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Dividing Complexity to Conquer New Dimensions – Towards a Framework for Designing Augmented Reality Solutions

Completed Research

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Abstract

Augmented reality (AR) can foster service innovation and thus cope with some of the most urgent challenges in the service science domain, namely supporting frontline workers while ensuring high safety standards. Therefore, the utilization of AR can help to achieve these goals. On the contrary, AR remains a complex technology with specific requirements and preconditions that demand expertise to overcome them. Based on a case study, we derive a framework for designing AR solutions, which helps divide the complexity of designing and developing AR-based services to support the adoption and diffusion of AR applications. Such an encompassing perspective on initial AR explorations helps to transform the acquired information into a thorough proof of concept, pilot implementations and ultimately productive software.

Keywords

Mixed reality, case study, service innovation, value creation.

Introduction

The transformative character of the last years leads to a new perspective on work and how the workforce should be supported (Ostrom et al. 2021; Wirtz et al. 2018). Especially service research must be aware of these changes, as the service sector is the driver of modern economies. We often focus on highly skilled and educated professionals with desk jobs within service research. However, approximately 75% of the global workforce is frontline workers who partially carry out physical work (Porter and Heppelmann 2020). Building on this estimate, one of the core priorities of our field is service research. This involves supporting frontline workers in service delivery through technological innovation to save costs and improve the customer experience (Ostrom et al. 2021).

A technology that helps address these issues is augmented reality (AR). AR is a disruptive technology that enables blending the analog world with digital information. AR bears the potential to increase employee productivity while reducing error rates (Porter and Heppelmann 2020). Despite the transformative nature of existing services, AR is a strategic driver of innovation (Panetta 2020). By enabling remote access for experts (Obermair et al. 2020) and immersive training possibilities (Büttner et al. 2020), AR is a response to the demand for workforce flexibility through cross-training (Ostrom et al. 2021). In addition to services in industrial settings, the retail, hospitality, and healthcare sectors also benefit from AR (Jingen Liang and Elliot 2021; Klinker et al. 2019; Zimmermann et al. 2022). Given these technological potentials, it remains counterintuitive that practical application is still scarce (Steffen et al. 2019). However, digital transformation and the adoption of emerging technologies are not trivial (Grotherr et al. 2019). The realization of the intended benefits often falls behind expectations and requires further lightweight methodological foundations (Semmann and Böhmann 2015). The barriers between an initial idea to use AR in services and the practical implementation remains significant. Piloting requires analysis and well-advised selection of the use case as well as a customized solution tailored to the organization and the service, which is highly time-consuming and knowledge-intensive. For this reason, the remaining option is often to obtain expertise through external consultations, which is associated with high costs. Alternatively, the organization must develop the competencies itself, which is not less time-consuming and expensive. This makes it challenging to evaluate quick and easy proof of concepts. Limited budgets and lack of technical experience are especially problems for SMEs (Stentoft et al. 2019). As organizations become more aware of the potential of AR as innovative technology and seek to reap the resulting benefits, there is a need for a supporting guideline on how to make piloting AR applications easily accessible to a broad audience.

To bridge this gap, we provide a design framework for systematically developing AR solutions to support its diffusion and adoption. In this regard, we answer the following research question: *How can organizations systematically approach AR as a technology to support services and improve productivity while reducing the initial barriers to AR adoption and diffusion?* To answer this question, we develop a design framework for AR solutions based on qualitative and quantitative data from a case study. The framework aims to enable a comprehensive approach and helps define and analyze AR use cases to support thorough proof of concepts and outline key aspects of an initial prototypical implementation.

The remainder of the paper is structured as follows: in the second section, we lay out related work regarding AR and the adoption of innovation. In the third section, we present our mixed-method approach, including the case study and data obtained. We subsequently develop the design framework and showcase its application using a scenario from the case study. Finally, we discuss the results, draw a conclusion, and outline future research avenues.

