Recombinant Innovation in Platform-Based Smart Service Ecosystems

Designing Conceptual Models and Methods for Industrial Companies

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Foreword

Was lange währt, wird endlich gut. The truth behind this old German proverb has rarely resonated as deeply with me as during the years this doctoral thesis came into being. As with the very nature of recombinant innovation—the core subject of this dissertation—the journey was not linear but a process of creative recombination, patient exploration, and meaningful growth. Some developments required time to mature; others emerged surprisingly, shifting the trajectory of thought and life alike. And some—like the joyful arrival of two wonderful children during this time—reminded us that the most impactful changes are often the most personal and profound.

The research at hand investigates recombinant innovation in platform-based smart service ecosystems—a topic as complex as it is timely. Today's industrial companies stand at a digital crossroads. As digital platforms become increasingly dominant structures in our economy, they are no longer merely technical systems but evolving ecosystems composed of diverse actors co-creating value across organizational boundaries. Understanding how to innovate in such environments—by recombining existing knowledge, competencies, and other resources, including data—is essential for establishing a competitive edge.

In her dissertation, Hedda Lüttenberg addresses this challenge head-on. She develops conceptual models and methods that support industrial companies in designing and managing recombinant innovation processes within platform-based ecosystems. Accounting for both theory and practice, her work illuminates the tensions, potentials, and pathways that emerge when firms seek to innovate not from scratch but by reusing, reconfiguring, and connecting what already exists. This is a powerful approach—pragmatic in its assumptions, visionary in its outcomes, and well-received in the service research field.

I like that Hedda's thesis contributes to the design-oriented research tradition in the information systems field. It offers new IT artifacts and theoretical frameworks, advancing our understanding of how platforms can enable industrial companies to orchestrate smart service in digital ecosystems. These results are fundamental as we witness a shift from isolated digital solutions toward interconnected smart service systems in which actors co-create value by combining their knowledge, skills, and resources.

Like recombinant innovation itself, this dissertation is a product of innovation through recombination—building on our workgroup's long-standing tradition of research in (smart) service systems engineering, its strong ties with industrial companies to conduct field research, and its quest to combine theoretical grounding with digital innovations that matter beyond research. In the spirit of recombination, the thesis's completion marks not just the end of an academic journey but might also be the beginning of many new ones. I am confident that the models, methods, and ideas developed here will serve researchers and practitioners alike in shaping the future of platform-based (smart) service ecosystems.

May you find inspiration in these pages—whether as a scholar, a designer, a leader in industry, or simply someone navigating the digital currents of our time.

Paderborn, May 2025 Prof. Dr. Daniel Beverungen

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For data protection reasons, the acknowledgments that appeared in the printed version of the dissertation have been removed in this file.

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Part A

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List of Abbreviations

API	Application Programming Interface
CO	Central Objective
DSML	Domain-specific Modeling Language
DSR	Design Science Research
ERP	Enterprise Resource Planning
IBM	International Business Machines Corporation
IoT	Internet of Things
IS	Information Systems
IT	Information Technology
NPD	New Product Development
NSD	New Service Development
PS^3	Platform-based Smart Service Systems
RO	Research Objective
S-D Logic	Service-dominant Logic of Marketing

Part A
Research Overview

1 Introduction

1.1 Background and Motivation

Over the past few decades, the world has witnessed a monumental transformation in how businesses, individuals, and communities interact and conduct their activities. This paradigm shift can be largely attributed to the emergence and rapid rise of digital platforms and their ecosystems (de Reuver et al., 2018; Parker et al., 2017). In the 1990s, e-commerce platforms like eBay and Amazon began to gain popularity. These early digital platforms provided a marketplace where sellers and buyers could interact, leading to the growth of online retail. The advent of smartphones and mobile internet connectivity in the 2000s significantly expanded the reach of digital platforms (Beverungen et al., 2021; Teece and Linden, 2017). Mobile apps and platforms allowed users to engage with services and content on the go. Platforms like Facebook, founded in 2004, played a crucial role in shaping the social media landscape by facilitating social interactions, content sharing, and networking on a global scale, redefining how people connect and communicate (de Reuver et al., 2018; Gawer and Cusumano, 2015). Companies like Google, Amazon, Facebook, and Apple pioneered the concept of digital platforms by offering diverse services on a single platform, revolutionizing industries and disrupting traditional business models (de Reuver et al., 2018; Gawer and Cusumano, 2015).

By leveraging technology—particularly the internet, mobile devices, and software—digital platforms create a digital space where users can easily engage in interaction (Hagiu and Wright, 2015; Teece and Linden, 2017; Tiwana et al., 2010). Digital multi-sided platforms create new services, business models and markets by enabling multiple groups of participants to exchange information, goods and social content (Eisenmann et al., 2006; Parker and Van Alstyne, 2012). As a result, companies can collaborate with partners and tap into a wider range of resources, capabilities, and expertise (de Reuver et al., 2018). This collaboration fosters innovation and enhances competitiveness (Armstrong, 2006; de Reuver et al., 2018; Parker and Van Alstyne, 2018). Individuals and businesses are able to reach global markets without the need for significant upfront investments. Uber and Airbnb, for example, empowered countless independent workers to offer their service and resources flexibly, creating new economic opportunities worldwide (Goodwin, 2015). Additionally, digital platforms provide companies with direct access to customers, allowing them to offer customized products, efficient purchasing processes, and enhanced customer support, aligning with the customers' evolving expectations.

Although non-digital platforms have been the subject of research for some time (Baldwin, Woodard, et al., 2009; de Reuver et al., 2018), it is only since the early 2000s that scholars from various disciplines have begun to develop theories of digital two-sided or multi-sided markets or platforms (Beverungen et al., 2021; de Reuver et al., 2018). While each of these disciplines has its own focus and perspective, research in Information Systems (IS) often takes a socio-technical or economic perspective on digital platforms to research specific aspects, such as the evolution (e. g., Fu et al., 2018; Tiwana et al., 2010), the design (e. g., Bakos and Katsamakas, 2008; Spagnoletti et al., 2015), and the governance of digital (multi-sided) platforms and their ecosystems (e. g., Huber et al., 2017; Song et al., 2018). From a technical perspective, digital platforms can be defined as "the extensible codebase of a software-based system that provides core functionality shared by the applications that interoperate with it and the interfaces through which they interoperate" (Tiwana et al., 2010, p. 676). From a socio-technical perspective, a digital platform orchestrates the interactions of different parties to create a mutual benefit. Third parties—in this context called complementors—can extend the functionality of the platform core by providing complementary applications (Baldwin, Woodard, et al., 2009; Boudreau and Hagiu, 2009; Gawer, 2014). A well-known example is the platform android that runs on mobile devices. The platform core—comprising of core functionality and an application programming interface (API)—is provided by Google, while complementors can use the API to develop applications that extend the functionality of the platform core (de Reuver et al., 2018; Eaton et al., 2015; Ghazawneh and Henfridsson, 2013). Users can access and buy these applications via Google's app store and use them on their mobile device.

Digital multi-sided platforms facilitate the emergence of platform ecosystems (Hein et al., 2020; Parker et al., 2017). These ecosystems are characterized by specific dynamics that arise between the groups of actors and other platforms. One of the most important dynamics of digital platforms is their ability to create network effects (Katz and Shapiro, 1994; Parker and Van Alstyne, 2005). As more users and businesses join a platform, its value increases exponentially, attracting even more participants (Katz and Shapiro, 1994; Parker and Van Alstyne, 2005). This virtuous cycle has led to the dominance of platforms in various sectors, ranging from e-commerce (e.g. Amazon or eBay) and social media (e.g. Facebook) to finance (e.g. Kickstarter) and healthcare (e.g. PatientsLikeMe) (de Reuver et al., 2018).

Taking a service-centered perspective on digital platforms, a platform ecosystem can be considered a subset of the broader concept service ecosystem. Service ecosystems are defined as "a relatively self-contained, self-adjusting system of mostly loosely coupled social and economic (resource-integrating) actors connected by shared institutional logics and mutual value creation through service exchange" (Lusch and Nambisan, 2015, p. 161). Thus, a platform ecosystem refers to a specific type of service ecosystem, centered around a digital platform, while a service ecosystem can also be found in the physical, analog world. Furthermore, a service ecosystem "must provide an architecture of participation that brings clarity to the way collaborative value cocreation occurs" (Lusch and Nambisan, 2015, p. 165). This architecture can be established by a digital (multi-sided) platform (Lusch and Nambisan, 2015) or a smart product serving as a digital platform (Beverungen et al., 2021, 2019).

While digital platforms can already be observed in various sectors, platform-based business models are often still new territory for industrial companies. Industrial companies can leverage platform mechanisms by providing or participating in a smart service platform. These platforms are defined as "a digital boundary object that builds on a smart product to enable direct interactions between two or more distinct but interdependent groups of users to create mutual value" (Beverungen et al., 2021, p. 516). Smart Service Platforms extend the concept of a smart service system, in which a company co-creates value with its customers through a smart product (Beverungen et al., 2019), by inviting "other companies to offer their knowledge and skills, making complementary value propositions through the platform" (Beverungen et al., 2021, p. 515). Thus, industrial companies can leverage their expertise, assets, and industry knowledge to create platform-based solutions that unlock new revenue streams, foster innovation, and create value in ways beyond their traditional manufacturing capabilities.

A significant driver in this context is Industry 4.0. It represents a paradigm shift in manufacturing, fueled by the integration of cyber-physical systems and the seamless interconnectivity of machines, processes, and humans, facilitated by the internet of things (IoT) (Gausemeier et al., 2016). Based on the rapidly advancing digitization—the binary conversion of analogous information into a digital format (Tilson et al., 2010)—physical products are transforming into cyber-physical systems that are also called intelligent technical systems (Gausemeier et al., 2016) or smart products (Beverungen et al., 2019). Through extensive networking and interaction between humans and connected, intelligent technical systems, companies are able to optimize their production processes, improve efficiency, and drive innovation (Gausemeier et al., 2016).

The integration of sensors, actuators, and intelligent algorithms—increasingly available through Industry 4.0—allows for real-time data collection, analysis, and decision-making, enabling businesses to adapt swiftly to a changing environment and market demands (Beverungen et al., 2019). By utilizing status, usage, and context data of their smart products (Beverungen et al., 2019), companies can customize their offerings to meet the specific needs and preferences of individual customers by providing smart service (Beverungen et al., 2019).

One notable trend that has been propelled by the advancements of Industry 4.0 is servitization (Vandermerwe and Rada, 1988). Servitization refers to the transformation of businesses from solely offering products to providing a combination of products and services (Vandermerwe and Rada, 1988). This shift enables companies to generate revenue beyond the one-time payment of a product and establish longer-term relationships with their customers (Müller, 2014). By embracing servitization, businesses can offer various value-added services that complement their core products (Müller, 2014). The stronger orientation towards customer needs is a fundamental aspect of servitization. Instead of merely selling products, businesses strive to understand their customers' pain points and deliver tailored solutions (Müller, 2014). This individualization not only enhances customer satisfaction but also opens up new ways for revenue generation. For example, industrial companies are able to foster new, outcome-based business models. Rather than simply selling products, they can offer outcomes or experiences that fulfill specific customer needs or objectives (Tukker, 2004). Traditional services related to the physical product often revolve around maintenance contracts, repair services, software updates, and customer support. By offering outcome-based, smart service, a company can ensure that their smart products operate optimally throughout their lifecycle, thus enhancing customer satisfaction and loyalty (Tukker, 2004). For instance, instead of purchasing manufacturing equipment, a company might opt for an outcome-based business model where they pay for the desired production output or efficiency (Tukker, 2004). This approach aligns the interests of the customer and the provider, as both parties share a common goal of achieving desired results.

As a next step to offering smart service, participating in or providing an smart service platform allows industrial companies to innovate in platform-based business models and take advantage of the opportunities offered by digital platforms. Additionally, new and innovative value propositions can be created through recombinant innovation. This approach embraces the idea that by breaking down the traditional boundaries and recombining different elements in creative ways, companies can generate innovative value propositions that were previously unexploited (Brynjolfsson and McAfee, 2014; Cecere and Ozman, 2014). Platform-based smart service ecosystems—taking an ecosystem perspective on smart service platforms—offer the perfect starting point for recombinant innovation, as numerous resources from various actors are available for recombination (de Reuver et al., 2018).

However, achieving innovative and successful innovation in smart service platforms requires an in-depth understanding of these platforms and their ecosystem, including the underlying dynamics, as well as knowledge of how service is designed in platform-based smart service ecosystems. This knowledge helps identifying opportunities for collaboration, innovation, and value co-creation, leading to enhanced customer experiences and sustained competitive advantage.

To sum up, this dissertation is based on the rapidly advancing technological developments that enable industrial companies to expand their core competence a) to provide smart service based on physical, smart products and b) to provide or participate in digital platforms to offer new, promising value propositions by recombining the resources available in the ecosystem.

1.2 Problem Statement and Research Objectives

For companies accustomed to traditional manufacturing-centric business models, embracing the world of platforms can present both opportunities and challenges (Matzner et al., 2021). Participation in digital platforms undoubtedly presents numerous advantages for industrial companies, constituting a strategic move that can enhance their competitiveness and adaptability in the digital business (Matzner et al., 2021). However, this transition is not done easily, as it introduces significant challenges that demand a paradigm shift in organizational thinking and operations (Beverungen et al., 2021; Hanelt et al., 2020; Matzner et al., 2021).

One of the foremost challenges that industrial companies are addressed with, is a deficiency in comprehending the dynamics of digital platforms, their ecosystems, and the underlying mechanisms (Hanelt et al., 2020; Matzner et al., 2021; Pauli et al., 2021). However, industrial companies need to understand the concepts and mechanisms that constitute digital platforms to make strategic decisions, design innovative value propositions, and successfully implement and maintain value co-creating processes in platform-based smart service ecosystems (Hanelt et al., 2020; Matzner et al., 2021).

Additionally, industrial companies are traditionally focused on designing, manufacturing, and selling tangible products instead of designing and implementing service systems that rely on intangible value co-creating processes (Müller, 2014). Their traditional ability to develop physical products does not translate seamlessly into the intangible and interconnected realm of digital and smart service (Hanelt et al., 2020). This lack of transferability requires knowledge of how to innovate promising value propositions, integrate digital or smart services into offerings, and articulate their unique value. Moreover, their traditional hierarchical structures and product-centric mindset may not align with the agility, collaboration, and customer-centricity required for service- and platform-based business models (Hanelt et al., 2020). Embracing a more agile and responsive approach to innovation becomes essential to meet the evolving needs and expectations of the diverse participants in the ecosystem (DIN, 2019).

Research on platforms and platform ecosystems is not new. Both have already been researched in various disciplines and from different perspectives. These disciplines mainly include economics, management, and engineering. While these disciplines are rich in knowledge on non-digital platforms, this knowledge does not easily transfer to digital platforms, since they differ substantially (de Reuver et al., 2018). In recent years, service science shifted its focus from researching service systems to service ecosystems, providing additional knowledge on value co-creation in ecosystems (Barile et al., 2016; Chandler et al., 2019; Edvardsson et al., 2018). Additionally, information systems scholars have increasingly turned their focus on digital platforms (Beverungen et al., 2021; de Reuver et al., 2018). Although a considerable body of knowledge is generated in the various disciplines, this knowledge is fragmented, as research is often carried out from specific perspectives or with a specific focus. Boundary spanning research is required to provide a comprehensive understanding of value co-creation, influenced by economic mechanisms in digital platform ecosystems.

While focusing on platform-based smart service ecosystems, the focal research streams on (smart) service (eco-)systems and digital platforms are mainly separate. Although there are influential conceptualizations of (smart) service systems (Beverungen et al., 2019) and service ecosystems-(Barile et al., 2016), they do not take into account platform-related concepts and mechanisms that have mainly been researched in economics and management. Research on digital platforms on the other hand, often focuses on technology (Ceccagnoli et al., 2012; Ondrus et al., 2015) or economic mechanisms (Benlian et al., 2015; Thies et al., 2016), but without adopting a value co-creation perspective.

To innovate in platform-based smart service ecosystems, a comprehensive approach is necessary, combining perspectives on value co-creation, economic mechanisms, and the design of information technology (IT) artifacts in digital platforms and their ecosystems. Knowledge from service science on how value propositions and service systems should be designed for value co-creation needs to be integrated with knowledge on platform mechanisms from economics and design knowledge of IT artifacts, which are crucial for the design and management of platform-based smart service ecosystems.

> ***Problem Statement.*** *Integrated knowledge on smart service ecosystems and digital platforms is scarce in the IS knowledge base. More specifically, the literature lacks knowledge on the prevailing relationships and mechanisms in platform-based smart service ecosystems, as well as models and methods that guide innovation and the design of IT artifacts in those ecosystems.*

In today's dynamic landscape of digital and smart service provision, there is a growing trend towards the utilization of digital platforms as the primary means of delivery. These platforms serve as crucial boundary objects (Beverungen et al., 2021), seamlessly integrating the actions of (multiple groups of) actors and enabling effective communication between actors and smart products (Beverungen et al., 2021). However, to successfully design or participate in a digital platform, industrial companies face the challenge of comprehending the structural concepts and mechanisms that govern digital platforms and their ecosystems (Hanelt et al., 2020). A clear conceptualization of digital platforms and platform ecosystems is required for their successful design and implementation.

Research cannot yet provide these clear conceptualizations because it is conducted across multiple disciplines, each with its own perspective and focus (de Reuver et al., 2018; Gawer, 2014). Consequently, there is a conceptual ambiguity of digital platforms and platform ecosystems (de Reuver et al., 2018) that limits comparability and identification of relevant research. Even with a focus on research in IS, knowledge on digital platforms, different types of platforms, and platform ecosystems stays fragmented due to lacking conceptual consistency. Sørensen et al. (2015, p. 196) see that an "ambiguity on what constitutes a platform or ecosystem prevails in both practitioner and academic debate." The absence of a common vocabulary results in potential misinterpretations and obstructed communication among stakeholders. Thus, de Reuver et al. (2018) call for clear definitions of digital platforms and ecosystems to provide conceptual clarity that is required to build a structured knowledge base. Clear and precise conceptual frameworks are necessary to establish a shared understanding and facilitate effective communication to harness the full potential of digital platforms.

Furthermore, current research often focuses on isolated mechanisms or dynamics of digital platforms or their ecosystems, such as network effects (Hagiu, 2006; Song et al., 2018) or openness (Boudreau, 2010; Simcoe et al., 2009), primarily emphasizing multi-sided platforms. Thus, research addressing multiple concepts from different disciplines is scarce. De Reuver et al. (2018) and Schreieck et al. (2016) take a broader perspective presenting several concepts but without providing a comprehensive structure. Hein et al. (2020) present a model of platform ecosystems but focus on three building blocks: platform ownership, value-creating mechanisms, and complementor autonomy. Therefore, a comprehensive and cohesive model that integrates and elucidates the mechanisms and their interrelationships within digital platforms and their ecosystems is missing. The absence of such an overarching model limits the ability to fully comprehend the complex dynamics and interdependencies within digital platform ecosystems.

Moreover, an important aspect missing from the current discourse is a transparent differentiation between aspects of digital platform ecosystems that can be influenced by different groups of actors and those that lie beyond their control. Tiwana et al. (2010) present a framework that distinguishes elements of platform design and governance from environmental dynamics. Based on this framework, research opportunities are identified. Although this framework is a good starting point for research, the elements and interdependencies it contains are incomplete. As a result, the framework presented by Tiwana et al. (2010) does not provide a comprehensive overview of the concepts, mechanisms and dynamics that can be influenced directly or indirectly within platform ecosystems. However, this overview is critical to understanding the complexities and limitations of digital platforms and their ecosystems, as well as their design and management.

Thus, the problem at hand necessitates a clear delineation of platform terms (de Reuver et al., 2018) that encompasses diverse perspectives on digital platforms, as well as a comprehensive conceptualization of digital multi-sided platforms and their ecosystem, their characteristics, and affecting mechanisms. Addressing these challenges will not only enhance effective communication but also drive research and innovation, fostering a deeper understanding of digital platforms.

> ***Research Objective 1 (RO1).*** *To identify and systematize the concepts and relations that constitute digital platforms and platform ecosystems.*

Today, research on digital (multi-sided) platforms and service science is being conducted separately and with a focus on different areas. On the one hand, research on digital platforms concentrates on exploring specific aspects of digital platforms and their ecosystems, such as platform business models and pricing strategies (Eisenmann et al., 2006; Parker and Van Alstyne, 2018; Teece and Linden, 2017), ecosystem dynamics (Huber et al., 2017; Song et al., 2018), network effects (Evans and Schmalensee, 2016; Hagiu, 2006), openness (Ondrus et al., 2015), the technical design (Ceccagnoli et al., 2012; Tiwana et al., 2010), governance structures (Huber et al., 2017; Schreieck et al., 2016), or competition (Mantena and Saha, 2012; Tiwana, 2015).

On the other hand, research in service science takes a broader perspective, concentrating on the design and improvement of service across various industries. This interdisciplinary field encompasses customer-centric perspectives and places a strong emphasis on understanding and meeting customer needs (Vargo and Lusch, 2004b). It recognizes the importance of customer satisfaction (Ramaswamy, 1996), experience (Chandler and Lusch, 2015; Edvardsson and Olsson, 1996), and engagement (Chandler and Lusch, 2015) in the design and delivery of service. The concept of value co-creation is central to service research (Vargo and Akaka, 2012; Vargo and Lusch, 2008a). It acknowledges that value is not created solely by service providers but is a result of interactions and resource integration between service providers and customers (Vargo and Lusch, 2008a), resulting in value-in-use (Vargo and Lusch, 2016). This perspective emphasizes the active involvement of customers in shaping their service experiences. Service research in IS focuses on the role of IT artifacts in shaping modern service delivery, including the integration of digital technologies and information systems to innovate and improve service (Beverungen et al., 2021). Although service research takes a systems (Beverungen et al., 2019; Vargo and Akaka, 2012)—or more recently ecosystems (Barile et al., 2016)—perspective, the focus here lies on the value co-creation process as well as the engagement, interaction, and resource integration of the actors (Beverungen et al., 2021; Chandler and Lusch, 2015).

