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Implementing ALiS: Towards a Reference Architecture for Augmented Living Spaces

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Abstract

Augmented reality (AR) is currently discussed as an approach to promote the personal health of elderly and cognitively impaired people, with spatial AR being a promising, wearable-less solution to enable. an augmented living space (ALiS) that immersively provides and communicates individual, needs-oriented functionalities in the areas of perception, mobility, organization, and medicine. To address the knowledge gap of missing knowledge concerning the implementation of such assistance systems that support autonomy in everyday life, we derived a reference architecture (RA) based on an existing design theory. Our RA contains UML diagrams for components and sequence flows, accompanying text descriptions, and a user interface design. We successfully implemented a prototype to show the RAs feasibility and conducted an expert survey for its general usefulness with positive results. Our contributions add to the prescriptive knowledge base of the community as the results may be adapted by researchers and practitioners.

Keywords: Spatial Augmented Reality, Augmented Living Spaces, Reference Architecture, IS Healthcare

1. Introduction

Despite an increasing number of information technology solutions to support the ever-aging society and cognitively impaired people at home (Fernando et al, 2016; Kosch et al., 2019; Mshali et al., 2018), there is a persisting lack of knowledge on the development of holistic augmented reality (AR) assistance systems that do not require any arduous wearables such as head-mounted displays (HMDs) or hand-held devices. In a first design science research (DSR) cycle (Böhmer et al., 2022), we found that elderly and cognitively impaired people have great difficulty wearing burdensome HMDs as their complex menus, low battery capacity, and the reduced field of view do not allow a holistic, yet easy-to-use solution. An AR approach that can do without wearables, is that of spatial augmented reality (SAR) and the use of projections and auditory communication (Raskar et al. 1998). Using SAR as an implementation technology, the cognitive load of the users can be reduced, which further increases the everyday suitability of the system (Baumeister et al., 2017). Furthermore, Von Arnim et al. (2019) and Gauthier et al. (2006) claim that persons with minor cognitive impairments who have yet been diagnosed with dementia may handle their daily lives independently, but they must accept cognitive impairments that can influence daily routines (e.g., cooking, dressing).

However, there is a prolonged absence of SAR-based assistance systems in healthcare as the primary application revolves around the industrial production and maintenance sector (Rupprecht et al., 2020; Cardoso et al., 2020; Tavares et al., 2019). Individual applications of spatial augmented reality regarding digital assistance systems and healthcare solutions are, e.g., found in projection-based reminder robots (Yang et al., 2018) or projected smart-home notifications (Wegerich et al., 2010). Yet, such solutions only address specific areas in the everyday life of elderly and cognitively impaired people and are incapable of dynamically reacting to complex processes or situations. To tackle the problem of missing holism, workflow management systems (WFMS) can be introduced to intelligently create context-awareness. Current state-of-the-art sensor technology provides hereby a sound foundation for real-time data transmission, which is ideal for WFMS and its healthcare application (Baig et al., 2019; Mshali et al., 2018).

Since guiding design knowledge for an information system (IS) exhibiting the aforementioned characteristics is lacking, we identified design requirements (DRs) and interrelated design principles (DPs) of a design theory (DT) as well as a simplified IS architecture in a first design science research (DSR) cycle (Böhmer et al., 2022). The DT hereby consistently supports IS researchers and developers when designing IS architectures (Baskerville and Pries-Heje, 2010). While DTs provide valuable guidance, reference architectures (RA) provide further guidance for

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implementation, especially for practitioners (Cloutier et al., 2009). However, such an RA for a context-aware IS incorporating SAR, context-depended sensors, and WFMS to support the elderly and mildly cognitively impaired individuals in their living spaces is currently lacking. To address this research gap we consequently define our research question (RQ) as follows:

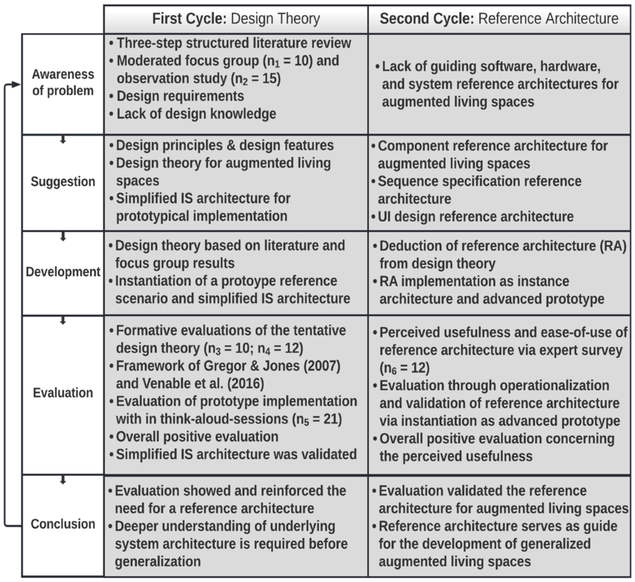
RQ: *What are the textual descriptions, models, and model elements of a system reference architecture for augmented living spaces, supporting the everyday life of the elderly and cognitively impaired?*

We address our research question by applying a DSR approach to develop a reference architecture for information systems utilizing spatial augmented reality, diverse sensors, and WFMS in support of elderly and cognitively impaired persons, which was initially termed as *augmented living space* (ALiS). Therefore, our contribution simultaneously extends the research field of spatial augmented reality, design science research, ambient assisted living (AAL), and general IT healthcare regarding personal health by defining a reference architecture with which future ALiSes can be developed. Furthermore, we show how design requirements and principles of a constituted design theory can be used for stringent conceptual modeling and the derivation of an RA for a specific IS.