Related Work

AR encompasses scenarios in which virtual, computer-generated objects extend or overlay reality. The components of reality are predominant and are enriched with digital content. Overall, AR can be located on a continuum ranging from the real world to a completely virtual environment. This continuum is known as the virtuality continuum (Milgram and Kishino 1994). With the help of AR, virtual objects can be blended into reality, while real objects can be removed with graphical overlays (Azuma 1997). Various hardware alternatives are available for implementing AR. These include head-mounted displays (HMDs) such as AR glasses and hand-held displays such as smartphones or tablets. Projection-based spatial AR uses projectors to superimpose reality with virtual objects (Bimber and Raskar 2006). Specific hardware requirements, particularly for HMDs, imply several challenges that must be handled. These include resolution, the brightness of the environment, brightness and contrast of the virtual overlays, the field of view, refresh rate and associated delays, as well as safety when wearing an HMD. When developing an AR solution, the system's portability and the different tracking technologies and interaction patterns should be considered (Azuma 1997).

Service design and alignment with organizations play a crucial role in service innovation. Especially with rapidly evolving technologies, it is even more important to consider these in service design and service innovation (Ostrom et al. 2015). Rapidly increasing digitalization makes it even more difficult to take advantage of new technologies. Therefore, early support is needed to understand what innovation means in an organizational context. Technochange management combines the use of IT and its organizational impact to optimize business performance (Markus 2004). It is crucial to align IT and business to achieve the most effective results. At the same time, IT innovation and change in the enterprise are mutually dependent, so new technologies cannot be deployed in isolation from the enterprise context.

Methodology

Our methodology for developing the framework follows a mixed-method approach (Venkatesh et al. 2013, 2016). To gain initial insights into the use of AR in a service context, we conducted a comprehensive case study (Yin 2009) at a large European maintenance, repair, and overhaul (MRO) service provider in the aviation sector. We investigated the inventory process in the warehouse of the in-house logistics service provider. In the given use case, the inventory process must be performed daily to record current inventory levels continuously. We chose different approaches to identify the different actors and resources involved as well as understand the value creation of the service and existing barriers to AR adoption.

First, we began with a qualitative approach, conducting observations at four different warehouses and the inventory coordination office to follow the service delivery of inventory directly in the field. We documented the observations using ethnographic field notes (Emerson et al. 2001, 2011). Because we did not intervene during the observations, we conducted additional qualitative, non-standardized interviews to gain further insights into the challenges during service delivery. We interviewed the logistics service provider employees who carry out the inventory service themselves or coordinate it and the associated IT department that maintains the logistics IT applications for a technically oriented impression. Moreover, we interviewed the healthcare management, the works council, and the coordinator responsible for the communication between the IT department and the logistics service provider. Last, we talked to the person responsible for mixed reality technologies to capture the organization's current state of AR usage. We documented the interviews using hand-written notes (Rubin and Rubin 2011).

To investigate the use of AR in a concrete example, we conducted a user study with 33 employees in which we piloted a prototypical AR application. The application assists in the inventory process by guiding wayfinding in the warehouse, overlaying important clues, and enabling the input of recorded quantities. Using questionnaires, we collected quantitative data that was further strenghtened by the think-aloud method (Van Someren et al. 1994) during the user study. Participants were asked to think aloud and verbalize everything that came to their minds during prototype use. To further enrich our findings, we conducted two workshops at the MRO service provider with seven experts from the MRO's IT department and the logistics service provider. The workshops were based on the design-thinking approach and focused on assessing the suitability of various services for the use of AR. We analyzed the documentation of the observations, interviews, workshops, and user study questionnaires and derived the requirements for environmental conditions for AR use. We consolidated similar requirements and enriched the data with insights from established ISO standards to ensure better generalizability. The results contribute significantly to the first level of the AR design framework.