In summary, while research on service ecosystems and digital platforms both involve the delivery of services, research on service ecosystems has a broader, more inclusive scope that goes beyond technology and focuses on customer engagement and value co-creation. In contrast, research on digital (multi-sided) platforms focuses on designing and managing a digital infrastructure that enables interactions and transactions and is subject to various ecosystem dynamics. Integrated research on (smart) service systems and digital platforms is scarce. Exceptions address, for example, alliance relationships for value co-creation on platforms (Ceccagnoli et al., 2012), required capabilities for transitioning from product to platform provider (Leijon, Erik, Joanda Svenheden, and Fredrik Svahn, 2017), Hein.2020, the adoption of a platform thinking mindset for incumbent firms (Matzner et al., 2021), and the role of platforms in smart service innovation (Matzner et al., 2021). Beverungen et al. (2021) are the first to integrate knowledge from Service Science and Management, Economics, and Information Systems, presenting three strategic options to transition from product to smart service platform provider. Each of these three options results in a different kind of smart service platform. Although they address four selected characteristics for differentiating the three platform types, a comprehensive ecosystem perspective is missing. Therefore, platform-based (smart) service ecosystems are lacking a clear conceptualization that takes into account multidisciplinary aspects of platform and service ecosystems. The two research streams on (smart) service (eco-)systems and digital platforms need to be integrated to provide a holistic understanding. This integration can be communicated with the help of IT artifacts, i.e. constructs and models. The resulting conceptualization can then serve as a basis for the design of platform-based service ecosystems.

> ***Research Objective 2 (RO2).*** *To design IT artifacts that industrial companies can use to conceptualize and design platform-based smart service ecosystems.*

Industrial companies encounter significant difficulties when innovating platform-based service systems due to their reliance on traditional pipeline business models (Van Alstyne et al., 2016). In contrast to these business models, service is continuous and relies on the ongoing integration of resources to co-create value-in-context (Akaka et al., 2013). Therefore, industrial companies often struggle to transition from their established product-centric approaches to the dynamic nature of service systems (Hanelt et al., 2020).

This struggle is reinforced by the fact that industrial companies often attempt to develop new value propositions in a similar way as their physical products. Therefore, methods for service engineering were introduced to cater to the specifics of designing service (Meyer and Böttcher, 2011). However, these methods have proven to be still predominantly product-oriented, overly complex, and typically follow a rigid linear model, similar to methods used for developing physical products (Becker et al., 2009; Meyer and Böttcher, 2011). This rigidity hampers the ability of industrial companies to adapt and respond quickly to evolving customer needs and market dynamics, which is crucial for successful service system implementation (Hanelt et al., 2020). Therefore, as applied in modern design thinking or software engineering methods (Kolko, 2015), an agile approach is required for service systems engineering.

Additionally, many existing methods for service engineering focus on internal resources while designing value propositions that are subsequently offered to the customers (Becker et al., 2011; Meyer and Böttcher, 2011). Since external resources of customers and partners are crucial for co-creating mutual value, methods of service engineering have to take the broader perspective of designing service systems, including “not only data and physical components, but also layers of knowledge, communication channels and networked actors” (Böhmann et al., 2014, p. 74). In service ecosystems, “the exchange of service is mediated by networks of interconnected relationships [...] and enable[s] actors to integrate resources within a broader social context to derive unique experiences while developing new norms and meanings (i.e., shared institutions) and contributing back to the social context [—relationships and resources—] through which value is derived” (Akaka et al., 2012, p. 35). Thus, by incorporating internal and external resources, companies can profit from innovation through recombination, which is also currently not considered in existing methods for service or service systems engineering. With increasing digitalization, driven by Industry 4.0, and the resulting availability of data and smart products, it is becoming easier to expand existing resources or recombine them in networks of actors to innovate.

> ***Research Objective 3 (RO3).*** *To design an agile method for recombinant innovation in platform-based smart service ecosystems.*

The three research objectives defined above add to an overarching research objective that solves the problem stated at the beginning of this section. While the fulfillment of each individual research objective already offers substantial contributions to research and management, the overarching research objective integrates these findings. Thus, the central objective provides a synthesizing scaffold for this dissertation.

> ***Central Objective (CO).*** *To design and demonstrate innovative IT artifacts for recombinant innovation in platform-based smart service ecosystems.*

1.3 Thesis Structure

The defined research objectives are fulfilled on the basis of rigorous research published in five peer-reviewed publications. Thus, this thesis is structured into two main parts: Part A and Part B.

Part A of this thesis puts the presented research into the context of recombinant innovation in platform-based smart service ecosystems. Its remainder is organized as follows: Section 2 provides the research background for this dissertation. First, the fundamental principles of service science are presented, providing a foundation for comprehending and contextualizing the subsequent research. Subsequently, the subject of innovation in service (eco-)systems is investigated in greater detail, including the principles of recombinant innovation. Finally, the theoretical background is completed by the definitions and presentation of digital platforms and platform ecosystems, including their essential concepts and mechanisms. In Section 3, the research design of this dissertation is presented. After providing an overview and an introduction to the research methods applied, the research process is outlined. Section 4 of this thesis illustrates the research results and integrates the contributions to address the research objectives. Subsequently, the contributions to research and management are outlined and discussed. In conclusion, a summary and an outlook for future research are provided.

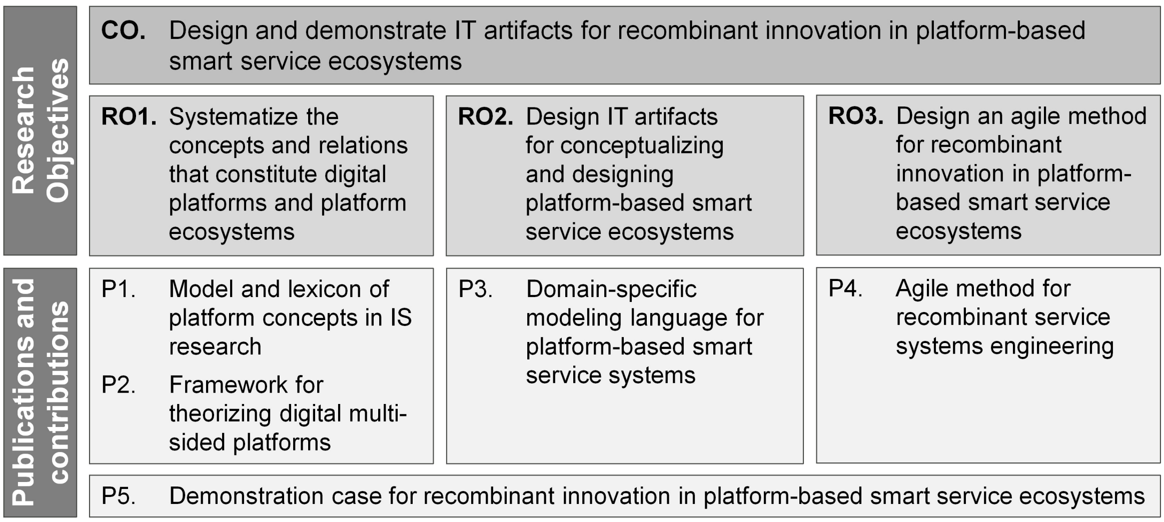

Figure 1.1: Organization of the research papers presented in Part B

Part B consists of five peer-reviewed and published publications. The contribution of the publications to the research objectives is illustrated in Figure 1.1. An overview of the publications included in Part B, their status, as well as their rankings based on the VHB-JOURQUAL3 ranking for Wirtschaftsinformatik (VHB e.V., 2015) and the VHB Rating 2024 (VHB e.V., 2024) is presented in Table 1.1.

For each publication in Part B, the motivation and contribution to the achievement of the defined research objectives are summarized below:

P1. *Systematizing the Lexicon of Platforms in Information Systems: A Data-driven Study*. Digital platforms have become indispensable in the everyday lives of many people. Since they are complex systems whose design, development, and management still raise questions, their importance in research has also increased significantly. However, research focuses on different aspects of digital platforms and therefore uses many different platform terms often used synonymously and not clearly defined or distinguished. This lack of clarity leads to the fact that related research stays separated, cannot be found or assigned, and that research results are ambiguous in their interpretation. Therefore, based on a data-science study, 11,049 publications, covering 44 years of IS research, were analyzed and interpreted to identify used platform terms. By further analyzing all platform terms that appear in at least 150 papers, six clusters of terms were identified and subsequently interpreted and discussed. In a next step, a hierarchically decomposed model was defined to structure platform terms and provide a basis for a lexicon of platform terms for IS research. This decomposed model organizes 16 platforms terms, that can be used in research on digital platforms from different isolated perspectives, on different aspects, or from an overarching perspective. Additionally, definitions for the platform terms in the decomposed model are provided, completing the lexicon of platform terms to guide IS research. This lexicon is essential for understanding different aspects and views on digital platforms and, therefore, marks the first step in fulfilling RO1, which aims at systematizing platform concepts and relations.

P2. *Three Layers of Abstraction—A Conceptual Framework for Theorizing Digital Multi-sided Platforms*. Digital platforms are researched in different research disciplines and even in these disciplines various research streams focus on diverse aspects of digital platforms. As a result, research on digital platforms is very widespread and connections are difficult to recognize. Additionally, misinterpretations can occur since terms are not clearly conceptualized or research focuses are assumed to be known and therefore not clearly communicated. Therefore, the body of knowledge requires a structure to enable research contributions to be allocated and interpreted in the right context and without misunderstandings. To ensure a boundary-spanning structure, a literature review was conducted, covering 140 papers from nine disciplines. Based on this literature review, 27 theoretical concepts were identified and structured. First, the concepts were hierarchically structured into eight main concepts and 18 sub concepts. Three of these main concepts were grouped under the term internal factors—aspects that can be directly designed and controlled by the platform owner. The remaining five main concepts were grouped as environmental dynamics—dynamics that a platform owner can only try to influence indirectly. Second, the identified concepts were further structured in a framework for theorizing digital platforms. This framework consists of three layers of abstraction, conceptualizing platforms as information systems, as systems for actor engagement, or as ecosystems. Based on the research contributions of P1 and P2, digital platforms as well as the concepts and relations that constitute digital platforms and platform ecosystems are identified and systematized, fulfilling RO1. Thereby, digital platforms can be thoroughly explored from different levels of abstraction and with different focal points, but clearly placed in context and communicated. Consequently, researchers and (industrial) companies can better understand and shape digital platforms as well as mechanisms and dynamics that occur on these platforms and in their ecosystems.

P3. *PS³—A Domain-specific Modeling Language for Platform-based Smart Service Systems.* The relevance of digital platforms is rapidly increasing in the everyday lives of many people. More and more companies are taking advantage of platform-based business models, or are planning this. For industrial companies that are already experienced in designing (smart) service systems, a platform-based business model can be the next evolutionary step. However, knowledge from designing smart service systems cannot easily be transferred, since a service systems perspective is currently missing in the research on digital platforms. Additionally, industrial companies face a challenging, cross-company process for designing a complex, platform-based, socio-technical (smart) service system that includes networked actors, IT infrastructure, and smart products. To support the design process of industrial companies, a conceptual meta-model is designed in a first step, which integrates established constructs of the two separate research streams on smart service systems and digital platforms. In a second step, this meta-model serves as a foundation for a domain-specific modeling language that companies can use to model all relevant elements of a platform-based smart service systems. This helps companies to decide which tasks and responsibilities to take on and what role to assume in the complex platform-based service system. In addition, the company can identify required resources and competencies, as well as needs for partners, interfaces, and boundary objects. Based on the modeling of the platform-based smart service systems, the cross-company communication during the design process can be improved. The developed modeling language is finally demonstrated and conceptually evaluated with the real case of an industrial company. With regard to the research objectives of this thesis, the developed meta-model contributes substantially to the conceptualization of platform-based smart service ecosystems (RO2).

P4. *Recombinant Service Systems Engineering*. Since the 1980s, research has addressed the structured development of service and service systems (Meiren and Barth, 2002). Various methods for guiding the development process have been published under the heading *New Service Development* (Johnson et al., 2000) or *Service (Systems) Engineering* (Fähnrich and Opitz, 2006). However, these methods are subject to several shortcomings. First, most of the methods presented have been adopted from product development and modified for service development. As a result, they are often very product- or outcome-oriented and follow a linear process that does not allow for a flexible adaptation to changing customer needs. Second, the proposed methods do not acknowledge recombinant innovation. Accelerated by technological progress and increasing digitalization, Brynjolfsson and McAfee (2014) assume that a large majority of innovations will result from the recombination of existing resources. Therefore, based on a literature review and a conceptual analysis of 24 service engineering methods, four design principles for designing recombinant service systems engineering methods were derived, which address the shortcomings of existing methods. Subsequently, these design principles were applied, resulting in a new, agile service systems engineering method for recombinant innovation (RO3). This conceptually developed method is then demonstrated based on a case of a predictive maintenance service system, which is described in detail in P5.

P5. *Designing Predictive Maintenance for Agricultural Machines.* Driven by a rapidly advancing digitalization, machines are transforming into cyber-physical systems or smart products that enable the provision of smart services. An example of a smart service in the industrial context is predictive maintenance. Here, smart products monitor and analyze their condition and environment to predict and prevent future defects before they occur. Thereby, unnecessary machine downtime is avoided and the efficiency of processes is increased. In this publication, a predictive maintenance method for agricultural machines is designed, demonstrated, and evaluated based on 3,407 real-world service records. For this case, the developed method can predict future defects with a mean accuracy of 86.34%. The case presented in this publication was also used in P4 to demonstrate the method for recombinant service systems engineering. Consequently, this paper contributes to RO3. In Figure 1, however, P5 covers all research objectives, as its use case is used in Section 4 to demonstrate the designed IT artifacts for recombinant innovation in platform-based smart service ecosystems. This demonstration finally fulfills the CO of this thesis.

#	*Publication*	*Type*	*Status*	*Ranking*
P1	C. Bartelheimer, P. zur Heiden, H. Lüttenberg, and D. Beverungen 2022. "Systematizing the Lexicon of Platforms in Information Systems: A Data-driven Study," *Electronic Markets* (32:1), pp. 375–396. (doi: 10.1007/s12525-022-00530-6).	JNL	published	B | B
P2	M. Poniatowski, H. Lüttenberg, D. Beverungen, and D. Kundisch 2022. "Three Layers of Abstraction—A Conceptual Framework for Theorizing Digital Multi-Sided Platforms," *Information Systems & e-Business Management* (20:2), pp. 257-283 (doi: 10.1007/s10257-021-00513-8).	JNL	published	C | C
P3	H. Lüttenberg 2020. "PS^3—A Domain-specific Modeling Language for Platform-based Smart Service Systems," in *Proceedings of the 15th International Conference on Design Science Research in Information Systems and Technology (DESRIST)*, Kristiansand, Norway, pp. 438–450. (single-author)	CNF	published	C | B
P4	D. Beverungen, H. Lüttenberg, and V. Wolf 2018. "Recombinant Service Systems Engineering," *Business & Information Systems Engineering* (60:5), pp. 377–391. (doi: 10.1007/s12599-018-0526-4).	JNL	published	B | B
	A previous version was published in *Proceedings of the 13th International Conference on Wirtschaftsinformatik 2017*, St. Gallen, Switzerland. Best Paper Nominee	CNF	published	C | B
P5	H. Lüttenberg, C. Bartelheimer, and D. and Beverungen 2018. "Designing Predictive Maintenance for Agricultural Machines," in *Proceedings of the Twenty-Sixth European Conference on Information Systems (ECIS)*, Portsmouth, UK, Paper 153.	CNF	published	B | A

Table 1.1: Publications included in Part B
(JNL - Journal, CNF - Conference; Ranking according to VHB Jourqual 3 (VHB e.V., 2015) | VHB Rating 2024 (VHB e.V., 2024))

2 Research Background

2.1 Fundamentals of Service Science

The recognition of service as a significant component of economies worldwide has driven the emergence of service science as a distinct field of study. The International Business Machines Corporation (IBM), along with several academic institutions, launched the *Service Science, Management, and Engineering* initiative, which aimed to promote research and education in the area of service systems (Chesbrough and Spohrer, 2006; Maglio et al., 2006; Spohrer et al., 2007). Maglio and Spohrer define *service science* as “the study of service systems, aiming to create a basis for systematic service innovation. Service science combines organization and human understanding with business and technological understanding to categorize and explain the many types of service systems that exist as well as how service systems interact and evolve to co-create value.” (Maglio and Spohrer, 2008, p. 18). Since then, the field of service science has continued to evolve, driven by technological advancements, evolving consumer behavior, and the resulting growth in the complexity of service systems (Breidbach and Maglio, 2015; Lusch and Nambisan, 2015; Maglio and Breidbach, 2014). Table 2.1 provides an overview of the concepts from service science that are most important for this dissertation.

In 2004, Vargo and Lusch proposed the Service-dominant Logic of Marketing (S-D Logic), which offers a new perspective shifting the focus from the traditional goods-dominant logic, where value is embedded in products, to one where value is co-created through interactions between service providers and customers (Vargo and Lusch, 2004a). According to the S-D Logic, *Service* is “the application of specialized competences [. . .] through deeds, processes, and performances for the benefit of another entity or the entity itself” (Vargo and Lusch, 2008b, p. 26). Thus, service does “not result in a transfer of ownership from seller to buyer” (Lovelock and

Gummesson, 2004, p. 37) but offers “benefits through access or temporary possession, instead of ownership” (Lovelock and Gummesson, 2004, p. 37). Here, service refers to the value-in-use that is co-created in interactions between service providers and service customers (Vargo and Lusch, 2004b, 2008a,b; Vargo et al., 2010). This value co-creation takes place in *service systems*, which are “configurations of people, technologies, and other resources that interact with other service systems to create mutual value” (Maglio et al., 2009, p. 395). In this dissertation, the notion of a service system follows that of Böhmann et al., who “conceptualize a service system as a socio-technical system that enables value co-creation guided by a value proposition”, including “not only data and physical components, but also layers of knowledge, communication channels and networked actors”(Böhmann et al., 2014, p. 74). It represents a “value-co-creation configuration of people, technology, value propositions connecting internal and external service systems, and shared information (e.g., language, laws, measures, and methods)” (Maglio and Spohrer, 2008, p. 18).

The trend of integrating physical products and (digital) service has led to the emergence of various specialized concepts, such as product-service systems, smart service, and smart service systems. A product-service system can be defined as “a system of products, services, supporting networks and infrastructure that is designed to be: competitive, satisfy customer needs and have a lower environmental impact than traditional business models” (Mont, 2002, p. 239). In those systems, “tangible products and intangible services [are] designed and combined so that they are jointly capable of fulfilling specific customer needs” (Brandstotter et al., 2003, p. 799). Even more specific is the term *smart service system*, in which “smart products are boundary-objects that integrate resources and activities of the involved actors for mutual benefit” (Beverungen et al., 2019, p. 12). They “network digital competencies of the actors involved in a digital service system and/or mediate their interactions” (Beverungen et al., 2019, p. 12). Figure 2.1 illustrates the conceptualization of a smart service system as proposed by Beverungen et al. (2019). Accordingly, the core of a smart service system is a smart product, acting as a boundary object between the service provider and the service consumer. A smart product is characterized by physical and digital features, including sensors, actuators, connectivity, a unique ID, location, data storage and processing, and interfaces (Beverungen et al., 2019). Based on those features, smart products can “observe, identify, and analyze physical and digital events, make decisions, and perform physical and/or digital actions. Therefore, a smart ser-

Concept	*Description*	*References*
Service	*Service* is “the application of specialized competences [. . .] through deeds, processes, and performances for the benefit of another entity or the entity itself”	Vargo and Lusch (2008b, p. 26)
Value Co-Creation	“value can only be created with and determined by the user in the ‘consumption’ process and through use or what is referred to as value-in-use. Thus, it occurs at the intersection of the offerer and the customer over time: either in direct interaction or mediated by a good”	Lusch and Vargo (2006, p. 284)
Resource Integration	“organizations, households, and individuals can be viewed as resource integrators that cocreate value with other entities. This resource-integration model can be expanded for understanding markets, international trade, outsourcing, and marketing.”	Vargo and Lusch (2008b, p. 29)
Value Proposition	“Enterprises can offer their applied resources for value creation and collaboratively (interactively) create value following acceptance of value propositions, but can not create and/or deliver value independently”	Vargo and Lusch (2008a, p. 7)
Customer Experience	“Customer experience is the internal and subjective response customers have to any direct or indirect contact with a company. Direct contact generally occurs in the course of purchase, use, and service and is usually initiated by the customer. Indirect contact most often involves unplanned encounters with representations of a company’s products, services, or brands and takes the form of word-of-mouth recommendations or criticisms, advertising, news reports, reviews, and so forth.”	Meyer and Schwager (2007, p. 117)
Context	“value is always contextual because it is based on a phenomenological perspective and influenced by time, place and social surroundings, as well as other environmental factors, including access to other internal and external resources.” “The viability of a system depends on its ability to adapt to a changing environment by identifying a role to play in each context—that is how to ‘serve’ a need”	Akaka et al. (2015, p. 211); Barile et al. (2016, p. 656)
Service Ecosystem	A service ecosystem is a “relatively self-contained, self-adjusting system of mostly loosely coupled social and economic (resource-integrating) actors connected by shared institutional logics and mutual value creation through service exchange.”	Lusch and Nambisan (2015, p. 162)
Institutional arrangements	“institutions—rules, norms, meanings, symbols, practices, and similar aides to collaboration—[...] and higher-order, institutional arrangements—sets of interrelated institutions (sometimes referred to as ‘institutional logics’)—and the process and role of institutionalization are the keys to understanding the structure and functioning of service ecosystems.”	Vargo and Lusch (2016, p. 6, 11)
Smart Product	Smart products display physical and digital features at the same time, such that they can observe, identify, and analyze physical and digital events, make decisions, and perform physical and/or digital actions.”, “value-in-use can be derived from using a smart product as a boundary object between a service’s consumers and its provider.”	Beverungen et al. (2019, p. 12, 15)
Smart Service	“A smart service is constituted by introducing smart devices into a digital service system. [...] Therefore, a smart service integrates physical and digital competencies in a complex socio-technical service system.” Thus, a smart service is the “application of specialized competences, through deeds, processes, and performances that are enabled by smart products.”	Beverungen et al. (2017b, p. 784-785); Beverungen et al. (2019, p. 12)
Smart Service Ecosystem	A *smart service ecosystem* can be defined as a “[service] ecosystem that is based on smart products’ material properties and constituted around smart services as (focal) value propositions”	Herterich et al. (2023, p. 529)
Service Innovation	“Service innovation can then be considered the rebundling of diverse resources that create novel resources that are beneficial (i.e., value experiencing) to some actors in a given context; this almost always involves a network of actors, including the beneficiary (e.g., the customer).”	Lusch and Nambisan (2015, p. 161)

Table 2.1: Overview of concepts from service research

vice integrates physical and digital competencies in a complex socio-technical service system" (Beverungen et al., 2017b, p. 784-785).