The description of the applied DSR research paradigm and its methodological groundwork is presented in Section 2. In Section 3, we describe the underlying theoretical and socio-technical foundations to further detail the knowledge gap and gain insights into possible solution characteristics. In Section 4, we concisely present the design theory from our initial design science cycle and describe the derived RA for ALiS in the form of UML diagrams and accompanying descriptions as the main contribution of our research in Section 5. Subsequently, the RA is evaluated through its operationalization as well as a quantitative survey with experts and researchers, presented in Section 6. Finally, Section 7 reflects the findings and limitations of our research.

2. Research method

The design science research methodology of Vaishnavi and Kuechler (2015) was applied to assure scientific rigor and execute the structural approach for an ALiS. Thereby, the following five steps were implemented: awareness of problem, suggestion, development, evaluation, and conclusion. We chose the methodological framework of Vaishnavi and Kuechler (2015) over other approaches since it has an explicit focus on the development of theoretically sound design requirements and principles to guide the development of an IS reference architecture as they act as the unconditional prerequisite for an RA (Oussalah, 2014). Hereby, the DSR methodology is a valid approach to conceptualizing requirements and proposals regarding information systems in digital healthcare and personal health (Miah et al., 2017). Our multi-cyclical research design follows the work of Meth et al. (2015), whereas two DSR cycles have been completed and further cycles can be applied if required (Figure 1). In this regard, our paper focuses primarily on the second completed design cycle, the outcome of which is an RA in the form of two UML diagrams as well as its implementation as an advanced prototype. In a first design cycle (Böhmer et al., 2022), the design theory was developed and instantiated, which was positively evaluated but showed the need for a deeper understanding of the underlying system and architecture.



	First Cycle: Design Theory	**Second Cycle:** Reference Architecture
Awareness of problem	• Three-step structured literature review • Moderated focus group ($n_1 = 10$) and observation study ($n_2 = 15$) • Design requirements • Lack of design knowledge	• Lack of guiding software, hardware, and system reference architectures for augmented living spaces
Suggestion	• Design principles & design features • Design theory for augmented living spaces • Simplified IS architecture for prototypical implementation	• Component reference architecture for augmented living spaces • Sequence specification reference architecture • UI design reference architecture
Development	• Design theory based on literature and focus group results • Instantiation of a protoype reference scenario and simplified IS architecture	• Deduction of reference architecture (RA) from design theory • RA implementation as instance architecture and advanced prototype
Evaluation	• Formative evaluations of the tentative design theory ($n_3 = 10$; $n_4 = 12$) • Framework of Gregor & Jones (2007) and Venable et al. (2016) • Evaluation of prototype implementation with in think-aloud-sessions ($n_5 = 21$) • Overall positive evaluation • Simplified IS architecture was validated	• Perceived usefulness and ease-of-use of reference architecture via expert survey ($n_6 = 12$) • Evaluation through operationalization and validation of reference architecture via instantiation as advanced prototype • Overall positive evaluation concerning the perceived usefulness
Conclusion	• Evaluation showed and reinforced the need for a reference architecture • Deeper understanding of underlying system architecture is required before generalization	• Evaluation validated the reference architecture for augmented living spaces • Reference architecture serves as guide for the development of generalized augmented living spaces

Figure 1. Design science research approach.

Hence, this paper presents the DT only superficially and addresses the DRs and DPs using the reference architecture models, as they symbolize the foundation of a design theory and contribute to the solution of the problem (Baskerville and Pries-Heje, 2010). Here, the DRs describe the principle objectives and, in a sense, represent meta-requirements for the subsequent RA and prototype artifact (Baskerville and Pries-Heje, 2010; Walls et al., 1992). This enables us to derive components, classes, and ontological relationships for our RA, showing how a design theory can be utilized for conceptual modeling. The DPs of ALiS are prescriptive and universal in that context, specifying how the reference architecture for the prototype should be designed to meet the DRs of our target group (Fu et al., 2016). In this context, the DPs were derived by a supportive approach following Möller et al. (2020), whose a priori specification suggests a prescriptive wording (Fu et al., 2016), facilitating meta-modeling instructions for the development of the RA. Furthermore, our DSR approach is oriented towards the ISO 9241-210:2020 standard and the human-centered design of interactive systems, which should be a priority for personal health applications.

