PROTOTYPING FOR SMART SERVICES

Investigation of data-driven value prototypes as an approach for requirements elicitation in the early development stages

Dissertation

zur Erlangung des akademischen Grades
Doktoringenieur (Dr.-Ing.)

vorgelegt der Fakultät für Elektrotechnik und Informationstechnik
Technische Universität Ilmenau

von M. Sc. Tobias Wienken
geboren am 27. September 1983 in Augsburg

Gutachter*innen: Prof. Dr. phil. Heidi Krömker
Prof. Dr. oec. habil. Ulrike Stopka
Prof. Dr. Jan Ehlers

Tag der Einreichung: 08.07.2021
Tag der wissenschaftlichen Aussprache: 25.04.2022

DOI: 10.22032/dbt.56739
URN: urn:nbn:de:gbv:ilm1-2022000579

ABSTRACT

To create smart services, intelligence - like awareness and connectivity - must be built into the products so that the service can collect and analyse data in real time and provide the information in the user interface (Allmendinger & Lombreglia 2005, Wünderlich et al. 2015). This emerging service era is shaped by new characteristics that pose challenges to the requirements elicitation (Lim et al. 2018b). A promising approach to address these challenges is prototyping. In disciplines such as product design, current innovation research recommends the use of prototypes in the early development phases to create radical innovations (vgl. Haines-Gadd et al. 2015, Leifer & Steinert 2011, Jensen et al. 2017). Motivated by these studies, the current thesis explores how prototypes can contribute to requirements elicitation for smart services in the early development phases.

At the beginning, the literature review revealed that the understanding of smart services varies from discipline to discipline, and that existing models and frameworks only rudimentarily address prototyping issues. As the basis for further research, a layer model was introduced that systematically describes the structure of smart services, and additionally the relevant dimensions for the composition of smart service prototypes were derived.

The second step was to explore what effect have prototypes on the elicitation of unknown requirements in smart services. The conducted multi-case study with 17 prototypes revealed that the existing approaches for prototype design are not able to capture the complex nature of data-based value creation in a target-oriented way. In contrast, a new identified prototyping approach showed to be particularly effective. The data-driven value prototypes uncover the mechanism of how value is created through data. The prototypes use the data value chain to demonstrate how activities and resources work together to create value, from data collection to use of a service.

In the third step, an empirical study with 48 tests compared the new approach with a traditional prototyping technique. The results demonstrated the improved effectiveness for requirements elicitation through the use of the data-driven value prototype.

With this contribution, the data-driven value creation will be introduced as a mindset in prototyping to rethink requirements elicitation in the early development phases.

ABSTRACT DEUTSCH

Um Smart Services zu entwickeln, muss Intelligenz - wie Kontextsensitivität und Konnektivität - in die Produkte eingebaut werden, so dass die Services die Daten in Echtzeit sammeln und analysieren und die Informationen in einer Applikation bereitstellen können (Allmendinger & Lombreglia 2005, Wünderlich et al. 2015). Diese aufkommende Dienstleistungsära ist geprägt von neuen Charakteristika, die die Anforderungserhebung vor Herausforderungen stellt (Lim et al. 2018b). Ein vielversprechender Ansatz zur Bewältigung dieser Herausforderungen ist das Prototyping. In Disziplinen, wie dem Produktdesign, empfehlen aktuelle Forschungen den Einsatz von Prototypen in den frühen Entwicklungsphasen, um radikale Innovationen zu generieren (vgl. Haines-Gadd et al. 2015, Leifer & Steinert 2011, Jensen et al. 2017). Motiviert durch diese Studien wird in der vorliegenden Arbeit erforscht, wie Prototypen zur Anforderungserhebung bei Smart Services in den frühen Entwicklungsphasen beitragen können.

Eingangs zeigte die Literaturrecherche, dass das Verständnis von Smart Services von Disziplin zu Disziplin variiert und die bestehenden Modelle und Frameworks nur rudimentär Fragestellungen des Prototypings adressieren. Als Grundlage für die weitere Forschung wurden ein Schichtenmodell eingeführt, dass die Struktur von Smart Services systematisch beschreibt, und zusätzlich die relevanten Dimensionen für die Zusammenstellung von Smart Service Prototypen abgeleitet.

Im zweiten Schritt wurde erforscht, welchen Effekt haben Prototypen auf die Erhebung von unbekannten Anforderungen bei Smart Services. Die durchgeführte Multi-Case-Studie mit 17 Prototypen zeigte, dass die existierenden Ansätze in der Prototypengestaltung nicht in der Lage sind, die komplexe Natur der datenbasierten Wertschöpfung zielgerichtet abzubilden. Im Gegensatz dazu erwies sich ein neu identifizierter Prototyping-Ansatz als besonders effektiv. Die Data-Driven Value Prototypes verdeutlichen den Mechanismus, wie durch Daten Wert geschaffen wird. Die Prototypen nutzen die datenorientierte Wertschöpfungskette um aufzuzeigen, wie Aktivitäten und Ressourcen zusammenwirken und Wert schaffen, von der Datenerfassung bis zur Nutzung einer Dienstleistung.

Im dritten Schritt wurde der neue Ansatz in einer empirischen Studie mit 48 Tests mit einer traditionellen Prototyping-Technik verglichen. Die Ergebnisse belegten die verbesserte

Effektivität in der Anforderungserhebung durch den Einsatz der Data-Driven Value Prototypes.

Mit diesem Beitrag soll die datenorientierte Wertschöpfung als Denkweise in das Prototyping eingeführt werden, um die Anforderungserhebung in den frühen Entwicklungsphasen neuzudenken.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Problem and motivation

Smart, connected services have unleashed a new era of competition and transform the companies (Porter & Heppelmann 2014, Porter & Heppelmann 2015). They are changing the nature of traditional products and also disrupting value chains (Porter & Heppelmann 2014). Using data from people and things, smart services co-create value between customers and providers based on a connected network, data collection, context-aware computation, and wireless communications (Lim & Maglio 2019). This emerging set of characteristics in smart services confronts requirements engineering with challenges, particularly the requirements elicitation (Lim et al. 2018b).

A promising approach to overcome these challenges is prototyping. Results from innovation research show that the use of prototypes can contribute to the elicitation of unknown requirements and radical innovations in the early phases of development (Dow et al. 2010, Leifer & Steinert 2011, Jensen et al. 2017). As Wunderlich et al. (2015) outline in their research agenda "futurizing smart service: implications for service researchers and managers", research on smart services in general is still in its infancy. The need for scientific debate exists equally for the area of smart service prototypes. The concrete lack of knowledge becomes visible through research projects on European as well as on German level. The research project "ProFI - Prototyping for Innovation" (2021) of the German Federal Ministry for Education and Research is representative of these efforts. The project explores the systematic use of prototypes in the early development phases in order to be able to cost-efficiently collect findings on the feasibility or viability of, for example, networked systems such as internet of things (IoT) applications or smart services.

Motivated by these trends, this thesis will examine to what extent prototypes can support the requirements elicitation for smart services in the early development phases.

1.2 Objectives and scope

The main research problem of this thesis is methodical and investigates the use of prototypes as a technique for requirements elicitation in smart services. Smart services are networked objects that are able to sense their own state and environment, enabling real-time data collection, continuous communication and interactive feedback (Wünderlich et al. 2015). This emerging era of services with its new characteristics is largely unexplored in terms of requirements elicitation as well as for prototyping. For this reason, this research is introduced in part A with a broad research question: How can prototypes contribute to the requirements elicitation for smart services in the early development stages? The overall research question is split into three more detailed research questions to review the state of the art and address the existing knowledge gaps. It explores what models exist in the literature that increase the understanding of designers and engineers regarding smart services in order to improve the systematic planning and design of prototypes. It also examines how smart service prototypes can be systematically composed and what strategies for prototype design exist in the literature.

Building on these results, part B investigates the effect of prototypes in requirements elicitation with the following research question: How does the use of prototypes affect the elicitation of unknown requirements for smart services in the early phases of development? The aim is to investigate in detail to what extent the structure of the smart service prototypes and the design of the individual prototype dimensions influence the elicitation of requirements. The effect is measured by the potential of the prototypes to elicit unknown requirements. Within a case study it will be investigated which existing prototyping approaches are useful for the identification of uncertainties and unpredictable details.

The results of the case study reveal that the existing techniques for prototype design do not meet the challenges of smart services. For this reason, data-driven value prototypes are introduced. Data-driven value prototypes are designed to support engineers and designers in the exploration and investigation of smart services in the early stages of development. The multi case study (Part B) conducted in this thesis provides first indications for a possible positive effect in requirements elicitation. However, evidence from a comparative study is missing so far. Motivated by this knowledge gap, part C investigates how the approach of data-driven value prototypes influences the effectiveness of requirements elicitation in the early development phases of smart services compared to an existing prototyping technique.

TABLE 1 |
RESEARCH QUESTIONS IN OVERVIEW

PART	RESEARCH QUESTION	
PART A	**RQ A**	**How can prototypes contribute to the requirements elicitation for smart services in the early development stages?**
	RQ A-I	How can the complex interplay of smart service elements, functions and interactions between providers and users be mapped in a model that supports the systematic creation of prototypes at the same time?
	RQ A-II	What dimensions must a prototype be composed of in order to adequately represent the potential characteristics of smart services?
	RQ A-III	What strategies exist for systematic prototype creation to support requirements elicitation in the early development phases?
PART B	**RQ B**	**How does the use of prototypes affect the elicitation of unknown requirements for smart services in the early phases of development?**
	RQ B-I	How do the elements of the future smart service represented in the prototype affect the elicitation of unknown requirements in the early phases of development?
	RQ B-II	How does the functionality and interactivity of the smart service prototypes and their context affect the elicitation of unknown requirements in the early phases of development?
PART C	**RQ C**	**How does the approach of data-driven value prototypes influence the effectiveness of requirements elicitation in the early development phases of smart services?**

1.3 Structure of the work

FIGURE 1 | THE STRUCTURE OF THE WORK IN OVERVIEW

INTRODUCTION Problem and motivation | objectives and scope

PART A - PROTOTYPES FOR SMART SERVICES: DEFINITIONS AND STRATEGIES

Research question
How can prototypes contribute to the requirements elicitation for smart services in the early development stages?

Research method
Literature research | integrative model building | case-by-case assessment

Results

Smart service model for prototype creation	Composition of smart service prototypes	Strategies for smart service prototypes

PART B - ELICITATION OF UNKNOWN REQUIREMENTS FOR SMART SERVICES: INTRODUCING DATA-DRIVEN VALUE PROTOTYPES AS A NEW APPROACH

Research question
How does the use of prototypes affect the elicitation of unknown requirements for smart services in the early phases of development?

Research method
Literature research | building theories from case study research

Results

Introducing data-driven value prototypes	Principles of data-driven value prototypes	Data-driven value prototypes in practice

PART C - AN EMPIRICAL INVESTIGATION OF REQUIREMENTS ELICITATION: COMPARING THE EFFECTIVENESS OF DATA-DRIVEN VALUE PROTOTYPES

Research question
How does the approach of data-driven value prototypes influence the effectiveness of requirements elicitation in the early development phases of smart services?

Research method
Literature research | comparison of elicitation techniques based on empirical study

Results

Empirical evidence | Data-driven value prototypes have a higher effectiveness in requirements elicitation than the established approach of experience prototypes

CONCLUSION AND FUTURE WORK

1.4 List of publications

Excerpts from this work have been published in books, conference publications, journals, and research reports. A selection of the works is listed in the following table in descending order of publication date.

PUBLICATIONS
Krömker, H., Mayas, C. and Wienken, T. 2021. Human-Computer Interaction in Mobility Systems. In VG Duffy, SL Landry, JD Lee and NA Stanton (Eds.). Springer: Switzerland (in press).
Wienken, T., & Krömker, H. (2020). Strategies for Smart Service Prototypes-Implications for the Requirements Elicitation in the Early Development Stages. In International Conference on Human-Computer Interaction (pp. 331-351). Springer, Cham.
Wienken, T., Ullrich, M., Krömker, H., & Steinert, T. (2019). Digitalisierte Mobilität: Mobilitätsplattformen– Herausforderungen auf dem Weg zum ganzheitlichen Mobilitätsservice. Der Nahverkehr, 37(5).
Wienken, T., & Krömker, H. (2018). Designing for mobility experience-towards an understanding. Mobilität & Kommunikation. Winterwork, Borsdorf.
Wienken, T., & Krömker, H. (2018). Experience maps for mobility. In International Conference on Human-Computer Interaction (pp. 615-627). Springer, Cham.
Wienken, T., Schoppe, C., & Krömker, H. (2017). Auf dem Weg zur Agendaplanung– Weiterentwicklung der Fahrplanauskunft zum Service-System für Mobilität. Der Nahverkehr, 35(9).
Wienken, T., Krömker, H., & Spundflasch, S. (2017). Agenda planning-design guidelines for holistic mobility planning. In International Conference on Human-Computer Interaction (pp. 713-720). Springer, Cham.
Krömker, H., & Wienken, T. (2015). Context elicitation for user-centered context-aware systems in public transport. In International Conference on Human-Computer Interaction (pp. 429-439). Springer, Cham.
Mayas, C., Hörold, S., Wienken, T., & Krömker, H. (2014). One Day in the Life of a Persona–A Framework to Define Mobility Agendas. In Advances in Human Aspects of Transportation: Part III. AHFE Conference (pp. 7516-7523).
Krömker, H., Pöhland, R., Schoppe, C., Weigert, S. & Wienken, T. (2014). ÖPNV als persönlicher Zeitmanager. Der Nahverkehr, 32(10).
Wienken, T., Mayas, C., Hörold, S., & Krömker, H. (2014). Model of mobility oriented agenda planning. In International Conference on Human-Computer Interaction (pp. 537-544). Springer, Cham.

2 PART A - PROTOTYPES FOR SMART SERVICES: DEFINITIONS AND STRATEGIES

2.1 Introduction

Technology has the potential to make users smart and overcome the limited capacities of the human mind (Norman 2014). To exploit the potential, it is important to understand how we can elicit user requirements and design solutions, to move from smart technologies to smart services that add value to users (Norman 2009, Wünderlich et al. 2015). In recent research on radical innovation, development of prototypes holds a considerable role (Haines-Gadd 2015, Leifer & Steinert 2011). In tangible, fast learning cycles, the prototypes can be used to investigate newly emerging user behaviour and preferences and finally convert them into requirements.

Thus, the main objective of this chapter is to investigate how can prototypes contribute to the requirements elicitation for smart services in the early development stages. Based on the fundamental clarification of the concept of smart services, the theoretical section of the article examines the relevance of existing prototype approaches for applying to smart services. The lack of understanding of prototypes in the field of smart services is what motivates the attempt to identify strategies for smart service prototypes. The strategy for prototypes defines the systematic design of the prototype components. The goal is to systematically influence the way participants perceive and interact with the prototype to achieve the desired prototyping aims. Due to the high complexity of smart services, a comprehensive understanding of the nature of smart services is indispensably for the requirements elicitation. By discussing existing models for smart services, the layer model for smart services is introduced (Wienken & Krömker 2020). This model aims to create a common ground, necessary for the understanding and prototyping of smart services in the early development phases. The findings are based on an extensive literature review and a multi-case study. Using case studies from public transport, a structured investigation will be carried out to determine to what extent strategies for prototypes can be transferred to the field of smart services.

2.2 Theoretical background

2.2.1 Current understanding of smart services in research

Smart services go beyond the traditional understanding of services. The term "smart" is thereby assigned to a variety of capabilities or requirements, from connected (Allmendinger & Lombreglia 2005) to context-aware (Lim & Maglio 2019), data-based (Kagermann et al. 2014), intelligent (Wünderlich et al. 2015), and even ubiquitous (Bruhn & Hadwich 2017). A comparison of the origins of the definitions reveals that each discipline has its understanding of smart services and sets its focus (see Table 2).

TABLE 2 |

COMPARISON OF SMART SERVICE DEFINITIONS FROM DIFFERENT DISCIPLINES

AUTHOR	DEFINITION
Allmendinger and Lombreglia 2005 Service Management	Smart services go beyond the kinds of upkeep and upgrades you may be bundling with your products, both in their value to customers and in their cost efficiency to you. To provide them, you must build intelligence - that is, awareness and connectivity - into the products themselves. And you must be prepared to act on what the products then reveal about their use.
Wünderlich et al. 2015 Service Management	A smart service – that is delivered to or, via an intelligent object, that is able to sense its own condition and its surroundings and thus allows for real-time data collection, continuous communication and interactive feedback (Allmendinger & Lombreglia 2005). The intelligent object of a smart service may be associated with an individual customer (e.g. health monitoring), a group of customers (e.g. family home monitoring) or a firm (e.g. monitoring of industrial equipment). Managers can use the information gathered through intelligent objects to improve their service offerings and let customers benefit from customized service features.
Kagermann et al. 2015 Service Engineering	The Smart Service World is centred around the users who employ services in their respective roles as consumers, employees, citizens, patients and tourists. As far as the customer is concerned, smart services mean that they can expect to obtain the right combination of products and services to meet the needs of their current situation, anytime, anywhere. Smart service providers therefore require an in-depth understanding of their users' preferences and needs. This calls for them to intelligently correlate huge volumes of data (smart data) and monetise the results (smart services). To do this, they require data-driven business models. In order to develop these business models, providers need to understand the user's eco system and situational context. This understanding is based on data and its analysis. All the actors in a network collect data.
Lim & Maglio 2019 Service Science	Smart service systems are service systems in which value co-creation between customers, providers, and other stakeholders are automated or facilitated based on a connected network, data collection (sensing), context-aware computation, and wireless communications. These systems enable customers to accomplish their tasks efficiently and effectively. Using data from people and things (e.g., specific objects, processes, and resources) is the key in smart service systems to manage and improve the value co-creation and system operations.

AUTHOR	DEFINITION
Carrubbo et al. 2015 Service Science	Smart service systems can be understood as service systems that are specifically designed for the prudent management of their assets and goals while being capable of self-reconfiguration to ensure that they continue to have the capacity to satisfy all the relevant participants over time. They are principally (but not only) based upon ICT as enabler of reconfiguration and intelligent behavior in time with the aim of creating a basis for systematic service innovation (IfM and IBM. 2007) in complex environments (Basole 2008, Demirkan 2008). Smart service systems are based upon interactions, ties and experiences among the actors. Of course, among these actors, customers play a key role, since they demand a personalized product/service, high-speed reactions, and high levels of service quality; despite customer relevance, indirectly affecting every participating actor, smart service systems have to deal to every other actor's behavior, who's expectations, needs and actions directly affect system's development and future configurations.
Spohrer and Demirkan 2015 Service Science	Smart service systems are ones that continuously improve (e.g., productivity, quality, compliance, sustainability, etc.) and co-evolve with all sectors (e.g., government, healthcare, education, finance, retail and hospitality, communication, energy, utilities, transportation, etc.). […] Because of analytics and cognitive systems, smart service systems adapt to a constantly changing environment to benefit customers and providers. Using big data analytics, service providers try to compete for customers by (1) improving existing offerings to customers, (2) innovating new types of offerings, (3) evolving their portfolio of offerings and making better recommendations to customers, (4) changing their relationships to suppliers and others in the ecosystem in ways their customers perceive as more sustainable, fair, or responsible.

According to the theories of service science, the composition of a system of people, processes, technologies, physical evidence, and other resources is a prerequisite for smart services and thus essential for the creation of value (Maglio et al. 2009). In addition to system thinking, the effects of smartness on value creation are investigated to better understand the nature of smart services and their evolution (Lim & Maglio 2019). In contrast, service engineering explores new technologies and methodologies to improve the scalability (Spohrer et al. 2007). This requires an intensive analysis of the networking of products and services and their technical implementation using integrated platforms (Bullinger et al. 2017). Emphasis is placed on how services are combined on the integrated platforms. The individual service components are no longer orchestrated in a supplier- but rather in a customer-oriented manner (Winter et al. 2012). According to Spohrer et al. (2007), service management deals with the question, how to invest to improve service systems. The focus lies on the investigation of the capabilities of smart services to optimize the value to customers and the cost efficiency for the providers simultaneously.

The comprehensive view into the disciplines helps to understand the diversity of the different approaches. A common capability emphasized by most approaches is the use of data. Based on this observation, services can be described as data-based, where the use of data plays a central role in the creation of value. In the first definition of smart services given by Allmendinger and Lombreglia (2005), they also describe the basic prerequisite for data-driven value creation: „To provide them, you must build intelligence - that is, awareness and connectivity - into the products themselves".

However, the question is still open what exactly makes services smart? The comparison of the disciplines shows that there is a lack of a common understanding. In addition, there also exists a missing knowledge on how to systematically create prototypes for smart services. To approach a common understanding, a perspective from the user-centred design can be used. Following Norman (2013), designers who create modern, complex systems are studying the functionality, handling and interaction between humans and technology. In line with Norman's approach, a model for smart services needs to be identified that addresses the complex interplay of smart service elements, functions and interactions between providers and users, while addressing the concerns of prototyping.

2.2.2 Role of prototypes in requirements elicitation

Creative thinking in the requirements engineering field is crucial to create new visions and discover requirements for future information systems (Robertson 2005, Hoffmann et al. 2005), such as smart services. A starting point for fostering creative thinking in requirements elicitation is the integration of creativity techniques (Nguyen & Shanks 2009). Jensen et al. (2017) consider that the use of prototyping techniques has significant potential to support the elicitation of requirements, especially when it comes to identifying uncertainties and unpredictability. In doing so, the prototype acts as a representative model or simulation of the final system (Warfel 2009). A prototype can be interpreted as an approximation of the product or service along one or more dimensions of interest (Ulrich & Eppinger 2016). In addition to increasing creativity, prototypes pursue three main aims across disciplines. They allow early evaluation of design ideas, help designers to think through and solve design problems, and support communication within multidisciplinary design teams (Beaudouin-Lafon & Mackay 2009).

In contrast to general prototyping research, the investigation of the role of prototypes in requirements elicitation is still in its early stages. In prototyping research, there are several streams that study prototyping and its effectiveness. Previous research has focused mainly on the following areas: Purpose of prototyping, prototyping process, anatomy of prototypes, involvement of users, and domain-specific application.

Above all, Houde and Hill (1997) should be mentioned with their study on the purpose of prototyping. They deal with the question which aspects of a product or service can be manifested by prototypes. They argue that by focusing on the purpose of prototyping, better decisions can be made for the structure of a prototype and its design. Houde and Hill (1997) introduce three fundamental questions: "What role will the artefact play in a user's life? How should it look and feel? How should it be implemented?"

Numerous works are dedicated to the prototyping process. In addition to the process itself, the approaches of rapid prototyping are the dominant topic. Holtzblatt and Beyer (2014) mention, for example, that the primary requirement of the prototyping process is ease and speed of building. Further research work addresses the simultaneous use of several prototypes. According to Dow et al. (2010), parallel prototyping leads to better design results, more divergence, and increased self-efficacy. Furthermore, the design of the prototypes is also being researched. For example, Lim et al. (2008) create with the anatomy of prototypes a fundamental and systematic understanding of the structure and design of prototypes. On this basis, it is investigated which correlations exist between the prototype shape and the results of prototyping. Several examples show how the levels of functionality influence the outcome of a prototypical interaction (cf. Blackler 2009, Hare et al. 2013, Leifer & Steinert 2011). The goal is to demonstrate and measure the possibilities and limitations of a design idea as simply and efficiently as possible. Besides the prototypes themselves, other work focuses on the participatory design approach in prototyping. At the centre of this research is the use of prototypes with the active involvement of users to discover and create new solutions (cf. Sanders 2002). Finally, applied prototyping research is also worth mentioning. In this field, new techniques, such as hybrid prototyping, are particular investigated. Hybrid approaches combine physical prototypes and digital models in virtual reality (Exner et al. 2016). Complementing this, the transfer and application of prototyping approaches to other disciplines, such as service prototyping, is being studied (Blomkvist & Holmlid 2011, Stickdorn et al. 2018).

The discussion of the current state of research shows that prototyping has been increasingly explored in new disciplines in the recent past, such as human-computer interaction and service design. However, there is a lack of understanding of prototyping in the field of smart services. For this reason, the question arises to what extent can existing approaches from other disciplines be transferred to prototyping for smart services?

2.2.3 Composition of prototypes and the existing design approaches

Discussions concerning the design of prototypes are mostly influenced by the approaches of horizontal and vertical prototyping as well as by the debate on fidelity. The motivation behind prototyping is to reduce the complexity of the implementation by eliminating parts of the entire system (Nielsen 1994). Horizontal prototypes reduce the level of functionality and therefore represent the user interface in its breadth. In contrast, vertical prototypes reduce the number of functions and implement the selected features in-depth. Nielsen's concept is complemented by scenario prototypes (Nielsen 1994). To meet the requirements of rapid prototyping, the number of features and the depth of the functional implementation is reduced. As a result, a minimum of the system will be implemented in one scenario, leading to cost and speed benefits.

Another ongoing controversy is how exactly a prototype should represent the final product in form and function. This debate relates to the fidelity of prototypes and discusses whether prototypes must be complete, realistic or reusable to be effective (Rudd et al. 1996). In designing the prototype, the question of costs is always part of the equation. For this reason, the use of low-fidelity prototyping techniques has been emphasized, especially in the early stages of development (Rudd et al. 1996). Although the fidelity approach is helpful for orientation in prototyping, several research results show that the simple distinction between low and high fidelity prototypes can be problematic (Lim et al. 2006, McCurdy et al. 2006). The concept leads to the fact that several aspects of the prototypes are considered in their entirety (McCurdy et al. 2006). Mostly it is not obvious whether the low fidelity refers to the degree of functionality, interactivity or other aspects, for example. McCurdy et al. (2006) demonstrate the effectiveness of a mixed fidelity approach by combining low and high fidelity on different dimensions of the prototype. Lim et al. (2006) also show that besides fidelity, other factors such as the material of the prototypes and the test settings affect the results.

The debate on these approaches is focused on the discussion of methods instead of further analysing the underlying composition of prototypes. According to Lim et al. (2008), there is a deficiency in the fundamental understanding of the prototypes themselves. They describe research in prototyping as a constant attempt to find out what to do with prototypes without understanding what they actually are (Lim et al. 2008). This discourse stresses the distinction between prototypes and prototyping. A prototype is a representative model or simulation of the final system (Warfel 2009). Consequently, this is an approximation of the product along one or more dimensions of interest (Ulrich & Eppinger 2016). Prototyping, on the other hand, is the process of developing such an approximation (Ulrich & Eppinger 2016) and describes the activity of making and utilizing prototypes (Lim et al. 2008).

McCurdy et al. (2006) confirms this view and calls it an oversimplification of the prototypes. The existing approaches to characterize prototypes are too crude to ensure that prototyping resources can be used efficiently and that the prototype provides the desired output. Instead, authors from the discipline of human-computer interaction advocate designing prototypes along various orthogonal dimensions (McCurdy et al. 2006, Arnowitz et al. 2010, Virzi et al. 1996).

From the different approaches, five core dimensions could be extracted for the characterization of the prototype composition: Breadth of functionality, depth of functionality, level of interactivity, level of visual refinement, and level of data model. Besides the discipline of human-computer interaction, authors try to develop dimensions that are valid beyond disciplinary boundaries. Lim et al. (2008) with the "anatomy of prototypes" can be named as representative of these classification efforts. The proposed anatomy of prototypes includes filter dimensions and manifestation dimensions. In analogy to the approaches from human-computer interaction, the filter dimensions consist of appearance, data, functionality, interactivity, and spatial structure. With these dimensions, the designer can focus on certain areas within the design space and exclude other areas that should not be investigated. Also, the cross-disciplinary classification approaches broaden the focus and consider the manifested form of the prototypes (Lim et al. 2008, Exner et al. 2015). Lim et al. (2008) recommend in detail the consideration of material, resolution, and scope as further dimensions.