According to Beverungen et al. (2019), smart service is created based on the condition, usage, and context data of the smart product, which it collects during its use by the service consumer. This data is monitored and analyzed by the smart product itself and/or backstage by the service provider to optimize its performance or adapt to changes. Based on its actuators, smart products can perform changes autonomously or remotely controlled by the service provider. Thus, *smart service* is defined as the "application of specialized competences, through deeds, processes, and performances that are enabled by smart products" (Beverungen et al., 2019, p. 12).

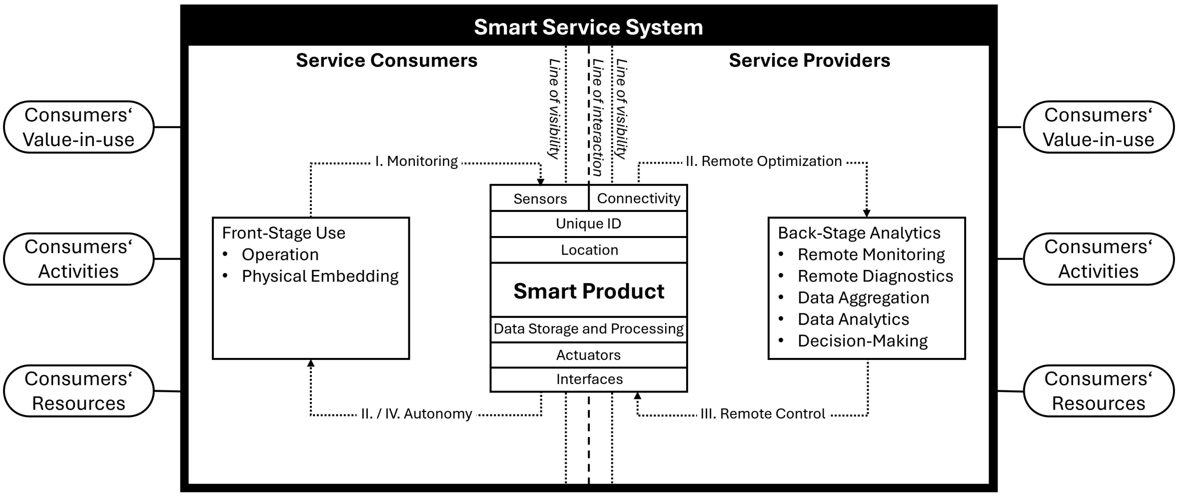

Figure 2.1: Conceptualization of a smart service system (Beverungen et al., 2019, p. 12)

Extending the definition of smart service systems to an ecosystem perspective, a *smart service ecosystem* can be defined as a "[service] ecosystem that is based on smart products' material properties and constituted around smart services as (focal) value propositions" (Herterich et al., 2023, p. 529). A comprehensive conceptualization of smart service ecosystems, analogous to that of smart service systems proposed by Beverungen et al. (2019), has yet to emerge in the current research literature. However, it is necessary because the traditional dyadic relationship between service providers and service consumers is being superseded by a network of actors (Beverungen et al., 2021; Lusch and Nambisan, 2015).

2.2 Innovation in Service (Eco-)Systems

In the 1930s, Schumpeter (1934) published an influential theory on *innovation*. He differentiates between an *invention* and an *innovation*. An *invention* can be defined as a "new product, service, process, or idea" (Gustafsson et al., 2020, p. 111). According to Schumpeter, "[a]s long as they are not carried into practice, inventions are economically irrelevant" (Schumpeter, 1934, p. 88). In contrast, an *innovation*, which he defines as "the carrying out of new combinations" (Schumpeter, 1934, p. 66), creates economic benefits. Further, he states that new combinations result in (1) a new good or a new quality of a good, (2) a new method of production, (3) the opening of a new market, "whether or not this market has existed before", (4) a new source of supply of raw materials or half-manufactured goods, or (5) the "carrying out of the new organisation [sic] of any industry" (Schumpeter, 1934, p. 66). This rather broad view on innovation is sometimes termed *Schumpeterian (view of) innovation* (Drejer, 2004; Snyder et al., 2016; Toivonen and Tuominen, 2009) and is also shared by theories on service innovation (Toivonen and Tuominen, 2009).

In the *Schumpeterian* innovation theory, innovation relies on a producer of goods as the initiator for economic change (Schumpeter, 1934). In line with this perception, service innovation is often considered from an inward perspective of a company to develop new (aspects of) processes, products or services, without taking into account the customer perspective (Gustafsson et al., 2020; Snyder et al., 2016).

This inside-out perspective can also be found in many approaches for the structured development of new services or value propositions. In the 1980s, first approaches were published in the Anglo-American literature under the notion of new service development (NSD) (Meiren and Barth, 2002). Johnson et al. (2000, p. 9) argue that "NSD research mirrors that in NPD" (new product development) while taking a service management or service marketing perspective (Edvardsson and Olsson, 1996; Meiren and Barth, 2002). Unfortunately, similar to NPD processes, NSD processes often focus on the development of saleable goods, i.e. products or value propositions for the customer (e.g., Ramaswamy, 1996; Scheuing and Johnson, 1989; Shostack and Kingman-Brundage, 1991). Thus, the proposed development processes often do not explicitly consider the design of the value co-creation processes, support processes, and required resources and partners. Accordingly, Johnson et al. (2000, p. 9) state that the developed approaches in NSD identify success factors that "address *what* should be done, not *how* it should be done." At the same time, many NSD approaches mainly focus on particular aspects of service development, e.g., quality of service (Edvardsson and Olsson, 1996; Ramaswamy, 1996), prerequisites for service (Edvardsson and Olsson, 1996), processes (Shostack and Kingman-Brundage, 1991), or enablers for service development (Johnson et al., 2000).

In the 1990s, another research stream, with a center of activities in Germany, started with a similar approach to the one in NSD (Fähnrich and Opitz, 2006). Under the term *service engineering*, know-how was transferred from engineering disciplines to service development (Fähnrich and Opitz, 2006). However, this approach presents a number of potential advantages and disadvantages. On the one hand, the utilization of existing product development processes provides a well-established foundation for efficient processes with reduced development time and costs, as well as increased quality (Meiren and Barth, 2002). On the other hand, these processes are focused on designing tangible products instead of intangible value co-creation processes. Thus, service engineering processes are often linear processes with a focus on designing value propositions (Beverungen et al., 2018). In contrast, service engineering processes are required to be agile or prototypical to facilitate close customer involvement, as well as rapid adjustments and decision-making. Furthermore, service engineering processes should encompass the design of the entire socio-technical service system, which is essential for effective service delivery and value co-creation. According to the underlying conceptualization of service systems as socio-technical systems in this thesis (cf. section 2.1), *service systems engineering* comprises defining service architectures (i.e., modules of a service system and their interactions), designing interactions in service systems, and mobilizing human, physical, and information resources (Böhmann et al., 2014).

A shift in focus from the design of new value propositions to the development of socio-technical service systems also allows for a shift in perspective from an inward, organization-centric view to one that encompasses a network of actors involved in the innovation process. This understanding of service systems engineering supports the fact that an increasing amount of innovations are emerging in (digital) networks of actors (Anke et al., 2020; Lusch and Nambisan, 2015). Furthermore, recombinant innovations facilitate an outside-in perspective on service innovation and design by combining existing resources and externally sourced solutions that are made available in service systems.

The theory of innovation through new combinations of existing resources has been frequently revisited in the context of both general innovation research and the area specifically concerned with service innovation (Edvardsson et al., 2018; Snyder et al., 2016). Research in service innovation that considers recombinative innovation often conceptualizes innovation in terms of a degree of change in offerings, categorizing it as either radical or incremental (Snyder et al., 2016). In other conceptualizations, innovation is defined according to the kind of change, differentiating between product and process innovations (Snyder et al., 2016). Furthermore, the degree of novelty serves as another defining factor, where innovations are classified as those that are newly introduced to the market or those introduced to the firm for the first time (Snyder et al., 2016). Additionally, innovation may be classified by the means of provision, differentiating between technology-based and organization-based innovations (Snyder et al., 2016). However, Brynjolfsson and McAfee point out that digital technology "has given birth to radically new ways to combine and recombine ideas" (Brynjolfsson and McAfee, 2014, p. 80) and that "the global digital network fosters recombinant innovation" (Brynjolfsson and McAfee, 2014, p. 80). Also, Gallouji and Weinstein (1997, p. 552) posit that "Recombinative innovation has now become a fundamental mode of creating innovations." This dissertation, therefore, concentrates on recombinant innovation, defining *service system innovation* as "recombinations of the roles and relationships among service system resources, including technological resources" that "also requires basic science and engineering" (Maglio and Breidbach, 2014, p. 167).

Recombinant innovation is achieved through three basic mechanisms—dissociation, association, and addition—that recombine internal and/or external resources (see Figure 2.2). *Dissociation* describes the decomposition of an existing service or service system into separate components. These decomposed components can then be reused in the innovation process (Gadrey et al., 1995) by transforming them into new marketable value propositions. *Association* describes two different types of recombination: new combination and new application. New combination, on the one hand, involves the integration of two or more previously independent resources (Cecere and Ozman, 2014). In a combination of recombinant mechanisms, these resources can also be made available through dissociation. New application, on the other hand, describes the transfer of an existing resource or service to a new context for which it was not originally designed (Toivonen and Tuominen, 2009). The third basic mechanism of recombinant innovation is *addition*, which pertains to the integration of two or more (existing) value propositions into a novel proposition (Tsur and Zemel, 2007).

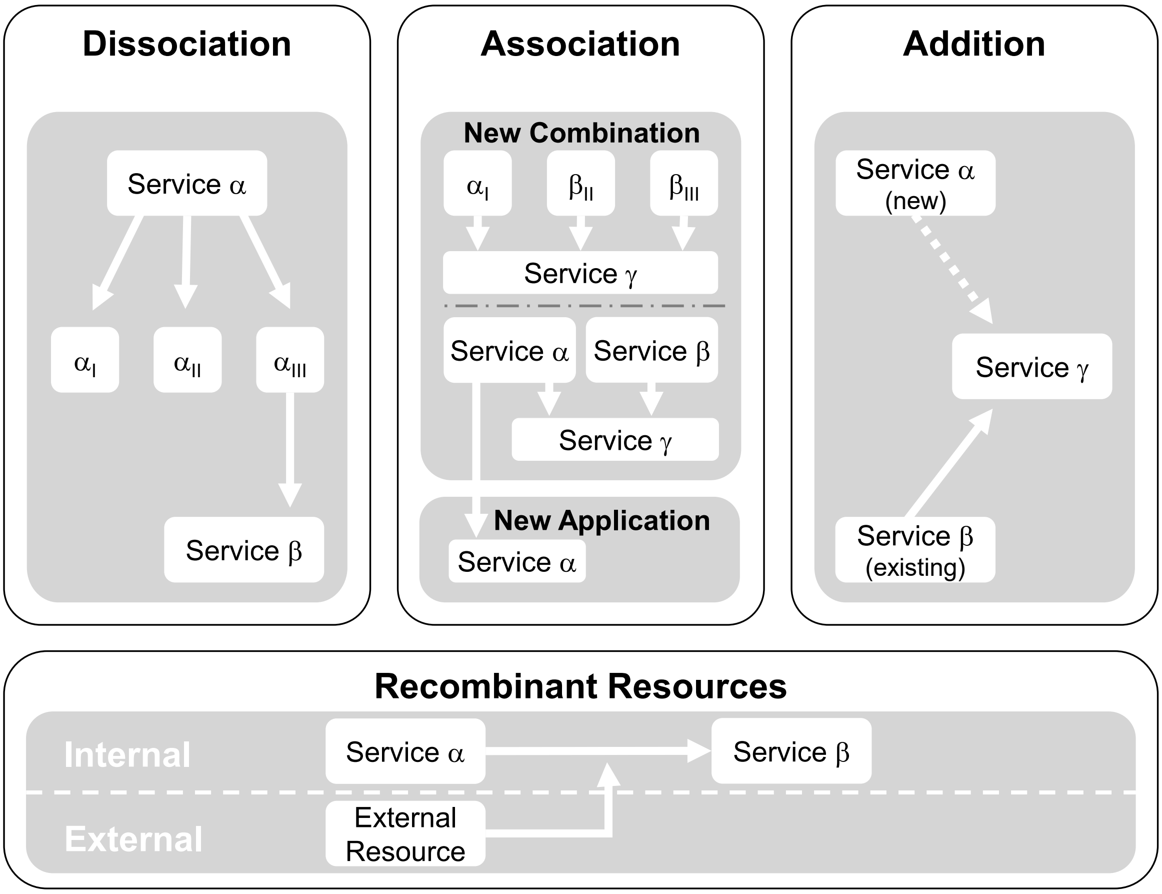

Figure 2.2: Mechanisms of recombinant innovation

Following the aforementioned conceptualization of service (eco)systems, both *internal* and *external resources* are considered within the context of recombinant innovation. *Internal resources* refer to a company's competencies and (existing) elements that can be used to create new value propositions (Gallouj and Weinstein, 1997). For example, a company's existing service can be transferred to another context (association) or broken down into new elements (dissociation) that can be recombined (association). The utilization of *external resources*, particularly those of partners, suppliers, customers, and other stakeholders, considerably enhances the potential for innovation, since in networks of actors, a significant quantity of resources is typically accessible for utilization in recombinant innovation.

The service ecosystems perspective provides a well-grounded theoretical foundation for discussing service innovation in networks of actors (Edvardsson et al., 2018).

While there has been considerable research into smart service innovation, there has been a distinct lack of research into innovation in smart service ecosystems. Pöppelbuß et al. define *smart service innovation* as "the process of reconfiguring resources, structures, and value co-creation processes in service systems that result in novel data-driven service offerings" (Pöppelbuß et al., 2022, p. 599). This definition is directly applicable to service ecosystems, which contain service systems and represent a different level of abstraction (Barile et al., 2016).

Lusch and Nambisan (2015) conceptualize service innovation based on a framework consisting of three elements: service ecosystems, service platforms, and value co-creation. Here, value co-creation refers to the processes and activities within a service ecosystem in which the actors involved integrate their resources within their roles (Lusch and Nambisan, 2015). This resource integration is enabled by a service platform, which Lusch and Nambisan (2015, p. 162) define as "A modular structure that consists of tangible and intangible components (resources) and facilitates the interaction of actors and resources (or resource bundles)." This service platform is situated within a service ecosystem that offers structural flexibility and integrity, a collective worldview among the relevant actors, and provides an architectural foundation that supports and enables participation (Lusch and Nambisan, 2015).

The framework presented by Lusch and Nambisan (2015) represents an initial, though limited, conceptualization of a service ecosystem that is based on a service platform. Despite Lusch and Nambisan's clear reference to digital platforms, they do not take into account strategic, organizational, or infrastructural aspects (e.g., openness, boundary resources, generativity, ownership, pricing and revenue sharing) that are inherent to platform ecosystems and crucial for successful innovation within these ecosystems (de Reuver et al., 2018; Ghazawneh and Henfridsson, 2013; Parker and Van Alstyne, 2018). Instead, they adhere to a perspective that is purely service-oriented with an emphasis on value co-creation.

This strong service orientation also applies to Herterich et al.'s empirically derived model, which aims to explain the emergence of smart service ecosystems (Herterich et al., 2023). Their model is based on the framework developed by Lusch and Nambisan (2015) and the affordance theory. It presents three classes of organizational affordances that detail the socio-technical antecedents for the emergence of smart service ecosystems: shared affordances, idiosyncratic affordances, and collective affordances (Herterich et al., 2023). In the case study Herterich et al. examined, the service platform is a data platform where data of smart products can be analyzed, but where there is no interaction between human actors or even networks of actors on the platform. This case corresponds to the second of three options—a *smart product platform*—identified by Beverungen et al. (2021) for transforming from a smart service provider to a platform provider.

Beverungen et al. (2021) differentiate between three distinct platform types that smart service providers may adopt to transition to a platform provider: *smart product platform*, *smart data platform*, and *matching platform*. A *smart product platform* is characterized by the ability of third parties to access data at the smart-product-level, thereby enabling them to offer value-added services (Beverungen et al., 2021). However, the platform provider may impose restrictions on the data available to third parties, thereby securing a competitive advantage by limiting access to certain data (Beverungen et al., 2021). In contrast to developing a *smart product platform*, smart service providers may also choose to transform themselves into platform providers by offering a *smart data platform* or a *matching platform*. Like a *smart product platform*, a *smart data platform* allows a platform provider to collect data at the level of its smart products. However, to establish a *smart data platform*, the platform provider can deny third parties access to the raw data and instead allow them to access cleansed or aggregated data (Beverungen et al., 2021). Potential third-party service providers on the platform can analyze the pre-processed data and offer value-added services to customers on this basis (Beverungen et al., 2021). In contrast to the aforementioned platform types, a *matching platform* is distinguished by the absence of a direct connection to the smart product and the data collected from this (Beverungen et al., 2021). Instead, the platform's service offering entails matching customer demand with the service provided by third parties (Beverungen et al., 2021). In their examination of the transformation strategies of smart service providers, Beverungen et al. (2021) explicitly consider the role of digital platforms within smart service ecosystems. However, they limit their analysis to five aspects of digital platforms—namely openness, affiliation, direct interactions, and network effects—to differentiate between the three identified platform types. Additionally, they do not address innovation processes or opportunities that may arise from participation in a platform-based smart service ecosystem.

An additional study that addresses innovation in smart service ecosystems is that of Anke et al. (2020), which analyzes and defines the roles of the various actors within such ecosystems. The study, based on empirical evidence, identifies a total of 17 roles that are assumed by different actors during the innovation process. Furthermore, the authors identify four distinct patterns of smart service innovation, in which different strategic constellations of actor-role assignments emerge in smart service ecosystems. These patterns offer insights into the contribution of skills and resources through the various actors involved in the innovation process. In particular, they elucidate which actors are the driving force and which actors assume a supportive role. As Beverungen et al. (2021) did concerning the three possible transformation paths, Anke et al. (2020) provide a crucial foundation for strategic decisions on innovation in smart service ecosystems with the patterns of smart service innovation. However, Anke et al. (2020) do not consider the characteristics and dynamics in digital platform ecosystems that influence the success of the innovation initiative.

2.3 Digital Platforms and Platform Ecosystems

Research on digital platforms has been conducted across a range of academic disciplines, with researchers employing diverse methodologies and theoretical frameworks. The evolution of research foci and perspectives on digital platforms has been shaped by the distinct disciplinary traditions within which they are situated (Baldwin, Woodard, et al., 2009; de Reuver et al., 2018; Hein et al., 2020). While some areas of research do exhibit intersections, they also demonstrate significant divergences, with each discipline implementing unique idiosyncratic perspectives and sometimes defining similar concepts in distinct ways (see Figure 2.3 for an overview). However, to achieve a comprehensive and multifaceted understanding of digital platforms, a holistic approach is essential, necessitating the integration of elements from relevant academic disciplines like management, economics, IS, and service science (Beverungen et al., 2021; de Reuver et al., 2018; Gawer, 2014; Schreieck et al., 2016).