3. Theoretical background

In our DSR approach, we conducted a total of three structured literature reviews (SLR) according to the rigorous methodology of Vom Brocke et al. (2009) as it allowed us to conduct a comprehensible, stringent, and sound literature review, incorporating the taxonomy by Cooper (1988). Our SLRs can be characterized as focusing on *research outcomes*, *theories*, and *applications* in regards to spatial augmented reality (SLR 1), digital assistance systems (SLR 2), and workflow management systems (SLR 3). The audience is *specialized* & *general scholars*, whereas the coverage is *representative* for SLR 1-2 and *exhaustive* & *selective* for SLR 3. All SLRs had the objective to integrate the literature, organize it conceptually as well as represent it from a neutral perspective. A detailed description of the search strings, databases, and results can be found in Böhmer et al. (2022). The overall goal of this three-step SLR was to find frameworks, ontologies, and RAs as well as methods and best practices. Besides the lack of design knowledge in the initial search, we found that no reference architecture is guiding the implementation of design conceptualizations for augmented living spaces, and hence, will focus on the relevant literature in this paper.

Spatial augmented reality. The term *spatial augmented reality* was initially defined by the work of Raskar et al. (1998) and thus, laid the foundation for our development and the design of ALiS. This initial contribution brought up and discussed surface shape extractions, rendering methods, and acquisition artifacts that were picked up by subsequent contributions in this research field discussed in Böhmer et al. (2022). To ensure relevant works regarding the implementation of such systems, SLR 1 was further performed on current ontologies, RAs, and techniques of SAR, where key findings covered error-free compensations methods for projection, projection manipulation, ideal projection surfaces, and successful practical applications of SAR in different areas such as cooking assistance for the cognitively impaired (Kosch et al., 2019). However, we found no reference architecture or ontology that guides the implementation of SAR system designs.

Digital assistance systems. Individualizing services is an essential part of healthcare delivery (Di Paolo et al., 2017). Yet, not only personalized medicine but rather individual assistance systems are becoming more significant for elderly and cognitively impaired people. Therefore, SLR 2 was aimed at neoteric digital assistance systems as well as ambient assisted living in healthcare, identifying possible technical and conceptual IS reference architectures that capture the essence of existing applications and could serve as a guide for developing user-centric requirements. Key findings include reference guidelines for projection design (Morris, 1994), conceptual (Tazari et al., 2010), and technical (Antonino et al., 2011) RAs for digital assistance and AALs for the elderly. Beyond that, Garces et al. (2020) and Memon et al. (2014) showed that current system implementation lacks a holistic approach, quality, and modularity while being elusive and difficult to understand.

Workflow management systems. SLR 3 extended the literature review to analyze state-of-the-art reference architectures for WFMS that could potentially serve as guidelines for developing concrete workflow concepts behind ALiS and thus, being consistent with the definition of RAs according to Cloutier et al. (2009). We found the WFMC (1995) as the most popular RA, with the architecture of Pourmirza et al. (2019) building upon that and providing an RA for business process management systems.

To the best of our knowledge, a holistic, dynamic, and modular approach to supporting the elderly and cognitively impaired does not exist in the literature and is therefore taken up with ALiS. Moreover, no reference architecture or ontology guides researchers through the conceptualization and implementation of ALiS systems.

4. Design theory

The first design cycle proposed an initial DT (Figure 2) that was based on the literature, moderated focus group, and observation study results, the results of which are extensively discussed in Böhmer et al. (2022). We meticulously followed the supportive approach of Möller et al. (2020), with the DPs aiming to provide design knowledge before the design process takes place. Hence, we developed the DT a priori, which allowed us to conceive design knowledge that is generally applicable and can be transferred from one application to multiple application scenarios depending on the corresponding target group and objective. Given a specific scenario, this allows for an intuitive adaptation of the ALiS system without needing to redefine DRs and DPs while also containing DPs that are target group independent.

The design theory for ALiS consists of 4 essential DRs, which are further addressed by 12 target group-specific DPs, and 13 specific use case-derived DFs for our advanced prototype instantiation of ALiS (Figure 2).