TABLE 3 |
DIMENSIONS FOR PROTOTYPE DESIGN IN DIFFERENT DISCIPLINES

AUTHOR	DIMENSIONS OF PROTOTYPE	
Arnowitz et al. 2007 Human-computer interaction	Interaction design and navigation model Visual design Editorial content Brand expression System performance/behaviour	
McCurdy et al. 2006 Human-computer interaction	Level of visual refinement Depth of functionality Breadth of functionality Level of interactivity Depth of data model	
Virzi et al. 1996 Human-computer interaction	Breadth of features Degree of functionality Similarity of interaction Aesthetic refinement	
Blomkvist and Holmlid 2011 Service design	Fidelity Representation	
Lim et al. 2008 Transdisciplinary	**Filtering dimension** Appearance Data Functionality Interactivity Spatial structure	**Manifestation dimension** Material Resolution Scope
Extner et al. 2015 Transdisciplinary	Form study Material study Proof of concept Proof of principle Proof of process Proof of function	

In the scientific discussion, however, the question remains open to what extent the discussed dimensions can be transferred to smart service prototypes. Moreover, previous research focuses on the anatomy of the prototypes and how the anatomy changes when the dimensions are consciously influenced. However, the anatomy itself does not instruct engineers and designers how to design prototypes (Lim et al. 2008). This research gap will be investigated with the strategies for prototypes in the present research work.

2.2.4 Research questions

The starting point of the present research is the potential of prototypes in requirements elicitation in early development phases. Motivated by research findings from other disciplines (cf. Leifer & Steinert 2011, Jensen et al. 2017), the aim is to investigate to what extent the use of prototypes can support the requirements elicitation for smart services. For the systematic investigation, the overarching question (RQ A) is concretised in three research questions:

RQ A How can prototypes contribute to the requirements elicitation for smart services in the early development stages?

RQ A-I How can the complex interplay of smart service elements, functions and interactions between providers and users be mapped in a model that supports the systematic creation of prototypes at the same time?

RQ A-II What dimensions must a prototype be composed of in order to adequately represent the potential characteristics of smart services?

RQ A-III What strategies exist for systematic prototype creation to support requirements elicitation in the early development phases?

2.3 Research design

2.3.1 Methods and data basis

The design of the study is structured in three steps to consider the different facets of the research work. In the beginning, a comprehensive literature review is conducted to describe the status quo of research on smart services, prototyping in requirements elicitation, and smart service prototypes. The literature review is conducted for all three detailed research questions (see chapter 2.2.4). The author combines a systematic literature search with a search using the backward snowball method. For the keyword search, the bibliographic databases ACM Digital Library, IEEE Xplore, and Clarivate Web of Science are selected to identify the most relevant published studies. The search is completed with Google Scholar. Here, the analysis of the results is limited to the first 200 results. The Google database is used to find empirical studies as well as identify grey literature. In the second step, the existing models in the literature are compared and assessed to what extent the models are suitable for the needs of smart services and smart service prototypes. Based on these findings, the existing smart service model and the prototype strategies are adapted to the needs of smart service prototypes. The third and final step is a multi-case study. Based on three cases from the public transport sector, a structured investigation is carried out to determine the extent to which the identified prototype strategies can be applied to the field of smart services. The evaluation of the case studies is based on secondary data collected by the author in the context of three projects.

2.3.2 Procedure

TABLE 4 |
RESEARCH PROCEDURE FOR PART A

STARTING POINT	
Research Question	RQ A | How can prototypes contribute to the requirements elicitation for smart services in the early development stages?
STEP I	
Objective	Description of the current state of research
Method	I. Systematic literature research II. Literature research using backward snowball procedure
Data basis	ACM Digital Library | IEEE Xplore | Clarivate Web of Science | Google Scholar
Data collection	I. Search string - Smart service model for prototype creation | Smart service AND prototype* AND (model OR framework) Publication Date: (01/01/2011 TO *) - Composition of smart service prototypes | Smart service AND prototype* AND (composition OR structure OR anatomy) Publication Date: (01/01/2011 TO *) - Strategies for systematic smart service prototype creation | Smart service AND prototype* AND (creation OR design OR build* OR develop* OR strategy) Publication Date: (01/01/2011 TO *) II. Research work for the start of the backward snowball literature review - Smart service model for prototype creation | Lim, C., & Maglio, P. P. (2019). Clarifying the concept of smart service system. Handbook of Service Science, Volume II, 349-376. - Composition of smart service prototypes | Lim, Y. K., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. ACM Transactions on Computer-Human Interaction (TOCHI), 15(2), 1-27. - Strategies for systematic smart service prototype creation | Buchenau, M., & Suri, J. F. (2000). Experience prototyping. In Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques (pp. 424-433). Jensen, M. B., Elverum, C. W., & Steinert, M. (2017). Eliciting unknown unknowns with prototypes: Introducing prototrials and prototrial-driven cultures. Design

	Studies, 49, 1-31. Hutchinson, H., Mackay, W., Westerlund, B., Bederson, B. B., Druin, A., Plaisant, C., ... & Eiderbäck, B. (2003). Technology probes: inspiring design for and with families. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 17-24).
Data analysis	Selection of literature by qualitative analysis of title and abstract of research articles Quality assessment by full-text analysis of the relevant articles Synthesizing the relevant data
STEP II	
Objective	Comparison of existing models, evaluation of suitability for smart services, and adaptation of models
Method	Integrative model building
STEP III	
Objective	Evaluation and description of the models based on case studies
Method	Case-by-case assessment
Data base	Findings from three projects in public transport | Secondary data - Project „DiMo-FuH | Digitale Mobilität - Fahrzeug und Haltestelle“ (Krömker et al. 2018) - Project „Move@ÖV | Intelligentes Dienstleistungssystem Elektromobilität: Mobilitätsdienstleistungen im öffentlichen Verkehr individualisieren, effektiv flexibilisieren und effizient integrieren“ (Schmermbeck et al. 2017) - Project „DynAPSys | Dynamisches Agendaplanungssystem“ (Wienken et al. 2017)

2.4 Results

2.4.1 Smart service model for prototype creation

Ulrich & Eppinger (2016) "define prototype as an approximation of the product along one or more dimensions of interest". For the approach, designers and engineers need a comprehensive understanding of the structure, functions and behaviour of the future system in order to illustrate the complex systems and their interrelationships by means of prototypes (cf. Haberfellner et al. 2002). Prototypes are abstractions and simplifications of reality and therefore only show partial aspects. It is important that the prototypes are sufficiently meaningful regarding the situation and problem, despite the simplification (Haberfellner et al. 2002). For the systematic planning and design of prototypes, the designers and engineers need a stereotypical model of smart services in order to transfer the individual dimensions of the future smart service into the prototype in an appropriate way.

Smart service offerings are enabled by complex service systems (cf. Winter et al. 2012). Maglio et al. (2009) define these systems as configurations of people, processes, technologies, physical evidence, and other resources that enable value co-creation. Due to the high complexity and the still emerging research on smart services in recent years, the issues of prototyping have not been considered in the smart services models so far. Motivated by this, the research investigates to what extent existing models from systematic smart service development can be transferred to prototyping. The literature research reveals models from different disciplines, as example, two models are discussed in detail.

Lim & Maglio (2019) understand smart services as a system "in which value co-creation between customers, providers, and other stakeholders are automated or facilitated based on a connected network, data collection (sensing), context-aware computation, and wireless communications". In an idealized way, a smart service system consists of a triangular relationship between customers, providers, and things (Lim & Maglio 2019). As representatives of the discipline of service science, Lim and Maglio (2019) describe the structure of smart services from the perspective of value creation.

Service engineering, on the other hand, understands smart services as integrated platforms that enable data acquisition, data storage, data analysis, and the design of smart services (Bullinger et al. 2017). The focus here is on the resources required for the provision of services. To structure smart service platforms, Bullinger et al. (2017) divides them into three levels (networked physical level, software-defined level, and service level) and thus provides a basic framework for service production. Across the different levels, smart service offerings can be composed by services, digital services, and intelligent products (cf. Bullinger et al. 2017, Neuhuettler et al. 2017).

Each of the previous models illustrates the structure and complex interrelationships of smart services from an isolated perspective. Lim and Maglio (2019) emphasize value co-creation with their model. Bullinger et al. (2017) focus on service production with a focus on the required resources and their feasibility. Therefore, it is important that a model is sufficiently expressive the situation and problem in prototyping. To support designers and engineers in the systematic creation of smart service prototypes, a model should take on three central tasks.

First, the model should foster understanding of the complex and distributed nature of smart services. The aim is to stimulate systems thinking for smart services. In this way, it should be possible to better understand and design the elements, functions, and dependencies of smart services.

Secondly. The model should help to separate design issues and align prototypes to the purpose of prototyping. Houde and Hill (1997) address this question with their framework "What prototypes prototype". They emphasise that designers and engineers can make better decisions about the type of prototypes to create if they focus on the purpose of the prototype, i.e. what the prototype represents.

Thirdly. The model should help to use prototypes as a filter and thus screens out unnecessary aspects of the product or service that a prototype does not need to explore (Lim et al. 2008). In the article "The anatomy of prototypes" Lim et al. (2008) introduce the so-called filter dimensions. In doing so, prototypes filter the qualities in which designers are interested, without distorting the understanding of the whole (Lim et al. 2008). The decision which aspects to filter out depends on the purpose of prototyping.

As the analysis and the examples of Lim & Maglio (2019) and Bullinger et al. (2017) show, the models promote a general understanding of smart services. However, they hardly address the needs of prototyping and offer limited assistance in the prototype creation for engineers and designers. To overcome this shortcoming, the layer model for smart services is introduced.

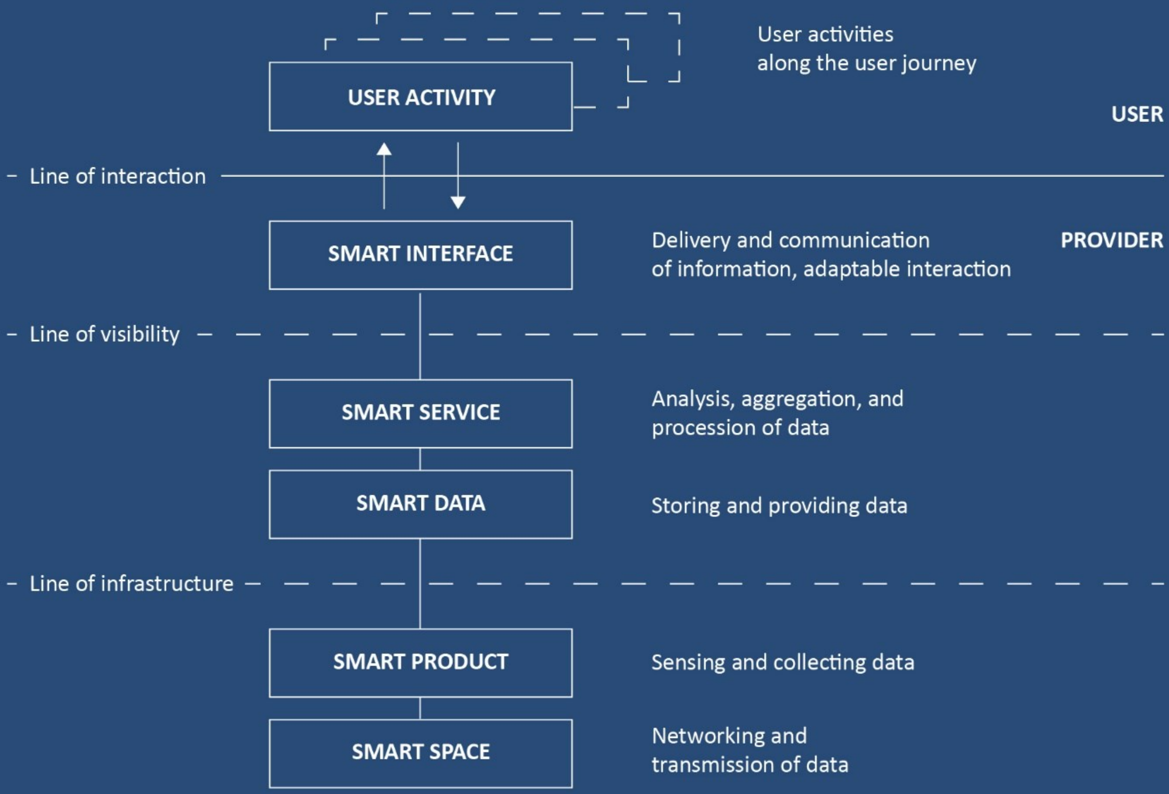
2.4.1.1 Layer model for smart services

The layer model according to Wienken & Krömker (2020), describes the basic structure of smart services in an abstract way. All components and functionalities required for the provision of a smart service are vertically orchestrated. The data processing process of smart services is thus made transparent based on the individual layers. To map the entire process, the "digital infrastructure layer model" according to Kagermann et al. (2014) is extended to five layers: smart space, smart product, smart data, smart service, and smart interface. Thus, the layer model depicts the entire data-based value creation, from the collection of data as raw material, to the analysis and processing of data into information, and finally to the provision of information and the creation of value in use. In this way, it becomes comprehensible which function is provided by the individual layers and how the layers create value in the data processing process.

The horizontal level of the model indicates the sequential character of smart services. As in traditional services, the service process plays a fundamental role in smart services. Lim et al. (2018a) emphasise that the value of data-based services is only created when users actually use the information they received for a specific purpose. Hence, the value of smart services is created when information is used (Lusch & Nambisan 2015, Vargo & Lusch 2004). For this reason, it is important for smart service prototypes not only to depict a punctual interaction, but to map the smart service as a dynamic process that takes place over a certain period of time (cf. Stickdorn 2011). The layer model illustrates the process using the horizontally arranged activities that users conduct along their user journey (see layer smart interface).

FIGURE 2 |

LAYER MODEL FOR SMART SERVICES (WIENKEN & KRÖMKER 2020)



Using the model, the interconnected and data-based nature of smart services can be mapped in a simplified way. At the same time, the layered model for prototyping also illustrates the problem areas and the design space of smart services, layer by layer.

In detail, the model also maps the different prototype categories according to Houde and Hill (1997). Houde and Hill (1997) distinguish three main categories of prototypes: "Role"-prototype investigates how the new solution creates value for users, "look and feel"-prototype explores the user experience and appearance of the solution, and "implementation"-prototype looks at the technical feasibility of the solution.

2.4.1.2 Implementation prototype

From a technological point of view, the realization of a smart service requires a complex structure of different resources. Using the layer model, the interplay between the components and functionalities of a smart service can be made transparent and provides valuable insights for the implementation. For example, in public transport smart services are used to inform passengers in real-time about changed departure times and available seats in the vehicles (cf. Wienken et al. 2017). Buses and trains themselves act as smart products. Via sensors and microprocessors in the vehicles, the required information is transmitted to the control center system. The basic prerequisite for this communication is usually digital radio. It forms an intelligent environment (smart space) in which digitally connectable objects and devices, such as the on-board computers of the vehicles, can be networked. Coupled with smart space, the networked information provider (smart products) is the technical infrastructure and forms the prerequisite for the smart data layer. In the smart data layer, the extracted data is collected, bundled, and evaluated. In the next step, at the service platform level, the data is combined and extended to smart services using context-specific algorithms. Finally, the information is provided to users by the smart interface. For passengers, this means that they can use the passenger information system to request a forecast for departure times and seat occupancy directly from the control system and thus assess whether they will take their bus as planned or look for a more suitable alternative.

2.4.1.3 Value prototype

The value of smart services is created by the direct interaction between users, providers, and smart products. The central element here is the data. By analysing the different actors, components and functionalities along the data transformation process, the direct and indirect contribution to the value of a service can be identified. Using the value creation perspective in the model, it is therefore possible to understand how the data-based value chain is shaped by the data transformation. Continuing the example of public transport, it becomes apparent that the simple data about a delayed departure time from the networked vehicle increases in value if this data is combined with the personal trip route of the passenger and continuously updated.

2.4.1.4 Look and feel prototype

The perspective on look and feel emphasizes the sequential nature of smart services and shows that user perception and feedback depend on the interaction with the provider and technology (see Figure 2 | Line of interaction). Services are dynamic processes consisting of user and provider activities that take place over a certain period (Stickdorn et al. 2011). Shostack (1984) distinguishes between activities visible to the user that directly influence the process and invisible activities in the background that indirectly affect the service (see Figure 2 | Line of visibility). In the so-called backstage area under the line of visibility, a distinction can be made between the physical infrastructure (see Figure 2 | Line of infrastructure), which is the technological prerequisite for networking and the software level.

2.4.2 Composition of smart service prototypes

“A primary strength of a prototype is in its incompleteness“ (Lim et al. 2008). The incompleteness of a prototype makes it possible to explore the qualities of an idea without building a copy of the final solution (Lim et al. 2008). Ulrich and Eppinger (2016) confirm this view and describe a prototype as an approximation of the future solution along one or more dimensions of interest. The intentional design of dimensions can also be used to systematically influence prototyping outcomes. Studies from innovation research, for example, demonstrate how an emphasis on the functionality dimension influences the outcome of a prototype-proband interaction (Blackler 2008, Hare et al. 2013, Jensen et al. 2017). The results suggest that designers and engineers need to have a comprehensive understanding of the nature of smart service prototypes for systematic planning and design.

In the field of smart services, prototyping is an emerging issue. The lack of scientific discourse is the underlying motivation for the investigation of the research question: What dimensions must a prototype be composed of in order to adequately represent the potential characteristics of smart services?

To address the research question, the relevant dimensions for smart service prototypes are derived in three steps:

1. In the first step, the nature of smart services is described and investigated based on the elements, properties and functions of smart services. In this investigation, the established concepts (see Table 2) from various disciplines are taken up and examined.
2. Subsequently, it is examined to what extent these characteristics of smart services can be mapped with the help of the prototype dimensions existing in the literature (see Table 3).
3. Finally, a set of relevant prototype dimensions is composed with the aim of mapping the complex nature of smart services as accurately as possible.

TABLE 5 |

DESCRIPTION OF THE CHARACTERISTICS OF SMART SERVICES (ELEMENTS, ATTRIBUTES, AND FUNCTIONS) FROM THE PERSPECTIVE OF DIFFERENT DISCIPLINES (EXTENSION OF THE **TABLE 2**)

AUTHOR	**SMART SERVICE ELEMENT**	**SMART SERVICE ATTRIBUTE**	**SMART SERVICE FUNCTION**
Allmendinger and Lombreglia 2005 Service management	- Intelligent products - Data points	- Data based - Connective - Context-aware - Proactive - Preemptive user benefits	- Data Digesting - Communication - Controlling
Wünderlich et al. 2015 Service management	- Intelligent objects - Data	- Information based value creation - Connective - Context-aware - Increasing value through customization	- Sensing the state of the object and its surroundings - Real-time data collection - Continuous communication - Interactive feedback
Kagermann et al. 2015 Service engineering	- Users - Combination of products and services - Smart Data - Data-driven business models	- Data based - User centred - Context-aware - Adaptive - Ubiquitous	- Data collection - Data analysis
Lim & Maglio 2019 Service science	- Customers - Providers - Other stakeholders - Things - Data - Information	- Data based - Connective - Context-aware - Automated - System thinking	- Facilitation based on a connected network - Data collection (sensing) - Context-aware computation - Wireless communication - Value co-creation

AUTHOR	SMART SERVICE ELEMENT	SMART SERVICE ATTRIBUTE	SMART SERVICE FUNCTION
Carrubbo et al. 2015 Service science	- Customers - Other actors - Data	- Context-aware - Self-reconfigurable - Interactive - System thinking	- Information processing - Communication
Spohrer and Demirkan 2015 Service science	- Customers - Providers - Data	- Continuously improving - Context-aware - Adaptive - Mutual benefits for customers and providers - System thinking	- Big data analytics - System adaptation - Machine learning

As a result of the analytical derivation, six dimensions could be identified that are potentially relevant for the systematic design of smart service prototypes: Representation, scope, functionality, interactivity, appearance, and data. All dimensions are discussed in detail in Table 6.

Considered individually, each dimension only provides information on how highly developed a characteristic is. For example, is the prototype highly interactive, such as a wizard of oz, or is it an advertisement prototype with almost no interactivity to communicate a product idea. However, designers and engineers must be aware that the conscious design of selected dimensions can significantly influence the probands´ perception regarding the smart services.

In sum, the dimensions together form the shape of the prototype. Lim et al. (2008) call this the "anatomy of prototypes" and emphasise in their discourse that prototypes are not identical to the final solution and can differ significantly. Creating a prototype is about finding the manifestation that filters out the characteristics that the designers and engineers want to explore in the most economical way, without distorting the understanding of the whole smart service (cf. Lim et al. 2008).

TABLE 6 |
DIMENSIONS FOR THE COMPOSITION OF SMART SERVICE PROTOTYPES

DIMENSION	DEFINITION
Representation	The representation indicates how prototypes are presented, what they actually look like and how they are materialized (cf. Blomkvist & Holmlid 2011). Due to its immateriality, the representation in services design focuses on the service encounter to make the intangible parts of service tangible (Stickdorn et al. 2011). In smart services, the interaction takes place in the layer smart interface (see Figure 1), but it can also be relevant to show the physical infrastructure and its relation to the software-based functionalities in the representation of the prototype.
Scope	The scope defines the range of what is covered and manifested within the prototypes (Lim et al. 2008). For smart services, this decision is challenged primarily by the service process and the context awareness of the services. Along the service process, it must be defined which touchpoint and which context of use should be considered in the prototype.
Functionality	The functionality dimension contains the functions that can be simulated by the prototypes. Focusing on this dimension, engineers and designers determine to what level of detail is any one feature or sequence represented (McCurdy et al. 2006).
Interactivity	Interactivity defines how interactive elements are captured in the prototypes and communicated to the users (McCurdy et al. 2006). The focus is on how test persons can interact with the system, e.g. through feedback, input behaviour, operating behaviour and output behaviour (Lim et al. 2008).
Appearance	Appearance can occur in a variety of forms, especially in smart services. Above all, it is the visual refinement that shapes the appearance. For example, digital elements are represented on the low end of the fidelity scale with hand-drawn sketches and in contrast, the high end includes pixel-accurate screen designs. Apart from the visual appearance, the auditory and haptic aspects can also be relevant for the service interface, as well as the spatial context in which the interface appears.
Data	The data dimension defines to what extent data is represented in the prototypes and whether it is real domain data. The data model is relevant for two segments in the case of smart services. On the one hand, it must be decided to what extent real data must be presented to the test persons in the smart interface. On the other hand, it must be defined to what extent real data is relevant for the simulation of data acquisition, transmission and processing in the layers below the line of visibility for the findings of the prototyping.

In summary, it can be stated that the dimensions for smart services represent no concrete design recommendations, but rather a way of thinking that shows the possibilities of the prototype creation. How the individual dimensions can be used strategically to influence prototype-proband interaction is discussed in the next section using various approaches from the literature.

2.4.3 Strategies for smart service prototypes

The quality of a prototype is defined by the information and insights gained with its help. According to this maxim, the prototypes must be designed in such a way that a maximum of new and correct knowledge can be collected. This is where the prototype strategy comes in.

The strategy for prototypes defines the systematic design of the prototype components. The goal is to systematically influence the way participants perceive and interact with the prototype to achieve the desired prototyping aims. In the strategy, the dimensions are consciously selected and designed to provoke responses from the probands. The results of the analysis presented above show that the dimensions representation, scope, functionality, interactivity, appearance, and data are valuable for the design of smart service prototypes.

Despite the emphasis on one dimension, the test persons do not perceive the individual dimensions in isolation, but the probands are influenced by the interplay of all involved dimensions (cf. Rudd et al. 1996). Crucial for the selection of a strategy is the assessment of the test persons. In line with Nielsen's findings in usability engineering (1994), knowledge about the participants and their individual differences can also improve the outcome of a study in the requirements elicitation for smart services. To make a decision, engineers and designers have to ask themselves which strategy will produce the highest quality outcome from the test persons.

Faced with these possibilities, the question arises: What strategies exist for systematic prototype creation to support requirements elicitation in the early development phases? (RQ A-III) In order to answer this research question, the first step is to identify adequate strategies from other design disciplines by means of a literature research. Then, in a second step, possibilities and limitations of the strategies are discussed via a case study.

For the sector of smart services three relevant strategies for prototypes in other design disciplines could be identified: Functional prototypes, experience prototypes, and contextual prototypes. Each strategy has its own focus and therefore influences how the prototype is perceived by the probands.

FIGURE 3 |
A COMPARISON OF STRATEGIES FOR SMART SERVICE PROTOTYPES

	FUNCTIONAL PROTOTYPES	EXPERIENCE PROTOTYPES	CONTEXTUAL PROTOTYPES
PROTOTYPE FOCUS	Structure and Function of the Smart Service	Experience of the Smart Service	Usage Situation of the Smart Service
PROTOTYPE COMPOSITION			
Relevant Dimensions	Functionality Data Model	Interactivity	Scope and Representation (to emphasize the context) Interactivity
IMPACT ON PARTICIPANTS			
Perspective of Analysis	Structure-oriented	Behavioural	Environment-oriented

Level of Immersion

Level of Involvement

	FUNCTIONAL PROTOTYPES	EXPERIENCE PROTOTYPES	CONTEXTUAL PROTOTYPES
REPRESENTATIVE	Prototrial-Driven Culture Jensen et al. (2017)	Experience Prototyping Buchenau and Suri (2000)	Technology Probes Hutchinson et al. (2003) Scenario Prototypes Beaudouin-Lafon and Mackay (2009)

2.4.3.1 Functional prototypes

Traditionally, the functionality of a prototype increases during the design stages with the understanding of the product (Ulrich & Eppinger 2016). However, innovation research in product design that aims to create radical innovations emphasizes the value of different functional prototypes already in the early stages of development (cf. Leifer & Steinert 2011). Jensen et al. (2017) as representatives from product design have developed the prototrials approach for this purpose. Prototrials cover high functional prototypes used in the concept development phases for requirements elicitation, but with low fidelity compared with the final product (Jensen et al. 2017). Exactly this approach is used in the strategy of functional prototypes. According to the name, the dimension functionality is very prominent. Considering the layer model of smart services (see Figure 2), it becomes clear that the layers below the line of visibility are the subject of these prototypes. Besides the software-based functionality in the smart service layer, the dynamic interdependencies and data transformation are also relevant for a functional investigation. This leads to the fact that elements from the layers smart data and smart product are also represented in functional prototypes. Designers and engineers must, therefore, decide which level of fidelity is sufficient for the dimension data in the prototype. Furthermore, the question also arises to what extent a representation of the smart products or a visualization of the data flows is relevant for explaining the functional relationships.

In order to discuss the possibilities and limitations of the functional prototypes, a case from public transport is illustrated. In a research project for public transport, the orientation and navigation within subway stations were investigated from the passengers' point of view. One of the aims was to develop a tool that identifies the right wagon for the passenger according to individual needs when entering the subway (Krömker et al. 2018). In the first step, a prototype was developed to test its feasibility. The object of investigation was the data transmission and processing in real-time as well as whether the identification of a wagon is possible with the beacon technology. The researchers tested the prototype with 15 probands with the aim of eliciting new requirements for further development. The prototype focused on the data exchange between beacon and a rudimentary information display on the smartphone. In addition to the functionality, the data had a high level of fidelity. For the test, real data was exchanged in real-time between the subway wagons and the smartphone. By integrating the wagon and the smartphone into the test, the probands were able to understand the dynamic interrelationships of the smart service. Compared to the final application, the dimensions of interactivity and appearance were hardly pronounced.