In the field of management, four overlapping research areas have emerged, each of which focuses on different aspects of platforms: products, technological systems, transactions, and platform ecosystems (Baldwin, Woodard, et al., 2009; Thomas et al., 2014). The first research area, related to products, researches strategic and technical aspects of planning and designing the architecture of physical products based on the same platform (Gawer, 2014). In this context, the term platform is used to describe a product family with a modular design and standardized interfaces (Baldwin, Woodard, et al., 2009). This allows for an easy creation of variants that can be tailored to meet

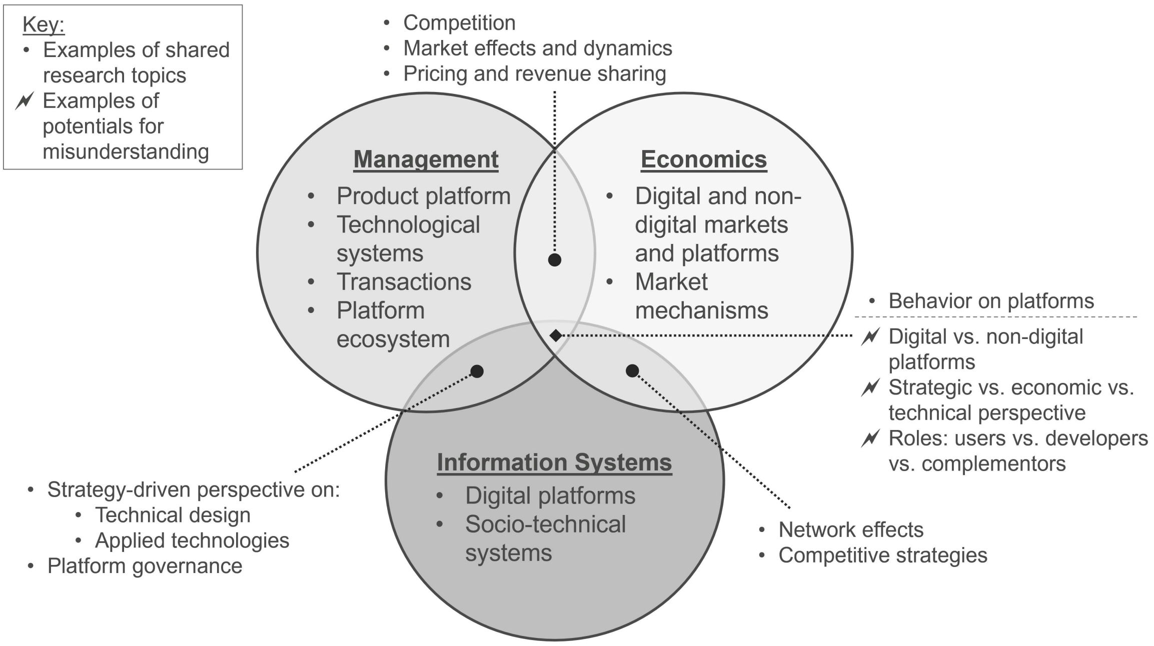

Figure 2.3: Foci in research on (multi-sided) platforms in management, economics, and IS (Poniatowski et al., 2022, p. 261)

specific customer needs (Baldwin, Woodard, et al., 2009). This understanding of a platform is similar to a technical perspective on digital platforms, which can be defined as an "extensible codebase of a software-based system that provides core functionality shared by the modules that interoperate with it and the interfaces through which they interoperate" (Tiwana et al., 2010, p. 676). This technical view on digital platforms is also applied in IS research. In both cases—that is, in the context of both physical products and digital platforms—the modular design allows third parties to contribute complements, thereby enabling the dynamic expansion of the functionality of the stable product or platform core (Baldwin, Woodard, et al., 2009; de Reuver et al., 2018; Ghazawneh and Henfridsson, 2013; Tiwana et al., 2010).

In the second field of management research, technology strategists address the issues of how to leverage technological advances to succeed in a competitive market and attain platform leadership (Baldwin, Woodard, et al., 2009). Research in this field is concerned with platform technologies (Cusumano and Gawer, 2002; Gawer and Cusumano, 2002) and a platform's governance (Boudreau, 2010; Gawer, 2014; West, 2003). Gawer (2014) differentiates internal platforms, supply-chain platforms, and industry platforms. Based on this differentiation, she presents patterns of platform innovation and competition by bridging an economic and a technical perspective on technological platforms (Gawer, 2014).

The third research field in management is concerned with the investigation of multi-sided platforms, with a particular focus on the analysis of transactions and the behavior observed on such platforms (Baldwin, Woodard, et al., 2009; Thomas et al., 2014). The defining characteristic of a multi-sided platform is that it acts as an intermediary between several distinct groups of actors, or alternatively, as a facilitator of a matching of interests (Eisenmann et al., 2006; Parker and Van Alstyne, 2012; Rochet and Tirole, 2003). In contrast to traditional market intermediaries, the ownership of goods and services involved in transactions facilitated by multi-sided platforms is not assumed by the platforms or platform owners themselves (Thomas et al., 2014). Instead, multi-sided platforms mitigate the constraints faced by the involved actors by providing the necessary infrastructure to enable their transactions with one another (Thomas et al., 2014). In line with de Reuver et al. (2018) and Van Alstyne et al. (2016), a multi-sided platform consists of a core, which is central to the functionality of the platform; and a periphery, which encompasses complements (e.g., (smart service) applications or (smart) products) provided by third parties that are engaged with the platform. It is the responsibility of the platform owner to provide and manage the platform core, which can then be accessed by complementors—depending on the degree of openness of the platform (Van Alstyne et al., 2016).

In the context of multi-sided platforms, the phenomenon of network effects is of particular interest (Baldwin, Woodard, et al., 2009). As the number of users and businesses on a given platform increases, the value of the platform itself increases exponentially, thereby attracting even more participants (Katz, Shapiro, et al., 1985; Parker and Van Alstyne, 2005). A distinction is made between direct and indirect network effects. Direct network effects arise "if the value of the platform depends on the number of users in the same group" (de Reuver et al., 2018, p. 125). In contrast, indirect network effects arise when the number of users in one group of stakeholders influences the value proposition of another group of stakeholders with regard to a given platform (Parker and Van Alstyne, 2005). In this context, it is important to reach a sufficient number of users within a given user group to utilize network effects (Parker and Van Alstyne, 2005). This difficulty is also referred to as the *chicken-and-egg problem* (Caillaud and Jullien, 2003; Parker and Van Alstyne, 2005). Concerning network effects, the chicken-and-egg problem, competition, as well as pricing structures and strategies are researched (Hagiu, 2006; Rochet and Tirole, 2006).

Building on the aforementioned research areas, the fourth research field in management is concerned with the analysis of platform ecosystems from a strategic technology and innovation management perspective (Thomas et al., 2014). Some scholars use the term *ecosystem* to delineate the organizational structure associated with an industry platform, as defined by Gawer (2014). Alternatively, the term is used to denote a “system or architecture that supports a collection of complementary assets” (Thomas et al., 2014, p. 200). In the field of management research, platforms are sometimes treated as a distinct concept, separate from the ecosystem construct, and at other times, they are considered an integral part of this construct (de Reuver et al., 2018). The field of management research on platform ecosystems addresses a number of key issues, including the impact of network effects, as well as the role of innovation, standards, modularity, and compatibility (Thomas et al., 2014).

The field of economics investigates multi-sided markets in both digital and non-digital contexts, with a particular emphasis on market mechanisms and market dynamics (Rochet and Tirole, 2003; Schreieck et al., 2016; Thomas et al., 2014). This research intersects with that of management, particularly in the areas of network effects (Katz, Shapiro, et al., 1985), competition (Armstrong, 2006; Rochet and Tirole, 2003), and pricing (Hagiu, 2006; Nocke et al., 2007).

Research on digital platforms in IS usually takes a technical or socio-technical perspective (de Reuver et al., 2018). Researchers examine the evolution (e. g., Fu et al., 2018; Tiwana et al., 2010), the design (e. g., Bakos and Katsamakas, 2008; Spagnoletti et al., 2015), and the governance of digital (multi-sided) platforms and their ecosystems (e. g., Huber et al., 2017; Song et al., 2018). The IS discipline shares common research interests with the field of management. For example, research in IS sometimes employs a strategy-driven perspective to examine the technical and architectural design of a platform and the applied technologies, as well as governance mechanisms associated with digital platforms (Boudreau, 2010; Tiwana et al., 2010; West, 2003). It also intersects with research in economics with regard to network effects and competitive strategies (Bakos and Katsamakas, 2008; Ceccagnoli et al., 2012; Mantena and Saha, 2012; Tan et al., 2015)

While some research draws upon elements from disparate research areas, there are only a few studies that systematically integrate these elements. Moreover, a comprehensive synthesis of platform concepts from different disciplines and their interdependencies remains to be accomplished. Additionally, it is notable that research on digital platforms and their ecosystems lacks a service science perspective. Adopting a service-oriented perspective may facilitate an understanding of the manner and means by which resources are integrated on a multi-sided platform, and how value is created for the various parties involved. In this context, for example the concepts of *value-in-use* and *value-in-context*, as well as other concepts of service science, can prove beneficial.

Tiwana et al. (2010) present a framework for studying platform evolution that covers the platform architecture, platform governance, and environmental dynamics. However, the presented framework takes a technical perspective without considering market mechanisms or aspects of service science. The framework developed by Gawer (2014) integrates research from economics and engineering management, but is focused on platform innovation and competition while considering three different platform types. This does also not apply a service science perspective of value co-creation. Thomas et al. (2014) present a framework for architectural leverage, differentiating between nine platform types. Their framework is exclusively built on management research and, therefore, does not add to integrating research of different disciplines. Another framework covering eleven research topics related to digital platforms was formulated by Fu et al. (2018). Similar to that proposed by Thomas et al. (2014), this framework is solely grounded in research within the field of management, but it integrates insights from disparate research streams within this discipline. The framework includes the concepts of *platform service innovation* and *value co-creation activities and open innovation*. However, it is focused on the evolution of platforms and does not consider further elements of service science. Hein et al. (2020) present a model designed to explain how digital platform ecosystems differ in terms of their composition, regarding three fundamental components: *platform ownership*, *value-creating mechanisms*, and *complementor autonomy*. Despite the incorporation of *value-creating mechanisms* in the model, a service science perspective is missing. This is because the mechanisms in question are considered to manifest in either transactions or innovations. However, they do not consider the integration of resources to co-create value, nor do they incorporate other key concepts from service science. Furthermore, there is no comprehensive consideration of concepts from other relevant disciplines.

A notable limitation of the research described above is the absence or inadequate structuring of concepts drawn from relevant academic disciplines, including IS, economics, management, and service science. Furthermore, there is a notable shortage of analysis concerning the interdependencies between these concepts. To gain a comprehensive understanding of digital platforms, it is essential to integrate findings from different research disciplines and, additionally, to address the various terminologies that are commonly used to describe these platforms. These terms, which are often used interchangeably, may refer to the same concept or may have different meanings within the same context. For instance, the terms *internet platform* and *online platform* are essentially synonymous, while the term *service platform* is used homonymously. On the one hand, the term *service platform* can refer to an environment that is digital or non-digital, and which enables actors to interact collaboratively, thus co-creating value. On the other hand, the term *service platform* can be used to describe a platform that provides IT services. As a consequence of this lexical fragmentation, researchers and practitioners encounter difficulties in consistently identifying and defining the characteristics of platforms and specific platform types (Sørensen et al., 2015).

In the context of platform-based smart service ecosystems, besides multi-sided platforms, both *IoT platforms* and *application platforms* are of crucial importance. "*IoT platforms* provide the software infrastructure to enable physical 'Things' and cyber-world applications to communicate and integrate with each other" (Yang et al., 2019, p. 1194, emphasis added). As smart products are essential for smart service, IoT platforms serve as the fundamental technological foundation for implementing smart service systems. The utilization of application-independent functionalities of IoT platforms enables the development and execution of IoT applications, also known as smart service applications, on an *application platform* (Porter and Heppelmann, 2014; Wortmann and Flüchter, 2015).

3 Research Design

3.1 Design Science Research Paradigm

Research in IS is characterized by its focus on the interplay between technology, people, and organizations, addressing how information systems can be effectively designed, implemented, and utilized to solve complex problems (Hevner et al., 2004; Peffers et al., 2007). This interdisciplinary field draws from areas such as computer science, management, sociology, and psychology, integrating theoretical and practical insights to enhance understanding and improve outcomes in organizational contexts (Hirschheim and Klein, 2012). Central to IS research is the recognition of socio-technical systems, which implies that technology should not be considered in isolation, but rather as part of a broader context in which human, organizational, and technological factors interact dynamically (Hevner et al., 2004). This perspective emphasizes the interdependence of technology and social elements, recognizing that technological systems are profoundly embedded in and shaped by their social environments (Hevner et al., 2004; March and Smith, 1995; Sein et al., 2011). Thus, IS research is often driven by practical problems, seeking to address real-world challenges (Gregor and Hevner, 2013; Hevner et al., 2004; Sein et al., 2011). This problem-oriented approach aims to produce not only theoretical insights but also solutions that are applicable and beneficial in practice (Gregor and Hevner, 2013; Sein et al., 2011).

In their framework for research in IS (Figure 3.1), Hevner et al. (2004) present a model for comprehending, executing, and evaluating research that can succeed in achieving the goal of improving both scientific knowledge and practice. The research endeavor is usually triggered by problems, goals, tasks, or opportunities in a defined environment—the problem space (Simon, 1996)—consisting of a configuration of people, organizations, and technology (Hevner et al., 2004). Resulting are business needs that are subsequently addressed through research: Behavioral science aims to "develop and justify theories [...] that explain or predict organizational and human phenomena" (Hevner et al., 2004, p. 76), whereas design science builds and evaluates artifacts to meet the identified business needs (Hevner et al., 2004). However, these two types of research are not separable, but inform each other (Hevner et al., 2004). Thus, the design of the IT artifacts is influenced by and based on theories and knowledge from the knowledge base, while the evaluation of the artifacts extends the knowledge base through theories about the application and impact of the artifacts (Hevner et al., 2004).

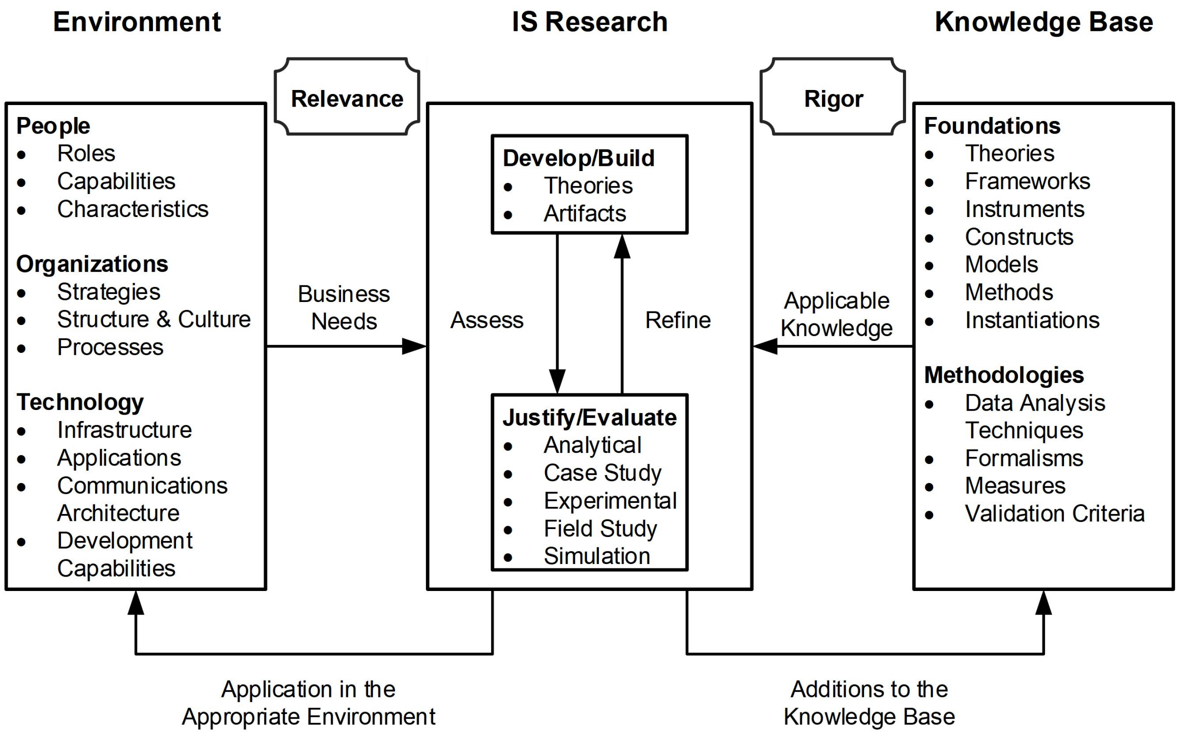

Figure 3.1: IS research framework (Hevner et al., 2004, p. 80)

According to Gregor (2006), research in IS can contribute five types of theory (see Table 3.1. The creation and evaluation of IT artifacts—as addressed in theories for design and action (type V)—is emphasized by the Design Science Research (DSR) paradigm. A research paradigm is a fundamental pattern of thought that shapes how research is conducted (Niehaves, 2005), encompassing the underlying beliefs and assumptions about the nature of reality (ontology), the nature of comprehending knowledge (epistemology), and the methods used to discover that knowledge (methodology) (Guba and Lincoln, 1994). It dictates what constitutes legitimate research questions, appropriate methodologies, and valid interpretations of findings

(Becker and Niehaves, 2007; Guba and Lincoln, 1994; Kuhn, 1962). Unlike traditional paradigms that focus primarily on explaining or predicting phenomena, DSR is action-oriented, aiming to develop innovative solutions that are both theoretically sound and practically relevant (Hevner et al., 2004; Sein et al., 2011).

Theory Type		**Distinguishing Attributes**
I.	Analysis	Says what is. The theory does not extend beyond analysis and description. No causal relationships among phenomena are specified and no predictions are made.
II.	Explanation	Says what is, how, why, when, and where. The theory provides explanations but does not aim to predict with any precision. There are no testable propositions.
III.	Prediction	Says what is and what will be. The theory provides predictions and has testable propositions but does not have well-developed justificatory causal explanations.
IV.	Explanation and prediction	Says what is, how, why, when, where, and what will be. Provides predictions and has both testable propositions and causal explanations.
V.	Design and action	Says how to do something. The theory gives explicit prescriptions (e.g., methods, techniques, principles of form and function) for constructing an artifact.

Table 3.1: A taxonomy of theory types in IS research (Gregor, 2006, p. 620)

The DSR paradigm is prescriptive and focuses on the development and evaluation of IT artifacts, which can be categorized into constructs, models, methods, or instantiations (Gregor and Hevner, 2013; Hevner et al., 2004; March and Smith, 1995). Constructs serve as the foundational elements that define concepts within the research domain, while models provide representations of systems and processes that help illustrate relationships and interactions (Jones and Gregor, 2007; March and Smith, 1995). Methods outline procedures for solving problems or achieving specific outcomes, and instantiations are practical implementations of constructs, models, or methods, demonstrating their applicability in real-world scenarios (Jones and Gregor, 2007; March and Smith, 1995). These artifacts are designed to address specific challenges or needs within a particular environment, contributing both to the improvement of practice and the advancement of scientific knowledge (Hevner et al., 2004).

It is important to differentiate design science from routine design. Gregor and Hevner 2013 provide a comprehensive framework for categorizing DSR knowledge by identifying different types of contributions that can arise from the design and development of IT artifacts. They categorize this knowledge into four key types: routine design, improvement, exaptation, and invention. According to Gregor and Hevner 2013, *routine design* is the application of known solutions to known problems. This type of contribution is often based on best practices and proven techniques, allowing researchers and practitioners to create reliable solutions based on existing knowledge. Consequently, a routine design exhibits a high degree of solution and application domain maturity and does not typically contribute novel knowledge (Gregor and Hevner, 2013). Furthermore, Gregor and Hevner 2013 characterize *improvement* as the development of new solutions for known problems (Gregor and Hevner, 2013). In contrast to routine design, this type of DSR contribution has a low level of solution maturity and, therefore, focuses on improving the performance, efficiency and/or effectiveness of solutions. The main challenge here is to show that the improved solution is a real improvement over what has been known so far. (Gregor and Hevner, 2013). Another type of DSR contribution—*exaptation*—refers to the application of existing solutions or knowledge to new/related contexts or problems (Gregor and Hevner, 2013). Thus, for exaptations, the solution maturity is high, while the application domain maturity is low (Gregor and Hevner, 2013). Finally, *invention*, involves the creation of entirely new solutions that address new problems (Gregor and Hevner, 2013). This type of DSR contributions are characterized by novelty and originality, often leading to breakthrough solutions that can significantly impact the field. Through this categorization, Gregor and Hevner (2013) provide a nuanced understanding of how DSR contributes to both theoretical and practical knowledge in IS.

3.2 Research Methods

3.2.1 Literature Review

A structured literature review is a systematic approach to identifying, evaluating, and synthesizing existing research on a particular topic or question (Webster and Watson, 2002). A literature review is an essential component of any research project, as it provides a fundamental understanding and overview of a given subject when conducted with rigor and transparency (Snyder, 2019; Webster and Watson, 2002). Nevertheless, it can also make a significant and valuable contribution when performed as a standalone approach (Vom Brocke et al., 2015). This research method is especially valuable in IS, where research often overlaps with various other disciplines, resulting in a vast and dispersed body of knowledge (Vom Brocke et al., 2015).

According to Webster and Watson (2002), the process of a structured literature review begins with a thorough search strategy that includes the definition of a search string and the identification of databases and journals to be utilized in the search for identifying relevant research. This step often comprises inclusion and exclusion criteria, which help to narrow down the identified literature to studies that are most relevant to the research project (Snyder et al., 2016). Furthermore, a backward and forward search is to be conducted (Webster and Watson, 2002). Initially, the researcher identifies key articles or 'core contributions' in the field by searching leading academic journals and databases (Webster and Watson, 2002). The backward search involves reviewing the references of these articles to identify earlier influential works, while the forward search looks at newer papers that have cited these core articles, ensuring that the review covers both foundational and recent studies (Webster and Watson, 2002). This process helps avoid the common pitfall of focusing only on a narrow subset of research, thereby providing a more holistic view of the literature (Webster and Watson, 2002). After gathering the relevant studies, the next step is to organize the literature into meaningful categories (Webster and Watson, 2002). Webster and Watson (2002) recommend using a concept-centric approach rather than an author-centric one and organizing the studies based on the topics, concepts, or theories they address rather than simply summarizing each paper (Webster and Watson, 2002).