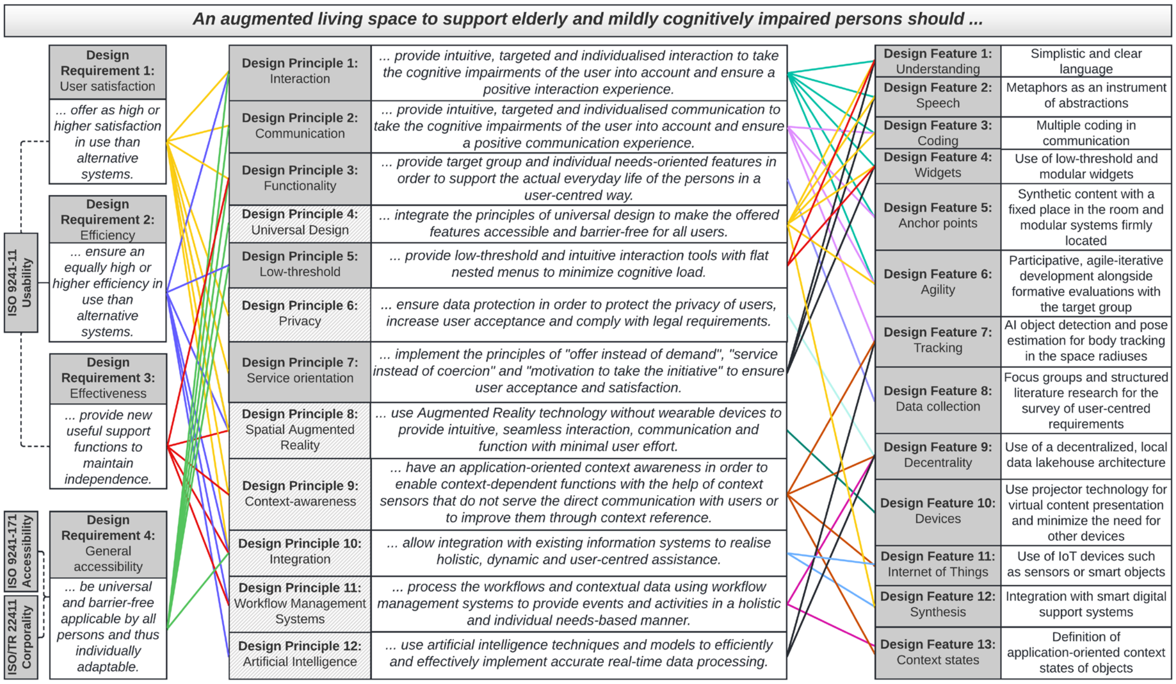


Figure 2. Design theory of ALiS (Böhmer et al., 2022).

Hence, the design requirements and principles describe components that every ALiS for the elderly and cognitively impaired should be built upon, whereas the design features refer to our prototype development features and do not represent an explicit component of the design theory. We further defined hatched DPs (Figure 2) that are generally applicable and describe principles any ALiS should consider to target their respective audience. The DRs, DPs, and DRs are further described in detail in Böhmer et al. (2022) and act as the theoretical foundation for the development of the reference architecture.

5. Reference architecture

Reference architectures are epitomized and theoretical architectures of end systems for a particular application domain (Angelov et al., 2009; Nakagawa et al., 2012). RAs have been designed in several application domains, positively influencing the productivity, performance, and quality of the systems (Oussalah, 2014). Hereby, Oussalah (2014) states that the design of an RA should incorporate pre-defined requirements as well as establish them, whereas also domain concepts are identified. Thus, this approach can use DRs and DPs of a general design theory as they respectively depict application-specific meta requirements (Baskerville and Pries-Heje, 2010; Walls et al., 1992) and the prescriptive implementation of these (Fu et al., 2016) to represent a sound foundation for the reference architecture.

The RA for ALiS is constituted by a reference user interface (UI) design as well as two models in the universally applicable UML component and sequence specification, supplemented with textual descriptions (Object Management Group, 2017). To show how the design theory is used to deduce RA objects, the DRs and DPs (Figure 2) are connected and given for the respective component of the reference architecture in the next section.

5.1. Reference user interface design

A first reference UI approach for ALiS has been proposed by Böhmer et al. (2022), implementing two possible application scenarios. Since then, further scenarios and widget compositions have been developed to embody a reference UI design. In Figure 3, the ALiS user story is instantiated via a virtually scanned Unity3D living environment. Thereby, the living environment contains several widget bubbles enhancing the stove area (top left), a phone augmentation (top middle) as well as a reminder and calendar widget (top right). Thereby, all widgets follow the so-called widget bubble *interface-rule,* providing users with a functioning widget on the one side, and an offering widget on the other as raised by the target group in Böhmer et al. (2022) and thus, implementing **DP2** and **DP3**. Furthermore, the widgets are in their active state, acting as if the user would move in their respective activation area. Using the stove widget as an example, there is a widget unit showing the stove plates and their

Figure 3. Reference user interface design.

temperature (functioning widget) as well as a recipe and cookbook service (offering widget). Thus, this enables the ALiS to adequately address the individual, needs-oriented requirements of the user, following the RA guidelines for digital assistance systems and AAL by Garces et al. (2020) as well as **DP2**, **DP3**, and **DP7**. Moreover, the phone augmentation offers speed dial for emergency or important contacts, implemented by a low-threshold voice command interaction (**DP1**, **DP5**) that enables call acceptation. Thus, users can do telemedicine activities or physical therapy to promote their personal health. Additionally, the reminder widget bubble shows items that are likely to be forgotten by the user (functioning widget) and possible meetup opportunities in the community (offering widget).

