and what they think and feel (thoughts, emotions, and attitudes, including motivations, fears and desires). *Journey maps* are often used to document, manipulate and play with the emotions of prospective customers and/or users (from positive to negative, with various degrees of frustration), focusing on their journey of trying to get something done. By analysing these pain points, designers can identify opportunities, laying the foundations for subsequent definitions of the requirements and specifications for value-adding solutions that can address user needs [29].

3.3 Ideating

IDEO U [18] presents seven rules forming the foundation of a productive and imaginative creative process in DT. First and foremost, it is advised to make everyone feel comfortable and welcome, deferring judgment. Knowing that all ideas are valued, great concepts can emerge from anyone and anywhere. Such a positive attitude (e.g., using the word "and" instead of "but" in conversations) is also crucial for ideas to evolve through collective input, building on the ideas of others. In parallel, DT urges everyone to explore unconventional and even wacky avenues of thinking, to uncover ground-breaking concepts and forge new connections. These rules are intended to foster collaboration and cooperation and maintain focus on the intended topic. IDEO U stresses the importance of dedicating attention to one conversation at a time to align the participants' efforts with the desired outcomes. This is also the reason why it is recommended to begin the creative session with a period of solitary ideation before engaging in group brainstorming. Brainwriting techniques like Rohrbach's 635 or Brainwriting Pool are often featured in ideation sessions to enable team members to generate ideas independently without influencing each other.

In addition to verbal negotiations, the approach stresses the power of written communication. By incorporating visual elements in the conversation, for instance, through drawing and sketching, participants have often been observed to communicate ideas more vividly, inspiring new avenues of exploration. At the same time, several sophisticated heuristic ideation techniques are associated with this phase of the DT process. They all share the same goal of breaking free from habitual thought patterns and generating unexpected concepts, encouraging novel solutions by presenting problems in a different light.

Lastly, DT stressed the importance of 'going for quantity' when generating ideas. As a rule of thumb, the design team shall aim to reach 100 ideas in a single session. Quantity is considered a main proxy for quality, leveraging the probability to uncover hidden gems among the generated ideas.

3.4 Prototyping, Testing and Iterating

Closing the loop in each micro-cycle involves creating a tangible representation of the proposed solutions. Prototyping is a crucial activity in the DT process, fulfilling several functions. Firstly and foremost, it is used to validate requirements, reveal critical design concerns, identify performance-enhancing design changes, and gradually improve a design. Prototypes are critical for sharing design information within a design team and with customers and users. They are used to explore the design space and to advance the designer's mental or analytical models of complex phenomenal interactions.

Prototyping is less about finding out if something (e.g., an idea) is "good" and more about understanding what a "good something" is. During the earliest micro-cycles, prototyping is all about building the 'right it', rather than building it 'right'. Low-resolution physical prototypes are quick and cheap to make. Nevertheless, they hold plenty of value when it comes to eliciting useful feedback from users and other stakeholders early in the process, gathering knowledge about what shall be designed. These rough product instantiations are often accompanied by storyboards in the form of a visual narrative of the user's journey, from initial awareness to post-purchase evaluation, which explains how the hardware is experienced.

In later stages, when the solution space is more constrained, and the team already has a precise description of what to do, the work is aimed at producing minimum viable products and testing the interaction with such artefacts. This involves observing individuals interacting with a product and gathering feedback to refine its design. Informal observation entails watching users interact with a product or solution and taking notes on their behaviour and feedback. Formal usability testing involves setting specific user tasks and collecting data on their performance and experience. User testing methods include in-person observation, remote observation, and automated tools.