The emphasis on the functional dimension leads the test persons to a structure-oriented view of the prototypes. In this way, the probands observe the functional elements of a system and their relationships, whereby the dynamic mechanisms and processes are of particular interest (cf. Haberfellner et al. 2002). The focus is on how the functions are used to generate value for the user. Due to the concentration on the functional aspects, these prototypes have a significant demonstration character and only a low potential for immersion and involvement for the proband during the prototyping session.

2.4.3.2 Experience prototypes

By the term "experience prototype" Buchenau and Suri (2000) mean to emphasize “the experiential aspect of whatever representations are needed to successfully (re)live or convey an experience with a product, space, or system”. The objective of the experience prototypes is the discovery of the probands' user experience. Based on the perceptions and responses of a test person resulting from the use of the system (cf. International Standards Organization 2010), new insights are generated for service development. The interaction of the test persons with the system is used as the central stimulus for the emergence of the user experience. Considering the experience prototypes in the layer model (see Figure 2), it becomes clear that these prototypes concentrate on the smart interface layer. Experience prototypes can be described using the technique wizard of oz. While a test person interacts with a system that feels real, an engineer or designer simulates the system in the background (cf. Kelley 1984). The goal is to create a high degree of interactivity while maintaining low functionality in the prototype at the same time. The focus is on the dialogue between user and provider, which is made tangible through user inputs and system feedback. In service prototyping, there are special requirements due to the characteristics of the services. Stickdorn et al. (2011) therefore stresses that intangible services should be visualised in terms of physical elements. In general, the immaterial character of smart services is further reinforced. The reason for this is that interaction in smart service is characterized by automation and implicit interactions, which are fostered by adaptivity and context awareness. As a result, users perceive only a fraction of the activities of a smart service. The majority of the activities are carried out in the backstage that is not visible to the user (see Figure 2). For this reason, experience prototypes face the challenge to make the interaction tangible for the probands using the dimension representation. Another challenge for experience prototypes is the sequential nature of smart services. Stickdorn et al. (2011) recommends that the service should be visualised as a sequence of interrelated activities. For the prototype, this means that within the dimension scope all touchpoints along the user journey should be checked for relevance to the prototype. The focus on interaction promotes the behavioural analysis of the prototypes. The probands are primarily concerned with system behaviour and the generation of value creation during use, rather than focusing on internal, functional relationships. Furthermore, the interactive character of the experience prototypes promotes active participation (Buchenau & Suri 2000) and the immersion of the probands in the test scenario.

Figure 4 shows a LEGO serious play prototype, which was carried out in combination with the technique desktop walkthrough. The aim of this experience prototype was to discover new requirements in the early phases of a research project within the first study with six test persons. The project explored the networking of local public transport and car-sharing with electric vehicles in a digital mobility platform (Schmermbeck et al. 2017).

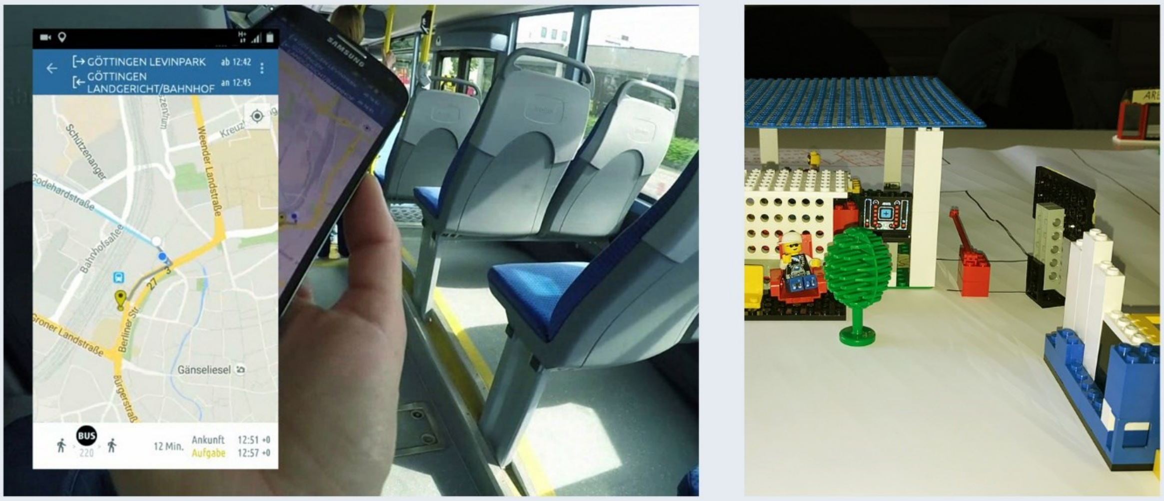


FIGURE 4 |

EXAMPLE OF A CONTEXTUAL PROTOTYPE EXPLORING AGENDA PLANNING AS A NEW APPROACH TO MOBILITY PLANNING IN A FIELD TEST (LEFT). & EXAMPLE OF AN EXPIERENCE PROTOTYPE THAT INVESTIGATES THE NETWORKING OF PUBLIC TRANSPORT WITH CAR-SHARING IN A DIGITAL MOBILITY PLATFORM (RIGHT).

Concretely, the process, as well as the interaction at the charging station and in the vehicles was investigated. The basic structure for the session was defined using the desktop walkthrough method. Along the user journey, the test persons visited selected touchpoints, which became tangible elements for the test persons in the form of LEGO objects. At the individual touchpoints, interactions with the digital platform were simulated using paper prototypes to capture the mobility experience of the travel chain (cf. Wienken & Krömker 2018).

2.4.3.3 Contextual prototypes

"Context … characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between an user and an application" (Abowd et al. 1999). Contextual prototypes thus emphasize the situation in which the system is applied. At the same time, they take the context of use as a stimulus for the test persons in the prototyping session. Beaudouin-Lafon and Mackay (2009) use the term "scenario prototypes" in this context and stress that prototypes are used in a more realistic scenario to simulate the system under real conditions. Hutchinson et al. (2003) went one step further with their technology probes approach. Technology probes are simple, flexible, adaptable technologies that combine the social science goal of collecting information about the use and the users of the technology in a real-world setting (Hutchinson et al. 2003). Contextual prototypes use the realistic representation of the usage situation as a stimulus for the participants in the prototyping session. Consequently, when constructing the prototype, the usage context within the scope dimension must be considered in addition to the interaction at the touchpoint. Bittner (1992) speaks in this context of servicescapes and mentions the possible factors influencing the user experience: Ambient conditions, spatial layout and functionality, signs, symbols, and elements as well as service typology, and environmental dimensions.

Due to the context awareness of smart services, contextual prototypes play a double role and contribute to clarify two questions. First, they provide information on how the context can hinder or improve the usage and experience of smart services. In this case, the focus of the prototypes lies on interactivity in combination with the representation to enable realistic interactions. Secondly, contextual prototypes offer the potential to understand how collected data from the usage context can contribute to the value generation of smart services. In doing so, no high fidelity in the dimensions data and functionality is required, but rather the logic of the system behaviour in the usage situation must be simulated. Both points lead to the fact that the participants analyse the prototypes from an environment-oriented perspective. The test persons perceive the external factors from the usage situation and their influence on the prototypes. Due to the real-world setting, a high level of immersion is generated among the probands during the prototyping session.

Figure 4 shows an example of a contextual prototype from a mobility research project. The project explored the agenda planning as a new mobility planning approach (cf. Wienken et al. 2017). In this study with 25 test persons, it was examined how, for example, changed opening hours of shops and the current seat occupation of vehicles can be integrated into a digital trip planning application. The aim was to identify new requirements in the early development phases. The prototype included a rudimentary digital smartphone application that could be used in the local bus and train network. When composing the prototype, the focus was on interactivity and the usage context. It was important that all participants could perform their tasks independently in real-life usage situations.

2.5 Discussion | Contribution to requirements elicitation for smart services

The strategies for prototypes define the composition of prototypes and thus systematically influence the way a prototype is perceived by the probands. They constitute the missing link between the dimensions of a prototype and the targeted outcome. Based on the presentation of the strategies and the case study carried out, the author sees two major contributions to requirements elicitation in the early development phases.

First, the strategies provide a critical thinking approach. The strategies can be used to better predict in advance of the requirements elicitation how a prototype will affect the test persons and which results can be achieved as outcome. The designers and engineers can thus better understand which features are important for prototyping in requirements elicitation. Furthermore, the strategy is the consequent continuation of the economic principle of prototyping: „The best prototype is one that, in the simplest and the most efficient way, makes the possibilities and limitations of a design idea visible and measurable" (Lim et al. 2008). By means of the outcome-oriented analysis, it opens up a possibility to assess in advance to what extent the effort for prototyping is cost-effective. Secondly, the strategies provide a guideline for the creation of prototypes in requirements elicitation. Following the example of a pattern language (cf. Alexander 1977), the strategies provide designers and engineers a kind of pattern for the composition of the different prototype dimensions. On the other hand, in conjunction with the layer model of smart services, the strategies show which dimensions are relevant for the investigation of the different layers.

As a limitation, it must be noted that the strategies are a mindset for the composition of prototypes for smart services. The strategies do not contain concrete recommendations for the efficient use of prototype resources in economic terms. This requires controlled and detailed studies to prove the effect of single dimensions on the outcome of prototyping (cf. Hare et al. 2013, Lim et al. 2006, Sefelin et al. 2003). Furthermore, the three strategies for smart service prototypes are only a selection. Although the various strategies have proven themselves in practice, they have their origins in other design disciplines. The question remains unanswered whether new strategies are better suited for requirements elicitation in the early development phases. With novel approaches, the complex structure of smart services could be addressed more precisely. One possible approach would be to focus on data-driven value creation, for example.

2.6 Conclusion

In this article the question is investigated, how prototypes can contribute to the requirements elicitation for smart services in the early development stages. Within an extensive literature review, the current state of science was analysed and knowledge gaps in the creation of smart service prototypes were identified. Towards the systematic creation of smart service prototypes, three initial fields of action were identified. First, the findings reveals that the understanding of smart services varies from discipline to discipline and that the existing models address only rudimentary prototyping issues. To overcome this shortcoming, the author introduces the layer model of smart services (Wienken & Krömker 2020) and build the foundation for the systematic investigation and creation of smart service prototypes. The layer model demonstrates that five layers with different functionalities are required for the provision of smart services and that a conscious focus must take place every time a prototype is created. Secondly, according to Ulrich and Eppinger (2016), designers generally use a prototype to create an approximation of the future product or service along one or more selected dimensions of interest. For smart services, the question arises: What dimensions must a prototype be composed of in order to adequately represent the potential characteristics of smart services? For the composition of smart service prototypes, six relevant dimensions could be identified: Representation, scope, functionality, interactivity, appearance, and data. Finally, the third field of action showed which strategies exist in the literature to systematically design the dimensions of a prototype. The goal is to systematically influence the way participants perceive and interact with the prototype to achieve the desired prototyping outcomes. For smart services, the authors identify three relevant strategies in related design disciplines: Functional prototypes, experience prototypes, and contextual prototypes. The relevance of the defined strategies is reviewed and illustrated by case studies from the mobility sector.

Overall, the research highlighted a general lack of knowledge about the systematic design of smart service prototypes and indicated for both academia and practice that the "anatomy" of prototypes needs to be more aligned with the data-based characteristics of smart services.

STRUCTURE OF THE WORK - PART B

INTRODUCTION Problem and motivation | objectives and scope

PART A - PROTOTYPES FOR SMART SERVICES: DEFINITIONS AND STRATEGIES

Research question
How can prototypes contribute to the requirements elicitation for smart services in the early development stages?

Research method
Literature research | integrative model building | case-by-case assessment

Results

- Smart service model for prototype creation
- Composition of smart service prototypes
- Strategies for smart service prototypes

PART B - ELICITATION OF UNKNOWN REQUIREMENTS FOR SMART SERVICES: INTRODUCING DATA-DRIVEN VALUE PROTOTYPES AS A NEW APPROACH

Research question
How does the use of prototypes affect the elicitation of unknown requirements for smart services in the early phases of development?

Research method
Literature research | building theories from case study research

Results

- Introducing data-driven value prototypes
- Principles of data-driven value prototypes
- Data-driven value prototypes in practice

PART C - AN EMPIRICAL INVESTIGATION OF REQUIREMENTS ELICITATION: COMPARING THE EFFECTIVENESS OF DATA-DRIVEN VALUE PROTOTYPES

Research question
How does the approach of data-driven value prototypes influence the effectiveness of requirements elicitation in the early development phases of smart services?

Research method
Literature research | comparison of elicitation techniques based on empirical study

Results

- Empirical evidence | Data-driven value prototypes have a higher effectiveness in requirements elicitation than the established approach of experience prototypes

CONCLUSION AND FUTURE WORK

3 PART B - ELICITATION OF UNKNOWN REQUIREMENTS FOR SMART SERVICES: INTRODUCING DATA-DRIVEN VALUE PROTOTYPES AS A NEW APPROACH

3.1 Introduction

Smart, connected services have unleashed a new era of competition and transform the companies (Porter & Heppelmann 2014, Porter & Heppelmann 2015). They are changing the nature of traditional products and also disrupting value chains (Porter & Heppelmann 2014). Using data from people and things, smart services co-create value between customers and providers based on a connected network, data collection (sensing), context-aware computation, and wireless communications (Lim & Maglio 2019). This emerging set of characteristics in smart services confronts requirements engineering, and in particular requirements elicitation, with challenges (Lim et al. 2018b).

Current research is therefore investigating the suitability of methods for requirements elicitation in smart services (Lim et al. 2018b, de Souza et al. 2019, Paldês et al. 2020). The focus here is primarily on the comparison of traditional methods. The use of creative techniques is still in its infancy. Creative techniques, such as prototypes, are not used in design and development processes to prove solutions, but to discover problems or explore new solutions and their requirements (Lim et al. 2018b). Sutcliffe and Sawyer (2013) emphasises for software engineering that creative approaches such as prototypes unfold their potential especially in requirements elicitation in green field developments. Furthermore, in recent product development research, rapidly developed and tangible prototypes play a significant role in the development of innovative solutions (Marion & Simpson 2009, Leifer & Steinert 2011, Haines-Gadd et al. 2015, Jensen et al. 2017).

Inspired by the findings in related disciplines, this paper explores the benefits and challenges of using prototypes in requirements elicitation for smart services. The focus of the investigation is on the early development phases.

The structure of this research is as follows: First, the research framework is set out by highlighting which dimensions influence the outcome of a prototype interaction and how prototypes currently try to map smart service characteristics. To complete the theoretical foundations, the status quo is presented, how can prototypes contribute to the elicitation of unknown requirements. This is the starting point for a explorative multi-case study, in which a comprehensive understanding of the effective use of prototypes in requirements elicitation for smart services is developed. In the study, eleven interviews with experts in smart service prototyping are conducted and 17 prototypes are extracted as a data basis for the multi-case study. The analysis compares existing approaches for prototype design and maps the performance of the prototypes in relation to the elicitation of unknown requirements. The comparison reveals the data-driven value prototypes as a new approach for the design of smart service prototypes. The data-driven value prototypes emphasise the potential of data for value creation and make data processing and data-based value creation within smart services tangible. The study concludes with the classification of data-driven value prototypes with regard to existing approaches and discusses their relevance for the domain of smart services.

3.2 Theoretical background

3.2.1 Prototypes and the relevance of functionality, interactivity, and context

A prototype is a representative model built to test an idea (Blacker 2019, Lim et al. 2008). According to Ulrich and Eppinger (2016), designers use a prototype to create an approximation of the future product or service along one or more selected dimensions. In the conception and design of prototypes, designers can use different approaches to generate the maximum amount of new insights. The most common prototyping approaches are: Functional prototyping, experience prototyping, and contextual prototyping. The individual approaches emphasise single dimensions, such as functionality, interactivity, or context, in order to guide the interaction of the test persons with the prototypes.

Depending on the intentions of the designers, the dimensions can be low or high. Examples demonstrate that varying the resolution for the dimensions influences the outcome of a prototype interaction (Rudd 1996, Houde & Hill 1997, Lim et al. 2006, Blacker 2009). Traditionally, fidelity increases with progress in the development process. However, studies from innovation research targeting radical new ideas emphasise the value of high functional and parallel prototypes in the early stages of development, in the so-called fuzzy frontend (Dow et al. 2010, Leifer & Steinert 2011). Jensen et al. (2017) confirm with their study on prototrial-driven culture that high functional prototypes can be successfully used to elicit unknown requirements. All these results come from the discipline of product design. The question remains open to what extent these results can be transferred to the functionality of smart services or whether the emphasis on other dimensions in prototypes is useful, such as interactivity and context.

Due to the lack of results for smart services in the literature, this multi-case study deals with the question to what extent the levels of functionality, interactivity and context affect the results of the requirements elicitation in the early development phases.

In the literature, there are various prototype approaches in which the levels of functionality, interactivity and context are shaped differently. One widely used approach in interaction design with very low functionality is paper prototypes (Snyder 2003). With the help of hand-drawn screens on paper, solutions can be quickly tested with users. This is followed by the click dummy. As a completely digital prototype, it depicts user flows on the user interface, but at the same time is only functionally implemented to a low degree (cf. Selefin et al. 2003, Lim et al. 2006). So-called works-like prototypes have the highest functionality; they are used at the end of development to check the final integration (Ulrich & Eppinger 2016, Lim et al. 2006).

In contrast to functional prototypes, experience or interact-like prototypes emphasise the interaction between user and system in order to investigate the user experience (Stickdorn et al. 2018). For a quick exploration of the future solution, the desktop walkthrough is suitable, where the quality of interaction is comparable to the final product only to a small extent. The technique uses a collaboratively built miniature environment to reconstruct knowledge about a particular service (Blomkvist et al. 2016). A prototype that generates high quality user feedback is the wizards of oz. In this technique, probands are made to believe that they are interacting with the final system, but instead a designer simulates the system feedback behind the scenes (Kelly 1984).

Contextual prototypes emphasise the situation in which a system is used and thus use the environment and its influences as a stimulus for the test probands (Beaudouin-Lafon & Mackay 2003). One technique that simulates context at a low resolution is cardboard prototypes (Kronqvist et al. 2013). With cardboard and other simple materials, the usage situations can be recreated and tested with test persons. The opposite of this low resolution technique are technology probes (Hutchinson et al. 2003). In these prototypes, the new technical solutions are placed in the expected usage situation in order to gather new insights based on the user interactions.

To maximise the efficiency of prototypes with a high resolution in the single prototype dimensions, the timing within the development process is critical. The aim is to identify unknown requirements as early as possible in the development process. Therefore, it is essential to include a temporal perspective when evaluating the analysed prototypes. For example, the usability engineering lifecycle according to Mayhew (1999) can be transferred to the development of smart services. Mayhew (1999) divides the user-centred development process into five phases: 1. requirements analysis, 2. concept development, 3. design, 4. detailed design, and 5. installation. In order to discover unknown requirements in the early development phases, the first two phases of the Mayhew's process must be considered: requirement analysis and concept development.

3.2.2 Prototypes and the mapping of smart service characteristics

Smart services are “delivered to or, via an intelligent object, that is able to sense its own condition and its surroundings and thus allows for real-time data collection, continuous communication and interactive feedback” (Allmendinger and Lombreglia 2005).

These new added values are created primarily through the integration of technology. The networking of intelligent products and services increases the performance of the offers, but at the same time the complexity increases enormously. The high level of complexity poses a conflict of objectives for prototyping. According to Lim's prototyping principles, prototypes are the simplest possible representation of the future solution without destroying the understanding of the whole smart service at the same time (Lim et al. 2008).

Compared to conventional software products, the human-automation relationship is shifting. Smart services make suggestions, decisions and even actions. The autonomy of the systems increases and at the same time the users lose their authority and their ability to intervene (cf. Parasuraman et al. 2000). Thus, the functionality of smart services becomes invisible to the users (Wünderlich et al. 2015). The functions are primarily controlled by implicit interactions. By means of tracked user behaviour or detected signals from the environment, the functions can be triggered without the initiative and attention of the users (Ju & Leifer 2008, Nazari Shirehjini 2009). To penetrate and understand the automation and implicit interactions, users need a high level of situation awareness (cf. Endsley & Kaber 1999). Situation awareness increases with the duration of system use and the domain experience of the users. For this reason, it is extremely difficult for test persons in time-limited prototyping sessions to understand and evaluate the functionality of smart services. Similar to the functionality, this challenge also exists for the communication of value creation. As Figure 2 shows, most of the data-driven value creation takes place below the line-of-visibility and is thus difficult for the subjects to understand when interacting with the prototypes. Additionally, according to the service-dominant logic, value generation is not a point-to-point exchange between providers and users (Vargo & Lusch 2008). Smart services generate value in use (cf. Grönroos & Voima 2013). As a consequence, the long-lasting usage processes must be mapped selectively and compressed in the prototypes. The basic prerequisite for value creation is the technical structure of smart services. Through the networking of smart products and services, data is collected, evaluated, combined and transformed into mutual added value for providers and users in various technical layers (Tombeil et al. 2016). This network-like structure of smart services leads to an increasing number of relevant elements. At the same time a simple representation in the prototypes is needed.

In view of these challenges for prototype design, the question arises which elements and processes of the prototypes generally contribute to the understanding of smart services and which elements can be neglected in the prototypes without destroying the understanding of the whole smart service.

3.2.3 Relevance of prototypes in the elicitation of unknown requirements

Requirements elicitation is the first step in the requirements engineering process. Prototypes are used for elicitation in the case of great uncertainty about requirements or when early feedback from future users is needed (Davis 1992, Nuseibeh & Easterbrook 2000). The specifications identified in the requirements elicitation can be categorised depending on their relative level of knowingness. The lack of knowingness increases the risk for uncertainties in product and service development. Sutcliffe and Sawyer (2013) describe the different types of requirements in their framework:

- Known knowns is knowledge that stakeholders can express and is also relevant to the development.
- Known unknowns is knowledge from stakeholders that they cannot express but is in principle accessible to them. This knowledge can potentially be relevant for development.
- Unknown knowns is knowledge that the stakeholders have and is accessible to them, but is not articulated during the elicitation. The challenge is to discover this tacit knowledge.
- Unknown unknowns are the greatest challenge in the requirements elicitation process because neither the designers nor the stakeholders are aware of the missing but still relevant knowledge and it is not accessible to either of them.

Unknown unknowns are most likely to appear in new domains or in radical changes, for example in the way of working (Sutcliffe & Sawyer 2013). Unidentified unknowns can have serious consequences. For example, if potentials for radical innovations in service development or sources of error in safety-critical systems such as power plants, remain undiscovered (Sutcliffe & Sawyer 2013, Ramasesh & Browning 2014).

According to Sutcliffe & Sawyer (2013), creative approaches such as prototyping are particularly suitable for the elicitation of unknown unknowns in new or greenfield domains where few requirements exist at the outset. Jensen et al. (2017) confirm these findings. With their work on prototrial-driven culture, they have proven the relevance of prototypes for identifying unknown requirements in product design.

Building on these results, the present study will investigate to what extent prototypes help in eliciting requirements for smart services in terms of knowns, known unknowns, unknown knowns, and unknown unknowns.

3.2.4 Research questions

The starting point for this research is the uncertainty of how the complexity of smart services can be represented in prototypes. In addition, prototypes should also be able to effectively support the elicitation of requirements in the early phases of development. Based on the examination of the existing literature, the overarching research question (RQ-B) is specified with the help of two more detailed research questions (RQ B-I and RQ B-II):

RQ B How does the use of prototypes affect the elicitation of unknown requirements for smart services in the early phases of development?

RQ B-I How do the elements of the future smart service represented in the prototype affect the elicitation of unknown requirements in the early phases of development?

RQ B-II How does the functionality and interactivity of the smart service prototypes and their context affect the elicitation of unknown requirements in the early phases of development?

3.3 Research design and methods

The theory of Eisenhardt (1989) is used as the methodological approach. Eisenhardt provides a guide for theory building from case studies that is particularly suitable for research in new topic areas.

3.3.1 Method and data basis

In accordance with Eisenhardt's framework, the multi-case study initially starts with a broad research question that is iteratively concretised. The starting point of the present research was the question of how the complex characteristics of smart services can be mapped in prototypes and how the prototypes can simultaneously support the discovery of unknown requirements. Eisenhardt (1989) emphasises that it is important to recognise that the initial research question is provisional and changes during the research process in this type of research.

Case selection is guided by theoretical sampling so that maximum theoretical insight is realised (cf. Döring & Bortz 2016). The cases are recorded within the framework of semi-structured expert interviews. In the interviews, the experts report on the prototypes created and their suitability for requirements elicitation. The experts are identified and selected in the authors' network in Germany and Austria. When selecting the interview partners, preference is given to experts who have actively participated in the development process of smart services. The experts had to be able to provide information about the creation process as well as the intended use of the prototypes. Table 7 gives an overview of the participating experts, including their fields of work and previous experience. The 17 prototypes selected for the study are presented with a brief explanation in Table 8. The data collection consisted of 11 semi-structured interviews, including visits to three development departments. One interview was conducted by video conference. The average interview length was 75 minutes.

Following Eisenhardt's (1989) approach, the data collection and analysis overlap. The overlap allows the researchers to take advantage of flexible data collection, for example by adding questions to the interview guide (Eisenhardt 1989). The interview guide in its final version can be found in the appendix Part B – . In addition to the recordings of the interviews, videos, pictures, and reports on the prototypes are gathered in the data collection.