The contributions of a structured literature review are significant. First, it provides a comprehensive and rigorous synthesis of existing knowledge, allowing scholars to see the current state of research more clearly (Vom Brocke et al., 2015; Webster and Watson, 2002). By following a transparent and rigorous process, it minimizes bias and offers a clear path that other researchers can follow (Snyder et al., 2016). Second, a literature review identifies gaps in the body of knowledge, making it an essential tool for guiding future research (Webster and Watson, 2002). Lastly, structured literature reviews contribute to theory development by consolidating existing knowledge into coherent frameworks, allowing scholars to refine or extend theoretical models (Snyder et al., 2016) and building the foundation for advancing theoretical knowledge in the field (Snyder et al., 2016; Webster and Watson, 2002).

3.2.2 Data Analytics for Research

Data analytics comprises the application of statistical methods, algorithms, and computational techniques to extract insights from structured and unstructured data (Berente et al., 2019; Müller et al., 2016). In research, data analytics can facilitate the automated processing of vast and complex data sets (Berente et al., 2019) that would otherwise be unmanageable (Debortoli et al., 2016). Consequently, the utilization of data analytics enables researchers to discover patterns, make predictions, and gain new insights (Müller et al., 2016). While data analysis can be largely automated with respect to the handling of large data sets, the research process itself remains dependent upon human actions at each stage (Berente et al., 2019).

The process of applying data analytics in research involves three phases (Müller et al., 2016). The initial phase is the collection of data, which is possible from a variety of sources, including surveys, experiments, and publicly accessible databases (Müller et al., 2016). It is essential to document the steps taken during data collection to ensure transparency and reproducibility (Müller et al., 2016). Since raw data is rarely ready for analysis, pre-processing steps are required for cleaning, transforming, and integrating data, removing inconsistencies or missing values, and ensuring that it is in a usable format (Shearer, 2000).

The second phase—data analysis—involves applying advanced analytical methods, often rooted in data mining, machine learning, or statistical modeling, to analyze the data (Müller et al., 2016). For example, machine learning algorithms can identify complex relationships within the data or make predictions (Debortoli et al., 2016), while natural language processing can be utilized to analyze text data (Müller et al., 2016).

The third and final phase is the interpretation of the results (Müller et al., 2016). While machine learning and data mining processes are capable of making precise predictions, the underlying correlations are frequently not explainable—the applied algorithms appear to be a black box (Müller et al., 2016). It is therefore essential to provide an interpretation and explanation of the results. Berente et al. (2019) propose the utilization of a lexicon for theorizing and explaining the results, which can be derived from the existing body of knowledge and is shared by the research community. Müller et al. (2016) also propose an interpretation and explanation of the results in the context of existing theories and related empirical studies.

3.2.3 Conceptual Research

Conceptual research is primarily theoretical in nature and is concerned with the synthesis of existing theories, the adaptation of existing theories (Jaakkola, 2020; Yadav, 2010), or the development of new typologies or models of concepts (Jaakkola, 2020). Furthermore, it can result in the development of entirely novel ideas or direct the attention to domains that have not been sufficiently explored (Yadav, 2010). Conceptual research can "bridge existing theories in interesting ways, link work across disciplines, provide multi-level insights, and broaden the scope of our thinking" (Gilson and Goldberg, 2015, p. 128). These characteristics are of particular importance in the context of this dissertation, as the integration of knowledge from disparate research disciplines is necessary at various points to achieve the research objectives.

Conceptual research involves a rigorous analysis, synthesis, and critical evaluation of existing literature and theories (Gilson and Goldberg, 2015). A phenomenon, concept, or theory can serve as a starting point for conceptual research (Jaakkola, 2020). These phenomena, concepts or theories are initially examined comprehensively, frequently drawing upon existing knowledge that is sometimes dispersed across disciplines (Gilson and Goldberg, 2015). As a result, concepts or theories are recombined, reinterpreted, refined, or concepts are categorized or structured in frameworks to predict relationships among those concepts (Jaakkola, 2020; Yadav, 2010).

Unlike empirical research, which depends on data collection and statistical analysis, conceptual research relies on logical reasoning and argumentation (Jaakkola, 2020). It is focused on assumptions, premises, axioms, or assertions that are not necessarily based on empirical evidence (Gilson and Goldberg, 2015; Hirschheim, 2008). Thus, the newly developed concepts, theories, typologies, or models need to be presented in a clear and concise manner, so that they can subsequently be evaluated (Hirschheim, 2008). This evaluation can be conducted, for example, with the help of empirical studies (Gilson and Goldberg, 2015; Mora et al., 2008) or, as proposed by Hirschheim (2008), based on the framework presented by Toulmin (2008).

3.2.4 Design Science Research Method

Building on the DSR paradigm, a variety of research methods was introduced with the intention of guiding design-oriented research. To ensure the rigorous and transparent application of DSR, a systematic and structured approach should be followed. Therefore, this dissertation applies the DSR methodology proposed by Peffers et al. (2007). An overview of the nominal research process is presented in Figure 3.2.

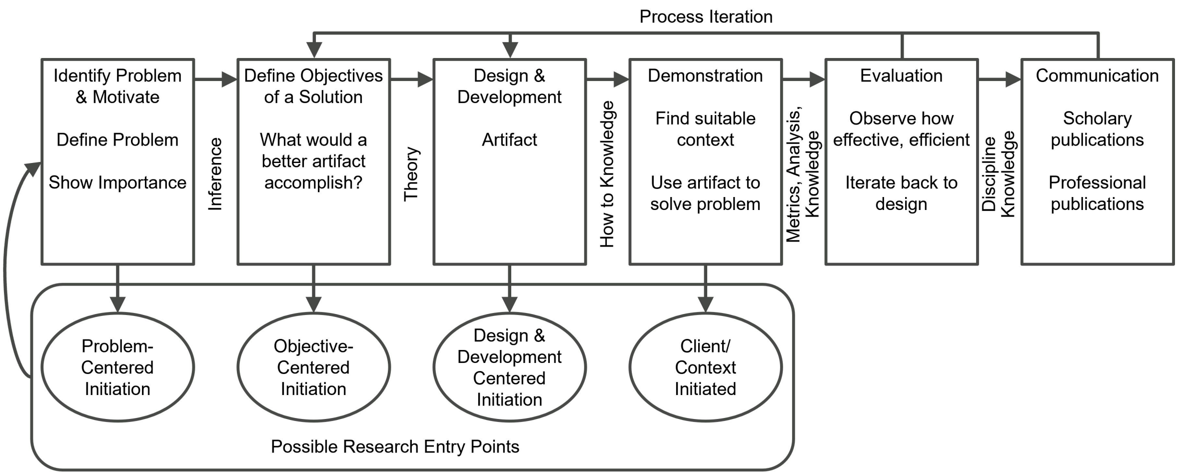

Figure 3.2: Nominal process sequence of DSR methodology (Peffers et al., 2007)

If the research process is initiated by a problem, the first step is to clearly identify a significant problem that requires a solution(Peffers et al., 2007). By justifying the value and importance of the solution, the subsequent research endeavor is motivated (Peffers et al., 2007). Researchers must ensure that the problem and the the class of problems it belongs to are well-defined and meaningful (Gregor and Hevner, 2013; Hevner et al., 2004), with potential implications for both practice and theory (Gregor and Hevner, 2013). As an alternative to the initiation of the research process from a problem-centered perspective, it is also possible to initiate the process at a subsequent stage from an objective-, design-, or context-centered standpoint (Peffers et al., 2007).

Once the problem is identified, the next step is to define the objectives that the solution should be designed to achieve (Peffers et al., 2007). These objectives are derived from the problem specification (Peffers et al., 2007). A literature review is conducted to identify existing descriptive and prescriptive knowledge, as well as relevant existing artifacts, that may inform the objectives and design of the solution (Gregor and Hevner, 2013). The objectives may be defined in either a quantitative or qualitative form (Peffers et al., 2007). Quantitative objectives can be expressed in terms of how a desirable solution would be an improvement on existing solutions, whereas qualitative objectives provide a description of how a new artifact is expected to address problems that have not previously been solved (Peffers et al., 2007).

Subsequently, the artifact—construct, model, method, or instantiation (March and Smith, 1995)—is designed and developed (Peffers et al., 2007). This step requires creativity and innovation, as researchers are tasked with designing a solution that addresses the identified problem and fulfills the defined objectives (Gregor and Hevner, 2013; Hevner et al., 2004). The design process should be guided by established theories, frameworks, and existing artifacts, ensuring that the artifact is not only functional but also grounded in existing knowledge(Hevner et al., 2004).

After the development of the artifact, it is applied in a suitable context to demonstrate that it solves the initial problem (Peffers et al., 2007). Demonstration can take various forms, including experimentation, case studies, and simulations (Peffers et al., 2007), depending on the nature of the artifact and the research objectives.

The purpose of the following evaluation is to assess the artifact's effectiveness, utility, and performance during demonstration (Peffers et al., 2007). This evaluation can be done based on quantitative measures, empirical evidence, or simulation (Hevner et al., 2004; Peffers et al., 2007). Furthermore, the accomplishment of the previously established objectives can be assessed to evaluate the results of the research process(Peffers et al., 2007). If the performance of the artifact is not sufficient, researchers can iterate back to the third activity to improve the design of the artifact (Peffers et al., 2007). Often, the build-and-evaluate cycle is iterated several times, before the solution reaches a sufficient utility and performance (Hevner et al., 2004).

Finally, the results and also all steps and decisions of the conducted research process should be communicated effectively (Peffers et al., 2007). Researchers should present their findings in a clear and structured manner, utilizing academic papers, presentations, and other formats that are accessible to both scholarly and practitioner audiences (Peffers et al., 2007).

3.3 Research Process

The applied research process is comprised of three phases, each of which contributes to a specific research objective. An overview of the process and the applied methods is provided in Figure 3.3. The applied research methods include data analysis (Müller et al., 2016), literature reviews (Webster and Watson, 2002), conceptual design (Jaakkola, 2020), and the design science research method (Peffers et al., 2007).

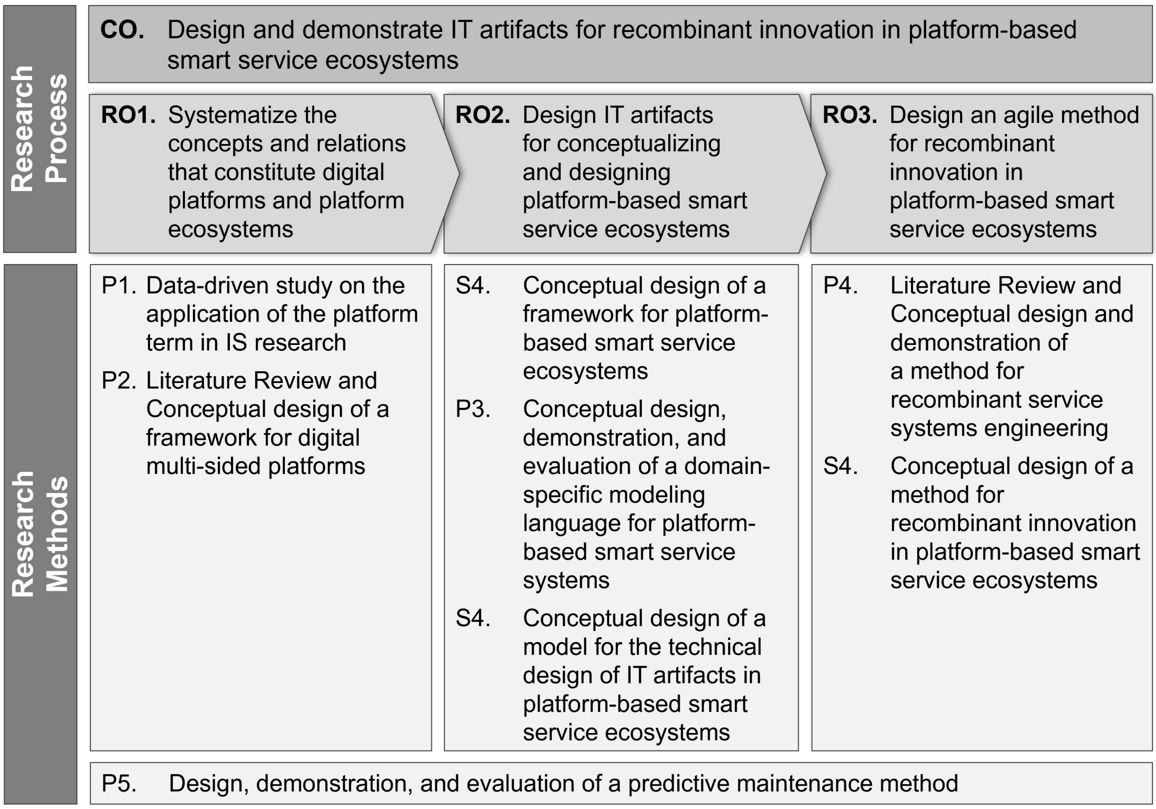

Figure 3.3: Contribution of publications to research objectives

To address RO1—*systematize the concepts and relations that constitute digital platforms and platform ecosystems*—two different methods for data collection and analysis were applied, followed by the conceptual design of a framework. A data-driven research study (Müller et al., 2016) was conducted to analyze the body of knowledge on platforms in IS. By employing text mining and machine learning techniques, the analysis of over 11,000 papers was conducted with the objective of identifying the specific platform terms and the contexts in which they are utilized. Based on these findings, the dominant platform terms were identified, structured in a decomposed model, and defined to provide conceptual clarity on different types of digital platforms in IS. To gain a comprehensive understanding of digital platforms and their ecosystem, as targeted by RO1, it is necessary to adopt a broad perspective that encompasses multiple research disciplines. Accordingly, a systematic literature review is conducted (Webster and Watson, 2002), covering 140 papers from nine research disciplines. The resulting concepts were subsequently structured in a conceptual framework (Jaakkola, 2020), which provides a comprehensive overview of the identified concepts and their interdependencies to conceptualize digital platforms and their ecosystems.

The knowledge gained in the first phase of the research process was subsequently extended to address RO2—*design IT artifacts for conceptualizing and designing platform-based smart service ecosystems*. Given that digital platform ecosystems constitute a distinctive form of service ecosystems, it is necessary to integrate research conducted in these two areas, which is currently conducted as two separate research streams. To achieve this integration, the conceptual framework of digital platforms and their ecosystems was extended conceptually (Jaakkola, 2020) by a smart service perspective, thus providing a framework for conceptualizing and theorizing platform-based smart service ecosystems.

For designing platform-based smart service ecosystems, a domain-specific modeling language (DSML) was designed, demonstrated, and evaluated, following the design science research method as proposed by Peffers et al. (2007), in combination with design guidelines for DSML, as proposed by Frank (2011; 2013). To develop an appropriate design, it was necessary to identify the relevant constructs for the DSML from the existing literature on smart service (eco)systems and digital platforms. Once these were identified, a meta-model and graphical notation was created in order to specify the modeling language. The resulting meta-model of this modeling language, again, integrates the two research streams on smart service systems and digital platforms. For evaluating the DSML, ten existing smart service systems were modeled, covering different platform types and industry sectors to cover a broad spectrum of use cases. Based on the modeling results, the DSML was evaluated in accordance with the predefined requirements. Furthermore, the meta-model and the graphical notation were refined through a series of iterative processes. Finally, a model for the design of IT artifacts in platform-based smart service ecosystems was conceptually designed (Jaakkola, 2020). This model also serves as a template for applying the DSML.

Following the conceptualization of platform-based smart service ecosystems and the development of a DSML for their design, the process of recombinant innovation in platform-based smart service systems remained a necessary step to achieve RO3 and the CO. To this end, a structured literature review was conducted initially to identify and analyze existing service engineering approaches with the help of a concept matrix (Webster and Watson, 2002). In this regard, an in-depth examination was conducted to ascertain whether the recombination of existing resources is taken into account in the existing approaches and, if so, which recombination mechanisms are addressed. Furthermore, the scope of the innovation process was examined, specifically whether the service engineering process is utilized to develop a value proposition or a service system. Moreover, the question of whether physical products are explicitly taken into account as resources was investigated, resulting in the design of product-service systems. Finally, the type of process was analyzed, distinguishing between linear, iterative, and prototypical innovation processes.

Resulting from this literature analysis are four conceptual insights that were identified from the review. As conceptual research can be utilized for initiating theory development and for evaluating and enhancing existing theories (Yadav, 2010), these insights were used as justificatory knowledge for developing the four essential design principles for enabling recombinant service systems engineering.

Based on these four design principles and using recombinant mechanisms, a service engineering process for recombinant innovation was subsequently designed by applying recombinant mechanisms to existing approaches and recombining their activities. The resulting service engineering approach explicitly fosters the application of the three key mechanisms of recombinant innovation while considering physical goods and service as resources. Furthermore, it takes on a socio-technical service systems perspective and facilitates the integration of internal and external resources for the co-creation of value in service systems.

To achieve the RO3, it is necessary to specify the recombinant service systems engineering method developed in P4 for use in platform-based smart service ecosystems. In accordance with the framework for the conceptualization of platform-based smart service ecosystems (second phase of the research process), the recombinant service systems engineering method was redesigned conceptually. The resulting method for recombinant innovation in platform-based smart service ecosystems was subsequently demonstrated with the case of an agricultural company.

In P5, a predictive maintenance method was designed, demonstrated, and evaluated for an agricultural company by applying the design science research method proposed by Peffers et al. (2007). The design process was conducted with two distinct objectives. The initial objective was to enhance the existing maintenance service for customers by minimizing downtime. The secondary objective was to enable service providers to operate more efficiently by avoiding resource shortages and optimizing the handling of spare parts during periods of high demand. A prediction method was developed based on actual service records provided by the agricultural company. The data set was first enhanced with external data to establish a data model that could be accessed by the aforementioned prediction method. Second, a knowledge-based expert system was designed to forecast the forthcoming harvesting season and the required workload. Third, a data-driven model was developed to predict the likelihood of critical components malfunctioning during this season. Subsequently, the prediction method was implemented for demonstration and evaluation based on 3,407 real-world service records.

To achieve the CO, in Section 4.1 of this dissertation, the case of the agricultural company was used to demonstrate the method for recombinant innovation in platform-based service ecosystems as well as the DSML and the model for the design of IT artifacts in platform-based intelligent service ecosystems, which were developed in the second phase of the research process.

4 Research Results and Contribution

4.1 Synopsis of Research Contributions

The research findings for recombinant innovation in platform-based smart service ecosystems are summarized in Figure 4.1. Structured according to the defined research objectives, the contributions are also described in the following sections.

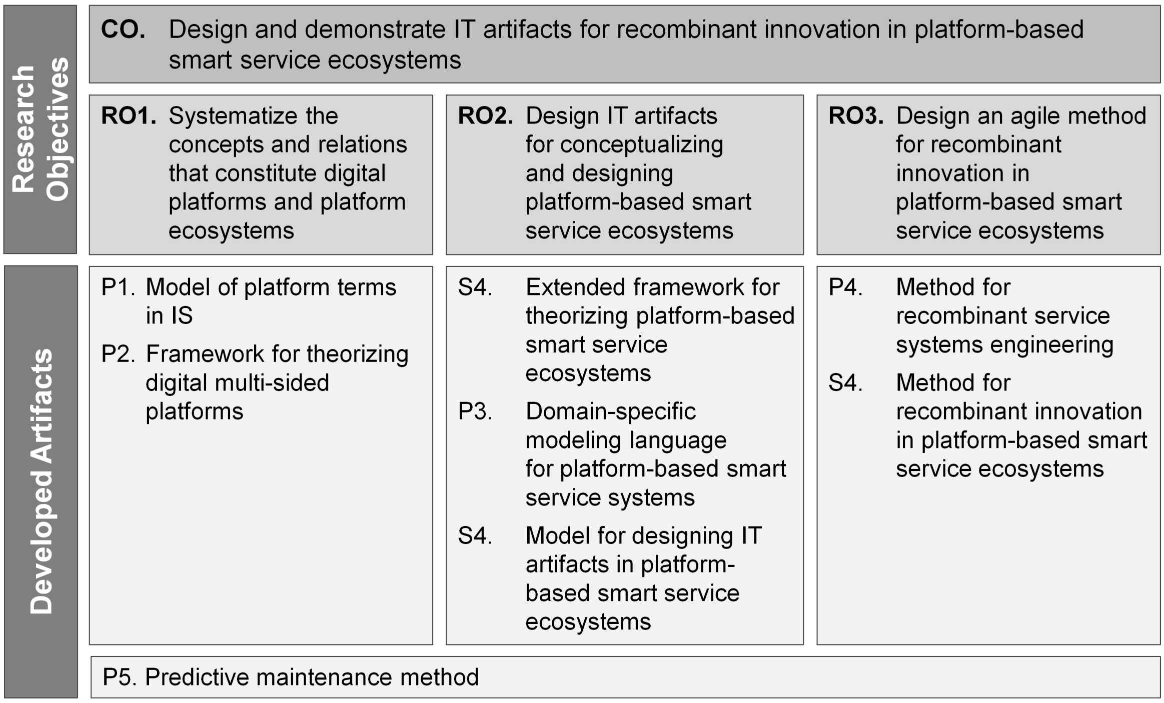

Figure 4.1: Overview of the main artifacts developed in this dissertation,
S4: Section 4 in Part A of this thesis

RO1. Systematize the Concepts and Relations that Constitute Digital Platforms and Platform Ecosystems

IS has been researching digital platforms for about 50 years, which has involved constantly changing types of platforms and thus also led to a large variety of platform terms. However, these terms are not used consistently. On the contrary, either different terms are used for the same concept, or the same terms are used for different concepts. This confusion in communication results in researchers not being able to consistently define distinct platform types and their characteristics (Sørensen et al., 2015).