4 Design Thinking for PSS Design: A Review

4.1 Review Approach

The research questions presented in the introduction were investigated by conducting a systematic review of the literature in the SCOPUS database, followed by snowballing. A dedicated search query was built in the SCOPUS database, including the following three concepts: 'Design Thinking', 'Product-Service Systems', and 'servitisation', as shown below. This returned a total of 56 papers in July 2023:

(TITLE-ABS-KEY ("Product-Service Systems") OR TITLE-ABS-KEY (serviti*) AND TITLE-ABS-KEY ("Design Thinking"))

Several inclusion and exclusion criteria were then applied to filter the results. Only peer-reviewed contributions written in English were deemed relevant. The search was further limited to peer-reviewed articles, conference proceedings, books, and book chapters. Only papers focusing on the 'act of design' were included. All those items that did not explicitly focus on design decision-making were excluded. Furthermore, the review retained only those contributions describing the application of DT as a means to develop a solution's product and service components. Snowballing was later applied to identify additional relevant studies. From a list of key articles, citation chaining identified additional references, which were assessed and followed up to identify more items of interest. At the end of the process, the work shortlisted 34 contributions, which are reviewed in the following section.

4.2 Considerations of DT Integration in the PSS Design Process

The discussion on how DT shall be integrated into the PSS realm kicked off in early 2010 and is anchored on the description of the PSS design process proposed during the 2000s (e.g., [30–36]). Several integration strategies are proposed with different characteristics. For instance, Pieroni et al. [37] describe the use of DT to support the definition of the value proposition for PSS. The process is iterative, with DT being used initially to generate empathy and identify problems related to customers' and stakeholders' experience with the product, to pinpoint shortfalls, and to identify strategies to leverage a PSS value proposition. DT further supports the design team in ideating solutions for the selected problems and in combining them into new concepts for customers to try out. More in detail, Scherer et al. [38] pick five items from the DT toolbox (Image sorting, Extremes, Five Human Factors, Trend Matrix and Empathy)—integrating them with the SEEM model proposed by Pezzotta et al. [39]—to enable a deeper understanding of articulated and unarticulated customer needs. They further emphasise the use of agile prototyping approaches—in-detail solution storyboards, appearance prototypes and performance prototypes—to enable the evaluation of a given concept and iterate the generation of innovative ideas.

In two separate contributions, Rosa and colleagues [40, 41] employ corpus linguistics to compare DT and PSS design activities to identify commonalities and differences. Several PSS design activities were found to overlap with DT, primarily during the front-end of innovation (FEI) and, more sporadically, during embodiment design, detailed design and implementation. According to the authors' calculations, 20% of the PSS design process is similar to DT. Conversely, 80% of the activities from PSS design process models are not found in DT methodologies. The authors also highlight some peculiarities of the PSS process that emphasise aspects lacking in DT, such as technology assessment, development, and market analysis-related activities. Furthermore, they note a lack of sustainability-related activities, which may turn DT into an incomplete option to choose as support for PSS. Conversely, PSS design process models lack conceptual prototyping and testing, a best practice in DT.

Later contributions have aimed at expanding and integrating DT with existing PSS design tools to establish a more consistent workflow for the benefit of PSS designers. Emerging from DT research, Kim et al. [42] demonstrate the context-based activity modelling (CBAM) as a schema for systematically imagining methods in service design thinking, mainly as a way to raise awareness of sustainability and circular economy aspects during PSS design. Alexandrakis [43] takes a different angle to analyse the integration of the co-creation method of Urban Design Thinking in a Sustainable Living Lab, gathering lessons learned by employing semi-structured interviews on how different stages of Urban DT can accelerate sustainability transitions via PSS. More recently, in the realm of smart PSS design, Karagiannis et al. [44] describe the combined use of DT, Agile Modeling Method Engineering, and Model-driven Engineering to achieve a higher Technology Readiness Level in digital innovation projects.

4.3 Case Studies and Applications

West and Di Nardo [45] are among the first to discuss the application of DT methods and tools in PSS design, focusing on how Swiss SMEs in the manufacturing sector could boost their product and service innovation capabilities by intersecting the two domains. The paper summarises key quotes from practitioners and elaborates on the value of the approach, yet mainly reflects on how to conduct workshops in a company environment. Kölsch et al. [46] present a five-step process based on DT to support availability-oriented business models, which was verified in collaboration with two OEMs in the capital goods industry. Olivotti et al. [47] propose using DT to guide the development of availability-oriented business models, exemplifying the approach in collaboration with a German manufacturer of drive and automation solutions for materials handling. More recently, Zelck et al. [11] describe a case in the port healthcare sector, while Rittershaus et al. [48] apply DT to support the identification of design concepts in small and medium enterprises in the plastic sector, supporting the transition towards circular value creation.