To further develop the AR design framework, we built on existing prior work (Bräker et al. 2022; Bräker and Semmann 2021) and conducted two additional workshops with a panel of experts. The expert panel consisted of five experts, three from academia in the field of human-computer interaction and information systems and two from practice, more specifically from one of the leading companies for custom AR applications in the industry. The focus in the third and fourth workshops was no longer on a specific use case but dealt with the development process of AR applications as well as its challenges in general. During the third workshop, we developed an initial user journey for the service design process of an AR application with the expert group. The results of the user journey are mainly reflected in the four levels of the framework. After creating a first version of the framework, we evaluated our results from different perspectives during a second workshop with the same group of experts. We used the results to develop the final framework, which we present in the following section.

Result – Conceptualizing the Design of Augmented Reality Solutions

To make the entry and use of AR in an organizational context as effortless as possible, we have developed the framework for the design of augmented reality solutions. As shown in Figure 1, our model is built on different levels of abstraction and follows a top-down approach. This way, we ensure that organizations, especially SMEs, can create and pilot AR applications by proceeding from the general requirements of the service context to technical details. The user's AR experience and technical expertise are irrelevant when applying the framework. Both technical and domain experts are empowered with this tool to pave the way for AR adoption.

Environmental Conditions. Our case data (observations, interviews, user study, workshops 1-4) suggest that when identifying and analyzing services, several requirements are essential for a use case to benefit from AR. These requirements are also covered in international guidelines such as the ISO standards ISO/IEC 25010 and ISO 6385, which explicitly address general software quality requirements and ergonomic principles (International Organization for Standardization 2004; International Organization for Standardization/International Electrotechnical Commission 2011).

Under environmental conditions, we subsume general factors in the service environment, which can relate to the entire service process or only to individual process steps. If the service occurs under changing environmental conditions, this can be annotated at the first level. The information documented here is used to evaluate the process's general suitability for augmentation. Subsequent decisions, such as selecting suitable hardware or tracking technology, can be supported by the information collected. In the context of environmental conditions, the location of service provision should be investigated in terms of technical prerequisites, location-related aspects, and potential interferences. Particularly in an industrial context, it may be noisy or dusty environments. In other contexts, the process may be exposed to challenging weather conditions, non-optimal or changing lighting. The need to wear work clothing, such as work gloves and the size of the environment play a role in the design of the AR application. For example, a small environment, such as a single workbench, has different requirements than a larger environment, such as an entire warehouse. Further, the distinction between changing and static environments has an impact. System integration and interfaces to other information systems, as well as technical factors such as the need for a permanent network connection, should be captured. It may be documented if the process is subject to special ergonomic requirements or demands hands-free or mobile working. There are specific service domain aspects in some cases, such as healthcare hygiene requirements (Klinker et al. 2019).

We propose a checklist approach for the environmental conditions to keep things simple. The result of this level can assist in selecting hardware and interaction techniques. Although our framework can support the recommendation of different hardware options, we do not force hardware decisions. One reason for this is the rapidly evolving hardware. On the other hand, our main focus is on how the intended information is displayed in an AR application, not on the hardware used to display that content. Nevertheless, hardware requirements, such as hands-free working or weather resistance, can be derived from the framework. In addition, we support technology and platform independence so that the augmentation can be displayed on a tablet as well as on an HMD or projection-based solution. In this way, we strive for a high degree of flexibility. Hardware selection, if the needed skills are not available in the organization, can be supported by experienced consultants who are knowledgeable about the technological state-of-the-art. Questions that can be answered based on the environmental requirements include: does the AR hardware need to be head-mounted? Is it required to fit beneath a helmet? What input capabilities are required, e.g., controller input, hand tracking, eye tracking? Is a video see-through device required for clearly visible augmentations, or does the work environment necessitate a latency-free, optical see-through display? Is it necessary for the device to be able to track itself in 3D space? Although these questions are reasonable, for the sake of this paper, we do not focus on them and refer to prior work on interaction classification (Bräker et al. 2022; Hertel et al. 2021) and hardware selection options (Bräker et al. 2021).

