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## ► To cite this version:

Henrik Kortum, Laura Sophie Gravemeier, Novica Zarvic, Thomas Feld, Oliver Thomas. Engineering of Data-Driven Service Systems for Smart Living: Application and Challenges. IFIP International Conference on Advances in Production Management Systems (APMS), Aug 2020, Novi Sad, Serbia. pp.291-298, 10.1007/978-3-030-57997-5\_34 . hal-03635644

**HAL Id: hal-03635644**

**<https://inria.hal.science/hal-03635644>**

Submitted on 30 Jun 2023

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# Engineering of data-driven Service Systems for Smart Living: Application and Challenges

Henrik Kortum<sup>1</sup>, Laura Sophie Gravemeier<sup>1</sup>, Novica Zarvic<sup>1</sup>, Thomas Feld<sup>2</sup> and Oliver Thomas<sup>1,3</sup>

<sup>1</sup> German Research Center for Artificial Intelligence (DFKI) GmbH,  
Parkstraße 40, 49080 Osnabrück, Germany

<sup>2</sup> Strategion GmbH, Albert-Einstein-Straße 1, 49076 Osnabrück, Germany

<sup>3</sup> Chair of Information Management and Information Systems, Osnabrück University,  
Parkstraße 40, 49080 Osnabrück, Germany  
{henrik.kortum, laura\_sophie.gravemeier, novica.zarvic,  
oliver.thomas}@dfki.de, thomas.feld@strategion.de,  
oliver.thomas@uni-osnabrueck.de

**Abstract.** Service systems in the smart living domain integrate a multitude of heterogenous data sources and affect the most private area of human lives. Therefore, particular challenges for service systems engineering arise in terms of interoperability of Internet-of-Things (IoT)-devices, privacy concerns and creating truly smart value propositions. By applying a promising approach, this paper examines smart service systems engineering and reveals the potential for extensions and adaptations of existing methods. A need for the integration of data science and software engineering approaches as well as a focus on acceptance, usability and the business perspective within a holistic smart service systems engineering method is discussed. This enables smart service systems to reconcile their human-centered and data-driven qualities.

**Keywords:** Smart Service, Smart Living, Service Engineering, Artificial Intelligence, Human-Centered Design.

## 1 Introduction

Smart service systems are immanently complex and dynamic since they are comprised of a variety of data sources, human actors with differing roles and IoT-devices that are capable of learning and reacting appropriately [1, 2]. While some Service Systems Engineering (SSE) approaches have been proposed [3], no common standard has been established. However, for smart service systems and especially the smart living domain, a more concrete data-driven engineering method could make the complexity more manageable. Such a method should be closely geared to the domain-specific needs and provide practical guidance. Therefore, this paper aims at clarifying challenges in smart SSE and the smart living domain in particular. For this purpose, the recombinant SSE [3] method is applied to a concrete use case: the intelligent gatekeeper, an Artificial Intelligence (AI)-based building access management system. Based on this preliminary

application, challenges of SSE in the smart living domain are identified and appropriate actions as well as necessary properties of a suitable SSE approach for this domain are discussed.

## 2 Background Information

Past service research has focused on (1) the shift from a product-centric exchange of goods towards a service-dominant logic [4, 5], (2) the enrichment of product offerings with associated services in the form of product-service systems [6], and an (3) integrative service-system-approach emphasizes the interrelationship of people, technologies and other resources with services and products [1, 7]. *Smart Service Systems* extend the concept of digital services [8, 9] by incorporating smart products, which enable the real-time capture, processing and analysis of continuously gathered data. This allows for the alignment and management of the service and its features to be pre-emptive, context-aware and dynamic [8–10]. These characteristics are of special importance in the smart living domain, which is addressed in this paper, and need to be considered for SSE.