In order to resolve the existing lexical confusion and thus address the first research objective of this thesis (RO1), a data-driven approach (Müller et al., 2016) was pursued in P1 to analyze and structure the existing research on digital platforms in IS research. Based on text mining and machine learning algorithms, 11,049 publications covering 44 years of IS research were analyzed and about 300 unique platform terms were extracted. By subsequently analyzing similarities of platform terms that were used in at least 150 publications, a dendrogram was calculated, building a first structure of 26 platform terms. Six clusters were identified on the basis of this dendrogram: (1) abstract technology views on platforms, (2) specific views on hardware and software platforms, (3) social communities and online platforms, (4) economic platforms as digital markets, (5) general properties of platforms as IT artifacts for value co-creation, and (6) sharing platforms.

Subsequent to the data-driven study, the results were interpreted and discussed. A model of platform terms was derived through decomposition, which is used to break down complex structures (Alexander, 1964) (Figure 4.2).

The decomposed model in Figure 4.2 presents a hierarchical structure of terms for digital platforms. On the second level of this hierarchy, the terms *service platform* and *could platform* represent two different perspectives on digital platforms: The term *service platform* refers to a service-oriented view on digital platforms, focusing on resource integration and co-creation of mutual value by multiple actors engaging on a platform. The term *cloud platform* takes a more technical perspective on platforms, representing an operating system that runs in the cloud and provides resources like infrastructure, development platforms for software, or software.

While both, service platform and cloud platform, refer to a more generalized view on platforms, three more detailed views can be found on the third level of the decomposed model: (1) *Information technology platform*, (2) *social platform*, and (3) *(two-/multi-)sided platform*. *Information technology platform* takes a technical view on platforms as IT artifacts. Considered an overarching concept, its more specific subclasses, e.g. software platform or hardware platform, are shown on level four of the

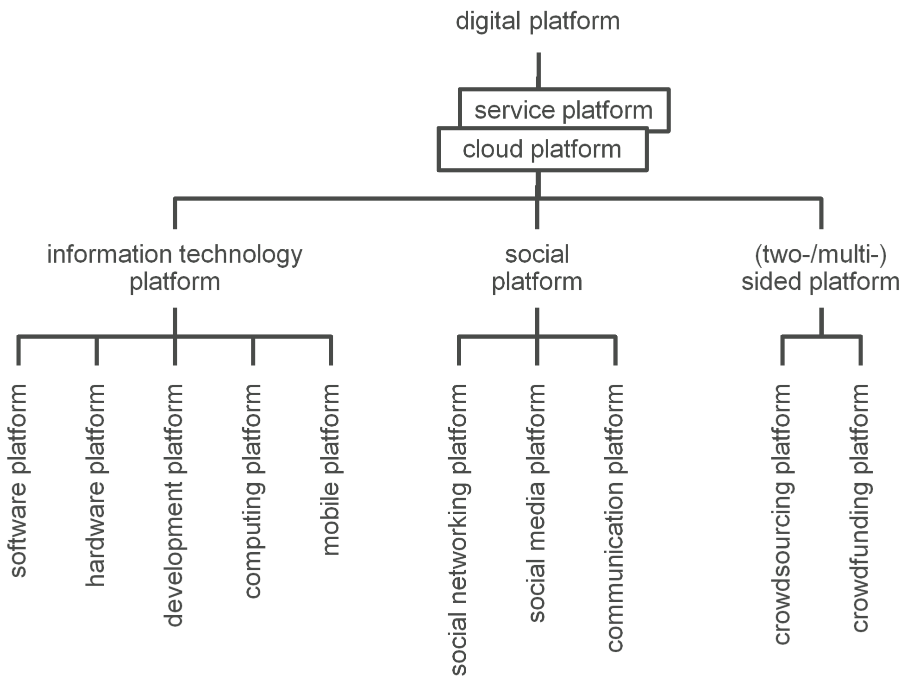

Figure 4.2: Model of platform terms

decomposed model. In contrast to this technical view, *social platforms* enable social interactions and communication between users. The subclasses of social platforms can be differentiated by the form of interaction or communication, e.g. direct messages between specific users of a communication platform versus shared user-generated content on a social media platform, which is accessible by a large group of users. The third, more detailed view on digital platforms—*(two-/multi-)sided platform*—focuses on the economic effects that arise when mediating between two or multiple groups of actors, including direct and indirect network effects. Two specialized forms of two-/multi-sided platforms, *crowdfunding platform* and *crowdsourcing platform*, are shown on level four of the decomposed model.

Although the decomposed model and lexicon of platform terms developed in P1 represents an initial systematization of platform concepts, digital platforms and platform ecosystems remain insufficiently characterized. Therefore, in P2, a conceptual framework was derived from a literature review of 140 papers from nine disciplines. This framework (Figure 4.3) systematizes 27 theoretical concepts (eight main concepts and 18 sub concepts) that constitute a multi-sided platform ecosystem on three layers of abstraction: (1) *Platform as an Information System*, (2) *Platform as a System for Actor Engagement*, and (3) *Platform as an Ecosystem*. These layers form a nested structure based on the systems theory principle of the distinction between systems and their environment (Luhmann et al., 2013).

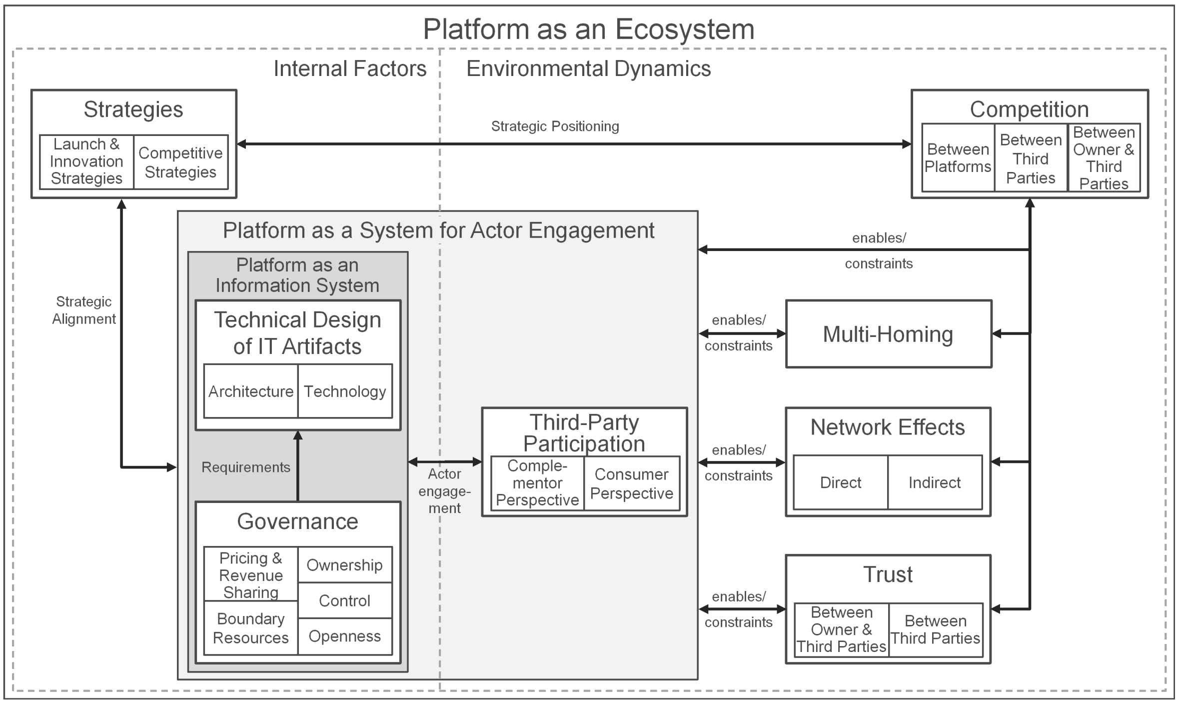

Figure 4.3: Framework for theorizing digital multi-sided platforms

The foundation of a digital platform is an information system, consisting of IT artifacts and their governance. This applies not only to multi-sided platforms, but also to closed platforms—for example IoT platforms—on which only selected actors can participate. The platform as an information system needs to be designed and managed by the platform owner in alignment with their strategies. The governance concepts have a significant impact on the platform since they contain all the rules and conditions for interacting with third parties. Furthermore, they are translated into requirements for the technical design of IT artifacts, including architecture and technology. This technical view of platforms is consistent with the first detailed view on platforms identified in P1: information technology platform.

A platform as an information system can be used by third parties, resulting in a platform as a system for actor engagement. To accomplish this, the platform must be designed to attract the engagement of third parties. It is important that the platform is of interest to both complementors and consumers in order to create added value and exploit network effects. Aspects of social platforms, which represent the second detailed perspective on platforms identified in P1, are relevant to the platform as a system for stakeholder engagement. For example, communication within or between user groups should be facilitated. Examples include rating systems in which consumers can exchange information and share their own content, as well as messages between consumers and complementors for support requests or to process purchases.

In a platform ecosystem, the platform owner has direct control over internal factors such as strategies and all concepts that are part of the platform as an information system. In contrast, the platform owner can only indirectly influence the environmental dynamics, as these emerge through the behavior of the actors in the ecosystem. By adapting the strategy, governance and IT artifacts, the platform owner can try to overcome challenges that arise due to changes in the environmental dynamics. This ecosystem perspective is in line with the third detailed perspective on platforms identified in P1: (two-/multi-)sided platforms.

The framework for theorizing digital platforms contributes to RO1 by providing a comprehensive and structured overview of concepts and relations in platform ecosystems. Since platform ecosystems are a special type of service ecosystems, the acquired knowledge contributes directly to the understanding of platform-based service ecosystems (CO).

RO2. Design IT Artifacts for Conceptualizing and Designing Platform-based Smart Service Ecosystems

The knowledge gained in RO1 is primarily based on research conducted on digital platforms and platform ecosystems. As discussed before, platform ecosystems constitute a specialized form of service ecosystems. However, since research on digital platforms and (smart) service (eco-)systems is conducted separately, a service perspective is missing in research on digital platforms, and—vice versa—the specialized case of platform-based smart service ecosystems is not sufficiently researched in service research.

To accomplish the integration of research on digital platforms and service science, the framework for theorizing digital platforms (RO1) is extended by nine core concepts of service research that are also presented in Table 2.1. The extended framework for theorizing platform-based smart service ecosystems is shown in Figure 4.4. This integration step allows relevant concepts to be structured and interdependencies to be identified, resulting in a comprehensive overview of the factors and dynamics in platform-based smart service ecosystems that can and cannot be influenced by the involved actors.

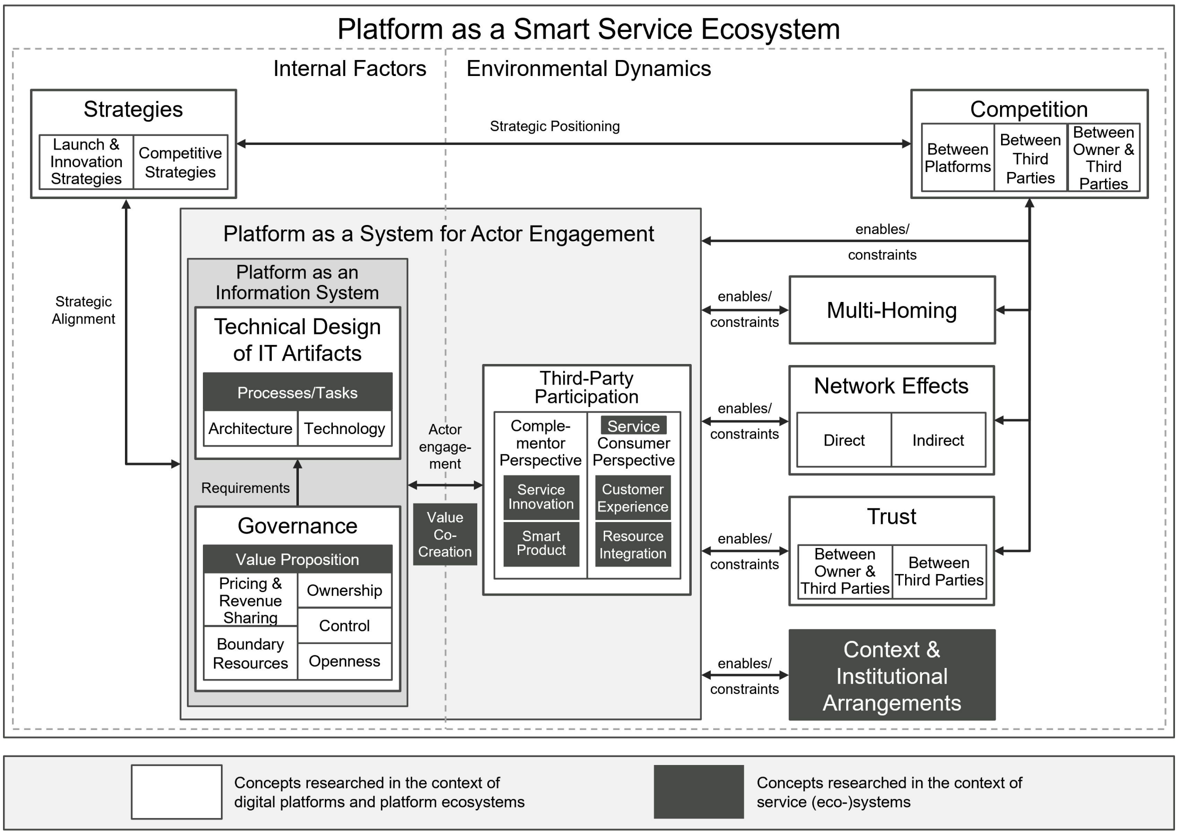

Figure 4.4: Extended framework for theorizing platform-based smart service ecosystems

In the extended framework, the layer *platform as an information system* is complemented by two concepts, that the platform owner can influence directly: (1) *processes/tasks* that actors perform on the platform to integrate resources and co-create value (Grönroos, 2015). These processes need to be designed and implemented in the software by the platform owner. The (2) *value proposition* is what the platform owner provides to the service customer, but also to third-party complementors. The value proposition, which is at the core of the platform's business model, must be designed by the platform owner to meet customers' needs and expectations. This is necessary for motivating customers to participate in the platform.

The *platform as a system for actor engagement* is extended by five additional concepts. If the value proposition of the platform owner is accepted by the service consumer, the process of (3) *value co-creation* can take place through (4) *resource integration* of the consumer and the service provider (platform owner and/or third-party complementor). Although resources are integrated from all parties involved, the concept *resource integration* was assigned to the *service consumer perspective*, as the customer's willingness to integrate their resources is essential for the provision of service. The second new concept for the *service consumer perspective* is the (5) *customer experience*, which determines the value of the service for the customer (Sandström et al., 2008). It is dependent on several aspects, including the social environment, service interface, price, former experiences, and situation and consumer moderators (Verhoef et al., 2009).

For the *complementor persective*, two concepts were added: (6) *service innovation* and (7) *smart product*. *Service innovation* is relevant for both the platform owner and the complementor. For the platform owner, however, *launch & innovation strategies* have already been included. Complementors are constrained in terms of service innovation, as they are dependent on the openness of the platform and the boundary resources provided by the platform owner. The smart product can itself be a complement and/or a complementor in the service ecosystem. As a complement a smart product can be designed and distributed by third-party complementors. Additionally, it can act as a complementor by contributing data, information, and additional functionality that extend the core of the platform.

The layer *platform as an ecosystem* was renamed to *platform as a service ecosystem* and extended by the concepts (8) *context* and (9) *institutional arrangements*. Both are closely connected since institutional arrangements are part of the context in a service ecosystem (Akaka et al., 2015; Edvardsson et al., 2018). They influence the behavior of the actors involved in a service ecosystem and determine the *value-in-context* perceived by the service consumer (Edvardsson et al., 2018; Vargo et al., 2015). Context influences the perceived value due to several different aspects, such as social, cultural, and technological structures (Akaka et al., 2013, 2015; Barile et al., 2016; Vargo et al., 2015). "Institutional arrangements [...] influence and are influenced by the ongoing value-creating actions and interactions among multiple actors. Thus, it is often the intersection of diverse institutions—e.g., educational norms and standards and prescriptions embedded in information technology—that contribute to both the maintenance and change of institutions, and thus, innovation." (Vargo et al., 2015, p.69). Consequently, institutional arrangements can only partly be designed directly by the platform owner or third-party contributors, i.e. prescriptions embedded in information technology (governance), while these prescriptions still have to be accepted and adopted by platform users. Therefore, the institutionalization—"the maintenance, disruption and change of institutions" (Vargo et al., 2015, p. 67) is dependent on the actions and interactions of all involved actors.

The developed framework in Figure 4.4 contributes to RO2 by providing a conceptualization of platform-based smart service ecosystems based on a structured overview of concepts and interdependencies. Additionally, it identifies entities that can be designed and directly influenced by the platform owner. Thus, the framework builds the foundation for designing and managing platform-based smart service systems.

For designing platform-based smart service systems, a conceptual, domain specific modeling language was designed, demonstrated and evaluated in P3. The developed modeling language can be applied for the technical design of IT artifacts in platform-based smart service ecosystems, since applying the ecosystem perspective does not add further IT artifacts, but shows dynamics and interdependencies that have to be considered during the design.

A modeling language consists of a meta-model and a graphical notation (Frank, 2011, 2013). For designing the meta-model (Figure 4.5), relevant constructs and sub-constructs from the literature on smart service systems and digital platforms were identified and integrated. Table 4.1 provides an overview of the identified concepts. Subsequent to the extended framework for theorizing digital platforms, this is a second, more detailed step on integrating previously separate streams of research on smart service systems and digital platforms.

As relevant entities for the meta-model, *actors* as well as *interfaces* between these actors, *tasks* that the actors perform, and *data* that are used or generated while fulfilling the tasks were identified. All mentioned entities comprise sub-concepts as specialization.

The meta-model of the developed modeling language was designed as an entity relationship model using the Chen notation with minimum and maximum values (Figure 4.5). It shows that two or more *actors* interact with each other via *interfaces* and perform *tasks* while generating or using *data*. According to the actor-network theory, actors can be humans (in different roles) or technological artifacts (Walsham, 1997). To reduce the complexity, the constructs *Smart Product*, *Role*, *Application*, and *Platform* were generalized to the construct *Actor*.For humans (as *roles*), the model

Concept	*Sub-concepts*	*Literature*
Role	Service Customer, Service Provider, Producer, Platform Owner	Beverungen et al., 2019; Boudreau and Hagiu, 2009; Van Alstyne et al., 2016; Gawer and Cusumano, 2002
Platform	IoT Platform, Application Platform, Multi-sided Platform	Yang et al., 2019; Wortmann and Flüchter, 2015; Porter and Heppelmann, 2014; Boudreau and Hagiu, 2009
Application	Monitoring, Control, Optimization, Autonomy	Porter and Heppelmann, 2014; Huber et al., 2019
Interfaces	Device-based, Smart Product-based, Human-based	Paukstadt et al., 2019
Tasks	Analyze, Alert, Vizualize, (Remote) Control, Define Rule, Make Decision, Recommend, Initiate Action, Perform Action, Prepare Data	Beverungen et al., 2019; Huber et al., 2019; Porter and Heppelmann, 2014; Rizk et al., 2018

Table 4.1: Overview of concepts for designing platform-based smart service systems

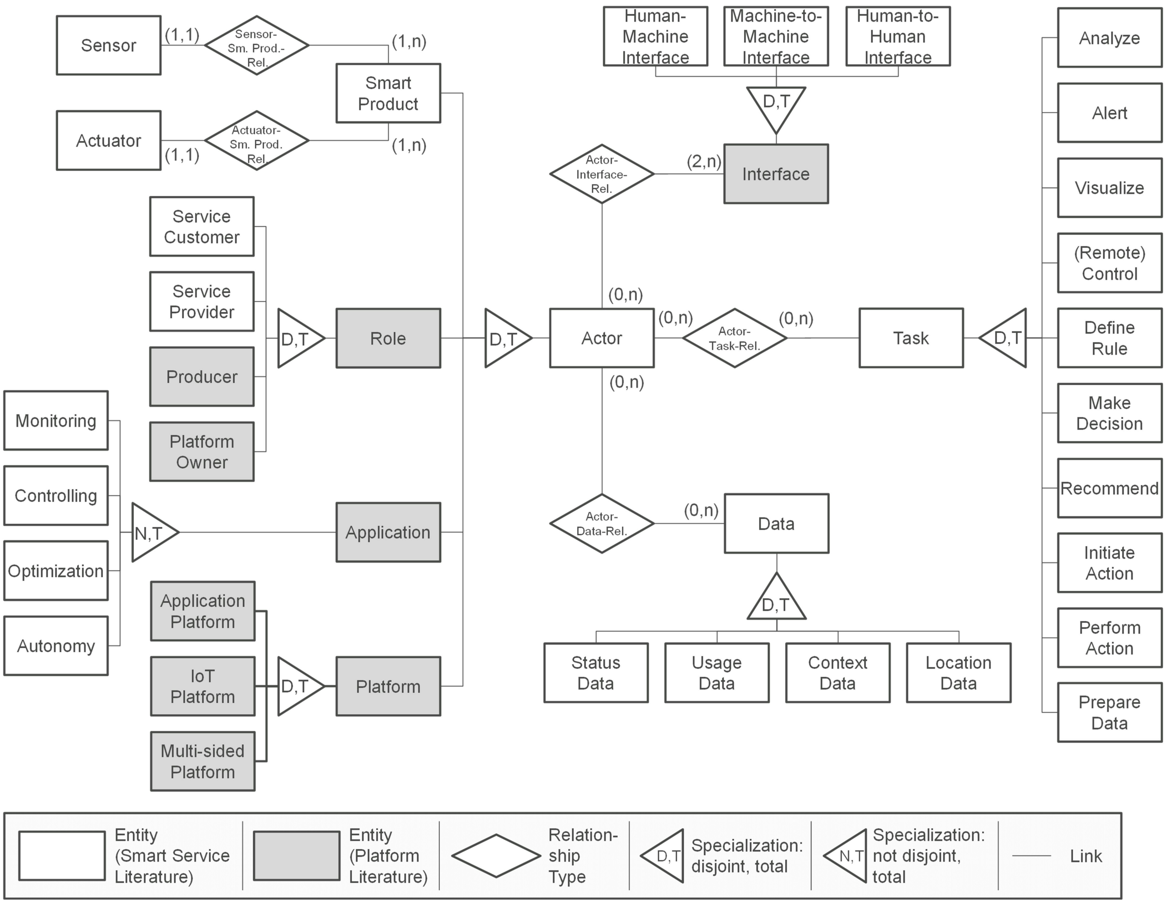

Figure 4.5: Meta-model for modeling language and integrating concepts from platform and service research

differentiates between the *platform owner*, *service customers* and two types of contributors: *service providers* and *producers* of smart products. Depending on the type of actor—smart product, role, application, or platform—the *interface* for interaction is a *human-machine interface*, a *machine-to-machine interface*, or a *human-to-human interface*.