Moreover, all widget bubbles in the augmented living space follow certain rules to enhance their flexibility, functionality, appearance, and implementation, addressing **DR1**, **DR2**, and **DR3**. With the widget bubble *interface-rule* already mentioned, there further is the *anchor-rule*, which specifies and realizes the need for anchor points in the form of the objects that are being virtually enhanced through ALiS (**DP1**, **DP2**). For example, the widget bubble enhancing the stove will be anchored to the stove, increasing the receptibility and intuitiveness in use for the residents (Böhmer et al., 2022). Furthermore, the *icon-rule* defines specific icons for widget bubbles representing their respective use case. These icons are shown if a widget bubble is not in its active but rather idle state, meaning a user is currently not in the specified area that would trigger the widget bubble. However, the widget bubble will be recognizable with an icon that depicts the enhanced object (i.e., phone icon for the phone call widget bubble). Lastly, there is the *responsiveness-rule* that enables widget bubbles to adequately react to their respective displayed widgets and their appearance/shape. Hence, widget bubbles can appear differently in their shape according to the projected information and composed widget design (**DP4**).

5.1. Component diagram

In general, the UML component diagram depicts the structure and relationships between the different components of an IS. Referred to our ALiS system, we have four nodes that represent stand-alone components at a higher level of granularity, consisting of more profound components (Figure 4). These high-level nodes include (1) *sensor node*, (2) *database node*, (3) *workflow node*, and (4*) output node*.

Sensor node. The sensor node of ALiS is the component that bundles all sensory hardware as well as machine learning-powered tracking. Thus, all sensors (e.g., heat sensors, water level sensors, fall detection sensors, etc.) are included and send their semi-structured or unstructured data to the data pre-processing unit that we realized with *NodeRED* as can be seen in the sequence diagram in Figure 5. Here, the data is parsed and every sensor is given a static ID for further processing. The data pre-processing unit then specifies where, what, and in which format data will be sent, enabling higher efficiency (**DR2**). The sensor components are further able to process data in *parquet* format, enabling fast processing of unstructured data. On the other side, we have a synthetically trained machine learning model to track people with 360-degree fisheye cameras to adequately project information in the user`s gaze direction (**DP12**). This data will be pre-processed and sent to the messenger workflow as well as directly to the output node, allowing fast process time for real-time information delivery, which is essential for the conceptualization of RAs for AAL (Antonino et al., 2011) and the realization of **DR1** and **DR2**. The processing sequence is depicted in Figure 5, specifying the data flow.

Database node. The database node is structured in the form of a data lakehouse as supposed by Armbrust et al. (2021), enabling near real-time data storage, processing, and retrieval. Hence, data can be structured or unstructured upon storage. Furthermore, the database node creates context variables through the incoming and pre-processed data from the sensor node, e.g., storing the stove temperature at a specific time with a defined ID. This specific context data is sent as a variable to the workflow node, which then reasons the data. Nonetheless, the database node also includes contextual states that come from the workflow node, storing context states (e.g., *stove is hot, door is open*) based on the context variables (**DP9**).

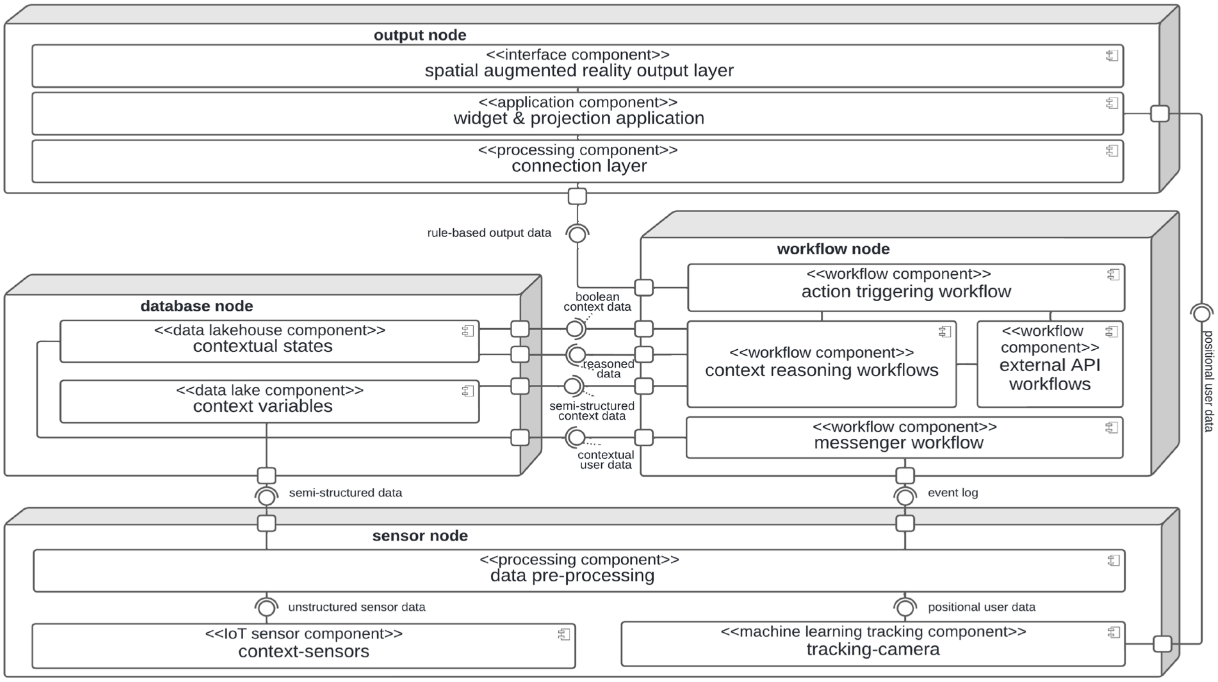


Figure 4. UML component diagram of ALiS.