### 2.1 Concepts from the Smart Living Domain

The terms smart home and smart living are not yet clearly defined in the literature and often used interchangeably. *Smart Homes* are understood as residences equipped with different smart technologies, which have the purpose of providing their users with tailored services [11]. *Smart Living* broadens the smart home concept beyond the home automatization aspect by including further areas, such as smart energy management and health [12, 13] and extends the view to building complexes and entire cities. Smart living thus combines different, often still completely separate areas, with the aim of improving the quality of life [14]. *Smart Living Services* are smart services that refer to use cases in the smart living domain. These services take into account a large number of dynamic parameters, distributed data sources and behavior variants that need to be processed in near real-time. Developing suitable AI-methods will therefore be a key component of smart living services in order to meet user requirements [15, 16].

### 2.2 Smart Service Systems Engineering

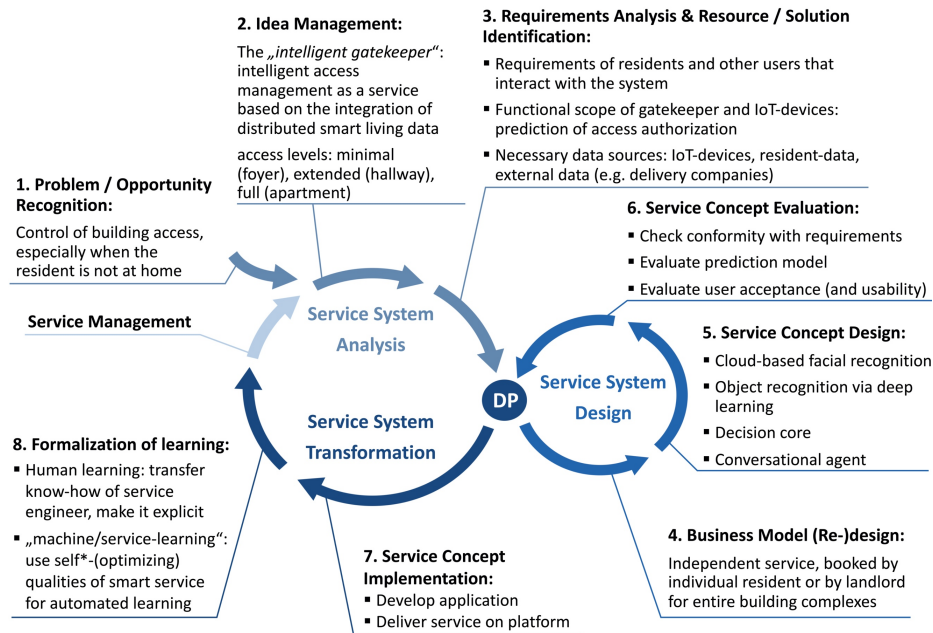
SSE broadens the scope of service engineering [17] by methods for the development of singular value propositions towards “designing integrated conglomerates of products, services, and information technology” [3]. While several methods for the development of classical product-service systems exist with perspectives ranging from general to domain-specific [18–21], there is still a lack of systemic approaches focusing on the orchestration of multiple service and product components with smart capabilities [22]. Based on reviewing different approaches for the engineering of value propositions and service systems, recombinant SSE was introduced [3]. Here, known recombination methods are used for service innovation: through dissociation, existing services can be split into singular elements, which have the potential to form novel services by crafting new combinations in the process of association or become part of an existing service

via addition. This is not in pursuit of designing singular value propositions but – aligning with the use case at hand – aimed at the development of integrative smart product-service systems. Following a prototyping approach, certain phases are proposed for the analysis, design and transformation of the envisioned service system [3].

### 3 SSE for the Smart Living Domain

#### 3.1 Application of Recombinant SSE in the Smart Living Domain

In the following, the method for recombinant SSE [3] will be applied to a concrete service in the smart living domain (see Fig. 1): *the intelligent gatekeeper*.