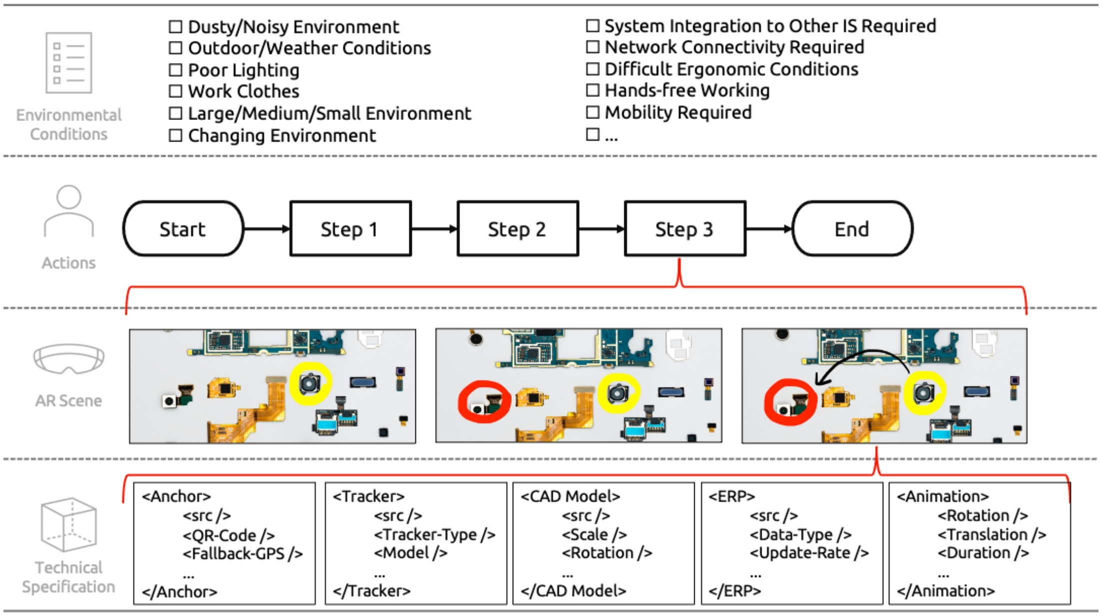


Figure 1. Design Framework for AR Solutions

Actions. At the actions level, we look at the service process and its actions. Existing process models, e.g., BPMN (Object Management Group 2011) or service blueprints (Bitner et al. 2008), can form the basis for this, but simple modeling using flowcharts can also be sufficient. One result of the analysis is to answer whether AR can be integrated into the existing process or whether it must be redesigned. In the case of established services, whether a process change provides value should be evaluated. As a recent study shows, no specific and widely acknowledged approach to business process modeling for AR exists, although the analysis of the process, in the beginning, is a success factor (Bräker and Semmann 2021). For this reason, the process modeling presented in our design framework for AR solutions should rather be seen as a placeholder. The third and fourth expert workshops confirm the importance of process understanding. Furthermore, it was examined that less complex forms of notation, such as flowcharts, should be investigated for their suitability for modeling innovations and AR specifically, as these promote accessibility, especially for SMEs (Bräker and Semmann 2021). Since most AR processes are relatively simple, sequential, and straightforward, we instantiated an example process using flowchart notation in Figure 1. In doing so, we encourage broader use in practice, as the flowchart notation is quite comprehensible. When multiple actors are involved in the service process, the framework can be applied and filled out for each process participant.

AR Scene. The design and content of the AR application are mapped on the AR scene level. The AR elements are documented, and, depending on the level of augmentation required, it is possible to specify one or more AR scenes for each process step. The data of the third and fourth workshops show that a direct annotation of photos is an accessible way for inexperienced users to visualize their idea of the AR scene. An image of the actual scene or the workplace can be used as a starting point. This way, it is easy to get a shared understanding of the goal. If an image of the scene is not available, a simple sketch is also appropriate.