TABLE 7 |

DATA BASIS - OVERVIEW OF EXPERT INTERVIEWS

NO.	COMPANY / ORGANISATION	PROFESSION	EXPERIENCE IN PROTOTYPING	INTERVIEW DURATION
E1	Research institute	Service engineer	8 Years	01 hour 15 minutes
E2	Design agency	Lead service designer	6 Years	01 hour 25 minutes
E3	Software development	CEO and service designer	12 Years	01 hour 15 minutes
E4	Consulting for service design and innovation	CEO, consultant, and actor	10 Years	01 hour 50 minutes
E5	Consulting for service design and innovation	CEO, consultant, and service designer	10 Years	01 hour 50 minutes
E6	Consulting for product and service design	Consultant, and service designer	10 Years	01 hour 33 minutes
E7	Software development	Service designer and user experience consultant	Not specified	01 hour 28 minutes
E8	Digital self-service in telecommunication	CEO and computer scientist	2,5 Years	36 minutes
E9	Research institute	Service designer and coach	5 Years	40 minutes
E10	Research institute	Service engineer	4 Years	01 hour 12 minutes
E11	Research institute	Usability engineer	12 Years	42 minutes

TABLE 8 |

DATA BASIS - EXPLANATION OF THE PROTOTYPES FROM THE MULTI-CASE STUDY

NO.	CASE	DESCRIPTION	FORM OF THE PROTOTYPE	DATE OF CREATION	PHASE
P1	Mobility hub for electric mobility	The prototype was developed to investigate the primary user activities such as parking, charging and waiting at a networked mobility hub for electric mobility.	Interactive virtual reality prototype	2017	Detail design
P2	Intelligent charging station for electric mobility	The prototype was developed to explore how drivers of electric vehicles are assisted via a remote service, including a call centre, in the event of a charging point defect.	Role play with customer journey canvas	2017	Concept phase
P3	Digital picture book for leisure experiences	The prototype explores a digital picture book in which children can document the experiences of their leisure activities. The application connects leisure parks and customers before and after their visit and at the same time enables the leisure activities to be booked.	LEGO serious play with desktop walkthrough and wireframes	2013	Concept phase
P4	Experience reports and rating of hotels	The prototype examines how customer experiences of the hotels can be recorded in a partially automated way using a location-based service and how the data should be processed and presented to the hotel operators via data analytics.	Paper prototype	2018	Concept phase
P5	Experience reports and rating of hotels	The prototype examines how customer experiences of the hotels can be recorded in a partially automated way using a location-based service and how the data should be processed and presented to the hotel operators via data analytics.	Click dummy with detailed screen design	2018	Concept phase
P6	Intermodal station for public transport	The prototype was a replica of a public transport station. The prototype investigated the information needs of passengers as well as the processing of the different digital information sources.	Card boarding in a real context	2017	Concept phase

NO.	CASE	DESCRIPTION	FORM OF THE PROTOTYPE	DATE OF CREATION	PHASE
P7	Ticket vending machine for public transport	The prototype was developed to explore a ticket vending machine in a real-world context. The prototype was investigated on a public transport platform.	Functional prototype in real context	2017	Design phase
P8	Scanning glove for order picking in warehouses	The prototype was a glove for scanning barcodes in a warehouse. The glove investigated hands-free scanning in the picking process and sends the data to the goods management system in the warehouse.	Functional prototype in real context	2018	Concept phase
P9	Intelligent charging station for electric mobility	The prototype was developed to investigate how peak loads in wind energy can be economically used for charging electric cars. The context-sensitive charging station can be configured and monitored by users via a smartphone application.	Functional prototype in miniature environment with technical components	2017	Concept phase
P10	Booking system for autobahn tolls	The prototype investigated a satellite-based toll system. In conjunction with the infrastructure on the road, the terminals in the vehicles could automatically charge for road use.	LEGO serious play with desktop walkthrough	2016	Concept phase
P11	Networked trailer for trucks	The prototype examined the digital networking of a truck trailer. By means of sensors in the trailer, the driver and dispatcher were able to query and control the status of the trailer via an application, as well as manage the locking system.	Functional prototype with smartphone application	2016	Concept phase
P12	Networked sanitary facilities	The prototype was developed to record the condition of sanitary facilities via sensors and to monitor them in a management system. The operating hours of the sanitary facilities were reported via the sensors and the cleaning staff was scheduled according to demand.	Functional prototype	2017	Concept phase

NO.	CASE	DESCRIPTION	FORM OF THE PROTOTYPE	DATE OF CREATION	PHASE
P13	Self-service for internet connection installation	The prototype investigated a self-service solution for the initial installation and troubleshooting of the internet connection by the customers. The prototype was used in a test environment.	Functional prototype	2016	Concept phase
P14	Networked street cleaning vehicle	The prototype was developed to investigate on-demand control of street cleaning vehicles. Using GPS sensors in the vehicles, citizens were able to use a smartphone application to locate the vehicles and request them for cleaning.	Card boarding, miniature environment in LEGO, and wireframes	2017	Concept phase
P15	Dynamic route planning for parcel delivery	The prototype was developed to explore the process in a dynamic parcel delivery. The delivery of parcels was to be aligned with the needs of the recipients. Through an application, recipients could individually change their location and the time period for parcel pick-up, so that the route of the parcel deliverers would change automatically.	Card boarding	2017	Concept phase
P16	Travel planning and assistance with real-time information for local public transport	The prototype was developed to investigate a passenger information system for local public transport. Through the smartphone application, users could plan their journey and get real-time information on buses and trams on the road. The prototype was used on a test route in local public transport.	Smartphone application in field test	2016	Concept phase
P17	Intermodal mobility platform for local public transport	The prototype was developed to investigate the use of a mobility platform for local public transport. Through the platform, users could plan, book, receive assistance, and pay for a journey using different modes of transport. The prototype was used on a test route in local public transport.	Smartphone application in field test	2018	Concept phase

3.3.2 Procedure

TABLE 9 |

RESEARCH PROCEDURE FOR PART B

STARTING POINT	
Research Question	RQ B | How does the use of prototypes affect the elicitation of unknown requirements for smart services in the early phases of development?
STEP I	
Objective	Description of the current state of research
Method	Literature research using backward snowball procedure
Data collection	Research work for the start of the literature review - Elicitation of unknown requirements with prototypes | Jensen, M. B., Elverum, C. W., & Steinert, M. (2017). Eliciting unknown unknowns with prototypes: Introducing prototrials and prototrial-driven cultures. Design Studies, 49, 1-31 - Development of smart services | Lim, C., Kim, K. H., Kim, M. J., Heo, J. Y., Kim, K. J., & Maglio, P. P. (2018). From data to value: A nine-factor framework for data-based value creation in information-intensive services. International Journal of Information Management, 39, 121-135.
Data analysis	Selection of literature by qualitative evaluation of title and abstract of research papers
STEP II	
Objective	Theory building | Theory for eliciting requirements with prototypes for smart services in early development phases
Method	Building theories from case study research according to Eisenhardt (1989)
Data collection	Semi-structured interviews with experts for smart service prototypes
Data base	Analysis of 17 prototypes (cases) based on the transcripts from the expert interviews, including image and video recordings
Data analysis	- Within-case analysis - Cross-case pattern search - Comparing with conflicting literature - Comparing with similar literature

3.3.3 Data analysis

The prerequisite for the analysis is the transcriptions of the semi-structured interviews. The eleven interviews are documented according to the minimal transcript of the "Gesprächsanalytisches Transkriptionssystem 2" (GAT 2) (Selting et al. 2009). The transcribed expert interviews can be viewed in the appendix Part B - Transcripts of the expert interviews. The analysis of the data essentially comprises three steps: Within-case analysis, cross-case analysis, and comparison of literature. In the within-case analysis, the interview material on the prototypes is reviewed and then coded in the sense of the "hermeneutic circle" (cf. Döring & Bortz 2016). The cross-case analysis takes up the preliminary theories from the individual case observations and creates superordinate categories and theories through the permanent comparison of the individual cases (cf. Eisenhardt 1989, Döring & Bortz 2016). In the third step, the results are compared with "conflicting" literature and "similar" literature in order to increase the internal validity of the theories and improve their generalisation (cf. Eisenhardt 1989).

The three steps case-based analysis, cross-case analysis, and theory comparison are carried out for both research questions. First, the structure of the smart services prototypes is examined. Subsequently, it is analysed which dimensions are particularly emphasised in the design of smart service prototypes. On the basis, the study examines how the structure and prototype design influences the elicitation of unknown requirements in the early phases of development. For this analysis, the classification of requirements according to Sutcliffe and Sawyer (2013) is used. As a final step, the relevant findings from both research questions are extracted and combined in the new approach of data-driven value prototypes.

3.4 Results

3.4.1 Effect of prototype composition on the elicitation of unknown requirements

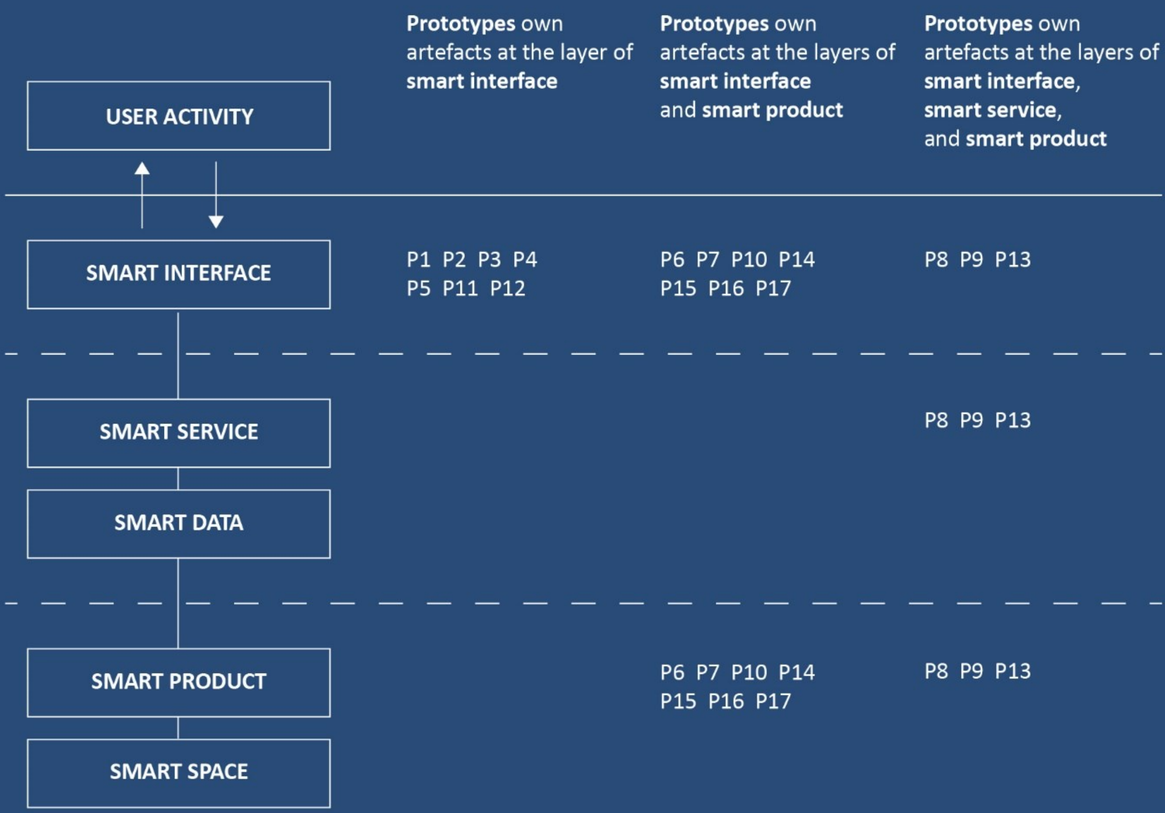
When designing prototypes, individual parts are filtered out of the whole smart service "idea" (Blomkvist and Holmlid 2011) so that designers and engineers can manifest selected aspects into tangible prototypes. For smart services, this filtering is challenging because the services consist of a multitude of elements that dynamically depend on each other. In prototype design, this complexity must be reduced without distorting the overall understanding of the system (Lim et al. 2008).

Inspired by the smart service layer model of Wienken and Krömker (2020), it will be investigated which elements of smart services are represented in prototypes. In the detailed analysis of the 17 prototypes of the multi-case study, three different categories can be identified:

1. Prototypes with elements from the layer smart interface,
2. Prototypes with elements from the layers smart interface and smart product,
3. Prototypes with elements from the layers smart interface, smart service, and smart product.

FIGURE 5 |

CLUSTERING OF COMPOSITION OF THE INVESTIGATED PROTOTYPES ACCORDING TO THE LAYER MODEL FOR SMART SERVICES



INFORMATION

P1 - P17 Prototypes investigated from the multicase study

The figure presents the prototypes of the multicase study from the requirements analysis and concept development phases. The prototypes P1 and P7 were used in the design phase and for this reason the prototypes are not included in the figure.

3.4.1.1 Prototypes with elements from the layer smart interface

The prototypes P1, P2, P3, P4, P5, P11, and P12 focus on the user interface and the process of smart services. The aim of the prototypes was to investigate the quality of the interaction in addition to the user value. The prototypes were implemented using traditional approaches from service design and human computer interaction. Figure 6 shows a LEGO prototype in combination with a cognitive walkthrough (prototype P3) and a paper prototype (P4, see Figure 8). On the one hand, such traditional prototypes reduce the complexity for probands in the test. On the other hand, they lead to the fact that all elements of the smart service below the line of visibility are not considered. Thus, the functionality and technical connections of the smart services are not the subject of the prototypes.

FIGURE 6 |

PROTOTYPE 3 & PROTOTYPE 5 – EXAMPLES OF HIGH INTERACTIVE PROTOTYPES

USING LEGO SERIOUS PLAY AND A DESKTOP WALKTHROUGH, PROTOTYPE 3 EMPHASISED INTERACTIONS ALONG THE ENTIRE SERVICE PROCESS (LEFT). PROTOTYPE 5, ON THE OTHER HAND, WAS FOCUSED ON THE INTERACTIONS IN THE USER INTERFACE VIA CLICK DUMMY WITH DETAILED SCREEN DESIGN (RIGHT).

FIGURE 7 |

PROTOTYPE P1 - EXAMPLE OF A PROTOTYPE COMPOSITION THAT EXCLUSIVELY USES ELEMENTS FROM THE SMART INTERFACE LAYER

THE INTERACTIVE VIRTUAL REALITY PROTOTYPE VISUALISES ONLY THE TOUCHPOINT AT THE USER INTERFACE, TECHNICAL COMPONENTS OF THE OTHER LAYERS WERE NOT INCLUDED.

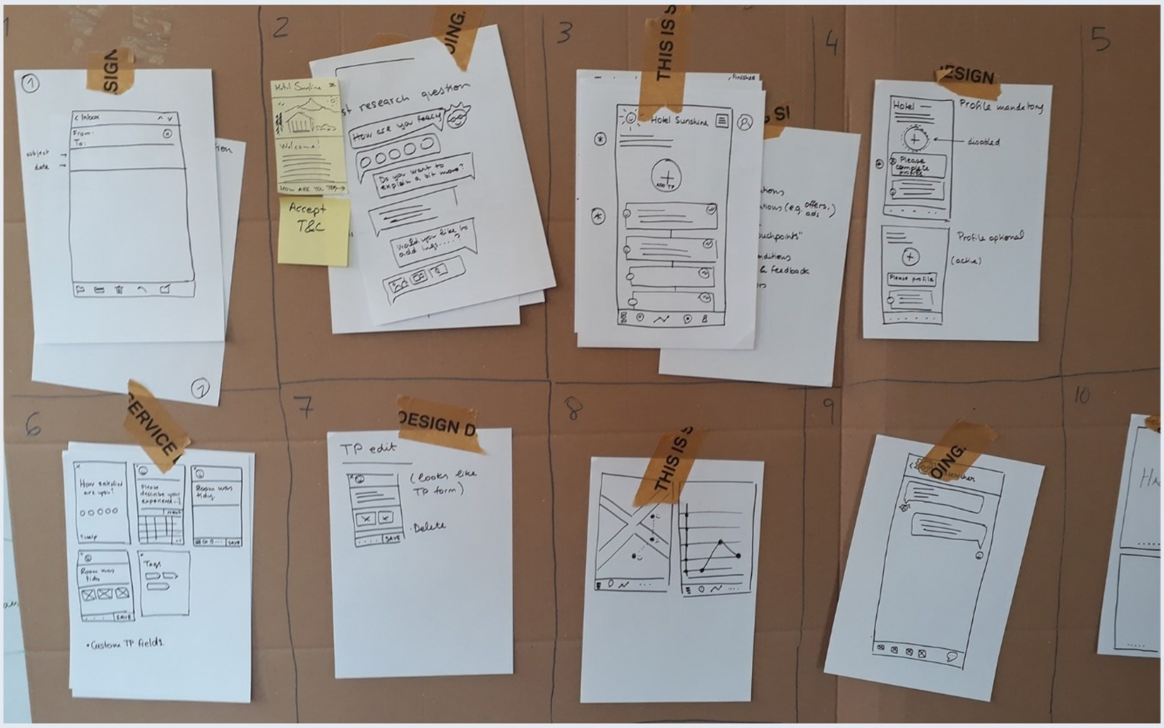


FIGURE 8 |

PROTOTYPE P4 - EXAMPLE OF A PROTOTYPE COMPOSITION THAT EXCLUSIVELY USES ELEMENTS FROM THE SMART INTERFACE LAYER

THE PAPER PROTOTYPE INVESTIGATED ONLY THE USER INTERFACE OF THE PLANNED LOCATION-BASED APPLICATION.

3.4.1.2 Prototypes with elements from the layers smart interface and smart product

The prototypes P6, P7, P10, P14, P15, P16 and P17 take into account the networked products (smart products) as a second layer in addition to the interface. The aim of the prototypes is to integrate context sensitivity as a central characteristic of smart services. The prototypes are used to show the test persons how a change in the context affects the system feedback in the interface and what benefits arise from this. Prototype P16, for example, depicts how a change in the position of buses is detected via GPS (smart product) and how a recalculation of the travel plan is triggered and thus the current arrival time of the buses is made available to the user in the application (smart interface).

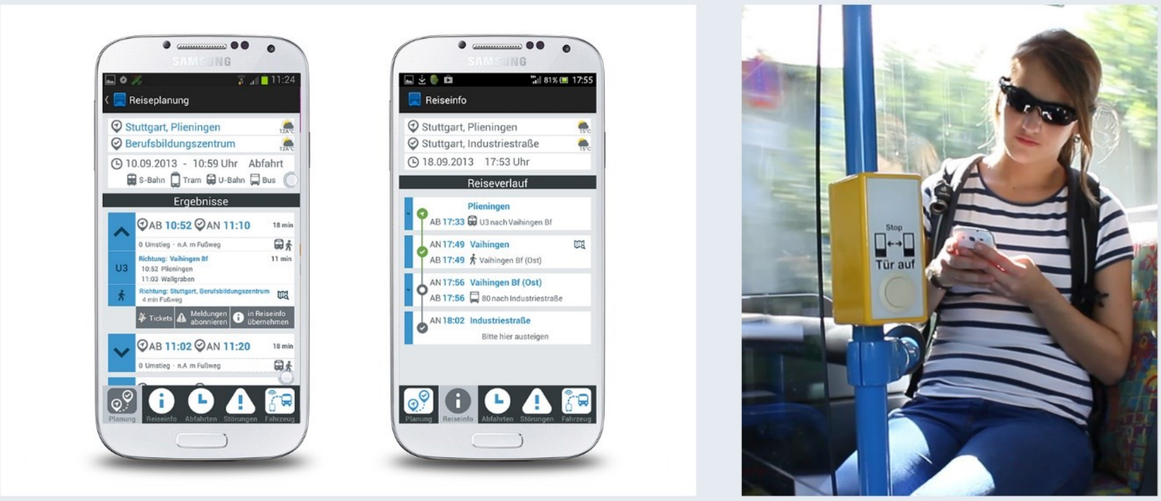


FIGURE 9 |

PROTOTYPE P16 - EXAMPLE OF A PROTOTYPE COMPOSITION THAT USES ELEMENTS FROM THE LAYERS SMART INTERFACE AND SMART PRODUCT (KRÖMKER ET AL. 2014)

THE SMARTPHONE APP (SMART INTERFACE) USES NETWORKED BUSES ON A TEST ROUTE AS A SMART PRODUCT

3.4.1.3 Prototypes with elements from the layers smart interface, smart service, and smart product

In the third category, an attempt is made to depict the "entire chain" of smart services in the prototypes (P8, P9 and P13). In addition to data collection in the context (smart product) and user interaction (smart interface), data processing (smart service layer) is also visible and can be experienced by the test persons in the prototypes. Through the integration of the smart service layer, characteristics of smart services that are usually not apparent to users, can be presented and made more comprehensible, such as data aggregation, automation, adaptivity or machine learning mechanisms. As an example, prototype P9 shows how peak loads in wind energy can be used economically to charge electric cars. The wind turbine serves as a smart product. A sensor on the wind turbine makes the prevailing wind strength and the generated energy visible to the test persons. The data processing (smart service), namely the control of the charging process and the comparison of the feed-in price with the electricity price exchange, is carried out in the charging box. The box is a haptic component of the prototype in the test setup. The test persons can monitor and control the process via the prototypical smartphone application (smart interface).

FIGURE 10 |
PROTOTYPE P9 – EXAMPLE OF A PROTOTYPE COMPOSITION THAT USES ELEMENTS FROM THE LAYERS SMART INTERFACE, SMART SERVICE, AND SMART PRODUCT

THE APP (SMART INTERFACE) CONTROLS A CHARGING STATION FOR ELECTRO MOBILITY, WHICH IS FED FROM PEAK LOADS OF THE WIND POWER PLANTS (SMART PRODUCT). INTELLIGENT DATA PROCESSING IS DEMONSTRATED IN THE APP AND IN HAPTIC ELEMENTS OF THE PROTOTYPE (SMART SERVICE).

3.4.1.4 Effect on the elicitation of requirements

The analysis shows that the designers represent three of the five layers of smart services in the prototypes for the requirements elicitation. For the interaction with the test persons, the smart interface layer is a central component of every prototype examined. However, focusing exclusively on the smart interface layer imposes limitations.

"If I ... only show the frontend here, only the app ... then it is much less plastic, so then he (the respondent) has much more problems recognising these connections" (Expert E10).

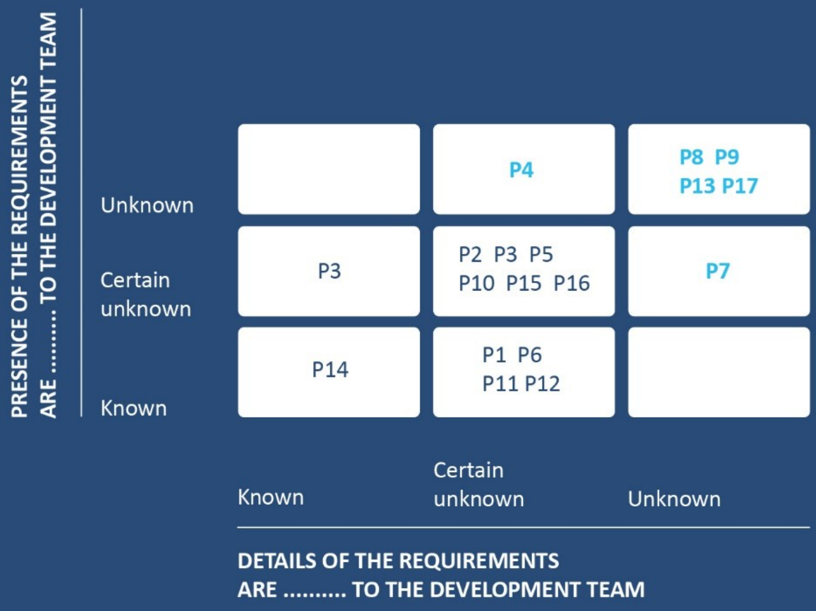
The figure shows that the prototypes that include the layers smart product and smart service in addition to the smart interface layer have a higher success rate in identifying unknown requirements. The bold letters in Figure 11 highlight the prototypes that particularly helped the designers and engineers to identify unknown unknowns.

The more detailed analysis shows that prototypes have elicited the unknown unknowns that have implemented the following characteristics in the smart product layer:

- The networked smart products with their sensors were haptic components of the prototypes, such as the wind turbine in prototype P9 (see Figure 19).
- The changes in the usage situation that trigger the data collection were made visible to probands. In prototype P9, the current wind strength or the amount of electricity generated was displayed via the rotation speed of the wind turbine.
- Via system feedback in the smart interface layer, the test persons were informed how the system reacted to the changed usage situation. In the user interface of the prototype P9, both the varying charging power and the corresponding electricity price on the market were displayed.

FIGURE 11 |

CLUSTERING OF THE PROTOTYPES ACCORDING TO THE RESULTS FROM THE REQUIREMENTS ELICITATION



LEGEND

P1 - P17 Prototypes investigated from the multicase study

P... Prototypes have helped engineers and designers to elicit unknown unknown

In the smart service layer, on the other hand, the successful prototypes tried to make the data processing processes transparent. For example, prototype P13 shows a self-service solution for the installation and the troubleshooting of the internet connection. The analysis and troubleshooting processes run automatically in the background, but were visualised in the prototype in the smart service layer. In this way, the test persons were able to follow step by step which data was being used at the moment and which processing steps were taking place.

In contrast, the analysis also shows that the layers smart space and smart data have no relevance for the identification of unknown unknowns. These two layers were not implemented in any of the prototypes in the multi case study. One possible reason for this was mentioned by the expert E10. The study of expert E10 involved end users as probands and focused on the system behaviour and the data-based value generation. In this case, the expert interpreted the smart space and smart data layers as technically given prerequisites for the operation of smart services, "*digital networking is basically also a prerequisite*" (Expert E10) and therefore the expert does not visualise them.

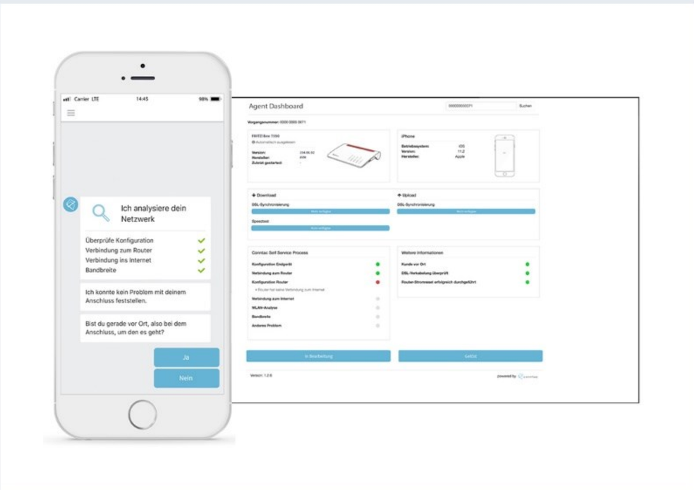


FIGURE 12 |

PROTOTYPE P13 - EXAMPLE OF A PROTOTYPE COMPOSITION THAT USES ELEMENTS FROM THE LAYERS SMART INTERFACE, SMART PRODUCT, AND SMART SERVICE

BESIDES A SMARTPHONE APP (SMART INTERFACE), THE PROTOTYPE CONSISTED OF THE ROUTER FOR THE INSTALLATION (SMART PRODUCT). THE PROCESSES RUNNING IN THE BACKGROUND (SMART SERVICE LAYER) WERE VISUALISED IN THE SMARTPHONE APPLIKATION.

3.4.2 Effect of functionality, interactivity, and contextualisation of the prototypes on the elicitation of unknown requirements

Traditionally, fidelity increases with progress in the development process. However, studies show that the outcome of a prototype interaction can be influenced in the early development phases by the deliberate manipulation of the resolution of a dimension (Rudd 1996, Houde & Hill 1997, Lim et al. 2006, Blacker 2009) and can generate radical new ideas (Dow et al. 2010, Leifer & Steinert 2011). For this reason, the extent to which the dimensions of functionality, interactivity, and context influence the elicitation of unknown requirements in the early phases of development is investigated for the new domain of smart services.

In the study, the 17 prototypes are analysed according to their different dimensions and the progress in the development process. A distinction is made whether a prototype is still in the concept phase or has already left it.

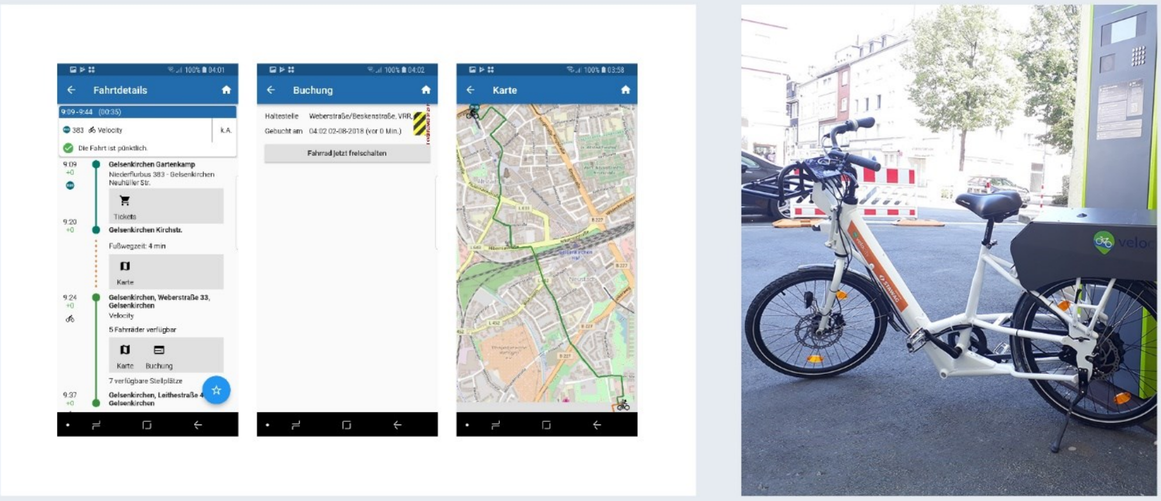


FIGURE 13 |

PROTOTYP 17 – EXAMPLE OF A HIGH FUNCTIONAL PROTOTYPE

IN THE SMARTPHONE APP, ALL THE REQUIRED FUNCTIONALITIES FOR TICKET BOOKING IN LOCAL PUBLIC TRANSPORT AND THE UNLOCKING OF BIKE SHARING FOR A PRE-SELECTED TEST ROUTE WERE IMPLEMENTED.

