Towards a transparency-oriented and integrating Service Registry for the Smart Living Ecosystem

Jonas Rebstadt[1], Henrik Kortum[2], Simon Hagen[3], Oliver Thomas[4]

Abstract: Many domains are increasingly dominated by interdependent services and data exchange between different actors, leading to the emergence of data ecosystems. As a result, service engineers are increasingly tasked with integrating existing service components and data sources into service systems and orchestrating them. In complex areas such as smart living, these tasks are even more difficult by the particular relevance of individual data protection requirements and the low fault tolerance of security-related systems. To address these issues, a central service registry for the domain smart living has been prototypically developed and evaluated, focusing especially on the transparency of data flows and the technical exchangeability of service components. In this way, added value is achieved for data providers and for data users by providing information on the forwarding of their own data as well as on the origin of the data and possible data quality.

Keywords: Transparency; Interoperability; Cyber-Physical Systems; Smart Living; Ecosystems

1 Introduction

Many offerings are providing their value by combining tangible products or product systems with intangible (technical) services [BT13]. This holds especially true for the domain of smart living. The smart living ecosystem links a variety of IoT devices and systems to provide smart solutions in a wide range of areas related to living and represents a multi-billion-dollar market [SD20]. However, even though the examination of the 'value added' from a business perspective is promising, especially for end-users in a private context many potentials remain unexploited, due to the complexity of integrating all components. A frequently used example of such a complex offering in the smart living domain [Ba19] is the intelligent gatekeeper - an automated, intelligent building door control system [Ko20]. Such a system enables the realization of various use cases, like automated door opening for workmen in the event of a water leakage, without the need for an occupant to be at home. An intelligent sensor system registers the defect at an early stage, reports it and later

[1] German Research Center for Artificial Intelligence, Smart Enterprise Engineering, Parkstraße 40, 49080 Osnabrück, Germany jonas.rebstadt@dfki.de

[2] German Research Center for Artificial Intelligence, Smart Enterprise Engineering, Parkstraße 40, 49080 Osnabrück, Germany henrik.kortum@dfki.de

[3] German Research Center for Artificial Intelligence, Smart Enterprise Engineering, Parkstraße 40, 49080 Osnabrück, Germany simon.hagen@dfki.de

[4] German Research Center for Artificial Intelligence, Smart Enterprise Engineering, Parkstraße 40, 49080 Osnabrück, Germany oliver.thomas@dfki.de

allows the workman to enter. It shows the multiple advantages from a business point of view, e.g. reduced time for ordered craftsmen due to an automated, biometrics based, entry, as well as reduced claims for delay. On the other hand, it also demonstrates several social and economic sustainability related obstacles that need to be tackled, to accomplish this comprehensive approach.
That said, this scenario will only become possible if a large number of previously unlinked products and services can be integrated into one (eco-)system. For example, in the context of housing, special security and data protection requirements must be met in order to achieve acceptance among all consumers involved. This results in the need for transparency, which is mainly in control of the service engineer (i.e. the developer) of the overall offer, who needs to take data flows and storage into account at an early stage of development. In addition to regulatory issues, there are also technical questions regarding the integration and interaction of systems from different manufacturers which need to be considered. These issues are related to both, social and economic sustainability. On one hand the link between products and services in data driven systems needs to be simplified [Ka19] and the exchange of data in ecosystems needs to be fostered [Ko21]. On the other hand, several roles required for the development of these systems need to be brought together and the access for potential customers needs to be enabled [SK20].
Science and practice have already tackled these questions from different directions and proposed approaches allowing combination of variously designed components. For example, the modularization of products and (technical) services [AS11] [JVD07] has been proposed, which allows the components to be orchestrated in regard of customer needs [Ba11]. [Ge20] extended this approach by tackling the relevance and challenges of solution space modeling out of the product system view. Furthermore, the standardization of interfaces plays an important role to ensure interoperability, as pursued by consortiums like the W3C[5]. However, the question arises how these different approaches can be brought together and used in a multi-layered domain like smart living to support the developer at an early stage. In the context of the ForeSight research project, therefore, two research questions have arisen, which are answered in the following paper:

1. *How to technically design a service registry, considering the integration of interoperable and domain-specific standards?*
2. *What added value is created for actors in the smart living ecosystem by disclosing service relations in regard to the derived requirements?*

These questions are addressed in a Design Science Research oriented way, focusing on the development and the evaluation of a service registry for smart living. For this purpose, central relevant concepts and the used methodical approach are explained in chapter 2 and chapter 3. In chapter 4 the derivation of requirements and the development of the prototype are presented, followed by an interview-based evaluation in chapter 5 and a concluding discussion section in chapter 6. Our work provides real-world value by providing service

[5] The World Wide Web Consortium has for example published a standard for Web of Things, which is of high interest in the domain smart living: `https://www.w3.org/WoT/`

engineers with a tool that increases transparency in the data ecosystem smart living and helps them develop privacy-friendly, explainable solutions. Additionally, the evaluated impact of exemplary transparency increasing tools generated theoretical value for the research community.