The result is a storyboard that defines one or more AR scenes for each process step. For example, in Figure 1, a specific part of a construction kit to be assembled is first highlighted. Then a second part is highlighted, and an arrow indicates that both components are to be assembled. However, the augmentation should not be limited to these two functions and can, for example, include text fields, buttons, or links to documents. Interactions between the user and the AR application can also be examined in this step (Hertel et al 2021; Bräker et al 2022). Such a representation can simplify the technical implementation enormously because widely used development platforms such as Unity are also scene-based (Unity Technologies 2021), so a transfer of the information to a Unity scene can be done quickly.

Technical Specification. Technical specifications can be defined for each AR scene at the final level. They are closest to implementation and refer to the attributes of the virtual objects or augmentations. If the user is unaware of the technical parameters or does not have the required technical knowledge, they are not compulsory, although beneficial. The relevance of the technical specification was confirmed in the third and fourth expert workshops, as it is the most precise kind of information for developers and authors of AR applications. For notation, we propose an XML-based approach, such as the augmented reality markup language (ARML 2.0) (Open Geospatial Consortium 2015). However, any form of notation can be used here that fits the state-of-the-art technological approaches. Thus, current frameworks like Google's ARCore or Apple's ARKit could be embedded in this layer. Tracking information such as anchors, i.e., the localization in reality, or tracking types such as markers or object-based tracking are specified here. If CAD models are helpful for the augmentation, these can be specified here as well. However, CAD models are not always mandatory, even if the data is available. Simple augmentations are often sufficient for simple and easy prototyping, so more details are not necessarily profitable. If virtual objects such as 3D models, documents, or text fields should be integrated, the user might specify these attributes. Furthermore, the specification of animations, e.g., the duration or type of animation, can be helpful for the later development of the AR application. However, data from information systems within an organization, e.g., data from an ERP system, could also be specified. We argue to define the technical specifications per AR scene and describe all augmentations in as much detail as possible.

Subsequently, using the data collected via the framework, the implementation of the AR application can begin. Due to the many implementation possibilities, our framework focuses on the steps before implementation and aims to provide a comprehensive description of the AR application. The development can be automated by entering the content into an appropriate authoring platform, or the application is developed manually. Following the development of the application, a piloting phase can be entered, in which its usefulness is evaluated. This may yield new information that can be utilized in a future iteration of the AR application. Finally, after piloting, the advantages and disadvantages can be weighed at the management level, and if the piloting is successful, the application can be transferred into practice.

Showcasing the Design Framework for Augmented Reality Solutions

To demonstrate the framework, we apply the model to the exemplary service of stock inventory in a warehouse. The process described below occurs in the context of a large European MRO service provider in the aviation sector, more precisely at their in-house logistics service provider. A so-called permanent inventory is performed daily to record the current stock levels in the warehouse. As shown in Figure 2, the service is delivered within a large environment that underlies changes, and work clothes must be worn. In addition, an interface to the data of the warehouse management system is essential, e.g., to retrieve current inventory orders or enter the quantities of the items. Furthermore, the process is subject to special ergonomic conditions, as materials must be moved and taken out. These are especially challenging when the user needs to operate a forklift. Since some materials are counted and recorded directly at the storage location, working hands-free is advantageous. The service delivery requires mobility because the materials are distributed over the entire warehouse. The service is also subject to special safety-critical requirements, as storage locations that are sometimes difficult to access are served with a forklift truck.