Several contributions describe DT implementations aimed at supporting PSS design in commodity markets. Langella et al. [49] present the outcome of a design research project aimed at applying the DT approach to develop products, services and experiences to raise consumers' awareness about domestic energy saving. Rau et al. [50] describe three lessons from applying service design thinking to create new value propositions in the commodity industry collaborating with a gas supplier. These include selecting suitable prototyping methods to support a collaborative ideation process, communicating narratives, and soliciting customer feedback. Later, Jadhav et al. [51] apply DT to design water supply solutions. Similarly, Bermejo-Martín et al. [52] propose a DT methodology to develop digital PSS solutions (a web-based prototype) to achieve more efficient and sustainable water consumption in an urban area.

Several papers, particularly from the early 2020s, investigate how to improve the design process for buildings and urban spaces using DT. Zhao et al. [53] borrow methods and tools from the Inspiration phase of the DT methodology to investigate with stakeholders and users how smart technologies like digital twins, internet-of-things, and augmented reality remote guidance are used to facilitate PSS innovation in smart buildings. Wang et al. [54] apply DT to design an intelligent air quality monitor PSS in the same domain. Rinaldi and Kianfar [55] propose using DT to develop a digital technologies-embedded urban furniture system, discussing DT as a cornerstone methodology to design for inclusion and cultural diversity in urban space. Boess [56] presents the lessons learned from the application of DT and other participatory approaches in 4 case studies related to the design of zero-energy buildings—which are considered by the author as sociotechnical PSS—emphasising the co-learning effect of using PSS prototypes in the early design phase.

More case studies are presented in the realm of public transport, such as the work of Li et al. [57], who apply service design thinking to redesign the passenger experience at a bus terminal. More conceptually, Fridman and Coxon [58] discuss the idea of visual conflict framing and reframing, emerging from DT research concerning the design of public transport solutions.

Bertoni and Ruvald [59] collect the experience from practitioners related to applying physical prototyping methods and tools from DT to design PSS in the construction sector. Along the same line, the authors investigate how PSS innovation can be enabled by using physical prototypes as boundary objects in the construction equipment sector to navigate early PSS design ambiguity [60].

In the retail sector, Ganvir and Kalita [61] show the use of the DT approach to innovating a grocery monitoring solution, while Vinzuda et al. [62] borrow DT methods and tools to obtain insights and define specific requirements concerning the need to establish design interventions at the PSS level in the vending sector in India.

In healthcare, Rosa et al. [9] describe the application of DT in collaboration with a mid-size Brazilian dental and hospital equipment manufacturer. The study identifies particularities and insights about applying the method in generating new concepts when transforming a product-oriented company into a PSS provider. Later, Hamilton et al. [10] show how some DT tools can support the design of PSS solutions for physical rehabilitation, including technologies, products and services. Yet, only a small subset of DT methods (mainly those aimed at obtaining insights from the target users and stakeholders, such as interviews and observations) are applied in the process, and the work does not elaborate further on the application of the minimum viable product technique in the process of designing the PSS.

A concluding reflection here is that most research contributions apply DT in a linear fashion, following a sequential pattern. Seldom is the application exemplified in a way that emphasises the macro and micro cycles that are typical of the approach. At the same time, few contributions elaborate on the issues and challenges related to the different iterations that characterise the DT methodology. Similarly, the academic discussion about the benefit of 'learning by prototyping' in PSS design is kept to a minimum. Overall, there is also a lack of reflective capability in the literature since the majority of contributions describe 'how' DT is implemented rather than 'why', neither elaborating on the implementation of the method nor proposing recommendations and implementation guidelines.