2 Related Work

The smart living domain is a highly interconnected data ecosystem. In general, data ecosystems describe the interplay of various actors, such as organizations and individuals, sharing data in networks and using it as resource [OL18]. Each actor in a data ecosystem occupies one or more of three central roles characterized by different functions. The three central roles are data consumer (utilization and analysis of data as well as provision of feedback), data producer (production and publication of datasets), and intermediary (provision of services and orchestration) [Ca19] [OL18]. A cross-enterprise, data-centric approach enables the emergence of new platform-based business models and provides added value for all actors in a data ecosystem [Ko21]. Since the simultaneous interaction of various actors in a cooperative and competitive relationship [GGO21] using external data is fraught with uncertainty, establishing transparency is central to the success of a data ecosystem. It must be ensured that all data processing, including the legal, technical, organizational and procedural conditions, can be traced at any time [Ja19]. This holds especially true for the data ecosystem of smart living.

Unlike industrial data ecosystems, smart living concerns a very private area of human life and requires the collection and processing of personal data [Ko20]. Within the domain, there are a large number of different entities and sensitive assets that need to be properly protected. Smart living in general expands the smart home concept beyond the aspect of simple home automation to include other areas, such as intelligent energy management and health [Ba14] [ND15]. Smart living solutions therefore operate in an environment where a heterogeneous mix of service systems must be consolidated [Ko20]. A key characteristic of the smart living domain is thus the connection of different subdomains and stand-alone solutions with the aim to improve the quality of daily life [MH18]. The connection of these individual solutions leads to the emergence of a complex data ecosystem in which sensor manufacturers record raw data from homes, make it available to service providers (intermediaries), who in turn aggregate it, process it intelligently and make it available to data consumers within the ecosystem.

To allow an easy interaction and identification of the manifold number of components offered for smart homes, a semantic representation incorporating data as well as rules for logical reasoning is highly beneficial [BHL01]. This representation should allow comprehensive manipulation and retrieval of data, accessible by humans as well as by computer systems [Ku04]. In case of cyber-physical or smart service systems, incorporating products, services and information technology [BLW18], considerations of different languages and domains need to be taken into account. In the context of smart living, a combination of WoT and existing deliberations from GAIA-X self descriptions for systems seems to be promising

to be compliant to possible future regulations in the European Union. WOT is extending the scope of classical web services by integrating cyber-world as well as physical-world services. It intends to create an ecosystem by orchestrating services gracefully in a human centered and intelligent way [SW16] [ZGC11]. GAIA-X self descriptions tackle a very similar issue, trying to be machine-readable, machine-evaluable and including expressive semantics [Ot21]. It is an important component of the GAIA-X Ecosystem, simplifying the exchange of information about services or other involved entities and trying to increase the trust between different actors in the ecosystem.

3 Methodical Approach

Following the Design Science Research (DSR) methodology, this paper aims at generating a) prescriptive knowledge about how artifacts can be developed and applied to solve existing problems and b) descriptive knowledge, extracted from the applied evaluation [SV12]. Setting up on the build-evaluate pattern, the development and evaluation of artifacts are the core aspects of most DSR Projects. As shown in fig. 1, extended the build-evaluate pattern, including four evaluation phases (ex ante and ex post the construction). Even though the solution design has been part of the development process, the focus of the paper is the construction and its ex post evaluation.