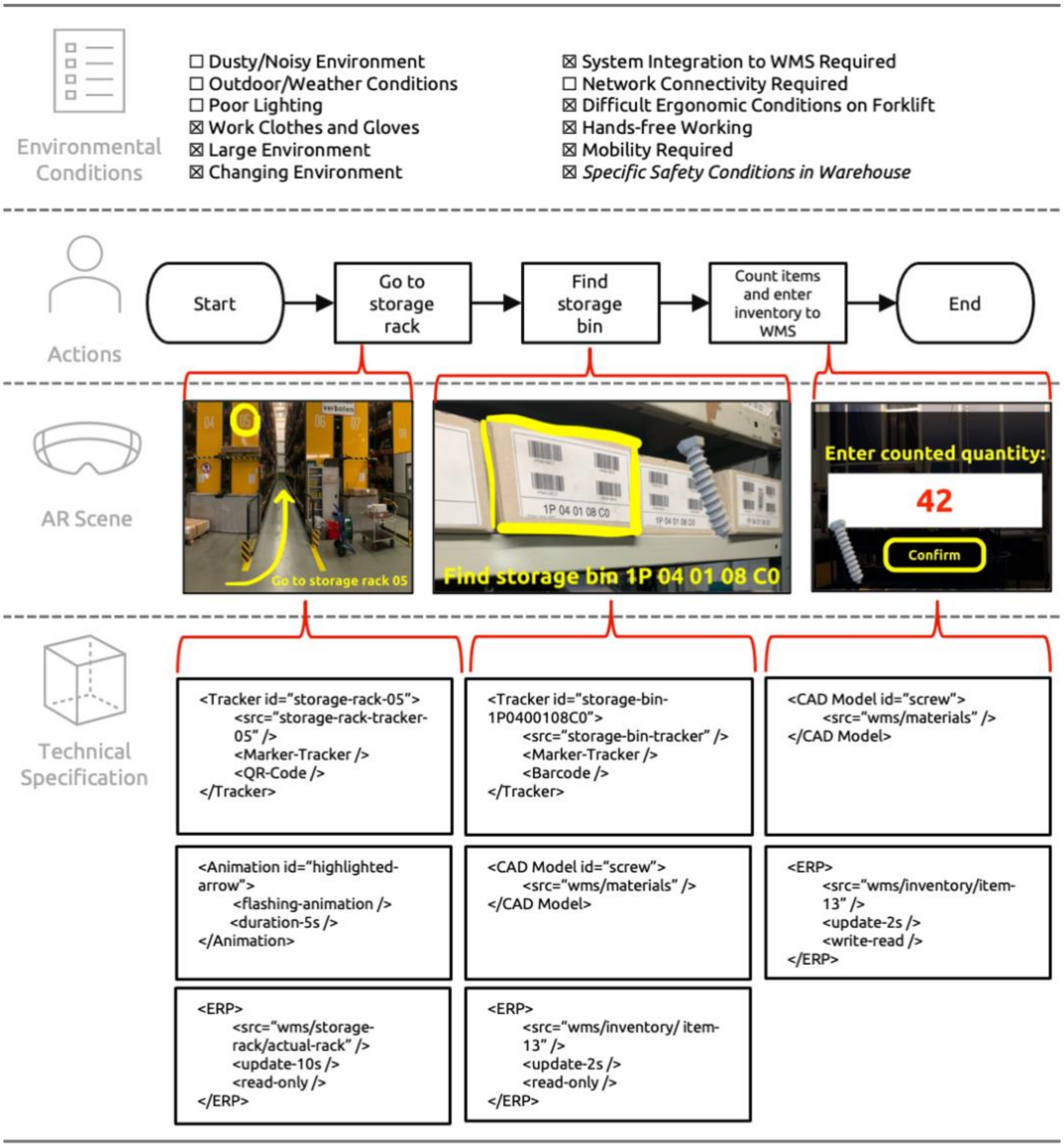
The inventory process itself is designed relatively simple. In the beginning, the user searches for the corresponding storage rack. Afterward, the user looks for the correct storage location in the storage rack where the material is located. Finally, the material must be counted, and the quantity is checked and stored in the warehouse management system (WMS). Throughout the entire process, the environmental conditions described above apply.

The next step at the AR scene level is to visualize the process augmentation. Navigation to the destination is helpful, but instructions on what to do next can support the process. In this example, the user must first go to the rack with the number five. Then the user can be navigated to this rack using an arrow, and the shelf number is highlighted. Once in the rack aisle, the task is to find the corresponding storage location. This can also be highlighted by the augmentation and supplemented by the textual display of the storage location. In addition, the material is displayed as a 3D representation in the form of a CAD file to avoid errors. Finally, the user receives an input mask to transfer the existing quantity to the WMS directly.