3.4.2.1 High functional prototypes in the concept phase

The prototypes P9, P13, P16 and P17 belong to the category of functional prototypes. All prototypes have a particularly high degree of functionality for individual elements without representing the entire final solution. This type of prototype is used in the concept phase to investigate different development approaches (Dow et al. 2010, Leifer & Steinert 2011). In this way, insights into the market, user needs and unintended consequences of new technologies can be collected and subsequently summarised into new requirements for further development. Unknown knowledge was identified in the test with prototype P9. For example, scenarios were discovered in daily use with electric cars that require a reserve for the battery. These requirements were not known in advance by the development team or the probands, they were identified during the interaction in the test.

What does high functionality mean for smart services? The functions are strongly interwoven with the layers of smart services. Each layer performs a specific functionality (see Figure 2). In prototype P9, the smart service collects the amount of electricity generated by wind power (sensing of data in layer smart product). The service then analyses how urgently the electric car needs a charge and how high the electricity price is currently trading on the market in order to decide whether to start the charging process or sell the electricity (Analysis, aggregation, and procession of data in layer smart service). The next step is to involve the users. Users are shown the analysis results on the display and can overrule the system's recommendation if necessary (Communication of information and adaptable interaction in layer smart interface). It should be emphasised that the highly functional prototypes only depict functions that directly contribute to the value creation of the information. This means that the prototypes visualise the transformation process from the captured raw data to the information in the user interface. With each function represented in the prototype, the data is processed further and the value of the information increases. The experts in the multi-case study also emphasised the value created by data processing:

"… this chain (data processing) was presented so that it is tangible for the visitor (proband) so that he can imagine … so we made sure that it (value creation based on data processing) can be understood quickly it is not easy to present modern complex systems (like smart services) to a user at a certain point in time" (Expert E10)

Networking and data transmission (smart space layer) and data collection and storage (smart data layer), on the other hand, are classified by the experts as indirect functions. These functionalities have no direct influence on the value increase of the information but ensure the continuous execution of the direct influencing functions. These supporting functions are not explicitly visualised in the prototypes.

3.4.2.2 High interactive prototypes in the concept phase

The majority of the prototypes had a high degree of interactivity (P2, P3, P4, P5, P10, P14, and P15). Buchenau and Suri (2000) describe this approach as experience prototypes. The aim is to make the solutions perceptible with low effort, so that the test persons interact with the prototypes and real user reactions can be gathered during the requirements elicitation. In practice, experience prototypes are widely used. The experts emphasise that above all the look and feel should be conveyed:

"... we pretend from the beginning that the services exist ... (we) always represent only the surface ... that means you have to make the surface, the look and feel as good as possible so that your customer can react to it" (Expert E6)

In prototype P2, for example, a desktop walkthrough was carried out to examine the error handling of an intelligent charging station for electric mobility. With the help of this experience prototype, the test persons were already involved in the development during the concept phase. The aim of the prototype was to explore the needs of the users through their live experience and to identify unknown gaps in the service process.

Compared to other digital systems, smart services have a predominant share of implicit interactions. While explicit interactions are based on obvious inputs and outputs, implicit interactions take place without the explicit input or awareness of the user (Ju and Leifer 2008). Smart services use implicit interactions and generate their added value through functionalities that require limited or no user attention and initiative (Ju and Leifer 2008), such as automation, adaptivity and context sensitivity. Ju and Leifer (2008) refer to this system behaviour as increasingly "invisible". Nielsen (1993) speaks of "non command interfaces" in this context. For prototyping, the implicit interactions are a challenge. The question arises how implicit interactions can be mapped in prototypes in order to increase the comprehensibility of the technical functioning and the generation of added value in smart services.

The prototype P13, for example, tries to make the analysis processes that run automatically in the background, visible to the user on the user interface. Prototype P9, on the other hand, uses context-sensitive functionality to adapt the charging process of electric cars to the prevailing wind strength. This logic is additionally influenced by the price of electricity, so that when needed, the electric car is not charged, but the electricity is fed into the grid and sold. With such complex context-sensitive functions, an awareness mismatch can occur during use. An awareness mismatch occurs when the system behaviour does not correspond with the users' expectations (Schmidt 2013). This phenomenon is also relevant for requirements elicitation with probands. The greater the awareness mismatch, the higher the risk that the prototype presented does not correspond to the known needs of the users and that unknown requirements remain undiscovered. Despite the central importance for smart services, only five of the 17 prototypes in the study address implicit interactions (P8, P9, P11, P13 and P17).

3.4.2.3 Prototypes with high contextualisation in the concept phase

Contextual prototypes particularly emphasise the situation in which the system is applied. Beaudouin-Lafon and Mackay (2003) speak of scenario prototypes in this context and recommend that these prototypes be used in a more realistic scenario to simulate the system under real conditions. The prototype P6 belongs to this category. With the help of card boarding, a low functional prototype for a networked mobility hub was created, but still tested in the real environment with test persons. The required interactivity was created with the help of the role play method. The goal in the concept phase was to identify how the real situation improves or hinders the use and experience at the mobility hub and what new requirements arise from this.

Figure 6 shows another example of a contextual prototype. In comparison, the context of prototype P3 has a significantly lower level of detail. LEGO Serious Play is used to simulate the real usage situation only to some extent. The aim of the prototype was to determine the needs of the test persons and to gain new insights for the design of the process and the individual touchpoints. With the help of the mapped context, the immersion for the probands was increased in order to increase the understanding of the touchpoints.

Other prototypes in the study use context even more selectively. Prototypes P9, P10, and P13 zoom in on the future use situation and only map explicit sections of the context. Prototype P9, for example, has a wind turbine to show the influence of wind strength on the charging process of the electric car. The aim of this selective context manifestation in the prototype is to make the context-sensitive functionality and the resulting system behaviour of the smart service understandable for the test persons.

3.4.2.4 High fidelity prototypes after concept phase (high functional / high interactive / high contextual)

The prototypes P1 and P7 can be classified as high fidelity prototypes. The high fidelity prototypes identified in this study have a high resolution in all dimensions (function / interactivity / context) and are used in the later phases of the development process. Figure 7 shows a prototype implemented in virtual reality. With the help of this prototype, the design of the servicescapes was investigated, e.g. the environmental conditions or the visual design of the interior. In principle, this prototype category is used, for example, to investigate user interfaces and servicescapes of solutions that are already well understood. In product development, they are called proof of product prototypes (Ulrich & Eppinger 2016), in service and interaction design they are called integration prototypes that are built to represent the complete user experience of a product (Houde and Hill 1997).

3.4.2.5 Effect on the elicitation of requirements

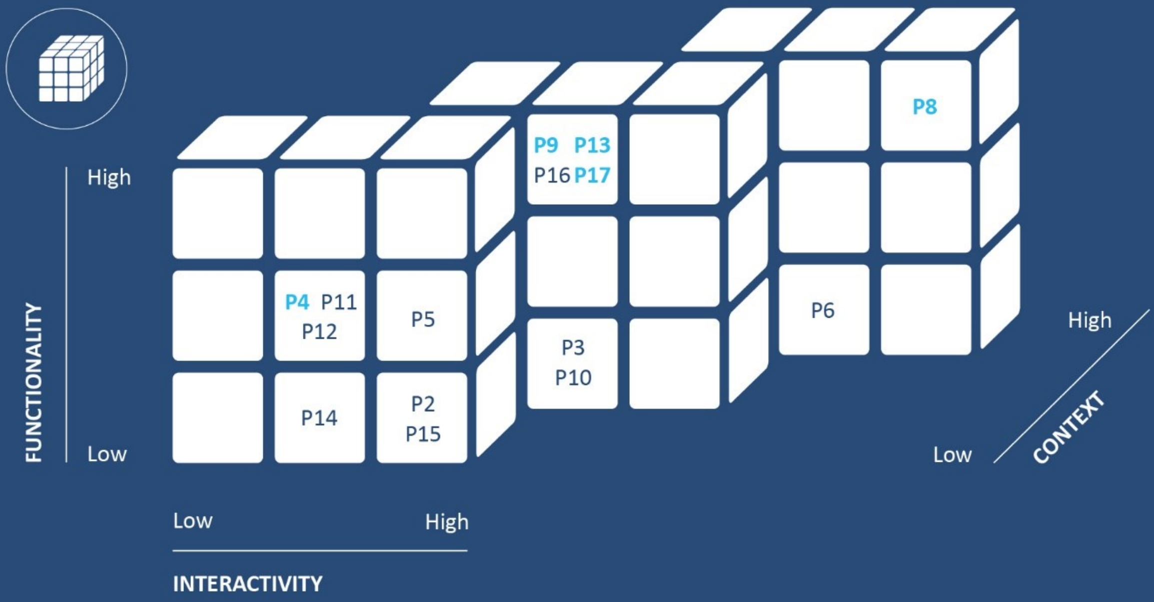
The starting point for the study was the question of what influence does the functionality and interactivity of the prototypes as well as the depicted context have on the elicitation of requirements. The analysis shows that the functional prototypes have a high potential for eliciting unknown unknowns in the early development phases. However, the results in Figure 14 also illustrate that in addition to functionality, selected interactive elements and contextual elements also contribute to requirements elicitation of unknown unknowns. This special combination of the dimensions functionality, interactivity, and context forms a new prototype category, the data-driven value prototypes.

The detailed investigation shows that the focus of these prototypes was on the transformation process of the data. It should be emphasised that high functional prototypes exclusively depict functions that directly contribute to the value creation of the data (functions: Sensing of data + analysis, aggregation, and procession of data + communication of information and adaptable interaction). In the prototypes, the stages of data processing are represented as an ordered sequence of activities. These activities create the value of the smart services and map the transformation process of the data. The process shows the path that the data goes through from acquisition at the sensors to presentation on the user interface.

According to Maglio et al. (2009), value in complex service systems is created as value co-creation through a configuration of users, processes, technology, physical and other resources. Users engage in value co-creation through interaction. It is worth noting that the prototypes that elicited unknown unknowns additionally mapped implicit interactions to make the transformation process of the data and the underlying functions transparent and understandable. Context was also part of the new prototype approach. On the one hand, the wind turbine integrated into the prototype (prototype P9), for example, illustrated the moment at which the transformation process is triggered. On the other hand, the visualisation of the context conveyed to the test persons how the system behaviour is influenced by changes in the situation and what the consequences are for the data transformation process.

FIGURE 14 |

CLUSTERING OF THE PROTOTYPES ACCORDING TO THE DIMENSIONS FUNCTIONALITY, INTERACTIVITY, AND CONTEXT



LEGEND

P1 - P17 Prototypes investigated from the multicase study

P... Prototypes have helped engineers and designers to elicit unknown unknown

3.5 Introducing data-driven value prototypes

The motivation for developing smart services is to design a service that is able to create value for users and providers or to improve value creation. Therefore, the design of new or existing services requires a fundamental understanding of value creation mechanisms (Friedman, Borning, & Huldtgren 2013, Lim & Kim 2014). The presented study results reveal that the existing approaches for prototype design are not able to capture the complex nature of data-based value creation in a target-oriented way. This is not to undermine the value of other approaches, such as functional prototyping, experience prototyping, or contextual prototyping. Rather, it is intended to illustrate that the new identified prototyping approach, the data-driven value prototypes, can help designers to quickly and effectively discover unknown requirements in data-intensive services in the early stages of development.

Data-driven value prototypes uncover the mechanism of how value is created through data. The prototypes use the data value chain to demonstrate how activities and resources work together to create value, from data collection to use of a service. (own definition)

The data-driven value prototypes can be used as a concrete technique. But beyond that, this approach can also be used as a new way thinking. The perspective of data-driven value prototypes allows designers and engineers to think about and discover the design problem from the perspective of data-driven value creation. This mindset can also be applied to other techniques, such as storyboards, scenarios, data stories, and simulations.

3.5.1 Principles of data-driven value prototypes

To create smart services, intelligence - i.e. awareness and connectivity - must be built into the products so that the service can collect and analyse data in real time and provide the information in the user interface (Allmendinger & Lombreglia 2005, Wünderlich et al. 2015). The complex structure and associated service characteristics pose problems for traditional prototype approaches. Some cases in the present study have shown how these shortcomings can be overcome and data-driven value prototypes can be used purposefully in requirements elicitation. The observed findings were generalised and summarised in the principles. Although the findings were derived from a limited number of cases, the principles provide a first guideline for the creation of data-driven value prototypes and should inspire engineers and designers to implement the approach in practice.

3.5.1.1 Principle I – Demonstrate the activities of data processing

Both innovation research (Dow et al. 2010, Leifer & Steinert 2012, Jensen et al. 2017) and the present study emphasise the high importance of functionality for eliciting unknown requirements with prototypes. When prototyping smart services, designers face the challenge of reducing the complex functionality to a simple representation in the prototypes without distorting reality. Inspired by Lim and Maglio's (2019) abstracted view, the functionality can be summarised as follows: Smart services collect data via sensors and transform it into information using computerised processes. To demonstrate the data processing, the three central activities can be mapped in the prototypes: Data collection, data analysis, and information delivery (see Figure 15).

With this principle, the path of the collected data, from the sensors through all smart service layers (cf. Wienken & Krömker 2020) to the information presentation in the user interface, becomes visible. In this way, it is possible to understand which technical infrastructure is required on the individual layers for the service and which dynamic relationships exist. On the other hand, the functions that process the data are illustrated.

FIGURE 15 |
DATA-VALUE CHAIN - ACTIVITIES OF DATA PROCESSING

LEGEND

Activities
Resources
Value in information use

Adapted from Lim et al. 2018a

3.5.1.2 Principle II – Visualize the data based value creation

Value creation is the core purpose of smart services. Value creation is a collaborative process between users, providers, or other stakeholders that is automated or supported based on a connected network, data collection, contextual computation, and wireless communication (Lim and Maglio 2019).

This type of value creation faces challenges for prototype creators. The problem is to provide users a concrete understanding of the data-based value creation mechanisms. Value creation is a dynamic and immaterial process which is based on a technically complex structure that usually orchestrates a branching network of data sources, and data aggregation and analysis. For this reason, the analysis and evaluation of smart services is cognitively demanding for the test persons in a prototyping session. In addition, difficult to understand, since almost all processes take place in the invisible area for the probands (see line of visibility - Figure 2).

FIGURE 16 |

DATA-VALUE CHAIN - CHARACTERISING THE DATA-BASED VALUE CREATION IN SMART SERVICES

LEGEND

Activities
Resources
Value in information use

Adapted from Lim et al. 2018a

The goal is to design the prototypes in such a way that it is recognisable which effects the applied resources have on the data-based value creation for users and providers. This is done using the data value chain. It maps the entire data-based value creation, from the collection of data as raw material, to the analysis and processing of data into information, and finally to the provision of information and the creation of value in use (Lim et al. 2018). In addition to the three activities of data processing (see Principle I), the required resources and the generated value are visualised and integrated in the prototypes (see Figure 16).

Value may assume a variety of forms, such as the improvement of operational processes, the effective and efficient completion of tasks, or the prevention of potential user problems (Lim et al. 2018). However, value is only created when people use the received information for a specific purpose (value in use) (Vargo & Lusch 2004, Grönroos & Voima 2013).

3.5.1.3 Principle III – Ensure visibility of system status

System design should always inform users what the current state of the system is through appropriate feedback. This guideline is based on the "usability heuristics for user interface design" by Nielsen and Molich (1990) and plays a significant role for context-sensitive applications such as smart services (Dey & Häkkilä 2008). The implicit nature of human perception of context and the complexity of context-sensitive applications mean that users may not be aware of changes in context, system logic or system actions (Dey & Häkkilä 2008).

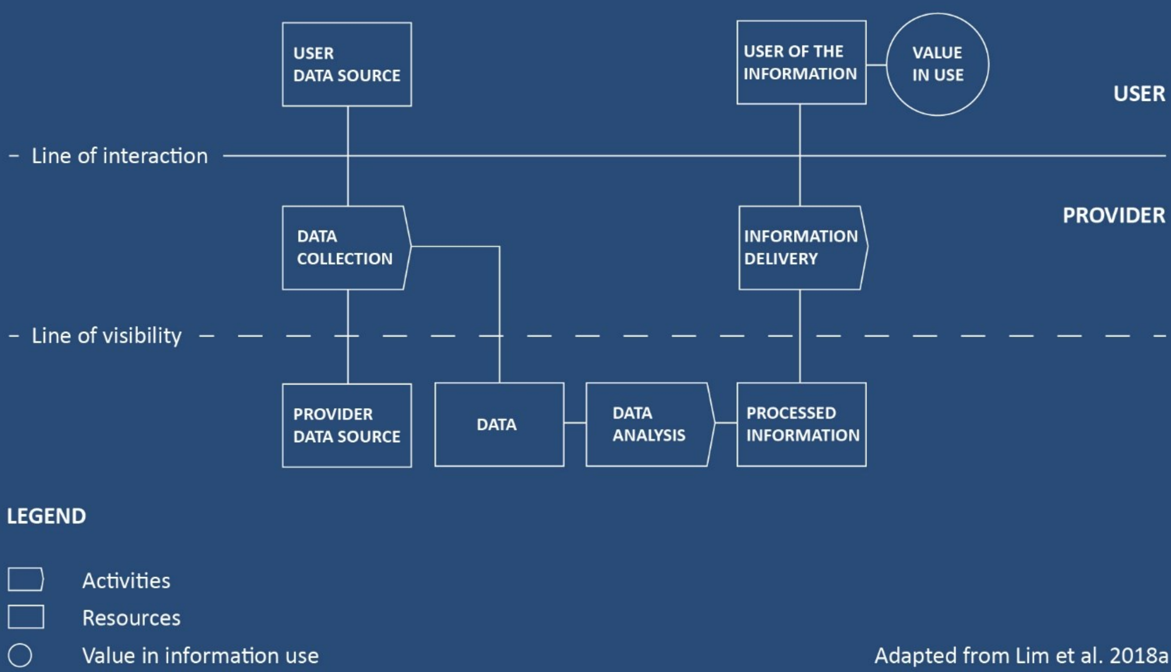
Smart services are characterised by implicit interactions, so that a large number of the functionalities are executed proactively and without the users' awareness (cf. Ju & Leifer 2008). Even in the investigation of prototypes, it can lead to the fact that the probands cannot comprehend the system behaviour or do not perceive the changed system status at all. As a consequence, misjudgement occurs in the requirements elicitation. This effect is usually intensified by the fact that the probands do not yet have adequate mental models to fall back on, since mainly new types of smart services are explored in the prototyping sessions.

The aim is to design the prototypes in such a way that the implicit interactions become tangible for the test persons. At the same time the prototypes should also enhance the understanding of the system behaviour and the value creation mechanisms. The focus lies on the interactions between users and providers. These points of contact become apparent when the data value chain is viewed through the lens of a service blueprint (Shostack 1984) (see Figure 17) or the framework for value co-creation (Payne et al. 2008).

In the present study, it could be shown that an effects-based perspective that contrasts input and output (Haberfellner et al. 2002) is a promising approach for the prototype design. The input indicates which state changes in the context or which user behaviour triggers the system reactions. As output, the consequences are immediately displayed to the users in the interface. Furthermore, it was also found that the mere manifestation of data collection in the context improves the understanding of the test persons regarding system behaviour and value creation mechanisms. One possible manifestation is the representation of smart products in a miniature environment. In short: Make the intangible tangible (Stickdorn et al. 2011).

FIGURE 17 |

DATA VALUE CHAIN - CO-CREATION MECHANISM BETWEEN USER AND PROVIDER



Adapted from Lim et al. 2018a

3.5.1.4 Principle IV – Select appropriate level of automation

Transforming a traditional service into a smart service means improving the decision making and operations within the service with connected things and automation (Lim et al. 2016). In general, the benefits of automation are also accompanied by a number of risks. In addition to the loss of control for users (cf. Endsley & Kaber 1999, Parasuraman et al. 2000), a large part of the system functions also become invisible to users (Wünderlich et al. 2015).

Automation also poses some challenges for prototyping. By nature, test persons in a prototyping session have only limited knowledge of the system functionalities. Combined with insufficient knowledge about the usage situation, it can lead to that test persons do not recognise the misbehaviour of the automation or incorrectly assess the quality of the automation. The actual added value of the automation only becomes apparent when there is knowledge about the automated individual work steps. If the designers decide on a high degree of automation, the complexity in the prototypes is reduced, but at the same time the probands are denied a detailed insight into the data processing of the smart services.

The aim is to design the prototypes in such a way that the automation is visible or can be experienced without distorting the understanding of the smart service. As a decision-making guidance, the higher the probability of misinterpretation by the test persons in the requirements elicitation, the more important it is not to automate.

3.5.1.5 Principle V – Visualize the user journey

An "intelligent" service system is one that augments or extends human capabilities to detect, learn, adapt, monitor and make decisions (National Science Foundation 2016). The system uses the received, transmitted or processed data in a timely manner to improve its response to future situations (National Science Foundation 2016).

The National Science Foundation's definition suggests the potential of smart service with machine learning algorithms and at the same time clarifies that certain added values can only be realised via adaptive mechanisms during the service process. Lim et al. (2018) confirm the importance of the use phase and emphasise that "value is not created until users actually use the received information for a specific purpose". Accordingly, it is crucial not to develop a static prototype, but to let the probands experience the use phase. The challenge is to compress the spatial and temporal dimension of the use phase into a limited prototype.

For the temporal representation of a usage phase, the prototype P9 from the present study extended the prototype to include a scenario with a time-lapse effect. In this way, entire daily routines could be simulated in short prototyping sessions. An established method to convey the spatial dimension of a user journey to the test persons is the desktop walkthrough. Using a miniature environment, the knowledge of the probands can be collected collaboratively and various touchpoints of the usage phases can be discovered (cf. Blomkvist et al. 2016).

3.5.1.6 Principle VI – Filter the areas that are relevant for elicitation

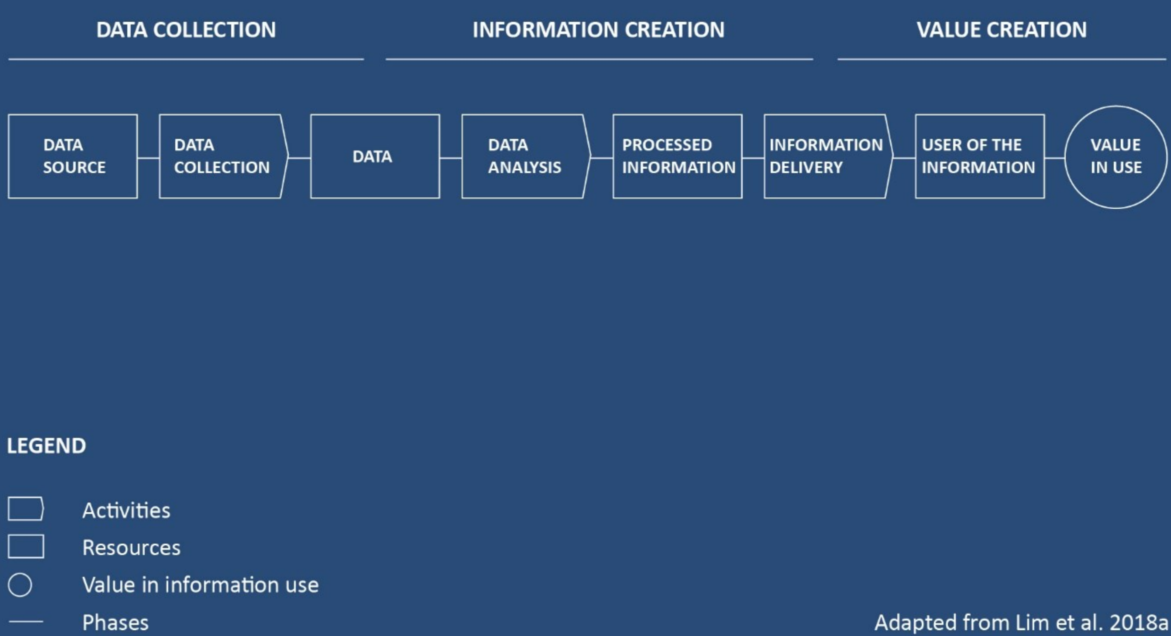
Smart services are extensive and complex. Porter and Heppelmann (2014) illustrate this with an example of the connectivity in agricultural services: "Multiple products connect to many other types of products and often also to external data sources. An array of types of farm equipment are connected to one another, and to geolocation data, to coordinate and optimise the farm system".

Such extremely large and complex design spaces usually cannot be fully mapped and explored in a prototype. Lim et al. (2008) therefore emphasise that a key strength of prototypes is their incompleteness. The incompleteness of a prototype allows the qualities of an idea to be explored without building a complete and final copy of the design (Lim et al. 2008). They interpret a prototype as the simplest representation of a service that filters the qualities designers are interested in without distorting the understanding of the whole (Lim et al. 2008).

In the multi case study, two basic types of filters for smart services were used. The aim was to focus the prototypes on specific areas of interest and thus explicitly reduce the scope and complexity of the prototypes.

1. Value chain as a filter: By analysing the value chain or the value network, the designers can extract the elements of smart services that contribute to value creation. The prototype only illustrates the relevant elements that contribute value to the investigated use case.
2. Zoom-in and zoom-out: With the help of different zoom levels, the focus of the prototypes can be deliberately placed on a specific part or phase of the smart services. For smart services, for example, it can be useful to discover the phases of data-based value creation separately with a prototype (see Figure 18).

FIGURE 18 |
DATA VALUE CHAIN - SUBDIVIDING DATA-BASED VALUE CREATION INTO PHASES



Adapted from Lim et al. 2018a

3.5.2 Data-driven value prototypes in practice

The prototype P9 can be mentioned as a representative for data-driven value prototypes. Figure 19 shows it in practise. The aim of the prototype was to investigate how peak loads generated by wind power can be used economically for charging electric cars. The prototype was used in the early development phase to explode the design space and to collect new requirements. It also demonstrated its potential for identifying unknown unknowns.

Analysing the prototype in detail, some of the developed principles for prototype design become visible. The structure of the prototype is designed to make the data processing process transparent. The process maps the entire path from the smart product (wind turbine) to the user interface (smartphone app application). In this way, the prototype illustrates the context-sensitive functionality of the smart service and shows which technological infrastructure is required. Due to the highly technical smart service, the designers reduce the complexity for the prototype. Using the integrative value chain (cf. Benkenstein and Waldschmidt 2014), the functions and interactions that create value for the user were identified. As a result, the designers integrated only three of the five smart service layers in the prototype. In addition to the data collection in the context (smart product layer) and the user interactions (smart interface layer), the data processing (smart service layer) was depicted. In this smart service, the majority of the functions also are carried out in the background. These functions can be made visible via service evidencing (Stickdorn et al. 2011), as the example of the integrated electronic circuit running in the background shows. Although this circuit does not have a user interface for the charging process, it was included in the prototype as a physical element, by showing the circuit as a separate haptic object in the prototype. In this way, the central importance of the circuit in the data processing process could be made tangible and incorporated into the exploration with the probands.