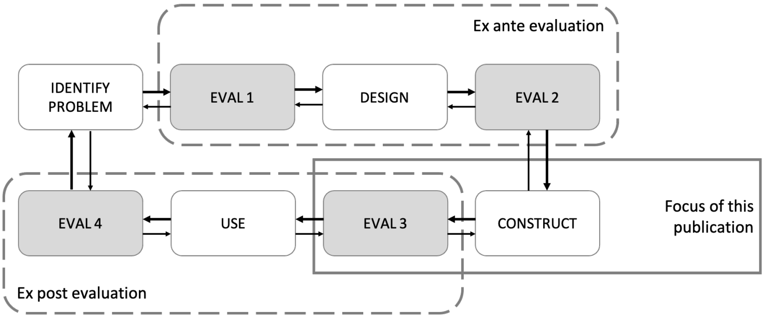

Fig. 1: DSR evaluation activities based on [SV12]

Due to the development of the described artifacts as domain specific implementations of GAIA-X, this paper sets up on defined and evaluated requirements, as further described in chapter 4.1. Using these requirements, three main components have been conceptually designed, a service self-description, a software architecture for the service registry itself and an improved type of visualization for the description of inter-service relations and data flows. These components have been developed and evaluated in a cooperative and iterative manner with weekly feedback meetings. The results of these steps are described in chapters 4.2, 4.3 and 4.4. The ex post evaluation (EVAL 3) happened in an artificial setting. It was carried out with five technical and domain experts who were surveyed with semi-structured interviews according to [MN07]. All interviewed company representatives are experts in the sense of [BLM09] interviewing and have several years of professional experience. An interview

guide consisting of 13 open-ended questions was prepared for conducting the interviews. For the evaluation, a multistage procedure for qualitative content analysis was applied, following the approach of [GL09]. The evaluation concept consists of the phases: (1) determining the research questions and analysis perspective, (2) developing a category system, (3) searching the texts for relevant information and assigning them to appropriate categories, (4) aggregating the information across different interviews, (5) analyzing the results to answer RQ2. The category system is based on the elicited requirements and distinguishes between positive and negative feedback. The categories as well as the assignment of the key statements to these categories are presented in chapter 5. Finally, we finish the evaluation by answering RQ2 in chapter 6 (5).

4 Prototype Development

4.1 Requirement Elicitation

Today, innovations and digital business models rely heavily on data and data streams, making them an important asset for companies requiring protection. Therefore, it is crucial for companies to retain data sovereignty and control over their data flows. In line with the European data strategy[6], GAIA-X pursues the goal of establishing such a networked data structure for a sovereign, European data ecosystem by breaking down data silos and helping users avoid data lock-ins. The service registry presented in this paper has been developed as a prototype of the smart living domain originating from GAIA-X. Its requirements are therefore derived from the GAIA-X essential characteristics and requirements formalized in [Ho20], which are also and especially relevant for the smart living data ecosystem with its many heterogeneous actors, interconnected service systems, and sensitive data. To derive the requirements, which are summarized in tab. 1, we analyzed the goals of GAIA-X (see above) and firstly selected the ones suitable for the present case. To validate them they were discussed with a group of partners from the ForeSight project, which are on one hand familiar with GAIA-X and on the other hand familiar with the domain smart living. Since our artifact is a prototype, most of the requirements are in line with the evaluation criteria proposed by [SV12] for instantiations, namely effectiveness and efficiency. However, since the service self description (c.f. chapter 4.3) can be understood as a model (generic description of a service, which can be instantiated), too, the evaluation criteria completeness, internal consistency and level of detail apply as well.

4.2 Proposed Architecture for the Service Registry

To develop a GAIA-X compliant service registry for the domain smart living, the mentioned requirements need to be considered in architectural and design specific decisions of the

[6] `https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-data-strategy_en`, accessed 19th of April 2021

ID	Requirement	Description
R1	European data protection	The developed artifact must enable implementation of the European General Data Protection Regulation (GDPR), as well as case-specific adaptability of data protection scenarios for diverse protection classes.
R2	Openness and transparency	Developed artifacts must create transparency to reduce transaction costs and increase data availability and exchange.
R3	Authenticity and trust	Artifacts should provide a self-description, for example on certified data protection as well as compliance with regulatory criteria, in order to strengthen the mutual trust of ecosystem actors.
R4	Digital sovereignty and self-determination	Developed artifacts should enable data sovereignty and control of data sovereignty: Each user decides for himself or herself, on the basis of his or her own data classification, where his or her own data is stored and by whom it may be processed and for what purpose.
R5	Free market access and European value creation	The use of verifiably secure, open technologies in an open ecosystem is intended to promote competitiveness, especially in international comparison. Services should be linkable to enable secure use of data and algorithms as well as the movement of data along the value chain to applications.
R6	Modularity and interoperability	The artifacts should enable interoperability both in terms of technical and semantic standards and in terms of interconnectivity at network, data and service level between edge or cloud instances. This interoperability is intended to avoid lock-in effects and prevent the emergence of data silos.
R7	User-friendliness	GAIA-X services should be clear and intuitive for all stakeholders.