Workflow node. Moreover, the workflow node can be seen as the brain of ALiS, establishing contextual connections between raw sensory data and its implications for the user, and thus, following the RA for context-aware systems by Alegre et al. (2016) and Costa et al. (2005) as well as addressing **DP11**. Our WFMS defines, interprets, instantiates, and manages the execution of workflows with software, integrates external applications, and interacts with human workflow participants according to the definition of the Workflow Management Coalition (1995). Moreover, it manages and controls the sequences as defined in the sequence diagram (Figure 5). Hence, it is responsible for creating, reasoning, and combining context (**DP9**). For example, a raw temperature context variable from the database node is not quite meaningful. However, if the WFMS “knows” that after 10 pm the stove plates should be off, but detects a hot temperature there, we created a reasoned context for the raw variables and added value. Furthermore, the WFMS also integrates external services such as the user’s phone, personal health applications, smart home systems, or health insurance services via a secured API (**DP7**, **DP10**). Lastly, the workflow node triggers projection or auditive communication, which is implemented through the application (e.g., triggering and augmenting the information of a hot stove plate).

Output node. The output node is represented through a spatial augmented reality application that parses the sent information to project or communicate a certain widget or widget bubble (**DP8**). With pre-defined widget appearances, it is possible to flexibly assemble certain widgets as well as orchestrate them. This allows the application to change color schemes or data composition according to the individual needs of the user (Antonino et al., 2011; Garces et al., 2020; Kosch et al., 2018; Tazari et al., 2010) and hereby account for individual impairments (**DR4**, **DP3**, **DP4**). Since the application also gets the positional user data, suitable projection mapping is enabled and the right projector or speaker can be selected.

5.2. Sequence diagram

The UML sequence diagram for ALiS (Figure 5) depicts the interaction between the components and flow of activities/processes regarding the IS. Thereby, the sequence diagram operates on a component level, making it easier to draw connections between the two diagrams as well as understand the relations, processes, and dependencies.

At the beginning of the sequence, or strictly speaking at any time within the augmented living space, a user is moving through his living environment. At this time, the user is tracked by the machine learning component, and sensors log the data as well as send it to the pre-processing unit. This process is repeated over and over again, yet respectively to the specific sensor schedule (e.g., a medication sensor does not need to send data every second). Looking at the component diagram, this data is sent from the sensor node to the database node, in which the data (context variables) will

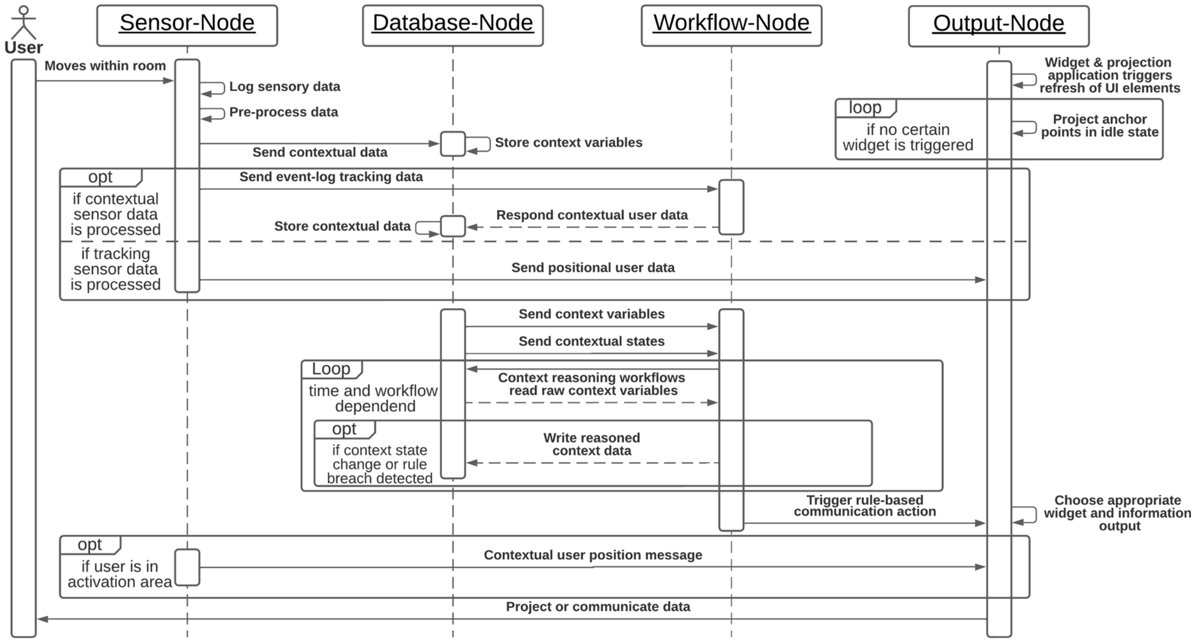


Figure 5. UML sequence diagram of ALiS.