Three basic types of *platforms* are relevant for designing IT artifacts in platform-based smart service ecosystems: IoT platforms, application platforms, and multi-sided platforms. IoT platforms facilitate communication with and between smart products, while application platforms use the functionality and data provided by these IoT platforms to create an environment for the development and execution of (smart service) applications. In contrast, multi-sided platforms are not dependent on the existence of smart products in their ecosystem, but provide the means for interaction between different groups of actors—human or not human.

In the context of smart service systems, four types of *applications* can be distinguished, depending on the purpose for the service consumer: applications for monitoring, controlling, optimization, or autonomy (Porter and Heppelmann, 2014). To execute these applications, smart products or platforms are required to perform tasks based on data generated or retrieved by their sensors or externally.

Based on the identified concepts for the modeling language, Figure 4.6 provides a model for the technical design of IT artifacts in platform-based smart service ecosystems. This model contains four different layers that need to be considered in the design and governance of platform-based smart service ecosystems. The stacked representation of layers is based on the model of digital infrastructures proposed by acatech (2015) and is used for explanatory purposes only. For modeling IT artifacts, the first layer—*actors*—serves as a canvas, in which the other layers are designed by nesting.

On the first layer, the *actors* are positioned in different areas, with the line of interaction (Bitner et al., 2008) along their boundaries. The *digital platform*, *applications*, and *smart products* are positioned on the intersection of all actors, as they enable the integration of actions and resources. In addition, service providers and service consumers can also interact directly via the boundary in the bottom area.

The remaining three layers of the model—*processes/tasks*, *data*, *technology/interfaces*—are modeled in a nested form. The graphical notation of the modeling language uses a container as structuring element for this purpose. The container consists of a head and a body. The head includes the graphical notation of the concept, its denotation, and a name. In later design stages, the body of the container specifies the

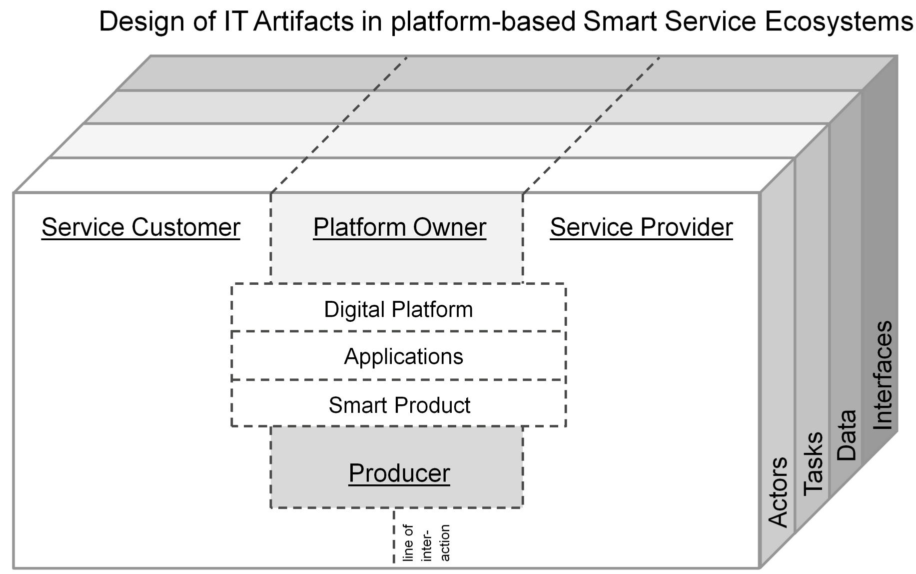

Figure 4.6: Model for the design of IT artifacts in platform-based smart service ecosystems

element shown in the head and can contain additional containers that provide further details, including those of other layers of the model. These containers are placed on the canvas depending on the responsibilities of the actors.

The modeling language is utilized to create a model that can be further refined in more detail during the course of the development process. Additional technological or organizational details may be included to establish a basis for developing the specific architecture and processes, as well as identifying the technology to be used for implementation. Thus, the developed model forms the basis for designing the IT artifacts within the framework for theorizing platform-based smart service ecosystems (Figure 4.4).

The domain-specific modeling language contributes to the conceptualization of platform-based smart service ecosystems by means of the two models developed and forms the basis for the design of the necessary IT artifacts in platform-based smart service ecosystems. The framework for theorizing platform-based smart service ecosystems also contributes to conceptualizing platform-based smart service ecosystems. Therefore, RO2 is achieved.

RO3. Design an Agile Method for Recombinant Innovation in Platform-Based Smart Service Ecosystems

The modeling language developed in RO2 provides the means for the technical design of IT artifacts in platform-based smart service ecosystems. However, it does not consider the design requirements of strategies, governance concepts, and environmental dynamics in platform-based smart service ecosystems. As a result, the modeling language can serve as a tool for a specific task within a much more complex innovation process. In order to support companies in this process, a guiding method for innovation in platform-based smart service ecosystems is necessary.

In P4, a literature review was conducted, examining 24 methods for service (systems) engineering. These methods were reviewed to determine whether innovation through recombination was considered, what the scope of the method was (development of a value proposition or a service system), what type of process it was based on (linear, iterative), and whether the method was designed to develop a service or a combination of service and (smart) product. Based on the findings of the literature review, we identified four design principles for recombinant service systems engineering:

1. Recombinant service systems engineering views service systems as socio-technical systems, not marketable objects.
2. Recombinant service systems engineering relies on associating, dissociating, and adding to existing internal and external resources
3. Recombinant service systems engineering includes both, access to external resources and transfer of ownership of physical goods.
4. Recombinant service systems engineering is an agile process.

Based on these design principles, in P4 a new method for recombinant service systems engineering was designed. To contribute to RO3 and the CO of this thesis, the developed method in P4 was further detailed based on the framework for theorizing platform-based smart service ecosystems (Figure 4.4). The result is a method for recombinant innovation in platform-based smart service ecosystems (see Figure 4.7).

The method for recombinant innovation in platform-based smart service ecosystems consists of three phases: service ecosystem analysis, service system design, and service system transformation. The innovation process starts in the first phase—service

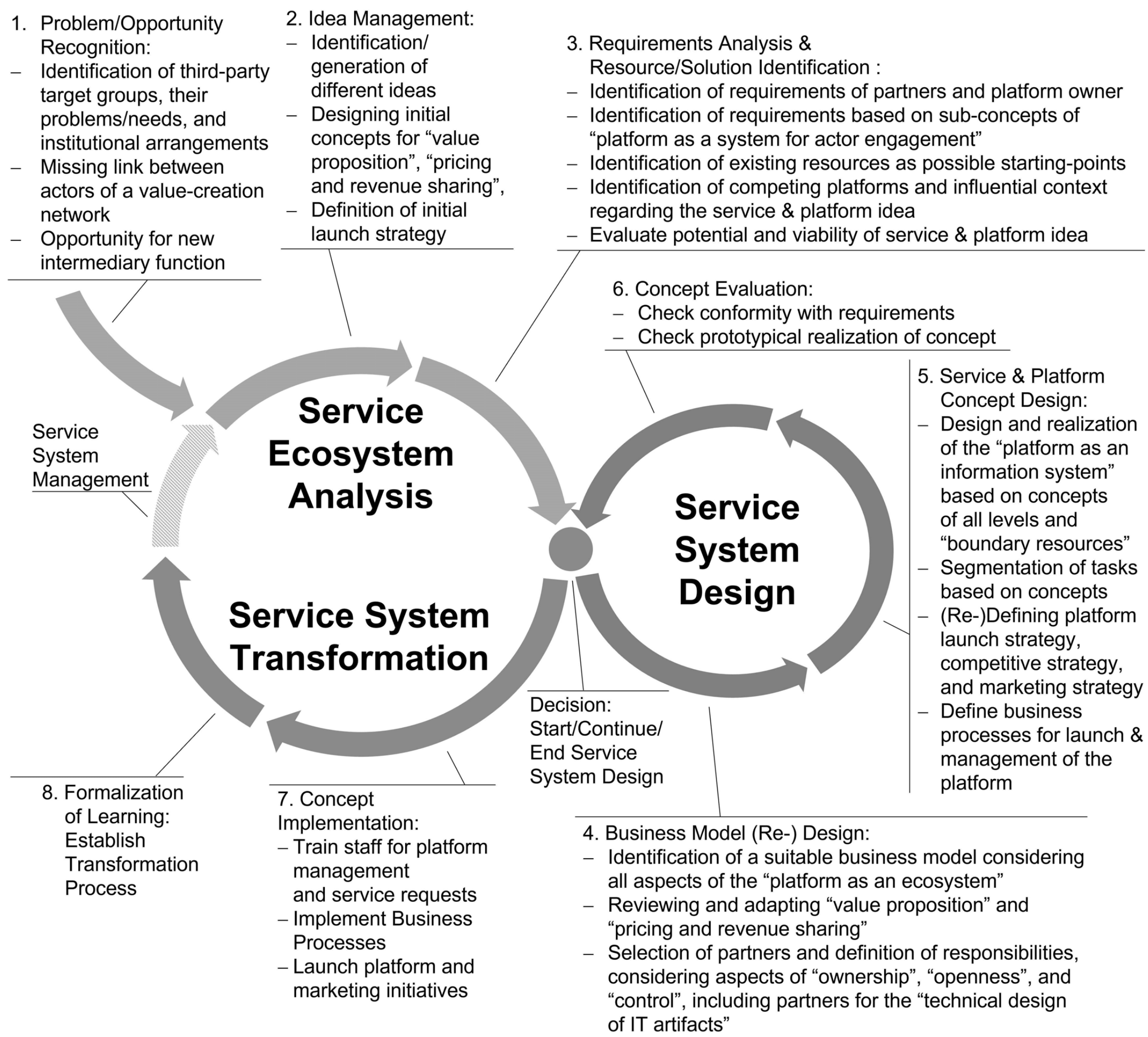

Figure 4.7: Method for recombinant innovation in platform-based smart service ecosystems

ecosystem analysis—with the identification of a problem or opportunity. In a platform-based smart service ecosystems different scenarios are possible that open up opportunities or problems for the stakeholders. This includes missing links between actors of a value-creation network or a new intermediary function. Both are relying on unfulfilled needs of (a group of) consumers. Therefore, third-party target groups, their needs, and already existing or missing shared institutional arrangements have to be identified in this first step.

The second step—idea management—starts with the (recombinant) generation of different ideas for solving the target group's problems or fulfilling their needs. These ideas include an initial outline of a value proposition and a preliminary draft of a concept for pricing and revenue sharing. In addition, initial assumptions must be made for the launch strategy to be able to investigate whether the idea would be accepted by customers.

The third step concludes the service ecosystem analysis by analyzing the requirements and resources for the new solution. The requirements of all involved actors need to be identified and analyzed. Additionally, it is necessary to investigate whether existing resources in the service ecosystem can be used as a starting point for recombinant innovation. If existing systems have already been developed using the modeling language developed in P3, the resulting models can provide a good starting point for identifying existing resources. To evaluate the potential and viability of the service and platform idea, competing platforms and influential contexts have to be identified and analyzed.

Phase one is followed by a decision point, at which the company needs to decide whether to start the service system design for the developed idea or, if the idea was evaluated not to be viable, to end the innovation process.

Phase two—the service system design—follows a prototypical approach with several design cycles. This phase is focused on the design of a socio-technical, platform-based service system, including all resources and networked actors. It contains three main activities, starting with the fourth step of the innovation process, in which a business model has to be (re-)designed. It needs to consider all identified requirements and influencing aspects identified in the service ecosystem analysis to adapt and detail the predefined value proposition and concept for pricing and revenue sharing. In addition, required partners for the design and management of the resulting platform-based smart service ecosystem need to be selected and involved, and responsibilities need to be assigned. However, a decision must first be made about the openness, ownership, and control of the platform.

The fifth step comprises all relevant activities for the service and platform concept design and prototypical implementation. The *platform as an information system*, as well as boundary resources need to be designed and realized. For this purpose, tasks can be segmented and assigned for parallel development. In addition, the launch, marketing and competitive strategies are (re-)designed and business processes for the launch and management of the platform and the service need to be defined.

In the sixth step of the innovation process, the developed concept is evaluated based on the requirements defined in the third step and the prototypical realization of the concepts. Ideally, the customers should be involved in the evaluation process. This involvement allows for early responses to changing requirements and helps to avoid misjudgments of the company.

At the end of each service system design cycle, the decision point is reached and the company must decide whether to proceed with another design cycle, begin the service system transformation phase, or—in case of very extensive changes in customer requirements or environmental dynamics—another service ecosystem analysis.

The third phase—service system transformation—starts with the concept implementation. This step comprises the transformation of the socio-technical service system, including the technical implementation, the launch of the platform according to the predefined launch strategy, and also the training of involved staff and the implementation of business processes.

The last step of the innovation process is the formalization of learning. This includes documentation and the transfer of knowledge for continuous improvement. After this step, the management of the service ecosystem starts. At any point, the innovation process can be started again to redesign existing service systems or to develop new solutions.

The developed method for recombinant innovation in platform-based smart service ecosystems is based on the integrated findings of RO1 and RO2 and fulfills RO3.

The method published in P4 was further developed and standardized by a committee of researchers and practitioners (DIN, 2019). The resulting DIN SPEC 33453 (DIN, 2019) presents a method for the development of digital service systems for industrial companies that also consists of the three phases *analysis*, *design*, and *implementation*. In this method, all three phases are connected by the decision point, making it even more flexible. Eleven design dimensions were identified that are to be detailed during the development process. In addition, 30 methods for supporting the development of service systems have been assigned to the three phases. These methods are summarized in standardized fact sheets. These methods are also applicable to the developed method for recombinant innovation in platform-based smart service ecosystems presented before.

CO. Design and Demonstrate IT Artifacts for Recombinant Innovation in Platform-Based Smart Service Ecosystems, with a Focus on Industrial Companies

The developed IT artifacts for recombinant innovation in platform-based smart service ecosystems comprise the framework for theorizing platform-based smart service ecosystems (RO2), the modeling language (RO2), the model for designing IT artifacts in platform-based smart service ecosystems (RO2), and the method for recombinant innovation in platform-based smart service ecosystems (RO3). To fulfill the CO, the demonstration of the IT artifacts is required. With the exception of the framework for theorizing platform-based smart service ecosystems, the developed IT artifacts are demonstrated based on the case of a predictive maintenance service system for agricultural machines (P5). This exception is allowed because the framework was developed to enhance the comprehension of intricate interrelationships in platform-based smart service ecosystems, rather than to be implemented within the innovation processes.

The instantiated method for recombinant innovation in platform-based smart service ecosystems is presented in Figure 4.8 for the demonstration case. The same case was used to demonstrate the method for recombinant service systems engineering in P4. The instantiation shown in Figure 4.8 expands the one in P4 by applying the further detailed method for recombinant innovation in platform-based smart service ecosystems.

The service ecosystem analysis started with the identification of a problem: resource shortages during harvesting season. Harvesting is dependent on environmental influences, such as the ripeness of the crops and the weather. Therefore, the harvest must be carried out in a very short time window in which these factors are the most ideal. Otherwise, the farmers suffer yield losses. If a machine breaks down during the harvesting period, it has to be repaired instantly. Sometimes even expensive express deliveries of spare parts and overtime of service employees are required to avoid long downtimes.

To solve the identified problem, the agriculture company responsible for the repairs developed the idea of offering a predictive maintenance service for tractors and harvesting machines. This service enables the company to identify critical parts before they break down and replace them early, while also maximizing intervals between repairs at the same time. This service improves harvesting efficiency and reduces costs for spare parts and repairs for farmers.

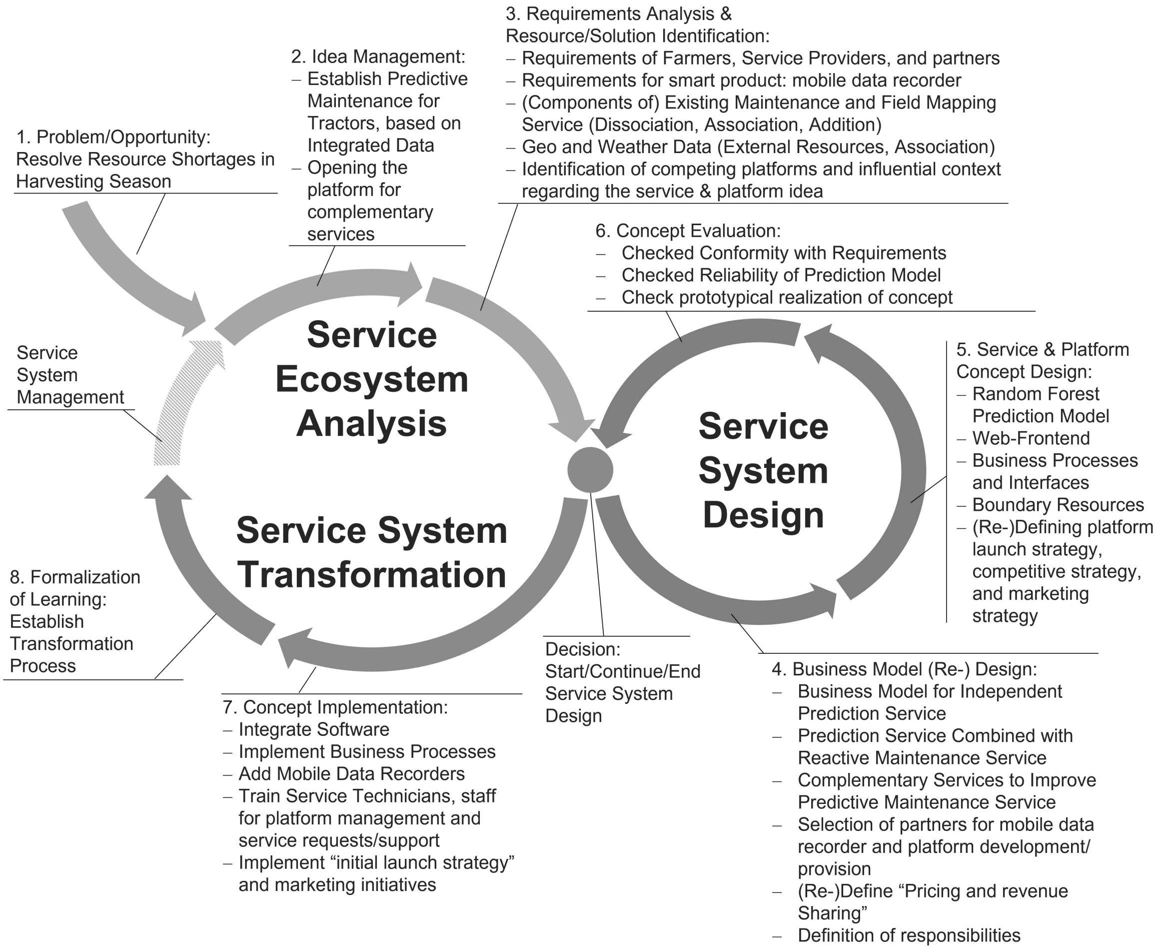

Figure 4.8: Demonstration of method for recombinant innovation in platform-based smart service ecosystems with a predictive maintenance case

The third step in the innovation process was to analyze requirements and identify resources. Requirements of the target groups—farmers and agricultural contractors—were analyzed. Subsequently, existing resources were identified, including data of eight information systems used by the agricultural company (e.g. enterprise resource planning (ERP), Customer Relationship Management, and Product Data Management). Dissociation was applied to identify elements of existing resources that can be used for the new service idea. We identified relevant data from the company's ERP system, as well as customer-related data such as geolocation data of machines from a field mapping service. Since harvesting is dependent on the environmental circumstances, open data (e.g., weather data and geological information) were included as external resources. By combining all identified resources, we applied dissociation and association as relevant operations of recombinant innovation.