Tab. 1: Requirements for the service registry derived from GAIA-X

service registry. In the current and the following two chapters these decisions and the resulting artifact are presented in more detail. Its core task is the collection and presentation of available services. The information required for this is largely determined by the requirements R1 to R5 and smart living specific requirements with regard to cyber-physical service compositions. In addition to the design of the content, R6 also stipulates a high degree of standardization of the format, which is reflected in the definition of a uniform self-description that need to be stored in the service registry in a form that is both machine-readable and intuitively comprehensible to humans. Due to this, the self-description was designed in a format based on existing semantic standards, as further described in chapter 4.3 and an intuitive user interface needed to be developed. To achieve this combination in a time efficient manner, Django has been chosen as web-framework to develop a prototypical application. Django takes over basic settings for web development and also provides functions such as full user authentication or a pre-installed admin area [Fo]. By default, Django uses an object relational mapper on top of a relational database to process the contained information using e.g. the model view template (MVT) pattern [HK09]. MVT is a slightly varied version of the model view controller pattern [LD85] which divides the view into two separate components called view and template, while most controller functionality is handled by the Django

framework itself [Fo]. To include the developed self description directly into the Django framework the ORM and the relational database have been exchanged by mongoDB [Gy15] as document-oriented database and a corresponding object document mapper[7]. To offer the mentioned REST-API, an extension of Django called Django REST[8] has been used. The resulting structure of the service registry is shown in fig. 2.

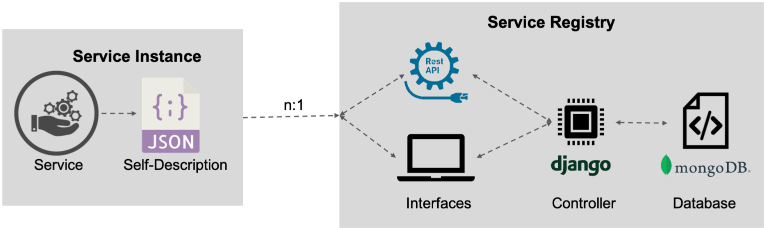

Fig. 2: General structure of the service registry

To integrate the prototype into the smart living application domain, the service registry has been dockerized and deployed in an open shift environment from an IT service provider of the housing industry. This facilitated further utilization and the possibility of a domain-specific evaluation, as described further in chapter 5.

4.3 Model Structure and Service Self Description

A key component of the model and thus a central feature of the registry concept is the self-description of each service. Each service registered in the registry is described by meta information using a Web of Things (WoT)-based description language. By describing services in a standardized format, the registry helps service engineers understand and orchestrate the components, thus promoting the creation of interoperable and transparent solutions within the data ecosystem. The registry supports the WoT standard classes (Properties, Actions and Events), as well as an extension of the Thing class with additional features of the respective service relevant for the data ecosystem. The extended attributes are divided into two subgroups: Attributes derived from GAIA-X requirements (GX) and smart living specific attributes (SL). Tab. 2 shows a detailed description of the extension made to the basic scheme.

4.4 View and Visualization of Services and Service Interdependencies

As described in the previous chapters, the core task of the service registry is the collection and presentation of services in a machine- and human-readable format. While the self descriptions and the REST-Interface are addressing the machine readability, in this chapter

[7] `https://github.com/django-nonrel/mongodb-engine`.

[8] `https://www.django-rest-framework.org/`.

Attribute	Description	GX	SL
Provider	Provider name of the respective service	x	x
Dependencies	Information about dependencies in the form of references to services and data sources used by the respective services	x	
Service ID	ID of the data supplying service		x
Data Type	Data type of the input data used by the respective service	x	x
Type of data use	Describes what the data is used for (e.g. training of an AI)		x
Smart readiness Indicator	Domain-specific assessment of the service with regard to its adaptability to the needs and preferences of individual users		x
Costs/billing unit	Contains information on possible costs arising from the use of the service and on the billing unit (e.g. per request)	x	x
Life Cycle stage	Contains information on the lifecycle status of the service in question (e.g. active, inactive, test)	x	
Location (physical)	Specifies the physical location (country) where the respective service is hosted	x	
Execution Node	References a particular GAIA-X node on which the service is hosted	x	
Security classification	Contains information about the security classification of the data provided and processed by the service in the form of a metric (0: none 6: very high)	x	
Processing of person-related data	Indicates whether personal data are processed that are subject to the GDPR	x	
Certification	List of certifications that the specific service has	x	

Tab. 2: Extension of the WoT standard by use case specific attributes

the human oriented visualization of information-based on the described requirements is presented. Even though the stored information is independent from the visualization and determined in the self-description, an intuitive visualization according to R7 can improve the usage of the service registry. According to this, the service registry is offering an overview of existing services and a detail view for each service. Due to the explicit relevance of execution location as well as provider and security information, these are already shown in the overview and part of the sort and search functionalities.