The prototype emphasised the implementation of context-sensitive functions, which were triggered by detected signals from the environment. For example, the charging process for the vehicle could only be started at a certain wind strength. This connection was demonstrated for the probands by displaying the generated energy in the application only when the wind turbine was rotating.

FIGURE 19 |

PROTOTYP 9 – EXAMPLE OF A DATA-DRIVEN VALUE PROTOTYPE IN PRACTICE

PRINCIPLE I | DEMONSTRATE THE ACTIVITIES OF DATA PROCESSING

IN THE PROTOTYPE, THE RELEVANT LAYERS OF THE SMART SERVICE WERE MAPPED FOR DATA PROCESSING, AND THUS THE VARIOUS FUNCTIONS WERE DEMONSTRATED FOR THE PROBANDS.

PRINCIPLE II | VISUALIZE THE DATA BASED VALUE CREATION

THE VALUE OF THE DATA HAS CONTINUOUSLY INCREASED ALONG THE PROCESSING CHAIN, FROM THE COLLECTION OF THE SIGNALS AT THE WIND TURBINE, THROUGH THE AGGREGATION AND COMBINATION OF THE DATA IN THE INTELLIGENT CIRCUIT, TO THE PRESENTATION IN THE APPLICATION.

PRINCIPLE III | ENSURE VISIBILITY OF SYSTEM STATUS

PRINCIPLE III WAS DEMONSTRATED BY THE INTERPLAY BETWEEN THE WIND TURBINE AND THE APPLICATION. WHEN THE PROBANDS TURNED THE MINIATURE WIND TURBINE, THE GENERATED ENERGY AND LOAD PEAKS WERE DISPLAYED IN THE APPLICATION.

PRINCIPLE IV | SELECT APPROPRIATE LEVEL OF AUTOMATION

IN THE PROTOTYPE, THE AIM WAS TO MAKE THE HIGHLY AUTOMATED PROCESSES VISIBLE AND TANGIBLE FOR THE PROBANDS. FOR THIS REASON, THE INTELLIGENT CIRCUIT WAS INCLUDED IN THE PROTOTYPE AS A HAPTIC ELEMENT (SEE BOX ON THE TABLE).

PRINCIPLE V | VISUALIZE THE USER JOURNEY

PRINCIPLE V IS NOT VISIBLE IN THE FIGURE. IN THE TEST, THE PROTOTYPE WAS COMBINED WITH A SCENARIO. A TIME-LAPSE EFFECT ALLOWED THE PROBANDS TO EXPERIENCE DIFFERENT PHASES OF THE USER JOURNEY.

PRINCIPLE VI | FILTER THE AREAS THAT ARE RELEVANT FOR DATA-DRIVEN VALUE CREATION

IN THE PROTOTYPE ONLY THE LAYERS WERE MAPPED THAT CONTRIBUTE TO THE TRANSFORMATION FROM DATA TO INFORMATION AND INCREASE THE VALUE OF INFORMATION: SMART PRODUCT, SMART SERVICE, AND SMART INTERFACE. THE SMART SPACE AND SMART DATA LAYERS DO NOT GENERATE ANY ADDED VALUE FOR THE THIS SERVICE.

3.6 Discussion

In the emerging field of smart services, prototyping is still a nascent topic and does not yet have a well-founded scientific discourse. For this reason, the derived approach of data-driven value prototypes is discussed with work from related disciplines.

The prototrial driven culture (Jensen et al. 2017) as well as other studies in the field of product design emphasise the effect of functionality on the elicitation of unknown requirements (Leifer & Steinert 2012). This is also the case for data-driven value prototypes. However, compared to product design, the functionality of data-driven value prototypes does not refer to material properties or technical functional principles, but rather to the data flow and the associated data processing. Compared to prototypes in service design, interactivity plays a subordinate role in smart services in the early phases of development. In service design, interactivity is the core of requirements elicitation to overcome the intangibility of the design scope and the overwhelming amount of elements (Passera et al. 2012, Shostack 1984, Blomkvist & Holmlid 2011). In data-driven value prototypes, on the other hand, interactivity is required to make the implicit interactions of the value-creating functions visible to the test persons. In the requirements engineering discipline, the prototyping method is generally studied for its suitability in identifying unknown requirements. The studies in the literature hint at the relevance of prototypes, but show no significant added value compared to traditional methods such as the semi-structured interview (see Davis et al. 2006). However, it is also pointed out that combining prototypes with other methods, such as scenarios, can increase the effectiveness and efficiency of the requirements elicitation (Carroll et al. 1996, Sutcliffe & Ryan 1997). The use of data-driven value prototypes in combination with other techniques should be further explored to increase their relevance in practice.

In an interdisciplinary comparison, it can be stated that the data-driven value prototypes have similarities to the prototrials (Jensen et al. 2017) and the high functional prototypes from product design (Leifer & Steinert 2012). Nevertheless, the generation of value through data represents a unique characteristic for smart service and must accordingly also be taken into account in the prototypes. According to Porter and Heppelmann (2015), smart services will fundamentally change companies and their value chain. One indicator of this is the connectivity. At the beginning of the smart service development, a smart product was usually connected within a smart service system. Today, smart services consist of complex interconnections between smart products and external data sources. In order to categorise the connectivity of smart devices, Porter and Heppelmann (2014) introduce three possible scenarios for connectivity: one to one, one to many and many to many.

An example from mobility is a bike sharing system. Sharing a bike was traditionally a one to one scenario. By connecting, the individual bikes (smart products) to a central rental system this is now transferred into a one-to-many scenario. And with the extension of the bike sharing system to an intermodal route planner, the many-to-many scenario is achieved. In addition to the bike sharing data, data from other means of transport, such as busses, underground trains and car-sharing, are also used for route planning. As a consequence, there is a highly branched data flow with a wide variety of sources and processing steps. With the data flow, the value creation in smart service is also changing. The simple traditional value chain becomes a network of elements that generates value. These branching structures and dynamics not only pose challenges for service providers (cf. Wienken & Krömker 2018, Winter et al. 2012), but also for designers and engineers who have to map the network structures in the prototypes in the early phases of development.

The change in smart services also affects the interaction between providers and users. Users increasingly expect to be able to select the service offer self-determined and to configure it individually (Winter et al. 2012). At the same time, companies are shifting more human-technology interaction from smart products to the cloud (Porter & Heppelmann 2014). This means that the range of functions is growing while at the same time the user interfaces are becoming leaner, and the explicit interactions via buttons on the user interface will be disappeared. Due to this development, the handling of implicit interactions will also increasingly become a key factor for prototyping. Currently, the approach of data-driven value prototypes looks like a promising approach for the discovery of unknown requirements. However, it should be further developed in order to meet the characteristics of smart services.

Although the results of the presented work strongly support the usage of data-driven value prototypes for requirements elicitation, it remains to be discussed that the used methodological approach entails certain limitations for the present study and its results. With Eisenhardt's theory building from cases (1989), a bottom-up approach is chosen in which the specifics of the data create the generalisations of the theory. As a result, there is a risk that the theory does not achieve the generality claim for smart services as a whole and instead works on a theory about specific phenomena of the analysed prototypes. Despite the adherence to quality criteria for qualitative research (cf. Döring & Bortz 2016), a "grand theory" will require several further studies, a collection of both theory-building and theory-testing empirical studies (Eisenhardt 1989).

3.7 Conclusion

This study investigates the research question: What effect do prototypes have on the elicitation of unknown requirements for smart services in the early development phases? To address this challenge, the author conducted a multi case study. The data basis consists of 17 prototypes, which are elicited and explored in the course of eleven expert interviews. The study evaluates the performance of the 17 prototypes and investigates to what extent the prototypes help engineers and designers to elicit the different types of requirements. Inspired by Sutcliffe and Sawyer (2013), the study distinguishes the elicited requirements into four categories according to their relative knowingness: Known knowns, known unknowns, unknown knowns and unknown unknowns. The category of unknown unknowns poses the greatest challenge for requirements elicitation. The reason for this is that there can be serious consequences if crucial information, that is relevant for the success of new products, is not collected in the requirements analysis (Ramasesh & Browning, 2014). The challenge of unknown unknowns lies in the fact that neither the requirements engineer nor the professional being interviewed are immediately able to identify the presence of unknown unknowns (Jensen et al. 2017).

The study results show that the existing approaches for prototype design are not feasible to target the complex nature of smart services and their data-based value creation. In contrast to these existing techniques, the newly identified prototyping approach, the data-driven value prototypes, proved to be particularly effective in eliciting unknown unknowns. The data-driven value prototypes are useful for discovering how providers and users co-create value through data and information exchange. In short, these prototypes serve as a lens for assessing the data's potential for value creation and identifying key problem and design areas in the context of smart services.

By introducing the idea of data-driven value prototypes, the aim is to inspire both engineers and designers to use this prototyping approach not only as a concrete technique, but rather as a mindset for requirements elicitation for smart services in the early development phases. It is the author's believe that such approaches will lead to the radical innovations of the future.

STRUCTURE OF THE WORK – PART C

INTRODUCTION Problem and motivation | objectives and scope

PART A - PROTOTYPES FOR SMART SERVICES: DEFINITIONS AND STRATEGIES

Research question
How can prototypes contribute to the requirements elicitation for smart services in the early development stages?

Research method
Literature research | integrative model building | case-by-case assessment

Results

- Smart service model for prototype creation
- Composition of smart service prototypes
- Strategies for smart service prototypes

PART B - ELICITATION OF UNKNOWN REQUIREMENTS FOR SMART SERVICES: INTRODUCING DATA-DRIVEN VALUE PROTOTYPES AS A NEW APPROACH

Research question
How does the use of prototypes affect the elicitation of unknown requirements for smart services in the early phases of development?

Research method
Literature research | building theories from case study research

Results

- Introducing data-driven value prototypes
- Principles of data-driven value prototypes
- Data-driven value prototypes in practice

PART C - AN EMPIRICAL INVESTIGATION OF REQUIREMENTS ELICITATION: COMPARING THE EFFECTIVENESS OF DATA-DRIVEN VALUE PROTOTYPES

Research question
How does the approach of data-driven value prototypes influence the effectiveness of requirements elicitation in the early development phases of smart services?

Research method
Literature research | comparison of elicitation techniques based on empirical study

Results

- Empirical evidence | Data-driven value prototypes have a higher effectiveness in requirements elicitation than the established approach of experience prototypes

CONCLUSION AND FUTURE WORK

4 PART C - AN EMPIRICAL INVESTIGATION OF REQUIREMENTS ELICITATION: COMPARING THE EFFECTIVENESS OF DATA-DRIVEN VALUE PROTOTYPES

4.1 Introduction

Data-driven value prototypes emphasise the processing and transformation of data in the smart service to convey the data-based value creation between user, provider, and technology. Theses prototype are any kind of representation in any medium that is used to explore how providers and users can create value together through data and information exchange in a networked and context-sensitive system. The underlying motivation for developing this type of prototype was to support designers and engineers in eliciting requirements for smart services in the early stages of development.

Although smart services are an emerging topic in industry and science, there are hardly any empirical studies on prototypes of smart services in the literature so far. A transfer of findings from other studies is only possible to a limited extent, since elicitation techniques are not interchangeable and have broad differences in requirements elicitation, such as in the type of information elicited or in effectiveness and efficiency (Davis et al. 2006, Dieste & Juristo 2010). For this reason, it is important to find out in which situations the technique of data-driven value prototypes should be preferred to another prototyping technique. In concrete terms, the present study compares the effectiveness of data-driven value prototypes with experience prototypes in order to find out under which circumstances the use of the elicitation techniques is purposeful and which is the most suitable prototyping technique for requirements elicitation for smart services in early development phases.

In order to compare the elicitation techniques, the section is divided into five chapters. First, the research is outlined by discussing the current state of the art on the effective use of prototypes in requirements elicitation for smart services. Furthermore, in the theoretical background, data-driven value prototypes are classified against existing approaches to prototype design. This is followed by an empirical investigation of the effectiveness of data-driven value prototypes as an elicitation technique in requirements analysis. The study contrasts the data-driven value prototypes with a traditional prototyping technique, the experience prototypes, and examines the effectiveness using defined metrics. The section is completed by the discussion of the results and implications for researchers and practitioners and concludes with the summary and an outlook for further research.

4.2 Theoretical background

4.2.1 Effectiveness of prototypes in requirements elicitation for smart services

Smart services are networked objects that are able to sense their own and the environment's state, perform real-time data collection and continuous communication to co-create value with users and providers (Wünderlich et al. 2015, Lim & Maglio 2019). This emerging era of services brings a new set of characteristics, which poses challenges for requirements elicitation (Lim et al. 2018b). Lim et al. (2018b) see the key challenge in the distributed network structure. Paldês et al. (2020) shows that traditional methods and techniques lack adequacy for eliciting requirements of smart services. New techniques for requirements elicitation need to create an understanding of the requirements of human and technical actors and their connectivity (Paldês et al. 2020). Paldês et al. (2020) emphasise the need to improve the quality of elicitation techniques in terms of interactivity, connectivity, environment, security, and privacy.

The systematic literature research carried out in this thesis reveals that the dominant topic of the scientific discourse is the development of new methods and procedures for requirements elicitation for networked systems such as smart services or IoT (cf. De Silva et al. 2014, Peruzzini et al. 2015, Kaleem et al. 2020, Howell et al. 2021). In contrast, the comparison of different survey techniques still plays a minor role. For example, Souza et al. (2019) investigate scenario-based requirements specification techniques to support the handling of smartness in IoT systems. Lim et al. (2018b) conducts a systematic literature review to identify current trends regarding elicitation methods in use in IoT. As part of their analysis, they identify, among other things, that interviews and prototypes are the most commonly used survey techniques (Lim et al. 2018b). Paldês et al. (2020), on the other hand, conducts a systematic mapping study to investigate techniques for eliciting functional requirements in IoT software systems. In this comparison, scenarios are identified as the most important method (Paldês et al. 2020).

Overall the results show that an intensive scientific examination of the effectiveness of the various elicitation techniques in the field of smart services has not yet taken place. This also applies in particular to the prototyping of smart services. A differentiated investigation or comparison of different prototyping techniques has not yet been carried out.

4.2.2 Prototyping techniques in the requirements elicitation of smart services and the relevance of data-driven value prototypes

In previous research, a general distinction is made between three types of prototypes: Functional prototypes, experience prototypes, and contextual prototypes (cf. Leifer & Steinert 2011, Buchenau & Suri 2000, Hutchinson et al. 2003). Functional prototypes have proven to be particularly useful for requirements elicitation in the early phases. Studies from the field of product design show that a high level of functionality influences the results of a prototype interaction in the fuzzy frontend (cf. Blackler 2009, Leifer & Steinert 2011, Hare et al. 2013). Such prototypes generally try to map the overall product with a low level of detail, but at the same time they provide a high level of functionality for the domain under investigation (Jensen et al. 2017). The advantage of these techniques is that the subjects deal with the elements of a system and their relationship during the evaluation and thereby analyse the dynamic mechanisms of action and processes (cf. Haberfellner 2002).

In contrast, experience prototypes are used to successfully (re) live or convey the experience of using a system (Buchenau & Suri 2000). This approach is widely used in service design and in the field of human computer interaction. The advantage of these prototypes is that prototype interaction reveals a person's perceptions and reactions resulting from the actual or expected use of a system (International Standards Organization 2010).

Finally, the contextual prototypes collect information about the use and the users of the technology in a real-world setting (Hutchinson et al. 2003). Beaudouin-Lafon and Mackay (2009) emphasise that prototypes should be used in a more realistic scenario to simulate the system under real conditions. In requirements elicitation, the context of use thus serves as a stimulus to encourage the discovery of requirements by the probands.

However, all these techniques have weaknesses for the requirements elicitation of smart services. This is due to the characteristics of smart services. As so-called hybrid product-service systems, they bring new challenges for the prototypes. Functional prototypes, for example, usually address material properties or technical functional principles in product design. With smart services, these aspects move into the background. More important is the high-performance transformation of data, from data acquisition at the sensor to the presentation of information in the user interface of the application. The value of smart services is generated through the combination or enrichment of data, the analysis of correlations and the automation of working steps. This data-driven value creation is difficult to make tangible with traditional prototypes and can only be mapped to a limited extent.

Compared to traditional digital products, the interactions shift from the user interface to the area that is not visible to the users (see Figure 2). The smart services are often no longer controlled by explicit input at the user interface, but by implicit interactions. Based on the recorded user behaviour, the service controls the functionalities proactively and without demanding the user's attention. This leads to the fact that an experience prototype, which makes the explicit interactions tangible for the test persons, is not sufficient to comprehend and assess the system behaviour. It is particularly challenging to model implicit interactions in time-limited prototyping sessions. For the execution of implicit interactions, user data is usually collected and analysed over a longer period of time. However, in a short test session, the probands have neither enough time to train the algorithms with their individual user data, nor is there enough time for the probands to discover and learn the system feedback.

In view of the challenges for prototyping in smart services, the approach of data-driven value prototypes was developed. The motivation for developing this new type of prototype was to help designers and engineers elicit requirements for smart services in the early stages of development. As the term suggests, data-driven value prototypes emphasise the processing and transformation of data to convey data-based value creation between users, providers and technology. The reason for this focus is that smart services are a type of service where value is primarily generated through information interactions rather than through physical or human interactions (Karmarkar & Apte 2007, Lim & Kim 2014). Hence, the data-driven value prototypes represent the whole process of data processing, from the collection of data at the sensor, to the analysis and aggregation of the data, to the presentation of the information in the user interface. In parallel, the data-driven value prototypes have the potential to make the creation of value transparent. Along the data processing process, it becomes visible which technology, actors and activities contribute to the data-based value creation and together form the data value chain. The data-driven value prototypes thus use the data and data value chain as a stimulus in the prototype interaction and thus improve the knowledge retrieval of relevant system requirements in the requirements elicitation of smart services.

In summary, data-driven value prototypes seem to be a promising approach for requirements elicitation in smart services. However, there is a lack of comparative studies that prove the effectiveness of the approach. Therefore, in a first step, this paper will investigate to what extent the data-driven value prototypes influence the effectiveness in requirements elicitation and how the effectiveness compares to existing prototyping techniques. As a subsequent step, the approach of the data-data value prototypes should be compared with established elicitation techniques such as interviews. However, this comparison to interviews is not part of this thesis.

4.2.3 Research question

Data-driven value prototypes aim to support engineers and designers in the exploration and investigation of smart services already in the early development phases. The multi case study conducted in this thesis (see Part 0) provides first evidence for a positive effect in requirements elicitation, however, evidence from a comparative study is missing so far. Motivated by this, the following research question should be investigated:

RQ C How does the approach of data-driven value prototypes influence the effectiveness of requirements elicitation in the early development phases of smart services?

To answer the research question, the study compares two elicitation methods in terms of effectiveness: data-driven value prototype and experience prototype. With the help of the comparison, the approach of data-driven value prototypes can be classified against traditional prototyping techniques. In the context of the study, the overall research question is split into four measurable hypotheses. The hypotheses are stated as alternative hypotheses. The selection of variables is based on the systematic review of empirical studies on requirements elicitation by Dieste and Juristo (2010) and has already been used in this combination in other studies on requirements evaluation (cf. Niknafs & Berry 2012).

Hypothesis HC I The total number of requirements elicited differs between the elicitation techniques data-driven value prototype and experience prototype.

Hypothesis HC II The number of elicited requirements that are considered relevant differs between the elicitation techniques data-driven value prototype and experience prototype.

Hypothesis HC III The number of elicited requirements that are considered feasible differs between the elicitation techniques data-driven value prototype and experience prototype.

Hypothesis HC IV The number of elicited requirements considered innovative differs between the elicitation techniques data-driven value prototype and experience prototype.

4.3 Experiment design

4.3.1 Method and procedure

The aim of the study is to investigate the effectiveness of data-driven value prototypes in the requirements elicitation of smart services. In a controlled experiment, the effectiveness of two types of prototypes is compared: The newly developed technique of data-driven value prototypes is compared to the conventional technique of experience prototypes. The experience prototypes were chosen as the comparative technique because they are a widely used approach for early-stage development in service design and human-computer interaction. The results of the part C lead us to a discussion on how prototypes for effective requirements elicitation for smart services in the early development phases must be designed in the future.

To compare the two prototype techniques, 24 sessions and 48 tests were conducted. Each test person was confronted with one data-driven value prototype and one experience prototype. In total, four prototypes of two different systems were developed for the study. The aim was to compare the data collection techniques in several settings in order to increase the power of the study results (cf. Davis et al. 2006). Accordingly, the probands were divided into four groups. The order of the systems and the type of elicitation techniques differed between the four groups so that order effects could be avoided. The division of the subjects was carried out using a random number table. As the central experimental task, the probands were asked to carry out the requirement elicitation and to generate as many requirements as possible.

Thematically, two different systems from the mobility sector were selected for the experiment. One system was the extension of a conventional public transport trip planner into an agenda planning system. The second system was an intermodal mobility platform. The platform combined a variety of transport modes and enabled the planning, booking and payment of intermodal journeys in one application. Both systems were developed within research projects. For this reason, it was assumed that due to the novelty of the systems, probands would have to be imaginative in formulating requirements and would not be able to rely on previously formed beliefs (cf. Browne and Rogich 2001). It should be ensured that the subjects were not familiar with the task. Otherwise, if the case were not new, the probands' answers could be based on previous experience with systems of this kind, which could lead to a bias in the results (cf. Browne and Rogich 2001).

All test sessions followed a fixed procedure (see Table 10). Before the session, the probands were screened by a questionnaire. After inclusion in the study, the purpose of the test session and the procedure were explained to the probands in the introduction phase. At the end of the introduction, the probands were randomly assigned to one of the four groups. During the session, the probands were guided along the user journey with the help of a desktop walkthrough and asked to perform the predefined tasks with the prototypical smartphone application. For example, the probands had to plan a daily schedule with predefined appointments and tasks using the agenda planning system. After each task, the probands had to record all identified requirements in a written description in the test protocol. During the requirements elicitation, the probands were free to explore the prototypes. The probands had a duration of 30 minutes per tested system for the execution of the tasks and the subsequent elicitation of the requirements. Probands who completed the task early were able to finish the test before the time limit expired. All probands performed the test individually in a laboratory setting.

TABLE 10 |
SCHEMATIC DESCRIPTION OF THE STUDY PROCESS

TEST PREPARATION	
Screening of the probands by questionnaire Consent to test participation and data collection	
TEST INTRODUCTION	
Introduction to the purpose and procedure of the test Randomised assignment to groups 1 - 4	
TEST EXECUTION	
Phase I	**Investigation of the first system and prototype according to group assignment**
	Execution of the predefined tasks with the prototype Free exploration of the prototype Recording the identified requirements in the test protocol
Phase II	**Investigation of the second system and prototype according to group assignment**
	Execution of the predefined tasks with the prototype Free exploration of the prototype Recording the identified requirements in the test protocol
TEST CONCLUSION	
Clarification of open questions with probands	

4.3.2 Description of tested systems and prototypes

In total, four prototypes of two different systems were developed for the study. For each system, a data-driven value prototype and an experience prototype were created.

4.3.2.1 Description of the tested systems

Thematically, two different systems from the mobility sector were selected for the experiment. One system was an agenda planning system. The system combines the trip planning of public transport with the personal daily schedule of passengers (Wienken et al. 2014, Wienken et al. 2017). In doing so, passengers are extensively freed from the complex and time-consuming trip planning and the reasons for mobility, such as settlements and appointments, are placed in the focus. Passengers thus only have to plan their tasks and appointments, and the time-consuming search for all arrivals and departures by bus and train is automatically taken over by the system. In this way, the user receives the optimal travel route with the most efficient order of appointments and tasks. The approach for mobility planning was newly developed as part of the DynAPSys research project funded by the German Federal Ministry of Economy and Technology (BMWi) (cf. Krömker & Wienken 2017).

The second selected system is also based on a research project. As part of the project "Digital Mobility - Open Mobility Platform", a reference architecture for intermodal mobility platforms with standardised interfaces was specified (cf. Wienken et al. 2019 | funded by German Federal Ministry of Transport and Digital Infrastructure (BMVI)). This new type of mobility platform combines a variety of transport modes, such as buses and trains as well as bike and car sharing, and enables the planning, booking, and payment of intermodal trips from a single source.

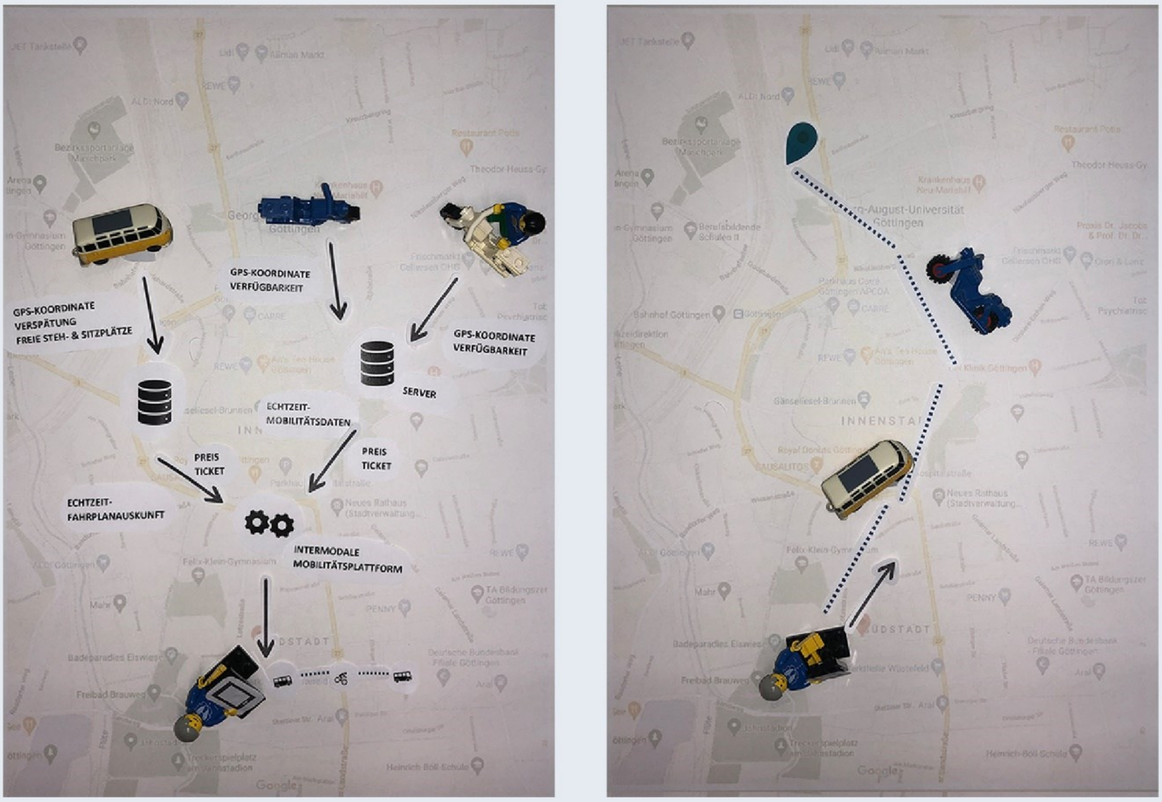


FIGURE 20 |

ILLUSTRATION OF THE DESKTOP WALKTHROUGH FOR DATA-DRIVEN VALUE PROTOTYPE (LEFT) AND EXPERIENCE PROTOTYPE (RIGHT) FOR THE SYSTEM INTERMODAL MOBILITY PLATFORM

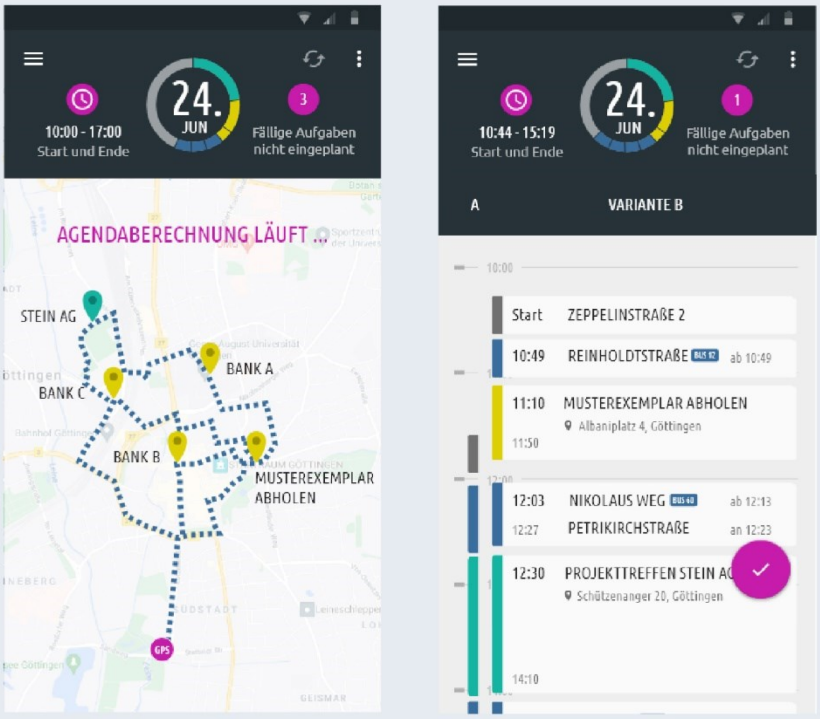


FIGURE 21 |

ILLUSTRATION OF THE PROTOTYPE SMARTPHONE APPLICATION FOR THE AGENDA PLANNING SYSTEM.