To include geolocation data of the field mapping service, a mobile data recorder was required, converting the agricultural machine to a smart product. For the development and production of the data recorder, an external partner was needed. The requirements of this partner were also analyzed in this step of the innovation process. Since the service is initially planed as a smart service of the agricultural company to its customers, there is no need for an open or multi-sided platform. Therefore, environmental dynamics are limited. However, competing service systems and influential contexts were analyzed nevertheless. Only original equipment manufacturers of the tractors and harvesting machines have access to the technical systems and sensors in agricultural machinery. They are therefore uniquely equipped to offer a comparable service. However, they are limited to their own machines and cannot offer a comprehensive service, especially in mixed vehicle fleets. The agricultural company, on the other hand, maintains and repairs machines from different manufacturers and therefore has a broader database. However, it is not able to constantly access and interpret the sensor data from the agricultural machinery. The integrated data from the company's existing information systems and the external data must therefore be sufficient for the service.

At the decision point, the agricultural company decided to continue with the service system design. The target for the first design cycle was to develop and evaluate a prediction method for further evaluation of the service idea.

During the business model (re-)design, two possible solutions were identified. The new predictive service could be offered independently to attract new customers. Alternatively, it could be offered in combination with the current (reactive) maintenance service, in which case addition would also be used as a recombination method.

In service concept design, a random-forest-based prediction model for the predictive maintenance service was developed, based on a machine's master data, usage data, position data, and context data. Additionally, business processes and a web interface were designed, which farmers and service technicians can use to see the status of their machines.

The modeling language for designing platform-based smart service systems was applied and a first model of the smart service system was created (Figure 4.9). This model is divided into four areas, each representing another role. The service provider and platform owner are shown as two separate roles, but the agricultural company plans to fulfill both roles. Additionally, a producer is included in the model that produces the mobile data recorder. The service customers—in this case the farmers or agricultural contractors—have direct interfaces to the service provider and the producer. The smart product serves as a boundary object that integrates the resources of all three roles. It is therefore placed on their boundaries. Service customers can interact with the smart product via an interface in the form of a small touchscreen on its housing. The main feature of the smart product is to collect, prepare, and send geolocation data. The receiver of these data is an IoT-platform that enables communication and interaction with the smart products. This IoT-platform is connected to an application platform, which integrates data from different sources (ERP, Product, and open weather and geological data). The condition monitoring application analyzes and visualizes the data, makes decisions, and alerts the customer and the service provider in case of any risks. This enables the agricultural company to schedule maintenance orders at an early stage and thus better allocate resources.

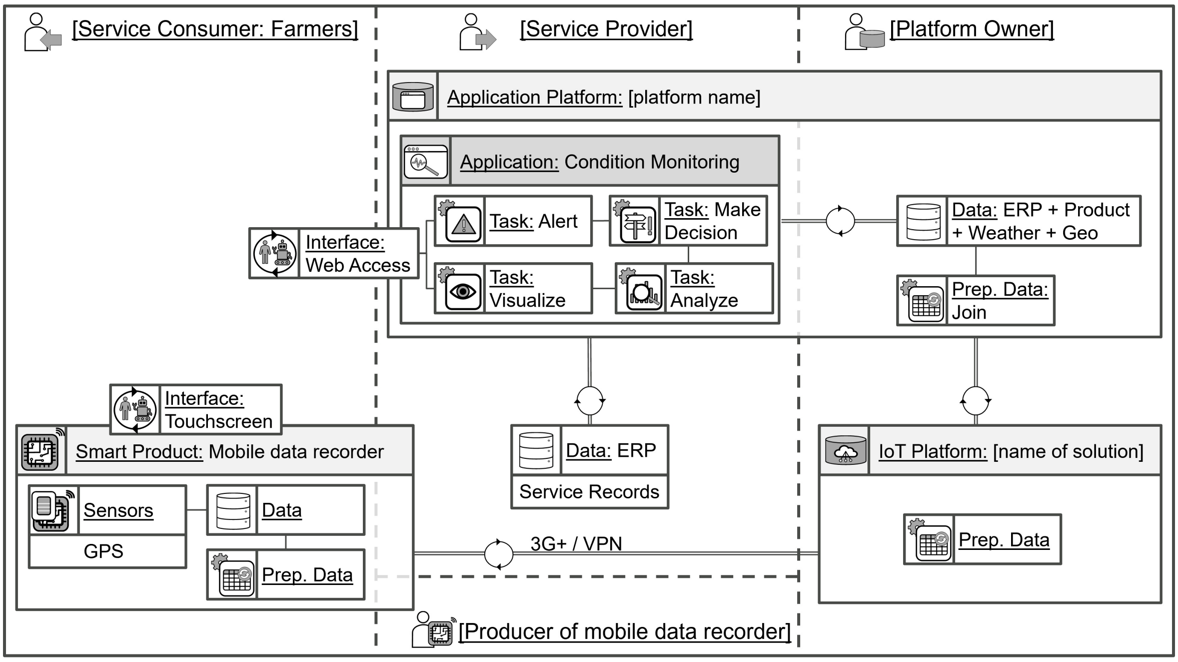

Figure 4.9: Demonstration of modeling language with a predictive maintenance case

The concept evaluation was done based on the requirements identified in service ecosystem analysis. In addition, the prediction method was evaluated with common measures for machine learning.

At the decision point, the results were presented to management, who decided to proceed with another design cycle to further detail and implement the designed concept. At this stage of the innovation process, the collaboration with the agricultural company ended before the design and transformation of the service system were complete. However, after the prototypical realization and evaluation of the service concept have reached the required maturity, the service system transformation will follow. This would involve integrating different information systems and implementing business processes, attaching the mobile data recorder to the agricultural machines, and training service technicians. This would be followed by the formalization of learning before operational service management begins.

Up to this point, the agricultural company has used the innovation process to develop and implement a smart service system. If the company successfully operates this smart service system, it may consider opening the application platform for complementors and thereby establishing a multi-sided platform. By opening the platform, customers can be offered a comprehensive solution to their problems. There are three approaches to achieve this: (1) The agricultural company can allow original equipment manufacturers to offer their own applications for condition monitoring of the machines on the platform. As the manufacturers also have access to sensor data from the machines, this can improve the existing predictive service for customers. (2) The agricultural company can provide the platform for commercializing free machine capacity. If the predictive maintenance service indicates that a machine is likely to break down soon, the customer can use the platform to locate available machines with free capacity nearby. Thus, machines can be utilized more efficiently and downtimes can be minimized. (3) The agricultural company could assign upcoming maintenance work to free external service technicians if they are already working at full capacity. In this case, it is important that the maintenance records and data are accessible to the agricultural company to ensure the continuity of the predictive maintenance service.

In order to pursue one of the three proposed approaches, another iteration of the innovation process is required, which is already included in Figure 4.8. The objective of this process is to expand the existing system. This involves analyzing existing resources and adapting or expanding them through recombination if necessary. Additionally, the service ecosystem must be analyzed and requirements identified in relation to the new direction. A pricing and revenue sharing strategy must be developed for the business model, and boundary resources must be established and made available to complementors. Finally, business processes need to be adapted to accommodate the changes. In service system transformation, it is essential to train staff on the changes and implement modified business processes. Additionally, launch and marketing strategies have to be implemented before the formalization of learning completes the service system transformation.

4.2 Contributions to Research and Management

By providing new insights into digital platforms and smart service (eco)systems, and by integrating knowledge from both streams, this dissertation contributes to research and management. The defined research objectives are achieved by developing three kinds of theory: Theory for analyzing (Type I), theory for explaining (Type II), and theory for design and action (Type V) (Gregor, 2006). An overview of the contributions is provided in Figure 4.10.

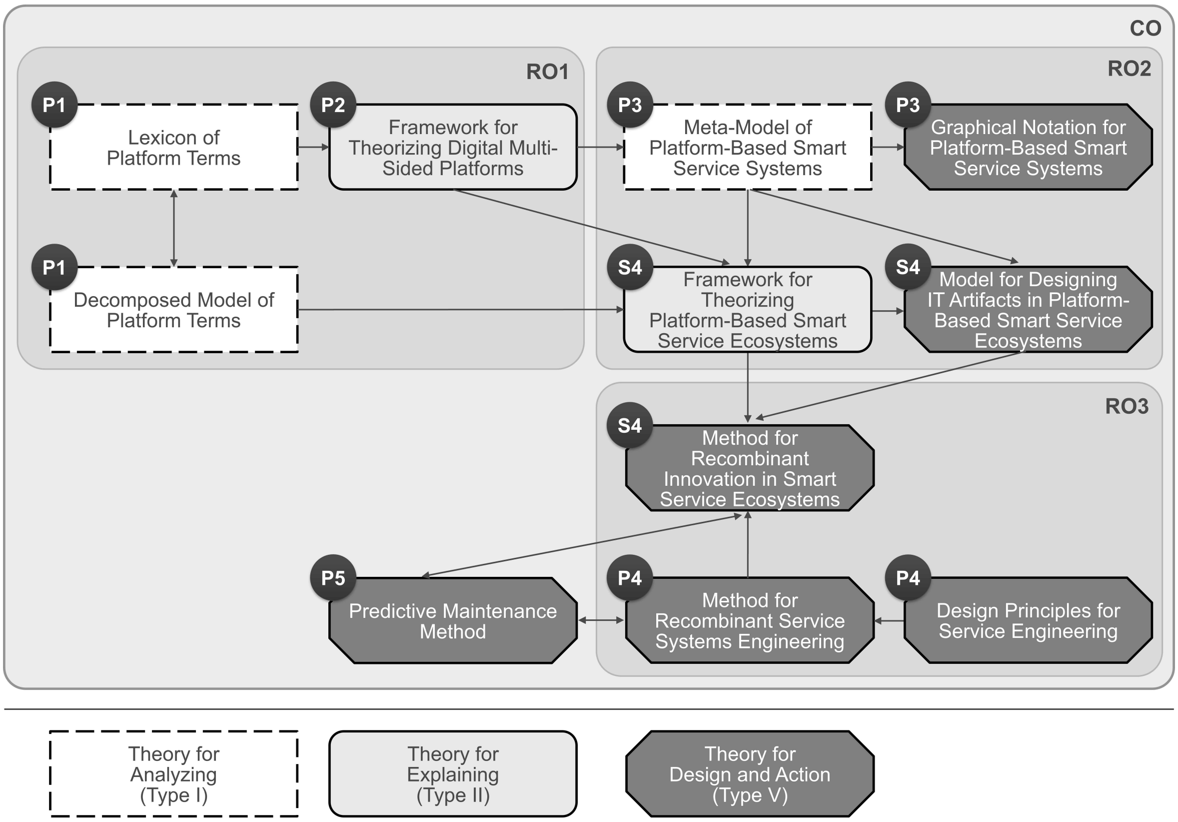

Figure 4.10: Knowledge contributions

The first research objective is achieved by systematizing the concepts and relations that constitute digital platforms and their ecosystems. First, the decomposed model of platform terms developed in P1 provides a theory for analysis (Type I) by structuring these terms hierarchically (Gregor, 2006). Second, by defining each of the platform concepts in the decomposed model based on the current state of knowledge, a lexicon of platform terms is created, providing a further theory for analysis (Type I) (Gregor, 2006). Third, based on an extensive literature research, a framework for theorizing digital platforms is developed. This framework explains the relations and interdependencies between 26 concepts that constitute digital platforms and their ecosystems. Therefore, it provides a theory for explanation (Type II) (Gregor, 2006). These three items answer the call of de Reuver et al. (2018) for clear definitions of platform concepts and reduce the existing ambiguity on what constitutes a digital platform or ecosystem as pointed out by Sørensen et al. (2015). They also facilitate communication among researchers by creating a common vocabulary and defining a structure for positioning their work to improve clarity for peers.

The second research objective is realized by four developed IT artifacts for conceptualizing and designing platform-based smart service ecosystems. First, the framework for theorizing digital multi-sided platforms developed for RO1 was extended in this dissertation by key concepts from service science to provide a conceptualization of platform-based smart service ecosystems. Like the original framework, it presents the relations and interdependencies of concepts in these ecosystems and can therefore be categorized as a theory for explaining (Type II) (Gregor, 2006). Second, a domain-specific modeling language for designing IT artifacts in smart service systems was developed, consisting of a meta-model and a graphical notation. The meta-model represents a theory for analyzing (Type I) by providing a structure for the relevant constructs used in the modeling language (Gregor, 2006). The modeling language, consisting of the meta-model and the graphical notation, is completed with an additionally developed model for designing IT artifacts in platform-based smart service ecosystems. Together, these IT artifacts represent a theory for design and action (Type V) (Gregor, 2006).

The meta-model and the framework for theorizing platform-based smart service ecosystems bridge the two previously separate research streams on digital platforms and (smart) service systems and provide an integrated perspective. This integration adds fundamental knowledge on the co-creation of value and presents interdependencies with main concepts from research on digital platforms. In contrast to the strategic options for industrial companies to transform themselves into platform providers presented by Beverungen et al. (2021), the framework developed in this thesis contains a multitude of relevant concepts and interdependencies that are relevant for both perspectives, that of the platform provider and that of the contributors.

The third research objective is accomplished by developing an agile method for recombinant innovation in smart service ecosystems. To reach this goal, first, a method for recombinant service systems engineering was developed based on four defined design principles in P4. This method was subsequently extended to include design elements from the framework for theorizing smart service ecosystems in order to adapt the focus of the method. The developed design principles and methods provide a theory for design and action (Type V) (Gregor, 2006). To the best of my knowledge, the developed method is the first one that explicitly builds upon recombinat innovation and includes the design of elements of a platform ecosystem. Additionally, it is applicable for innovation by platform providers and contributors and includes a technology- and a market-oriented perspective, as proposed by Schreieck et al. (2016).

All developed IT artifacts contribute to the central objective of this thesis by fostering the understanding of platform-based smart service ecosystems, enabling and guiding recombinant innovation in these ecosystems. Both the developed method for recombinant innovation and the modeling language are demonstrated in the case of a predictive maintenance service of an agricultural company. Thus, the overall research objective is achieved by developing a theory for analyzing, a theory for explaining, and, based on that, a theory for design and action (Gregor, 2006).

This dissertation also provides managerial contributions, in particular for industrial companies that are planning to innovate in digital or smart service (eco)systems. The framework for theorizing platform-based smart service ecosystems provides a comprehensive foundation for understanding interdependecies in platform-based smart service ecosystems, comprising technical and economic aspects, as well as the interactive nature of value co-creation processes. Companies can use this framework as a starting point for further investigating relevant aspects, that are widely researched in various disciplines. Additionally, they can understand, which factors can be designed or influenced directly and which only indirectly. By focusing on the layer *platform as an information system*, the framework is also applicable in closed platforms that can be used in traditional pipeline business models. In this case, the platform can be realized as an IoT platform or an application platform, which is only accessible to selected users and partners. Based on these closed platforms, companies can choose one of the three strategic options to open the platform for additional actors as described in Beverungen et al. (2021).

The method for recombinant innovation in platform-based smart service ecosystems guides industrial companies in the design and implementation of smart service (eco)systems. It addresses all relevant aspects for the design of smart service systems and, optionally applicable, for platform-based solutions. During this innovation process, the developed domain-specific modeling language can be applied for the design, analysis of the developed service and platform concept. Thus, the model of the smart service system supports developing and integrating complex socio-technical systems, identifying and defining interfaces, and making design decisions while considering the whole service system. Additionally, it can be used for efficient and unambiguous communication among the various stakeholders that are involved in the innovation process.

4.3 Outlook

This dissertation provides new and innovative theory on recombinant innovation in platform-based smart service ecosystems. While the framework for theorizing platform-based smart service systems contains a multitude of concepts from research on digital platforms and service science, the interdependencies between these concepts are not specified in detail. Our literature review revealed that many of these concepts are already being researched, some also from different perspectives. However, usually, only dependencies and interactions between individual concepts are examined, but a holistic view is still missing and can ideally be achieved through long-term empirical studies.

Another avenue for researchers could be to add different perspectives to the framework. On the one hand, it is possible to investigate which aspects and dependencies are of particular importance at specific points in the evolution of a platform. To do this, it is first necessary to identify certain stages of evolution so that these can subsequently be examined in more detail. In this context, it is also of interest whether certain stages occur for all digital platforms or only for certain types. On the other hand, the question arises of whether all concepts are relevant for all types of multi-sided platforms or which concepts are of particular importance for specific platform types.

The method developed for recombinant innovation in platform-based smart service systems was designed using a variety of approaches for service engineering. In addition, tasks based on the framework for theorizing platform-based smart service systems were added. Although the developed method was conceptually demonstrated in this dissertation, a thorough empirical evaluation is still outstanding. Researchers could address this point and iteratively apply the developed method, analyze the results, and adapt the method if required.

Finally, while industrial companies are the obvious choice for the development and implementation of (platform-based) smart service, the underlying conditions for these companies need to be better researched and considered in theory. For example, existing business relationships and processes result in requirements for supply chains that may not be fulfilled on digital platforms (Matzner et al., 2021). It is therefore necessary to investigate, which transformation steps are required for incumbent industrial companies to successfully participate in a digital platform. In this case, too, empirical studies are required to obtain the required knowledge.

Part B
Included Publications

P1 Systematizing the Lexicon of Platforms in Information Systems: A Data-Driven Study

Title	**Systematizing the Lexicon of Platforms in Information Systems: A Data-Driven Study**	
Publication Type	Journal Article	
Publication Outlet	Electronic Markets	
VHB Ranking	JOURQUAL3: B	Rating 2024: B
Status	Published	
	Name	**Contribution**
Authors	Christian Bartelheimer	30%
	Philipp zur Heiden	30%
	Hedda Lüttenberg	30%
	Daniel Beverungen	10%
Full Citation	C. Bartelheimer, P. zur Heiden, H. Lüttenberg, and D. Beverungen 2022. "Systematizing the lexicon of platforms in information systems: a data-driven study," *Electronic Markets* (32:1), pp. 375–396. (doi: 10.1007/s12525-022-00530-6).	

Table P1.1: Fact sheet of Publication P1

P2 Three Layers of Abstraction—A Conceptual Framework for Theorizing Digital Multi-sided Platforms

Title	**Three Layers of Abstraction—A Conceptual Framework for Theorizing Digital Multi-sided Platforms**	
Publication Type	Journal Article	
Publication Outlet	Information Systems and e-Business Management	
VHB Ranking	JOURQUAL3: C	Rating 2024: C
Status	Published	
	Name	**Contribution**
Authors	Martin Poniatowski	45%
	Hedda Lüttenberg	40%
	Daniel Beverungen	10%
	Dennis Kundisch	5%
Full Citation	M. Poniatowski, H. Lüttenberg, D. Beverungen, and D. Kundisch 2022. “Three layers of abstraction: a conceptual framework for theorizing digital multi-sided platforms,” *Information Systems and e-Business Management* (20:2), pp. 257–283. (doi: 10.1007/s10257-021-00513-8).	

Table P2.1: Fact sheet of Publication P2

P3 PS^3—A Domain-specific Modeling Language for Platform-based Smart Service Systems

Title	**PS^3—A Domain-specific Modeling Language for Platform-based Smart Service Systems**	
Publication Type	Conference Proceedings, Full Research Paper	
Publication Outlet	International Conference on Design Science Research in Information Systems and Technology (DESRIST)	
VHB Ranking	JOURQUAL3: C	Rating 2024: B
Status	Published	
	Name	**Contribution**
Authors	Hedda Lüttenberg	100%
Presentation	Hedda Lüttenberg	100%
Full Citation	H. Lüttenberg 2020. "PS^3—A Domain-specific Modeling Language for Platform-based Smart Service Systems," in *Proceedings of the 15th International Conference on Design Science Research in Information Systems and Technology (DESRIST)*, Kristiansand, Norway, pp. 438–450.	

Table P3.1: Fact sheet of Publication P3

P4 Recombinant Service Systems Engineering

Title	**Recombinant Service Systems Engineering**	
Publication Type	Journal Article	
Publication Outlet	Business & Information Systems Engineering	
VHB Ranking	JOURQUAL3: B	Rating 2024: B
Status	Published	
	Name	**Contribution**
Authors	Daniel Beverungen Hedda Lüttenberg Verena Wolf	40% 30% 30%
Presentation	Hedda Lüttenberg Verena Wolf	50% 50%
Full Citation	D. Beverungen, H. Lüttenberg, and V. Wolf 2018. "Recombinant Service Systems Engineering," *Business & Information Systems Engineering* (60:5), pp. 377–391. (doi: 10.1007/s12599-018-0526-4).	
Previous Version	D. Beverungen, H. Lüttenberg, and V. Wolf 2017a. "Recombinant Service System Engineering," in *Proceedings of the 13th International Conference on Wirtschaftsinformatik (WI2017),* J. M. Leimeister and W. Brenner (eds.). St. Gallen, Switzerland, pp. 136–150.	
Awards	Best Paper Nominee	

Table P4.1: Fact sheet of Publication P4

P5 Designing Predictive Maintenance for Agricultural Machines

Title	**Designing Predictive Maintenance for Agricultural Machines**	
Publication Type	Conference Proceedings, Full Research Paper	
Publication Outlet	European Conference on Information Systems (ECIS)	
VHB Ranking	JOURQUAL3: B	Rating 2024: A
Status	Published	
	Name	**Contribution**
Authors	Hedda Lüttenberg Christian Bartelheimer Daniel Beverungen	60% 30% 10%
Presentation	Christian Bartelheimer	100%
Full Citation	H. Lüttenberg, C. Bartelheimer, and D. and Beverungen 2018. "Designing Predictive Maintenance for Agricultural Machines," in *Proceedings of the Twenty-Sixth European Conference on Information Systems (ECIS)*, Portsmouth, UK, Paper 153.	

Table P5.1: Fact sheet of Publication P5

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