One aspect overarchingly relevant for requirements R1 to R5 is the possibility to understand necessary data flows and service dependencies of complex cyber-physical service compositions. Even though the required information regarding direct service relations in the presented self-description might be sufficient to understand service relations step by step, the representation of complex service relations keeps still quite hard. As one major contribution of this paper a dataflow representation has been developed to increase this transparency of service compositions for data consumer, data producer as well as intermediates. As shown in fig. 3 this representation can show the incorporated components in a cyber-physical system and help users to understand how their data will be used (R1 & R4) and help other actors to exchange services by for example more secure alternatives (R6).

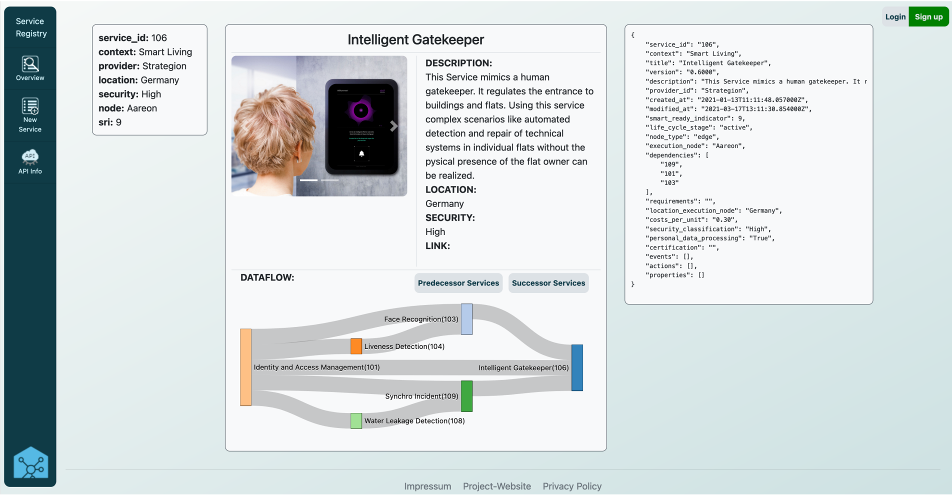

Fig. 3: Service registry GUI: Service details including a dataflow representation of complex service dependencies

Fig. 3 shows the use case of the intelligent gatekeeper outlined in chapter 1 for emergency access in the event of a water leak. Using this representation, possible users of the gate keeper are able to identify all involved components, such as face recognition or liveness detection. Additionally, it can help service engineers to understand dependencies, if a service should be exchanged by another one or a complementary service should be developed, like in the case of the face recognition and its integration of a liveness detection service. Summarizing the implications of the presented architecture, the self-description as well as the view, we find that our service registry design, which focuses on the integration of interoperable and domain-specific standards, can answer RQ 1.

5 Evaluation

The evaluation of our prototype is part of the ex post evaluation according to [SV12] (c.f. chapter 3). It aims at verifying, that the previously described requirements (c.f. chapter 4.1) were met to judge the overall success of the implementation and to identify weaknesses and unexploited potentials for the next development iterations. We therefore transferred the requirements into a set of questions for the expert interviews to a) obtain an overall estimate per requirement, if the prototype is suitable, and b) to gain detailed feedback. Due to current travel restrictions the interviews were conducted via video conferences. If feasible the experts were granted access to our prototype and used it after the introduction of the interview. In case direct access was not possible the prototype was presented via screensharing and the interviewees could ask questions or request an in-depth presentation of certain features. To provide a structured overview, of the results we summarized them in

tab. 3. In addition to the requirement abbreviation (column one; the abbreviation referenced in chapter 4.1), the aggregated rating is listed on a scale from "fully met" (+ +) to "not met at all" (–) (column two) and specific feedback is mentioned in a condensed form (column three). The following section briefly describes the aspects rated by the experts.