THE DATA-DRIVEN VALUE PROTOTYPE DEMONSTRATES THE AUTOMATED STEPS OF THE AGENDA CALCULATION (LEFT). THE EXPERIENCE PROTOTYPE SHOWS THE SELECTION OF A DAILY AGENDA (RIGHT).

4.3.2.2 Composition and differences of the tested prototypes

Crucial for the study was that stereotypical representatives of the prototype techniques were created and tested. For this reason, the principles developed in chapter 3.5.1 were applied to the design of the data-driven value prototypes. For the experience prototypes, the design was based on the explanations of Buchenau and Suri (2000).

The basic structure of all prototypes was identical. The prototypes consisted of a desktop walkthrough and a prototypical smartphone application. Along the desktop walkthrough, the probands were able to experience the user journey and complete tasks with the applications at selected touchpoints.

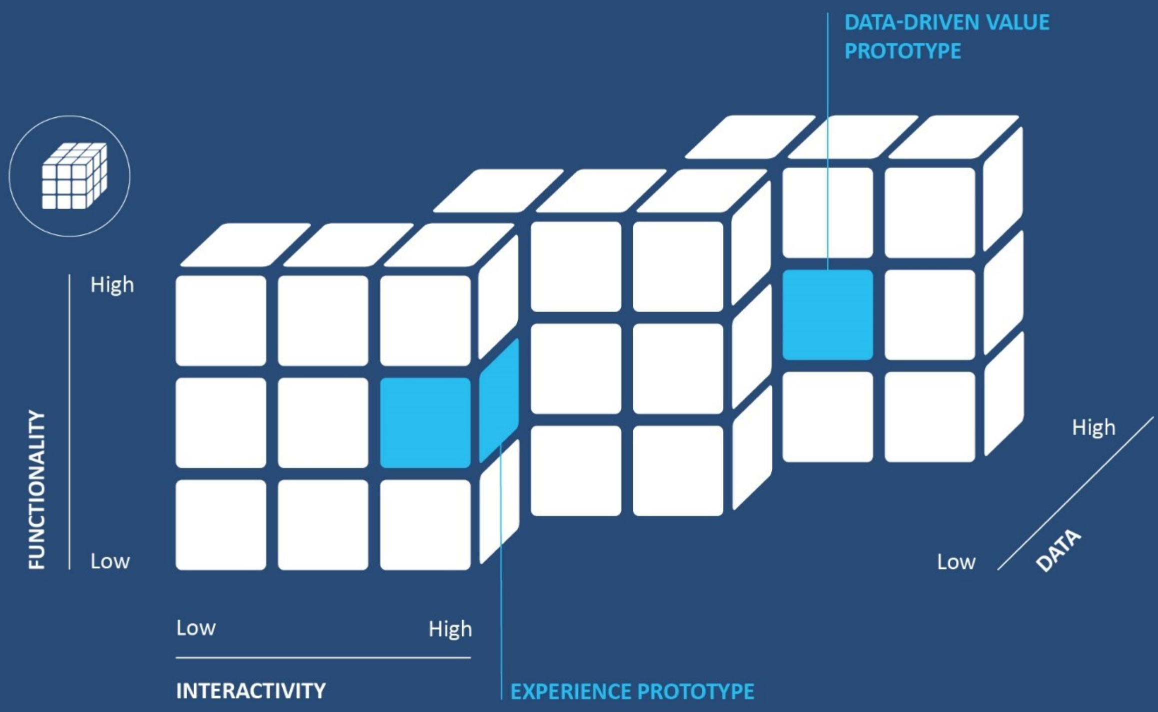
However, the composition of the smart service prototypes differed between the data-driven value prototypes and the experience prototypes. The prototypes differed in three of the six dimensions for smart service prototypes (see Table 6): Interactivity, data, and functionality. In contrast to the data-driven value prototypes, the experience prototypes had a higher level of interactivity. This means, the probands had significantly more interactions for inputs and outputs in the smartphone applications. The aim of the experience prototypes was to enable the probands to explore and successfully experience the smart services through the interactions. The prototypes also differed in the implicit interactions. The data-driven value prototypes showed how the applications were influenced by the context of use. For this purpose, the prototypes used the interplay between desktop walkthrough and smartphone application (Principle III of data-driven value prototypes, see 3.5.1.3).

Functionally, the data-driven value prototypes and experience prototypes simulated the identical functionalities in the smartphone application. However, according to principle IV (see 3.5.1.4), the data-driven value prototypes made the highly automated steps of the smart service visible in the user interface for the probands.

The prototypes also differed significantly in the dimension of data. While the processed data was identical, the way of presentation differed. According to principles I and II (see 3.5.1.1), the activities of data processing and data-based value creation are visualised in the data-driven value prototypes. In addition, the desktop walkthrough showed which components are required in the individual layers of the smart services and which data are transformed into valuable information.

FIGURE 22 |

DISTINCTION BETWEEN DATA-DRIVEN VALUE PROTOTYPE AND EXPERIENCE PROTOTYPE FOR THE COMPARATIVE STUDY



NOTE

The other three of the six dimensions for composing smart service prototypes were implemented identically in all prototypes (representation, scope, and appearance).

All other dimensions of the smart service prototypes (representation, scope, and appearance - see Table 6) were implemented identically in the prototypes. The aim was to minimise possible confounding variables for the study. As described, the representation dimension for all prototypes consisted of a prototypical smartphone application, which was completed by a desktop walkthrough. The scope of the data-driven value prototypes and the experience prototypes was also identical. Both prototypes mapped the identical user journey and touchpoints. The identical use cases were also implemented in all smartphone applications. There were also no differences in terms of appearance; both the screen designs of the smartphone applications and the walkthroughs were prepared identically.

4.3.3 Participants

In total, 24 voluntary probands took part in the study. The sample consisted of 41 % women and 59 % men, with an average age of 36 years. The criteria for selection were that the subjects use smartphones in their daily lives and have experience in public transport and use mobile application for trip planning in public transport. Persons with previous knowledge in requirements engineering were excluded from the experiment. The experiment was conducted in German, the native language of all probands.

4.3.4 Metrics for evaluation

The key metric for this study is the quantity of information collected. Davis (1982) as well as Vessey and Conger (1994) emphasise the quantity of information collected because missing information not taken into account in system development can have a negative impact on the quality of the final system. Furthermore, Browne and Rogich (2001) assume that the analysts do not know a priori the relevance and usefulness of the elicited requirements. Therefore, gathering as much information as possible provides the best opportunity to identify the most relevant information for a planned system (Brody 1982). In this study, this metric is distinguished by the total number of functional and non-functional requirements.

TABLE 11 |
METRICS FOR EVALUATION

HYPOTHESIS	IMPACT ON	VARIABLE
Hypothesis HC I	Quantity	Number of functional requirements + non-functional requirements
Hypothesis HC II	Quality	Relevance | Number of requirements considered as relevant
Hypothesis HC III	Quality	Feasibility | Number of requirements considered as feasible
Hypothesis HC IV	Quality	Innovation | Number of requirements considered as innovative

Based on the amount of information collected, the quality of the requirements will be of interest as well. Since the quality of a requirement can only be accurately assessed much later in the system development, it is necessary for the present study to use a surrogate metric for the quality of requirements (cf. Pitts & Browne 2007). Following Niknafs and Berry (2012), the quality of a requirement can be described by the characteristics relevance, feasibility, and innovation. The selection of the characteristics is based on the IEEE standard "Recommended Practice for Software Requirements Specifications" (Doe 2011). The present study uses this approach and evaluates each requirement elicited from the probands on the basis of the three characteristics (cf. Niknafs & Berry 2012):

- Relevance: A requirement is considered relevant if it relates to the context of the system.
- Feasibility: A requirement is considered feasible if it is relevant, correct, and implementable.
- Innovation: A requirement is considered innovative if it is feasible and the analyst is not aware of any existing implementation in the domain.

4.3.5 Data analysis

The starting point for the data analysis were the test protocols that the probands filled out during the test session. The test protocols were the only data source for the analysis. Before it was possible to code the data, all the protocols had to be broken down into meaningful units. Following the model of Mayring and Fenzl (2014), the recorded requirements were paraphrased and generalised. After generalisation, the data collected from each respondent was checked and redundant requirements were removed. For the evaluation of the data, an alphabetically sorted list of all requirements was created.

After data preparation, the requirements were coded according to the defined variables (functional, non-functional, relevant, feasible, and innovative). A scoring method was used in which the frequencies of the requirements were listed in tabular form (cf. Todd & Benbasat 1987). The coding was done by two experts who were blind to the hypotheses of the study. To ensure the reliability of such an evaluation, it is a common procedure that two independent experts evaluate the results separately according to a given set of rules (cf. Browne & Rogich 2001, Pitts & Browne 2007). Subsequently, an inter-rater reliability coefficient between the two evaluations can be calculated. Due to research economics, the second expert in the present study reviewed a random sample of 20 per cent of the elicited requirements. The inter-rater reliability coefficient between the two experts was 91 percent. The value reached a sufficient significance for inter-rater agreement, i.e. agreement between the examiners. (cf. Clark-Carter 1997). This demonstrated the reliability of the method. Accordingly, the results of the first expert were considered reliable and used as a basis for the further analyses.

4.4 Results

The aim of this study is to investigate the effectiveness of the data-driven value prototype in eliciting requirements for smart service in early development phases. Therefore, the data was analysed to determine whether the probands who interact with the data-driven value prototypes elicited significantly more requirements than the probands who used the experience prototypes.

Table 12 shows the mean values and standard deviations for the quantity, relevance, feasibility and degree of innovation of the requirements elicited by the probands with the two types of prototypes. For the analysis of the data, t-tests for independent samples were applied. With the help of t-test it is possible to determine whether two groups under consideration show a real difference in an examined variable or not (Bortz & Schuster 2011). The t-test has already been used in comparable studies that compare two elicitation techniques with each other (cf. Pitts & Browne 2007, Sefelin et al. 2003). The analysis was carried out with the help of statistical software SPSS. The preconditions of the t-test for independent samples, such as the normal distribution of the data, and the homogeneity of the variances (Levene test) were also examined with the help of SPSS.

In line with Davis (1982) and Vessey and Conger (1994), the quantity of requirements was examined as the central metric for this study. The results show that probands in both settings elicited a significantly higher number of requirements using the data-driven value prototypes. For example, for the setting agenda planning system, the probands with the data-driven value prototype elicit a higher number of raw requirements ($M = 18.33$, $SD = 7.58$, $n = 12$) than the probands ($M = 12.17$, $SD = 3.68$, $n = 12$) who used the experience prototype, $t(22) = 2.511$, $p = 0.020$. With a p-value of less than 0.05, the difference between the data-driven value prototypes and experience prototypes is significant. These results support hypothesis HC I.

TABLE 12 |

MEANS AND STANDARD DEVIATIONS FOR RAW, RELEVANT, FEASIBLE, AND INNOVATIVE REQUIREMENTS (NUMBER OF CODED REQUIREMENTS FOR BOTH SETTINGS AND ALL PROTOTYPES)

	RAW REQUIREMENTS		**RELEVANT REQUIREMENTS**		**FEASIBLE REQUIREMENTS**		**INNOVATIVE REQUIREMENTS**	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AGENDA PLANNING SYSTEM								
Data-driven value prototype	18.33	7.58	17.92	7.54	17.50	7.36	1.25	1.36
Experience prototype	12.17	3.86	11.33	3.75	10.75	3.62	0.33	0.65
INTERMODAL MOBILITY PLATFORM								
Data-driven value prototype	20.00	3.28	19.42	3.45	19.08	3.18	1.58	1.68
Experience prototype	15.67	3.70	14.75	3.67	14.42	3.58	0.33	0.651

Sample size per group N = 12 | SD = standard deviation

TABLE 13 |
t-TEST AND COHEN'S d FOR RAW, RELEVANT, FEASIBLE, AND INNOVATIVE REQUIREMENTS

	t	df	p-VALUE (2-TAILED)	COHEN'S d
AGENDA PLANNING SYSTEM				
Raw requirements	2.511	22	0.020	1.025
Relevant requirements	2.709	22	0.013	1.106
Feasible requirements	2.852	22	0.009	1.164
Innovative requirements	2.110	22	0.046	0.861
INTERMODAL MOBILITY PLATFORM				
Raw requirements	3.037	22	0.006	1.240
Relevant requirements	3.209	22	0.004	1.310
Feasible requirements	3.379	22	0.003	1.379
Innovative requirements	2.408	22	0.025	0.983

Significance level 0.05 | df = degrees of freedom

However, not only the number of requirements is crucial for requirements elicitation, but also the quality of the elicited information. For this reason, it was investigated to what extent the data-driven value prototypes enable the elicitation of relevant, feasible, and innovative requirements. Also for the qualitative categories relevant, feasible and innovative, a significantly higher number of requirements were elicited by the probands with data-driven value prototypes. The significance could be measured in both settings agenda planning system and intermodal mobility platform. The probands using the data-driven value prototype in the agenda planning system setting, for example, elicited a higher number of relevant requirements ($M = 17.92$, $SD = 7.54$, $n = 12$) than the probands ($M = 11.33$, $SD = 3.75$, $n = 12$) who used the experience prototype, $t(22) = 2.709$, $p = 0.013$. All results are shown in Table 13. Thus, the difference between the data-driven value prototypes and the experience prototypes is significant with a p-value of less than 0.05. The results of the study support the hypotheses HC II - HC IV.

Furthermore, it is analysed how much the two samples differ. Cohen's d is calculated using SPSS. For the example of the relevant requirements in the setting of the agenda planning system, the value 1.106 is above the threshold for a strong effect. The classification of effect sizes according to Cohen (1992) contains the following values:

- d = 0.20 indicates a small effect,
- d = 0.50 indicates a medium effect,
- d = 0.80 indicates a large effect.

Thus, all differences between the two elicitation techniques in the study can be classified as a strong effect.

Overall, the present results illustrate that the use of data-driven value prototypes leads to a more comprehensive set of requirements elicited regarding quantity and quality.

Detailed statistical calculations can be studied in the appendix Part C - Statistical calculation.

4.5 Discussion

The study and its results contribute to the research of requirements elicitation in smart services. As the literature review revealed (see chapter 4.2), no comparable studies have so far investigated the effectiveness of prototypes in requirements elicitation for smart services.

From a scientific point of view, this study is an initial step to start the discourse. In detail, the study indicates that data-driven value prototypes are more effective in terms of quantity and quality in requirements elicitation than the established approach of experience prototypes. The results support the findings from the qualitative study in chapter 3.

The findings can probably be explained by the fact that the data-driven value prototypes directly address the new characteristics of smart services. As the term suggests, data-driven value prototypes emphasise the processing and transformation of data to convey data-based value creation between users, providers and technology. The prototypes represent the whole process of data processing, from the collection of data at the sensor, to the analysis and aggregation of the data, to the presentation of the information in the user interface. In comparison, the experience prototypes demonstrate only the mostly explicit interactions at the user interface and their consequences in order to (re)live or convey an experience with a system (Buchenau & Suri 2000). The data-driven value prototypes, on the other hand, broaden this perspective and provide insights below the line of visibility (see Figure 2). For the probands, the components, processes and context-driven implicit interactions of the smart services become visible and tangible.

Overall, the importance of prototypes as an elicitation technique is increasing. Lim et al. (2018b) identify in their systematic literature review that interviews and prototypes are the most frequently used elicitation techniques for networked systems, such as IoT or smart services. For this reason, it is necessary to further expand the research. The aim should be to learn more about the nature of data-driven value prototypes and how the prototypes can be used in practice in the future. For example, it can be assumed that a combination with other techniques, such as scenarios, has a positive impact on requirements elicitation (cf. Sutcliffe & Sawyer 2013). Not only the combination with other techniques is of interest, but also the direct comparison regarding the effectiveness with traditional methods, such as interviews. In addition, an interesting question is whether the positive effect from the present study also occurs when experts instead of end users apply the data-driven value prototypes in the requirements elicitation.

As any other empirical study, the present study has methodological limitations that threaten the validity of the results. Particularly, the low statistical power based on the sample size should be noted. Beforehand, a post-hoc power analysis was conducted to determine the minimum sample size that would provide a power of at least 0.80. To achieve a large effect with d = 0.80 (cf. Cohen 1992), a sample size of 26 probands would be required for each group. Due to the COVID-19 pandemic and the resulting hygiene regulations, it was not possible to conduct the empirical study with the targeted sample size. For this reason, the present study and its design follows other scientific studies that have conducted experiments with comparable sample sizes in other disciplines (cf. Lim et al. 2006, Rueda et al. 2020, Virzi et al. 1996). Despite its low sample size, the results clearly support the improved effectiveness for requirements elicitation through the use of the data-driven value prototype. However, if additional experiments on other aspects are conducted an increased sample size could be used for confirming the results of this study.

4.6 Conclusion

The starting point of the research is the question: How does the approach of data-driven value prototypes influence the effectiveness of requirements elicitation in the early development phases of smart services? To address this question, this empirical study compares the data-driven value prototypes with a traditional prototyping technique, the experience prototypes according to Buchenau & Suri (2000), and investigates the effectiveness using defined metrics.

The study proves that probands who use the data-driven value prototypes as an elicitation technique elicit quantitatively more requirements. In addition to the quantity, the quality of the elicited requirements is also crucial. Compared to the experience prototypes, the data-driven value prototypes elicit a higher number of relevant, realisable, and innovative requirements. The results clearly support the improved effectiveness for requirements elicitation through the use of the data-driven value prototype. The empirical study is an evidence that the complex components, functionalities and characteristics of smart services can be adequately mapped in data-driven value prototypes and that the designers as well as the engineers are supported in the discovery of new requirements in the early development phases. However, demonstrating the higher effectiveness compared to established prototyping techniques is only an initial step in the investigation of data-driven value prototypes. For this reason, it is necessary to further expand the research. The aim should be to empirically compare the data-driven value prototypes with traditional elicitation techniques, such as interviews, and furthermore to investigate the combination with other techniques, such as scenarios.

5 CONCLUSION AND FUTURE WORK

Smart services are networked objects that are able to sense their own and the environment's state, perform real-time data collection and continuous communication to co-create value with users and providers (Wünderlich et al. 2015, Lim & Maglio 2019). This emerging era of services brings a new set of characteristics, which poses challenges for requirements elicitation (Lim et al. 2018b).

In other disciplines like product design, recent innovation research emphasizes the value of prototypes already for the early stages of development to create radical innovations (cf. Haines-Gadd et al. 2015, Leifer & Steinert 2011, Jensen et al. 2017). Motivated by these studies, in the present work it is explored how prototypes can contribute to requirements elicitation for smart services in the early development phases. To address this challenge, a three-part research procedure was conducted.

At the beginning, the findings of the comprehensive literature research reveals that the understanding of smart services varies from discipline to discipline and that the existing models and framework address only rudimentary prototyping issues. To overcome this shortcoming, a layer model was introduced to create a common understanding for the investigation of smart services (Wienken & Krömker 2020). Furthermore, for the systematic design of the prototypes, there was a need to investigate which dimensions a smart service prototype must be composed of in order to adequately represent the characteristics of smart services. For the composition of smart service prototypes, six relevant dimensions could be identified: Representation, scope, functionality, interactivity, appearance, and data.

Based on the presented state of the art, the effect of prototypes on the requirements elicitation of smart services in the early development phases was investigated. The results of the conducted multi case study show that the existing approaches for prototype design are not feasible to target the complex nature of smart services and their data-based value creation. In contrast to these existing techniques, a newly identified prototyping approach proved to be particularly effective in eliciting unknown requirements. Data-driven value prototypes emphasise the processing and transformation of data in the smart service to convey the data-based value creation between user, provider, and technology.

For the practical use, it is important to find out in which situations the technique of data-driven value prototypes should be preferred to another prototyping technique. To answer this question, an empirical study was conducted comparing data-driven value prototypes with a traditional prototyping technique, the experience prototypes according to Buchenau & Suri (2000), and investigating the effectiveness of both techniques. The results clearly support the improved effectiveness for requirements elicitation through the use of the data-driven value prototype. The empirical study is evidence that the complex components, functions, and characteristics of smart services can be adequately represented in data-driven value prototypes and support designers as well as engineers in discovering new requirements in the early development phases.

Overall, the importance of prototypes as an elicitation technique is increasing. Lim et al. (2018b) identify in their systematic literature review that interviews and prototypes are the most frequently used elicitation techniques for networked systems, such as IoT or smart services. For this reason, it is necessary to further expand the research. The questions and results discussed in this thesis represent a first step in the exploration of data-driven value prototypes and should encourage researchers as well as practitioners to address the requirements elicitation for smart services intensively in the future. The aim should be to learn more about the nature of data-driven value prototypes and how the prototypes can be used in practice in the future. For example, it can be assumed that a combination with other techniques, such as scenarios, has a positive impact on requirements elicitation (cf. Sutcliffe & Sawyer 2013). Not only the combination with other techniques is of interest, but also the direct comparison regarding the effectiveness with traditional methods, such as interviews. In addition, an interesting question is whether the positive effect from the present study also occurs when experts instead of end users apply the data-driven value prototypes in the requirements elicitation.

6 BIBLIOGRAPHY

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

Alexander, C. (1977). A pattern language: towns, buildings, construction. Oxford university press.

Allmendinger, G., & Lombreglia, R. (2005). Four strategies for the age of smart services. Harvard business review, 83(10), 131.

Arnowitz, J., Arent, M., & Berger, N. (2010). Effective prototyping for software makers. Elsevier.

Basole, R. C., & Rouse, W. B. (2008). Complexity of service value networks: Conceptualization and empirical investigation. IBM systems journal, 47(1), 53-70.

Beaudouin-Lafon, M., & Mackay, W. (2003). Prototyping tools and techniques. Human Computer Interaction-Development Process, 122-142.

Benkenstein, M., & Waldschmidt, V. (2014). Wertkettenanalyse und Service Value–eine Diskussion im Lichte der Service-Dominant Logic. In Service Value als Werttreiber (pp. 205-221). Springer Gabler, Wiesbaden.

Bitner, M. J. (1992). Servicescapes: The impact of physical surroundings on customers and employees. Journal of marketing, 56(2), 57-71.

Blackler, A. (2008). Applications of high and low fidelity prototypes in researching intuitive interaction. In Proceedings of DRS2008, Design Research Society Biennial Conference (pp. 1-17). Sheffield Hallam University.

Blomkvist, J., & Holmlid, S. (2011). Existing prototyping perspectives: Considerations for service design. Nordes, (4).

Blomkvist, J., Fjuk, A., & Sayapina, V. (2016). Low threshold service design: desktop walkthrough. In Service Design Geographies. Proceedings of the ServDes. 2016 Conference (No. 125, pp. 154-166). Linköping University Electronic Press.

Bortz, J., & Schuster, C. (2011). Statistik für Human-und Sozialwissenschaftler: Limitierte Sonderausgabe. Springer-Verlag.

Brody, R. (1982). Problem solving: Concepts and methods for community organizations. Human Sciences Press.

Browne, G. J., & Rogich, M. B. (2001). An empirical investigation of user requirements elicitation: Comparing the effectiveness of prompting techniques. Journal of Management Information Systems, 17(4), 223-249.

Bruhn, M., & Hadwich, K. (2014). Service Value–Eine Einführung in die theoretischen und praktischen Problemstellungen. In Service Value als Werttreiber (pp. 3-31). Springer Gabler, Wiesbaden.

Bruhn, M., & Hadwich, K. (2017). Dienstleistungen 4.0–Erscheinungsformen, Transformationsprozesse und Managementimplikationen. In Dienstleistungen 4.0 (pp. 1-39). Springer Gabler, Wiesbaden.

Buchenau, M., & Suri, J. F. (2000). Experience prototyping. In Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques (pp. 424-433).

Bullinger, H. J., Ganz, W., & Neuhüttler, J. (2017). Smart Services–Chancen und Herausforderungen digitalisierter Dienstleistungssysteme für Unternehmen. In Dienstleistungen 4.0 (pp. 97-120). Springer Gabler, Wiesbaden.

Cambridge University Press, https://dictionary.cambridge.org/de/worterbuch/englisch/connectivity, last accessed 2020/02/24.

Carroll, J. M., Duffy, T. M., Osgood, D., Holyoak, D., & Monson, D. (1996). Scenario-based design: envisioning work and technology in system development. IEEE Transactions on Professional Communications, 39(4), 241-241.

Carrubbo, L., Bruni, R., Cavacece, Y., & Moretta Tartaglione, A. (2015). Service system platforms to improve value co-creation: Insights for translational medicine. 2015), Service Dominant Logic, Network and Systems Theory and Service Science: Integrating three Perspectives for a New Service Agenda.

Clark-Carter, D. (1997). Doing quantitative psychological research: from design to report. Psychology Press/Erlbaum (UK) Taylor & Francis.

Cohen, J. (1992). A power primer. Psychological bulletin, 112(1), 155.

Davis, A. (1992). Operational Prototyping: A New Development Approach. Software, 9(5): 70-78.

Davis, A., Dieste, O., Hickey, A., Juristo, N., & Moreno, A. M. (2006). Effectiveness of requirements elicitation techniques: Empirical results derived from a systematic review. In 14th IEEE International Requirements Engineering Conference (RE'06) (pp. 179-188). IEEE.

Davis, G. B. (1982). Strategies for information requirements determination. IBM systems journal, 21(1), 4-30.