**Fig. 1.** Application of recombinant SSE [3] for the intelligent gatekeeper

When applying the recombinant SSE approach, first an opportunity is identified (1). Given the proliferation of sensors and IoT-devices in smart living contexts, access control of buildings and other assets can be assisted and even automated. On this basis, a more complex idea management (2) is initiated. The intelligent gatekeeper is concretized as a smart service concept for access management. A focus group identifies different viable use cases: not only keyless building access for residents, but also emergency access and regular external access for suppliers, parcel carriers and technicians. For example, parcel carriers can be given automatic or regulated access, where the implantation of a user-controlled differentiation of access levels from minimal access to

the foyer, extended access to the hallway or full access to the apartment has to be considered. In the following, the use case of regular external building access is further explored. In terms of the requirements analysis and identification of resources and solutions (3), the needs and wants of all involved parties are taken into consideration. This includes residents, landlords and providers of external services like delivery companies. Following this, necessary functions and data sources of the gatekeeper are identified. Besides collecting data from IoT-devices within the building complex, residents should provide data regarding eligible persons for entry and their authorized access levels. On top of that, the integration of data from delivery companies or online retailers is essential to verify the context of a delivery. In addition, modeling current processes of human gatekeepers could prove beneficial for identifying critical steps and possible problem sources. After reaching a satisfying service concept and therefore completing the phase of service system analysis, the process of service system design is started by designing a business model (4). The intelligent gatekeeper is intended as an independent service, that could be delivered to individual residents or landlords and entire building complexes. The service concept design (5) unites different, originally decoupled data sources and functions into a new service that predicts authorization and controls access. These components include AI-services such as neural networks for facial recognition and object detection – e. g. for the identification of different access roles, a conversational agent serving as a user interface and a decision component, that either makes the access decision automatically or passes it on to the resident when a sufficient level of certainty is not reached. The resulting recombinant service concept is evaluated (6) by reviewing its performance and conformity with initial requirements, as well as user acceptance. After a successful pass of the decision point, an application is to be implemented (7) and offered on a service platform. In the end, a formalization of learning (8) is pursued for both human service engineers and the smart service itself.

Applying recombinant SSE to a smart living use case reveals the need for extensions and adaptations to better cover challenges in the domain and complex smart service systems in general. During step (3) a distinction between necessary requirements on the one hand and desirable but not indispensable requirements on the other hand seems appropriate. In the context of the intelligent gatekeeper, for instance, there are data sources, such as data from delivery companies or parcel services, that appear suitable for improving the prediction - and thus the quality of service - which cannot be connected at present. In this case, it is advisable to continue the SSE process and integrate additional data sources at a later stage. When developing a business model (4) an iterative approach has to be emphasized, so that first prototypical design-increments can be implemented without being based on a comprehensive business model. The data-driven design of the service system is mainly handled during step (5) of the recombinant SSE approach. However, data analysis and its necessary preceding steps are not considered in detail, even though the parallel use of data science methods, e.g. the CRISP-DM model [23] might be needed. Furthermore, for smart services utilizing machine learning, the formalization of learning (8) should include model improvement through continuous evaluation and re-training. On top of that, the recombinant SSE approach defines decision points to assess the present solution. For this assessment, key performance indicators (KPIs) for each decision point would be of practical use. Necessary

steps backward whenever decision points are not passed successfully need visual representation in the method. In general, involved products and users in the smart service system should play a more central part in its engineering process.

### 3.2 Challenges for Smart Living Service Systems Engineering

The current smart home landscape is characterized by a multitude of stand-alone solutions [16] only able to handle small tasks, which limits the perceived customer benefit. The goal must therefore be the orchestration of customer-centric services, bundling the functions of individual smart home devices. This combination of previously unrelated resources describes the process of recombinant innovation [24]. A cross-system data exchange, currently hardly possible due to the lack of interoperability [16, 25], is a necessary prerequisite for the implementation of data-driven SSE. This is an even greater obstacle for smart living services, where the boundaries of single smart homes are left behind [26]. Another problem arises from the heterogeneity and multitude of devices and providers: individual service providers usually don't have access to all the data needed to develop meaningful services. The IoT-device manufacturer might only disclose this data to the service providers if they benefit financially. On top of that, the training of machine learning models as a central component of most smart services will be affected by incompatibilities of IoT-devices and heterogeneous user behavior. The recognition of patterns across apartments, e.g. to classify certain activities, will be hindered by variations in data. Thus, the SSE approach should integrate a machine learning perspective. Just as for the intelligent gatekeeper, most smart living use cases are based on personal data [27]. As opposed to industrial contexts, the living space is a private area of human life, where personal behavioral profiles could be gathered that are critical in terms of privacy. Therefore, the circumstances under which residents are willing to share relevant data need to be examined. If consumers are not willing to provide necessary data and thus inhibit the process of value co-creation, the provision of smart living services is hindered. User reservations are expected to be greater where the handling of personal data becomes non-transparent, which is particularly relevant for service providers using cloud applications. Under these circumstances, offering value propositions that are truly beneficial for consumers is crucial. Issues of privacy concerns or negative attitudes might be resolved by taking socio-economic, age-related and personal differences into account. Value-propositions could then be tailored toward customer groups with heterogeneous needs [15] to find a suitable trade-off between service features and privacy requirements. For example, tracking the movement within the apartment might be rejected by most customers, could however be accepted by residents with health impairments in order to ensure emergency care.