Evaluation related to previously defined requirements		
Req.	Eval.	Requirement specific suggestions for extensions
R1	+	• More detailed description of the security level • Information on anonymization or pseudonymization of the data • Extension of the visualization function
R2	++	• More granular description of individual data sources of a service
R3	+	• Certification of the correctness and quality of services and data sources
R4	0	• Enabling the replacement of unwanted service components • Provide information about service calls • Clearer definition of the target group
R5	0	• Extension by detailed technical description of the services
R6	+	• Specification of rules, e.g. to avoid too high granularity of services
R7	+	• Integration of a development component for the orchestration of services
Further suggestions for expansion		
• Different domain registries should be interoperable • Consistent implementation of registries • Standardization of interfaces • Promote the interplay of different data ecosystems • Enabling clustering of services • Add information about services rollout • Extend service description and service classes (e.g. start service, processing service) • Increase data and information coverage • Support of established standards • Consideration of cross-domain requirements		

Tab. 3: Results of the user evaluation

First of all, the requirement for digital sovereignty and self-determination (R4), which was rated by interviewees as neither "fully met" nor "not met at all", should be named. This is primarily due to the different views on the extent to which the user is given options to actively influence the services listed in the service registry. On the one hand, it has been criticized that the prototype does not allow active interference with the services or their data flows. On the other hand, it has been stressed that the provision of information provides the opportunity to make an informed decision and thus increase sovereignty . The requirement of free market access and European value creation (R5) has also been evaluated neutrally, due to the differences between the two aspects merged into one requirement. A public service registry allows new or small players to easily enter the market (e.g. as in app stores), which was considered very positive. However, the extent to which this strengthens European value creation has been strongly questioned. Finally, modularity and interoperability (R6),

which, despite its generally positive assessment, has been interpreted differently. This mainly concerned the question of whether excessive granularity, as promoted by the service registry, has a positive or negative influence. On one hand, modularity tackles the increased understandability of the functionality of specific services as well as the increased ability to include already implemented functions. On the other hand, the need to modularize services can also foster the deployments of various subservices, decreaing the overview in a ecosystem based on the overload of information.

6 Discussion & Conclusion

This article presents the concept, development, and evaluation of a service registry for the domain smart living in the context of GAIA-X. The latter was achieved by extending a common standard to include domain-specific aspects (c.f. RQ2). The evaluation was used to verify functionality regarding requirements and suitability in supporting a service engineer (RQ2). This is also the key distinction to be made from existing systems, which offer broadly similar functionality. With developers as a target group and the GAIA-X smart living domain as a framework, the tool offers added value in developing innovative services consisting of products and services that have not yet been linked.

This has been confirmed by largely positive feedback on usefulness and usability during the, mainly technically oriented, evaluation. Some possible methodical limitations regarding the assumptions of the user centric elicitation of GAIA-X requirements including an ex ante evaluation and a quite small number of experts can be pointed out. However, regardless of this, extensive qualitative feedback was collected, which can form the basis for further development and evaluation steps. The feedback of the interviewed experts includes the possibility of directly influencing data flows (as opposed to purely destructive presentation) and the integration with other registrations within the meaning of GAIA-X funding (e.g. from other domains). Furthermore, specific instances of services and concrete physical devices should be integrated as instantiation of abstract services offered from providers. Next to this, currently all dependencies visualized in the service registry are based on the aggregated data of the service providers. To increase the trust and in order to prevent abuse, a neutral instance can be included, extending and certifying the identified dependencies.

In the context of this work, the registry was developed according to the specific requirements of the smart living data ecosystem. However, there is a need for transparency in many domains, therefore we want to encourage the application of the registry concept to other domains as well. Even more, the unwillingness to share data and services is a major obstacle to the establishment of data ecosystems and for the implementation of data-based business models [Ko21]. The service registry offers a way to increase this willingness by reducing uncertainty and creating transparency for all actors of the data ecosystem. It thus contributes to economic sustainability by reducing transaction costs.

Finally, the focus of the presented service registry has been the presentation of inter-service relations, neglecting the design and data processing of the system itself. To increase the transparency of services containing machine learning-based components, the interpretability

of the involved systems need to be considered in more detail to disclose the decision making process and prevent security threads or possibly discriminatory behavior. The latter aspect is of crucial importance in terms of social sustainability and is currently receiving a lot of attention in the scientific discourse on AI.

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