De Silva, L., Goonetillake, J., Wikramanayake, G., Ginige, A., Ginige, T., Vitiello, G., ... & Tucci, M. (2014). Design science research based blended approach for usability driven requirements gathering and application development. In 2014 IEEE 2nd International Workshop on Usability and Accessibility Focused Requirements Engineering (UsARE) (pp. 17-24). IEEE.

de Souza, B. P., Motta, R. C., & Travassos, G. H. (2019). Towards the Description and Representation of Smartness in IoT Scenarios Specification. In Proceedings of the XXXIII Brazilian Symposium on Software Engineering (pp. 511-516).

Demirkan, H., Kauffman, R. J., Vayghan, J. A., Fill, H. G., Karagiannis, D., & Maglio, P. P. (2008). Service-oriented technology and management: Perspectives on research and practice for the coming decade. Electronic commerce research and applications, 7(4), 356-376.

Dey, A. K., & Häkkilä, J. (2008). Context-awareness and mobile devices. In Handbook of research on user interface design and evaluation for mobile technology (pp. 205-217). IGI Global.

Dieste, O., & Juristo, N. (2010). Systematic review and aggregation of empirical studies on elicitation techniques. IEEE Transactions on Software Engineering, 37(2), 283-304.

Doe, J. (2011). Recommended Practice for Software Requirements Specifications (IEEE). IEEE, New York.

Dow, S. P., Glassco, A., Kass, J., Schwarz, M., Schwartz, D. L., & Klemmer, S. R. (2010). Parallel prototyping leads to better design results, more divergence, and increased self-efficacy. ACM Transactions on Computer-Human Interaction (TOCHI), 17(4), 1-24.

Döring, N., & Bortz, J. (2016). Forschungsmethoden und evaluation. Wiesbaden: Springerverlag.

Eisenhardt, K. (1989). Building theories from case study research. Academy of Management Review, 14(4), 532-550.

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics, 42(3), 462-492.

Exner, K., Lindow, K., Stark, R., Ängeslevä, J., Bähr, B., & Nagy, E. (2015). A transdisciplinary perspective on prototyping. In 2015 IEEE International Conference on Engineering, Technology and Innovation/International Technology Management Conference (ICE/ITMC) (pp. 1-8). IEEE.

Exner, K., Sternitzke, A., Kind, S., & Beckmann-Dobrev, B. (2016). Hybrid prototyping. In Rethink! Prototyping (pp. 89-127). Springer, Cham.

Friedman, B., Kahn, P. H., Borning, A., & Huldtgren, A. (2013). Value sensitive design and information systems. In Early engagement and new technologies: Opening up the laboratory (pp. 55-95). Springer, Dordrecht.

Grönroos, C., & Voima, P. (2013). Critical service logic: making sense of value creation and co-creation. Journal of the academy of marketing science, 41(2), 133-150.

Haberfellner, R., Nagel, P., Becker, M., Büchel, A., & von Massow, H. (2002). " Systems Engineering" Methodik und Praxis. Industrielle Organisation Zürich.

Haines-Gadd, M., Hasegawa, A., Hooper, R., Huck, Q., Pabian, M., Portillo, C., ... & McBride, A. (2015). Cut the crap; design brief to pre-production in eight weeks: Rapid development of an urban emergency low-tech toilet for Oxfam. Design Studies, 40, 246-268.

Hare, J., Gill, S., Loudon, G., & Lewis, A. (2013). The effect of physicality on low fidelity interactive prototyping for design practice. In IFIP Conference on Human-Computer Interaction (pp. 495-510). Springer, Berlin, Heidelberg.

Hoffmann, O., Cropley, D., Cropley, A., Nguyen, L., & Swatman, P. (2005). Creativity, requirements and perspectives. Australasian journal of information systems, 13(1).

Houde, S., & Hill, C. (1997). What do prototypes prototype?. In Handbook of human-computer interaction (pp. 367-381). North-Holland.

Holtzblatt, K., & Beyer, H. (2014). Contextual design: evolved. Synthesis Lectures on Human-Centered Informatics, 7(4), 1-91.

Howell, S., Beach, T., & Rezgui, Y. (2021). Robust requirements gathering for ontologies in smart water systems. Requirements Engineering, 26(1), 97-114.

Hutchinson, H., Mackay, W., Westerlund, B., Bederson, B. B., Druin, A., Plaisant, C., ... & Eiderbäck, B. (2003, April). Technology probes: inspiring design for and with families. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 17-24).

IfM and IBM. (2007). Succeeding through service innovation: a discussion paper. In Cambridge Service Science, Management and Engineering Symposium. Cambridge: University of Cambridge Institute for Manufacturing.

International Standards Organization. (2010). Ergonomics of Human-System Interaction—Part 210: Human Centred Design for Interactive Systems, ISO 9241-210.

Jensen, M. B., Elverum, C. W., & Steinert, M. (2017). Eliciting unknown unknowns with prototypes: Introducing prototrials and prototrial-driven cultures. Design Studies, 49, 1-31.

Ju, W., & Leifer, L. (2008). The design of implicit interactions: Making interactive systems less obnoxious. Design Issues, 24(3), 72-84.

Kagermann, H., Riemensperger, F., Hoke, D., Helbig, J., Stocksmeier, D., Wahlster, W., ... & Schweer, D. (2014). Smart service welt: Umsetzungsempfehlungen für das Zukunftsprojekt Internetbasierte Dienste für die Wirtschaft. Berlin: acatech.

Kaleem, S., Ahmed, S., Ullah, F., Babar, M., Sheeraz, N., & Hadi, F. (2020). An Improved RE Framewrok for IoT-Oriented Smart Applications Using Inetgrated Approach. In 2019 International Conference on Advances in the Emerging Computing Technologies (AECT) (pp. 1-6). IEEE.

Karmarkar, U. S., & Apte, U. M. (2007). Operations management in the information economy: Information products, processes, and chains. Journal of Operations Management, 25(2), 438-453.

Kelley, J. F. (1984). An iterative design methodology for user-friendly natural language office information applications. ACM Transactions on Information Systems (TOIS), 2(1), 26-41.

Kronqvist, J., Erving, H., & Leinonen, T. (2013). Cardboard hospital: Prototyping patient-centric environments and services. Nordes, 1(5).

Krömker, H., Hörold, S., Mayas, C. (2014). Internet Protokoll basierte Kommunikationsdienste im öffentlichen Verkehr - Schlussbericht Technische Universität Ilmenau.

Krömker, H., Schöne, C., Wienken, T., Steinert, T. (2018). DiMo-FuH - Digitale Mobilität - Fahrzeug und Haltestelle - Schlussbericht. Ilmenau: Technische Universität Ilmenau.

Krömker, H., & Wienken, T. (2017). Schlussbericht des Verbundprojektes dynapsys: Entwicklung eines dynamischen Agendaplanungssystems: Laufzeit des Vorhabens: 01/2013-09/2016, Berichtszeitraum: 01/2013-09/2016. Technische Universität Ilmenau, Fakultät für Elektrotechnik und Informationstechnik, Fachgebiet Medienproduktion.

Leifer, L. J., & Steinert, M. (2011). Dancing with ambiguity: Causality behavior, design thinking, and triple-loop-learning. Information Knowledge Systems Management, 10(1-4), 151-173.

Lim, C. H., & Kim, K. J. (2014). Information service blueprint: A service blueprinting framework for information-intensive services. Service Science, 6(4), 296-312.

Lim, C., Kim, K. H., Kim, M. J., Heo, J. Y., Kim, K. J., & Maglio, P. P. (2018a). From data to value: A nine-factor framework for data-based value creation in information-intensive services. International Journal of Information Management, 39, 121-135.

Lim, C., & Maglio, P. P. (2019). Clarifying the concept of smart service system. Handbook of Service Science, Volume II, 349-376.

Lim, C. H., Maglio, P. P., Kim, K. J., Kim, M. J., & Kim, K. H. (2016). Toward smarter service systems through service-oriented data analytics. In 2016 IEEE 14th International Conference on Industrial Informatics (INDIN) (pp. 936-941). IEEE.

Lim, T. Y., Chua, F. F., & Tajuddin, B. B. (2018b). Elicitation Techniques for Internet of Things Applications Requirements: A Systematic Review. In Proceedings of the 2018 VII International Conference on Network, Communication and Computing (pp. 182-188).

Lim, Y. K., Pangam, A., Periyasami, S., & Aneja, S. (2006). Comparative analysis of high-and low-fidelity prototypes for more valid usability evaluations of mobile devices. In Proceedings of the 4th Nordic conference on Human-computer interaction: changing roles (pp. 291-300).

Lim, Y. K., Stolterman, E., & Tenenberg, J. (2008). The anatomy of prototypes: Prototypes as filters, prototypes as manifestations of design ideas. ACM Transactions on Computer-Human Interaction (TOCHI), 15(2), 1-27.

Lusch, R. F., & Nambisan, S. (2015). Service innovation: A service-dominant logic perspective. MIS Quarterly, 39(1), 155–175.

Maglio, P. P., Vargo, S. L., Caswell, N., & Spohrer, J. (2009). The service system is the basic abstraction of service science. Information Systems and e-business Management, 7(4), 395-406.

Marion, T. J., & Simpson, T. W. (2009). New product development practice application to an early-stage firm: the case of the PaperPro® StackMaster™. Design Studies, 30(5), 561-587.

Mayhew, D. J. (1999). The usability engineering lifecycle. In CHI'99 Extended Abstracts on Human Factors in Computing Systems (pp. 147-148).

Mayring, P., & Fenzl, T. (2014). Qualitative inhaltsanalyse. In Handbuch Methoden der empirischen Sozialforschung (pp. 543-556). Springer VS, Wiesbaden.

McCurdy, M., Connors, C., Pyrzak, G., Kanefsky, B., & Vera, A. (2006). Breaking the fidelity barrier: an examination of our current characterization of prototypes and an example of a mixed-fidelity success. In Proceedings of the SIGCHI conference on Human Factors in computing systems (pp. 1233-1242).

National Science Foundation (2016). Partnerships for Innovation: Building Innovation Capacity (PFI:BIC). http://www.nsf.gov/funding/pgm_summ.jsp?pims_id¼504708. last accessed 2021/05/30.

Nazari Shirehjini, A. A. (2009). Interaktion in Ambient Intelligence--Konzeption eines intuitiven Assistenten zur ganzheitlichen und konfliktfreien Interaktion in adaptiven Umgebungen (Doctoral dissertation, Technische Universität).

Neuhuettler, J., Ganz, W., & Liu, J. (2017). An integrated approach for measuring and managing quality of smart senior care services. In Advances in the Human Side of Service Engineering (pp. 309-318). Springer, Cham.

Nguyen, L., & Shanks, G. (2009). A framework for understanding creativity in requirements engineering. Information and software technology, 51(3), 655-662.

Nielsen, J. (1993). Noncommand user interfaces. Communications of the ACM, 36(4), 83-99.

Nielsen, J. (1994). Usability engineering. Morgan Kaufmann.

Nielsen, J., & Molich, R. (1990). Heuristic evaluation of user interfaces. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 249-256).

Niknafs, A., & Berry, D. M. (2012). The impact of domain knowledge on the effectiveness of requirements idea generation during requirements elicitation. In 2012 20th IEEE International Requirements Engineering Conference (RE) (pp. 181-190). IEEE.

Norman, D. (2009). The design of future things. Basic books.

Norman, D. (2013). The design of everyday things: Revised and expanded edition. Basic books.

Norman, D. (2014). Things that make us smart: Defending human attributes in the age of the machine. Diversion Books.

Nuseibeh, B., & Easterbrook, S. (2000). Requirements engineering: a roadmap. In Proceedings of the Conference on the Future of Software Engineering (pp. 35-46).

Paldês, R. A., Canedo, E. D., Guimarães, F. D. A., & Calazans, A. T. S. (2020). Functional Requirements Elicitation in IoT Systems: a follow-up study. In 19th Brazilian Symposium on Software Quality (pp. 1-10).

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. IEEE Transactions on systems, man, and cybernetics-Part A: Systems and Humans, 30(3), 286-297.

Passera, S., Kärkkäinen, H., & Maila, R. (2012). When, how, why prototyping? A practical framework for service development. In ISPIM Conference Proceedings (p. 1). The International Society for Professional Innovation Management (ISPIM).

Payne, A. F., Storbacka, K., & Frow, P. (2008). Managing the co-creation of value. Journal of the academy of marketing science, 36(1), 83-96.

Peruzzini, M., Marilungo, E., & Germani, M. (2015). Structured requirements elicitation for product-service system. International Journal of Agile Systems and Management, 8(3-4), 189-218.

Pitts, M. G., & Browne, G. J. (2007). Improving requirements elicitation: an empirical investigation of procedural prompts. Information systems journal, 17(1), 89-110.

Porter, M. E., & Advantage, C. (1985). Creating and sustaining superior performance. Competitive advantage, 167, 167-206.

Porter, M. E., & Heppelmann, J. E. (2014). How smart, connected products are transforming competition. Harvard business review, 92(11), 64-88.

Porter, M. E., & Heppelmann, J. E. (2015). How smart, connected products are transforming companies. Harvard business review, 93(10), 96-114.

ProFI – Prototyping For Innovation (2021). Forschungsprojekt ProFI – Zielgerichtetes Prototyping für gesteigerte Innovation. *https://prototyping4innovation.de/* last accessed 2021/05/30.

Ramasesh, R. V., & Browning, T. R. (2014). A conceptual framework for tackling knowable unknown unknowns in project management. Journal of operations management, 32(4), 190-204.

Robertson, J. (2005). Requirements analysts must also be inventors. IEEE software, 22(1), 48.

Rueda, S., Panach, J. I., & Distante, D. (2020). Requirements elicitation methods based on interviews in comparison: A family of experiments. Information and Software Technology, 126, 106361.

Rudd, J., Stern, K., & Isensee, S. (1996). Low vs. high-fidelity prototyping debate. interactions, 3(1), 76-85.

Sanders, E. B. N. (2002). From user-centered to participatory design approaches. In Design and the social sciences (pp. 18-25). CRC Press.

Schmidt, A. (2013). Context-Aware Computing: Context-Awareness, Context-Aware User Interfaces, and Implicit Interaction. The Encyclopedia of Human-Computer Interaction, 2nd Ed.

Sefelin, R., Tscheligi, M., & Giller, V. (2003). Paper prototyping-what is it good for? A comparison of paper-and computer-based low-fidelity prototyping. In CHI'03 extended abstracts on Human factors in computing systems (pp. 778-779).

Selting, M., Auer, P., & Barth-Weingarten, D. (2009). Gesprächsanalytisches Transkriptionssystem 2 (GAT 2).

Schmermbeck, Sebastian; Krömker, Heidi; Sommerfeld, Cornelius; Kummer, Robert; Wienken, Tobias; Rohde, Jannis; Sander, Bastian. (2017). Mobil im ländlichen Raum dank innovativer Dienstleistungen. In Dienstleistungen als Erfolgsfaktor für Elektromobilität (pp.128-139). Stuttgart: Fraunho-fer Verlag.

Shostack, G.L. (1984). Designing services that deliver. Harvard Bus. Rev. 62(1), 133–139.

Snyder, C. (2003). Paper prototyping: The fast and easy way to design and refine user interfaces. Morgan Kaufmann.

De Souza, B. P., Motta, R. C., & Travassos, G. H. (2019, September). Towards the Description and Representation of Smartness in IoT Scenarios Specification. In Proceedings of the XXXIII Brazilian Symposium on Software Engineering (pp. 511-516).

Spohrer, J., & Demirkan, H. (2015). Introduction to the smart service systems: Analytics, cognition, and innovation minitrack. In 2015 48th Hawaii International Conference on System Sciences (pp. 1442-1442). IEEE.

Spohrer, J., Maglio, P. P., Bailey, J., & Gruhl, D. (2007). Steps toward a science of service systems. Computer, 40(1), 71-77.

Stickdorn, M., Hormess, M. E., Lawrence, A., & Schneider, J. (2018). This is service design doing: applying service design thinking in the real world. " O'Reilly Media, Inc.".

Stickdorn, M., Schneider, J., Andrews, K., & Lawrence, A. (2011). This is service design thinking: Basics, tools, cases (Vol. 1). Hoboken, NJ: Wiley.

Sutcliffe, A., & Ryan, M. (1997). Assessing the usability and efficiency of design rationale. In Human-Computer Interaction INTERACT'97 (pp. 148-155). Springer, Boston, MA.

Sutcliffe, A., & Sawyer, P. (2013). Requirements elicitation: Towards the unknown unknowns. In 2013 21st IEEE International Requirements Engineering Conference (RE) (pp. 92-104). IEEE.

Todd, P., & Benbasat, I. (1987). Process tracing methods in decision support systems research: Exploring the black box. Mis Quarterly, 493-512.

Tombeil, A. S., Neuhüttler, J., & Ganz, W. (2016). Dienstleistungsproduktivität und-qualität: eine kritische Würdigung. In Kundenbindung durch kosteneffiziente Service Excellence (pp. 51-68). Nomos Verlagsgesellschaft mbH & Co. KG.

Ulrich, K. T., & Eppinger, S. D. (2016). Product design and development. McGraw-Hill Education.

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a New Dominant Logic for Marketing. Journal of Marketing, 68(1), 1–17.

Vargo, S. L., & Lusch, R. F. (2008). Service-dominant logic: continuing the evolution. Journal of the Academy of marketing Science, 36 (1), 1-10.

Vessey, I., & Conger, S. A. (1994). Requirements specification: Learning object, process, and data methodologies. Communications of the ACM, 37(5), 102-114.

Virzi, R. A., Sokolov, J. L., & Karis, D. (1996). Usability problem identification using both low- and high-fidelity prototypes. In Proceedings of the SIGCHI conference on human factors in computing systems (pp. 236-243).

Voss, C., & Zomerdijk, L. (2007). Innovation in experiential services: an empirical view. AIM Research.

Warfel, T. Z. (2009). Prototyping: a practitioner's guide. Rosenfeld media.

Wienken, T., Krömker, H.: Designing for mobility experience - towards an understanding. In: Stopka, U. (ed.) Mobilität & Kommunikation, edition winterwork, Borsdorf (2018)

Wienken, T., & Krömker, H. (2018). Experience maps for mobility. In International Conference on Human-Computer Interaction (pp. 615-627). Springer, Cham.

Wienken, T., Krömker, H., & Spundflasch, S. (2017). Agenda planning-design guidelines for holistic mobility planning. In International Conference on Human-Computer Interaction (pp. 713-720). Springer, Cham.

Wienken, T., Mayas, C., Hörold, S., & Krömker, H. (2014). Model of mobility oriented agenda planning. In International Conference on Human-Computer Interaction (pp. 537-544). Springer, Cham.

Wienken, T., Schoppe, C., & Krömker, H. (2017). Auf dem Weg zur Agendaplanung–Weiterentwicklung der Fahrplanauskunft zum Service-System für Mobilität. NAHVERKEHR, 35(9).

Wienken, T., Ullrich, M., Krömker, H., & Steinert, T. (2019). Digitalisierte Mobilität: Mobilitätsplattformen– Herausforderungen auf dem Weg zum ganzheitlichen Mobilitätsservice. Der Nahverkehr, 37(5).

Winter, A., Alt, R., Ehmke, J., Haux, R., Ludwig, W., Mattfeld, D., ... & Paech, B. (2012). Manifest–Kundeninduzierte Orchestrierung komplexer Dienstleistungen. Informatik-Spektrum, 35(6), 399-408.

Wünderlich, N. V., Heinonen, K., Ostrom, A. L., Patricio, L., Sousa, R., Voss, C., & Lemmink, J. G. (2015). "Futurizing" smart service: implications for service researchers and managers. Journal of Services Marketing.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
df	Degrees of freedom
IoT	Internet of Things
GAT 2	Gesprächsanalytisches Transkriptionssystem 2
HC	Hypothesis from Part C
RQ	Research question
SD	Standard deviation

APPENDIX

Part B – Guide of the expert interviews

The expert interviews were conducted in German. The interview guide was translated into English after the study.

ISSUE | INTRODUCTION AND PROTOTYPING PROCESS	
Leading question	**Supplementary question**
Please introduce yourself. Briefly describe your experience in developing smart services and your position in the company.	
How does a prototyping process for new smart services usually work in your organisation - from the initial idea to the final launch?	Which people are involved in the prototyping process? (Stakeholder type and their role)

ISSUE | DISCUSSION OF PROTOTYPING BASED ON CONCRETE EXAMPLES	
Leading question	**Supplementary question**
Please briefly explain the prototype.	What were the goals of the prototyping? What was the task? What were the requirements / restrictions for the prototyping?
Which features of the future smart service have already been considered in the prototype?	Reasons? Which features could not be implemented?
Please describe the prototyping process followed?	What factors influenced the prototyping?
Which prototyping method did you use?	Reasons?
What features of the prototype did you focus on during creation and design?	What relationships exist among the different characteristics?
Who was involved in the prototyping?	Stakeholder type - internal/external (internal to team, internal to company, external to company).

	Reasons? How do you adapt prototyping to the people involved?
What insights did you gather from the prototyping for the further development?	
To what extent were the findings from prototyping still unknown to you in advance of the study?	What insights were new for you?
To what extent were you aware of the existence of unknown requirements that were relevant for the smart service in advance of the investigation?	

Part B - Transcripts of the expert interviews

All transcripts of the eleven expert interviews can be viewed digitally on the enclosed USB flash drive due to the large number of pages.

Part C - Statistical calculation

Calculations for the setting agenda planning system

The figures show an excerpt of the calculations from the statistical software SPSS.

Gruppenstatistiken

	Prototype	N	Mittelwert	Std.-Abweichung	Standardfehler des Mittelwertes
Re_Raw	DDVP	12	18,33	7,584	2,189
	EXP	12	12,17	3,857	1,114
Re_Rel	DDVP	12	17,92	7,537	2,176
	EXP	12	11,33	3,750	1,082
Re_Fea	DDVP	12	17,50	7,355	2,123
	EXP	12	10,75	3,621	1,045
Re_Inn	DDVP	12	1,25	1,357	,392
	EXP	12	,33	,651	,188

Test bei unabhängigen Stichproben

		Levene-Test der Varianzgleichheit		t-Test für die Mittelwertgleichheit							
						Signifikanz				95% Konfidenzintervall der Differenz	
		F	Sig.	T	df	Einseitiges p	Zweiseitiges p	Mittlere Differenz	Differenz für Standardfehler	Unterer Wert	Oberer Wert
Re_Raw	Varianzen sind gleich	6,790	,016	2,511	22	,010	,020	6,167	2,456	1,073	11,260
	Varianzen sind nicht gleich			2,511	16,334	,011	,023	6,167	2,456	,968	11,365
Re_Rel	Varianzen sind gleich	7,645	,011	2,709	22	,006	,013	6,583	2,430	1,543	11,623
	Varianzen sind nicht gleich			2,709	16,131	,008	,015	6,583	2,430	1,435	11,732
Re_Fea	Varianzen sind gleich	7,344	,013	2,852	22	,005	,009	6,750	2,367	1,842	11,658
	Varianzen sind nicht gleich			2,852	16,038	,006	,012	6,750	2,367	1,734	11,766
Re_Inn	Varianzen sind gleich	7,663	,011	2,110	22	,023	,046	,917	,434	,016	1,818
	Varianzen sind nicht gleich			2,110	15,814	,026	,051	,917	,434	-,005	1,839

Effektgrößen bei unabhängigen Stichproben

		Standardisierer[a]	Punktschätzung	95% Konfidenzintervall	
				Unterer Wert	Oberer Wert
Re_Raw	Cohen's d	6,016	1,025	,160	1,870
	Hedges' Korrektur	6,232	,990	,154	1,805
	Glass' Delta	3,857	1,599	,540	2,614
Re_Rel	Cohen's d	5,953	1,106	,232	1,959
	Hedges' Korrektur	6,166	1,068	,224	1,891
	Glass' Delta	3,750	1,756	,655	2,814
Re_Fea	Cohen's d	5,797	1,164	,283	2,023
	Hedges' Korrektur	6,004	1,124	,273	1,954
	Glass' Delta	3,621	1,864	,733	2,952
Re_Inn	Cohen's d	1,064	,861	,013	1,692
	Hedges' Korrektur	1,102	,832	,013	1,633
	Glass' Delta	,651	1,407	,398	2,375

a. Der bei der Schätzung der Effektgrößen verwendete Nenner.
Cohen's d verwendet die zusammengefasste Standardabweichung.
Hedges' Korrektur verwendet die zusammengefasste Standardabweichung und einen Korrekturfaktor.
Glass' Delta verwendet die Standardabweichung einer Stichprobe von der Kontrollgruppe.

Calculations for the setting intermodal mobility plattform

The figures show an excerpt of the calculations from the statistical software SPSS.

Gruppenstatistiken

	Prototype	N	Mittelwert	Std.-Abweichung	Standardfehler des Mittelwertes
Re_Raw	DDVP	12	20,00	3,275	,945
	EXP	12	15,67	3,701	1,068
Re_Rel	DDVP	12	19,42	3,450	,996
	EXP	12	14,75	3,671	1,060
Re_Fea	DDVP	12	19,08	3,175	,917
	EXP	12	14,42	3,579	1,033
Re_Inn	DDVP	12	1,58	1,676	,484
	EXP	12	,33	,651	,188

Test bei unabhängigen Stichproben

		Levene-Test der Varianzgleichheit		t-Test für die Mittelwertgleichheit							
						Signifikanz				95% Konfidenzintervall der Differenz	
		F	Sig.	T	df	Einseitiges p	Zweiseitiges p	Mittlere Differenz	Differenz für Standardfehler	Unterer Wert	Oberer Wert
Re_Raw	Varianzen sind gleich	,151	,702	3,037	22	,003	,006	4,333	1,427	1,375	7,292
	Varianzen sind nicht gleich			3,037	21,679	,003	,006	4,333	1,427	1,372	7,295
Re_Rel	Varianzen sind gleich	,111	,743	3,209	22	,002	,004	4,667	1,454	1,651	7,683
	Varianzen sind nicht gleich			3,209	21,916	,002	,004	4,667	1,454	1,650	7,683
Re_Fea	Varianzen sind gleich	,464	,503	3,379	22	,001	,003	4,667	1,381	1,802	7,531
	Varianzen sind nicht gleich			3,379	21,692	,001	,003	4,667	1,381	1,800	7,534
Re_Inn	Varianzen sind gleich	3,855	,062	2,408	22	,012	,025	1,250	,519	,173	2,327
	Varianzen sind nicht gleich			2,408	14,247	,015	,030	1,250	,519	,138	2,362

Effektgrößen bei unabhängigen Stichproben

		Standardisierer[a]	Punktschätzung	95% Konfidenzintervall	
				Unterer Wert	Oberer Wert
Re_Raw	Cohen's d	3,495	1,240	,349	2,108
	Hedges' Korrektur	3,620	1,197	,337	2,035
	Glass' Delta	3,701	1,171	,217	2,086
Re_Rel	Cohen's d	3,562	1,310	,410	2,186
	Hedges' Korrektur	3,690	1,265	,396	2,110
	Glass' Delta	3,671	1,271	,294	2,208
Re_Fea	Cohen's d	3,383	1,379	,470	2,264
	Hedges' Korrektur	3,504	1,332	,454	2,186
	Glass' Delta	3,579	1,304	,319	2,248
Re_Inn	Cohen's d	1,272	,983	,122	1,824
	Hedges' Korrektur	1,317	,949	,118	1,761
	Glass' Delta	,651	1,919	,772	3,023

a. Der bei der Schätzung der Effektgrößen verwendete Nenner.
Cohen's d verwendet die zusammengefasste Standardabweichung.
Hedges' Korrektur verwendet die zusammengefasste Standardabweichung und einen Korrekturfaktor.
Glass' Delta verwendet die Standardabweichung einer Stichprobe von der Kontrollgruppe.