The last level contains the technical specifications. Here, the properties of the virtual objects can be defined for each AR scene if the information is available. For example, in the first scene, marker tracking in the form of a QR code is used to detect the storage rack. In addition, the arrow has an animation that lasts for five seconds and flashes. Furthermore, data from the WMS is needed to show the current storage rack. This data is updated every 10 seconds, and the interface only needs to be given read access to retrieve the information. In the second scene, tracking is also used, but this time through the already existing barcodes. In addition, the source of the CAD model of the material to be counted is defined. In order to display the correct storage location, access to the WMS is required, which is updated every two seconds and needs read-only access to retrieve the data. In the third and last scene, the 3D model of the screw is used again to prevent errors. Write access to the WMS is now required to enter the counted quantity and, if necessary, read access to compare the entered data.

To showcase another exemplary application of the framework, we applied it to an example from the consumer shopping sector, the IKEA Place app, released in 2017 (Ozturkcan 2021). This AR application allows customers to view IKEA furniture in their own house before purchasing and assembling it. The application of our framework to this app can be imagined as follows: Because the environment is comparatively less demanding and usually not exposed to dust, disturbing weather conditions, or workplace safety conditions, the environmental conditions are relatively simple and have minimal impact on the subsequent steps. The process and user actions are relatively straightforward. Objects can be selected and placed in the room. The user must select a piece of furniture and choose a position in the room to accomplish this. In that position, the piece of furniture should be placed in the room, aligned in the correct size. This requires a tracking mechanism that reliably recognizes the room's structure, such as the floor. Furthermore, lightweight CAD models of the furniture components are required, and synchronization of the associated data from the IKEA Shop system.

Another use case for the framework is an assembly and maintenance process in an industrial context. AR is already used successfully in these areas, but the development of customized applications still involves a great deal of effort (Mourtzis et al. 2017). To map an assembly process, the environment must be analyzed initially. For example, if it is a factory floor, the requirements for the specific case must be given. Especially during assembly, a hands-free operation is critical. If a plant is imagined to be located outdoors, the process is sensitive to weather conditions and changing lighting circumstances. If work clothes, such as work gloves, are worn, and the user has to visit various stations on an outdoor site, we have entirely different requirements than with the IKEA app. However, the process is usually relatively straightforward, with few variations and ramifications in the process. It would then be important in the augmentation that parts to be assembled or maintained are highlighted, and the user can see the steps of the instructions. In this way, the user does not have to carry extra instructions and receives all the information for the respective work step, depending on the context. This also requires tracking on the technical side, which could be object-based in this case. In addition, the associated CAD models and the work steps from the user manual are required.



☐ Dusty/Noisy Environment
☐ Outdoor/Weather Conditions
☐ Poor Lighting
☒ Work Clothes and Gloves
☒ Large Environment
☒ Changing Environment

☒ System Integration to WMS Required
☐ Network Connectivity Required
☒ Difficult Ergonomic Conditions on Forklift
☒ Hands-free Working
☒ Mobility Required
☒ *Specific Safety Conditions in Warehouse*

```
<Tracker id="storage-rack-05">
      <src="storage-rack-tracker-
      05" />
      <Marker-Tracker />
      <QR-Code />
</Tracker>
```

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<Animation id="highlighted-
arrow">
      <flashing-animation />
      <duration-5s />
</Animation>
```

```
<ERP>
      <src="wms/storage-
      rack/actual-rack" />
      <update-10s />
      <read-only />
</ERP>
```

```
<Tracker id="storage-bin-
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      <src="storage-bin-tracker" />
      <Marker-Tracker />
      <Barcode />
</Tracker>
```

```
<CAD Model id="screw">
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</CAD Model>
```