## 4 Discussion

Based on the application of recombinant SSE and the consideration of the smart living domain, this chapter discusses implications and opportunities for future SSE methods. A heterogeneous, short-lived infrastructure and the lack of standards are problems not

exclusive to smart living but transferable to many domains. This technical complexity asks for compatible solutions and not developing product-specific services. In this light, reusable design patterns could help create sustainable and transferable solutions [28]. While the need for technical interoperability in smart living is already addressed by various platform projects [16], future work has to answer how cooperation between suppliers can be fostered to form unified markets and enable the orchestration of multiple service offerings. In order to react to fast-moving, complex ecosystems, SSE methods should be agile and aimed at fast prototyping. AI models play an important role in realizing characteristics of smart service systems. SSE methods should therefore be combined with data science methods, such as the CRISP-DM model, to create a holistic approach which consistently includes the data-driven idea in all design phases.

In addition to technical complexity, the human factor poses a great challenge for engineering data-driven services. In the smart living domain it is evident that a service can only generate real value by interacting with its users as part of a co-creation process. For this purpose, it is necessary that the user is willing to contribute sensitive, personal data to the service system. SSE should therefore center the user and his requirements throughout the process of service development. The consideration of general conditions such as data security, transparency and explainability appear necessary to increase user acceptance and should be explicitly included in an SSE approach. In addition, smart services should give users agency over the amount and purpose of shared data. This passes on the trade-off between functionality and privacy to the user.

In general, including data science and software engineering methods as well as the business perspective in a consolidated SSE seems to be necessary. Within this integrative approach, user acceptance and usability are crucial to develop truly beneficial value propositions. The use of KPIs for each perspective could support the service systems' continuous improvement. Utilizing indicators of model performance for the data science perspective, profitability and efficiency measures for the business perspective, acceptance and usability scores in relation to the user as well as software engineering performance indicators can quantify progress and give insight during SSE. When developing and enhancing an SSE method for smart services, a simultaneously human-centered and data-driven approach must be pursued. While smart services need to realize the collected data's potential, humans should be in charge of high-level governance.

## 5 Summary and Conclusions

This paper is motivated by challenges in smart living where a complex interplay of IoT-devices, service concepts and stakeholders dominates SSE. In the sense of the system of systems perspective [29], multiple smart products and value propositions supplement each other within the smart service system, which will in turn be connected to other systems. The intelligent gatekeeper exists within the context of a smart home and an even larger scope of smart living, where a heterogenous blend of service systems need to be consolidated. Applying a suitable method for recombinant SSE helps managing a complex process and simultaneously reveals further necessary alterations and perspectives in order to make SSE for smart services data-driven and human-centered. The

focus on these initially conflicting but ultimately symbiotic perspectives during the development of SSE is content of necessary future research on smart service systems.

### Acknowledgements

This contribution is part of the research project “ForeSight” that aims at advancing the adoption of Smart Living with a consortium of more than 30 partners from science and industry. It was developed in the context of subproject “Smart Service Engineering and Business Models” and is partly funded by the Federal Ministry for Economic Affairs and Energy of the German Government. We would like to thank them for their support.

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