be initially stored and prepared for further processing. However, there is an alternative if-else-condition that depends on the form of contextual data. If sensory data is processed, this kind of data needs to be stored and put into context, embedding the workflow node. Here, the workflow node will also store contextual data as contextual states in the database node. On the other side, positional user data from the tracking is sent to the output node to adequately map the projection or audio. Given a specific schedule, context variables, as well as already stored contextual states (e.g., user position, temperature), are sent to the workflow node, which reasons and interprets the data based on certain rules (e.g., stove should be off after 10 pm). The context reasoning can thereby be very complex and draws on all possible context data for decision making. Depending on a specific workflow, e.g., for the stove temperature, reasoned data is exchanged between the database and workflow node, while also storing it. Furthermore, there is another alternative sequence as reasoned data should only be overwritten or added, if the system detects a change within the contextual states (e.g., temperature) or a rule breach (e.g., stove is running for more than an hour). Once the data has been reasoned and a certain rule was activated (e.g., stove warning needs to be shown), the workflow node sends information to the output node application, and thus, triggering the adequate projection or auditive communication. However, there is an alternative sequence, since the application does not only rely on rule-based triggers, but rather on the positional user data as well. Consequently, if a user enters the activation zone of a widget bubble (Böhmer et al., 2022), the need for projection or audio is equally triggered and the general information of that widget bubble is presented. Lastly, the information will be projected or communicated through the SAR output layer, augmenting the user's living environment.

Interestingly, the output node, as well as the user, are always present during the sequence. On the one hand, the output application triggers a scheduled refresh of the UI elements, while simultaneously projecting the widget bubble anchor points throughout as they serve as memory references. On the other hand, the users always more or less interact with the ALiS, observing the anchor points or triggering widget bubbles with their position.

Since the whole sequence runs in nearly real-time, is secure in regards to data protection, interoperable, scalable, accessible, and flexible, our reference architecture for ALiS follows the guidelines and requirements for RAs in the context of AAL and digital assistance systems (Antonino et al., 2011; Garces et al., 2019; Tazari et al., 2010).

6. Evaluation

6.1. Evaluation by operationalization

To evaluate whether the developed design and derived reference architecture is *feasible*, we orient ourselves on the framework by Sonneberg and Vom Brocke (2012) and perform *evaluation activity 3* via a *demonstration with a prototype* (Sonneberg and Vom Brocke, 2012). This ex-post evaluation activity assesses if and how well the protype artifact functions as well as the potential usefulness of it, making it essential for reflecting the design and trigger further design science cycles. The input of the evaluation activity is hereby an instance of an artifact in the form of our prototype as can be seen in Figure 6. Our prototype acts as proof of applicability, demonstrating that it integrates the defined principles of form and function specified by our design theory and RA.

Figure 6. ALiS prototype as floor lamp.

6.2. Perceived usefulness expert survey

Regarding general RA quality ascertainment, we conducted a questionnaire-based expert survey to evaluate the perceived usefulness (PU), conciseness (CON), extendibility (EXT), and explanatory power (EXP) of the RA.

Since the PU as a qualitative and soft construct is not directly measurable, we drew on the six scale items (SI) by Davis (1989) for the summative evaluation: quickness (SI1), performance (SI2), productivity (SI3), effectiveness (SI4), easiness (SI5), and overall utility (SI6). We specified the SIs for our application context, i.e., for the development and design of an ALiS. Additionally, we asked the experts about the conciseness, extendibility, and explanatory power of the artifact, following the approach of Nickerson et al. (2013) regarding subjective ending conditions from their stringent taxonomy development method. The issued questionnaire included: 1) an introductory text about the research project, 2) the RA as presented in Section 5, 3) a prompt to imagine an application scenario for the RA, 4) the questions on the SIs, CON, EXT, and EXP as well as 5) some socio-economic questions. For data collection, we used interval-scaled verbal-numeric 7-point Likert-style scales, from 7 (strong agreement) to 1 (strong disagreement).

In choosing the sample size, we followed the so-called "10±2 rule" (Hwang and Salvendy, 2010), which states that 8 to 12 respondents are sufficient for usefulness evaluations. Based on an expected response rate of 50%, we sent the questionnaire to a total of 27 experts/researchers and received 12 completed questionnaires (actual response rate: 44,4 %). Regarding their job role, respondents hold professions as CEOs in a care facility (1), project leads (2) as well as software developers in AR/VR corporations (2), senior researchers in process management (2), research assistants working on healthcare projects (3), and AR practitioners (2), all with expertise in the AR and IS domain. Professional job experience of the participants ranged from 3 to 37 years, with former professions in research, healthcare, cognitive support, and dementia care.

Table 1. Construct validation.