```
<ERP>
      <src="wms/inventory/ item-
      13" />
      <update-2s />
      <read-only />
</ERP>
```

```
<CAD Model id="screw">
      <src="wms/materials" />
</CAD Model>
```

```
<ERP>
      <src="wms/inventory/item-
      13" />
      <update-2s />
      <write-read />
</ERP>
```

Figure 2. Application of the Design Framework for AR Solutions for the Inventory Service at an MRO Logistics Provider

Discussion

Applying the design framework for AR solutions presents that a comprehensive overview of AR scenes helps identify the benefits of innovative solutions for services. The framework enables an incremental development of an understanding of how AR can be applied and what is needed to support services. An initial assessment of the environmental conditions allows to reflect the institutional arrangements of service and delineate critical resources. Building upon and extending the resources applied, the process behind the service is laid out as an anchor for the design of AR scenes. These scenes represent the integration of physical and digital resources to fulfill tasks in a service system. The actual implementation of the service is represented in the technical specification that defines crucial resources technically to enable a representation within the AR scene.

Based on this understanding of developing a framework for AR in services by applying the design framework for AR solutions, further specifications within the framework need to be considered. First, the interplay of actions and AR scene levels could be further elaborated. It could be beneficial to specify the types of interaction users take in an AR scene. As the purpose of the framework is to provide an accessible tool as a starting point for the application of AR that should enable end-users to assess their services regarding the applicability of AR, we did not add individual interactions in the framework. Such specification would require a perspective with expertise in AR to define what interaction would fit the purpose within the AR scene. In the same regard, a professional assessment is needed to evaluate if representations and interactions in an AR scene are needed and beneficial for service delivery. Representing too much information in an AR scene could lead to information overload, as Yang et al. (2003) described for the internet. A solution could be to guide inexperienced users with examples and interaction patterns typically applied in AR scenes. This could lead to an increase in the maturity of the AR scene descriptions that build the foundation of prototypical implementations of the service with AR.

Another aspect to consider is interactions with trackable objects. Such interactions increase the complexity of AR scenes as CAD data need to be integrated and manipulations on the objects are performed. Maintenance and repair services (Metzger et al. 2018) or remote services (Aleksy et al. 2014; Mourtzis et al. 2017) are typical examples. Such services can be represented within the framework but rather as a rough estimate than a full-fleshed conceptualization. In addition, specific templates for reoccurring tasks could be integrated into the framework. These tasks could include, for example, the search and discovery of specific objects and points of interest. However, data input or tasks like communication and collaboration can be prefilled exemplarily. So far, there is no standard for typical AR tasks in the literature, so future research should aim for a classification.

Finally, there are limitations to our approach. First and foremost, an application and evaluation in practice are needed to refine the framework further and validate its usability by domain experts with limited AR experience. Additionally, it would be beneficial to gain a deeper understanding of the actual influence of AR on value creation and the perception of the service by customers and service providers.

Conclusion

Based on a guiding case study, we aimed to reduce the barriers to utilizing AR for improved services, especially for SMEs. Therefore, we propose the design framework for AR solutions that enables actors with limited experience in AR to establish a proof of concept and follow a pilot AR implementation. This is enabled by dividing the complexity of AR applications into smaller sections that can be tackled step by step. Following the levels of the framework, services are assessed comprehensively at multiple levels and potentially by multiple actors with ideally a diverse set of backgrounds and expertise. By doing so, key information is gathered about institutional arrangements, the working environment, and core resources. By laying out the resource integration within the AR scenes, relevant information for a later implementation is given by simultaneously providing a better understanding of the AR-based solution.

The lightweight approach reduces the barriers for organizations to explore use cases for AR and guides this process aiming to design an initial proof of concept that easily can be extended towards prototypes and, in the long run, to productive AR solutions for services. From a research perspective, our framework bridges the gap between more process-oriented IS research to more interaction and AR scene-driven research in the area of human-computer interaction.

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