Loadings	**SI1**	0.935
	SI2	0.552
	SI3	0.654
	SI4	0.660
	SI5	0.696
	SI6	0.902
AVE		0.557
CR		0.879

Note. SI: scale item; AVE: average variance extracted; CR: composite construct reliability.

We examined content validity, individual item reliability (loadings), composite construct reliability (CR), and average variance extracted (AVE) for construct validation (Hulland, 1999). Content validity aims to assess whether the items of a measurement instrument can generally be considered representative and relevant to a construct (Haynes et al., 1995). We judge our construct PU and the underlying items to be content-valid since we adopted them from the study by Davis (1989) and since they have been used successfully in numerous other studies. Item reliability is measured by the loadings on the construct PU, for which we conducted a confirmatory factor analysis in R. Items loading low on the construct should be dropped (rule of thumb: < 0.4) as they may bias parameter estimates while offering little additional explanatory power (Nunally, 1978; Hulland, 1999). However, in our factor analysis, loadings are above this threshold for each item (see Table 1).

The proportion of variance explained (AVE) by the construct is also above the threshold of 0.5 (Fornell and Larcker, 1981), meaning that the variance captured by the construct is greater than the measurement error. Moreover, the overall reliability of the items loading on our construct (CR) is also above the threshold of 0.7 (Nunally 1978; Hulland, 1999). Accordingly, our measurement model with six items for the construct PU is suitable for our evaluation.

Figure 7 depicts the boxplots of the responses. We received high levels of agreement for all items, with medians of m=6 and m=7. Small downwards fluctuations are present for SI5 and CON, which we both attribute to the complexity of the subject matter. Overall, respondents show strong agreement with the statements that the RA enables them to accomplish tasks (i.e., designing and implementing new ALiSes) more quickly (SI1), improves their job performance (SI2) as well as their productivity (SI3) and effectiveness (SI4), with only a few outliers. Moreover, respondents feel that the RA simplifies the development and implementation of new ALiSes (SI5). Finally, the high rating of SI6 with m=7 can be seen as a confirmation of the overall usefulness of the RA. For the sum scores of the scale items, we got m=39 on the 7-42 scale, resulting in an overall positive evaluation of the RA.

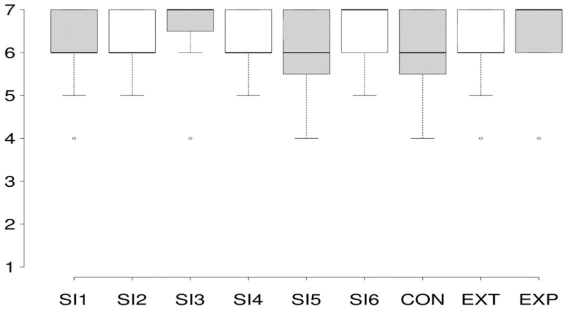


Figure 7. Scale items of perceived usefulness.

7. Conclusion

The augmented living space DSR project aims to design and conceptualize an IS for elderly and cognitively impaired users, ensuring a low-threshold, unobtrusive, yet effective, and individual needs-oriented service. Addressing the persistent lack of reference architectures to foster a detailed insight on how to implement an ALiS that supports the autonomy of the elderly and cognitively impaired, we used the validated design theory from the first design cycle and presented an RA, consisting of two UML diagrams, text descriptions, and a reference UI design. We further implemented the reference architecture, demonstrating its feasibility, and finally conducted an expert survey on the perceived usefulness for a general assessment with highly positive feedback. Regarding the theoretical and practical implications, practitioners and researchers can use and adapt our RA to efficiently develop and implement augmented living spaces for their respective application scenarios. Furthermore, the RA contributes to the prescriptive knowledge base of the IS community according to Gregor and Hevner (2013) along with the IS design science knowledge base according to Woo et al. (2014), further showing how a DT can be used for conceptual modeling. Consequently, future research could be conducted in large-scale evaluations of augmented living spaces and their benefit for users in everyday life. Researchers could look into adapting, adjusting, or improving the reference architecture as well as the design theory. Moreover, the general user acceptance of augmented living spaces yields great potential.

For an adequate interpretation of our results, a few limitations should be considered. Firstly, an inherent weakness in the development of RAs is the subjectivity of underlying architectural decisions by the researchers (e.g., components). However, not all design decisions must or can be grounded in theory and a degree of creativity is unavoidable and essential in the conceptual DSR process (Hevner and Chatterjee, 2010; Baskerville et al., 2016). Nonetheless, we considered the sate-of-the-art of relevant literature, showed the lack of RAs in this research field (cf. Section 3), have taken guidelines for the conceptual modeling of RAs into account (Antonino et al., 2011; Garces et al., 2020; Oussalah, 2014; Tazari et al., 2010), and drew connections between the design theory and RA components. Secondly, our evaluation depends on one sample, i.e., the choice of other participants for the survey might have led to different results. However, we believe that by selecting subject-specific experts and users for the survey, and considering the homogeneity of the results, we have obtained a robust evaluation, indicating that our RA adds value to the IS knowledge base and is useful for personal health, AAL, and SAR researchers as well as practitioners.

8. References

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