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RESEARCH PAPER

Engineering of Augmented Reality-Based Information Systems

Design and Implementation for Intralogistics Services

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Abstract The development of augmented reality glasses is still ongoing and faces barriers in diffusion and concerns about their impact on users, organizations and society. The study aims to find sufficient solutions for this struggling digital innovation and to provide guidance for the implementation of augmented reality glasses in design-oriented projects. During a 3-year consortium research, acceptance and privacy have been identified as major phenomena that influence the adoption of augmented reality glasses in the logistics domain. To forge ahead digital innovation research, the focus of the presented research lies on the diffusion of this technology with design knowledge for the development of augmented reality glasses-based systems. Evidence and artifacts contribute to the still limited knowledge of system design based on augmented reality glasses from a domain-specific instantiation and an implementation framework.

Keywords Augmented reality · Design framework · Digital innovation · Design science research · Acceptance · Privacy · Intralogistics services · Consortium research · Mobile information systems engineering

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1 A Struggling Digital Innovation

Today, multiple new innovation waves are approaching global markets (Fichman et al. 2014). Augmented reality (AR), described as an innovative technology (Hein and Rauschnabel 2016), or technical (Koelle et al. 2017) and technological innovation (Herterich et al. 2015), is one of them. New products enabled by digitization are described as digital innovations (Yoo et al. 2010a). This concept is not limited to hardware and can manifest itself in three different layers, (1) products, (2) processes, or (3) business models (Fichman et al. 2014). Innovative technologies such as AR glasses can appear as a digital innovation in all three layers. These (1) products are equipped with sensors to collect environmental data and display functions to visualize information in the user's field of vision (Niemöller et al. 2016). But the hardware is still under development and only few applications are available. (2) Data can be processed by the device to enable context-adaptive functions and restructure established business processes. New workflows and the intelligent functionalities of the systems enable innovative (3) service models for AR glasses and industries. AR glasses are a digital innovation as their status and the evolving usage scenarios are new to users and the market. The development of corresponding products, services and business models is still ongoing and faces barriers concerning adoption and concerns about the device's impact on users, organizations and society. For example, due to missing market support, Intel had to shut down the development of its AR glasses product "Vaunt" in April 2018 (Bohn 2018). On the positive side, AR glasses offer the potential to improve knowledge intensive and bimanual tasks (Niemöller et al. 2016). Furthermore, Herterich et al. (2015) called for further research related to the support of service processes with wearable technology, such as augmented reality. Augmented reality is also well suited for process guidance systems and therefore a valuable mobile information system for the logistics service domain (Rauschnabel and Ro 2016). As staff turnover rates are high and employees must carry out activities with a high information demand and the use of both hands, logistics is an ideal application domain for AR-based information systems. Not only do logistics possess a huge amount of recurrent activities, they also are highly interconnected with the manufacturing and commerce domain. As a result, the logistics domain is the 5th biggest industry sector in Germany (Statistisches Bundesamt 2017), generating a total revenue of 263 billion Euro in 2017 (Fraunhofer 2018). Due to their central position and proximity to the end-customer, logistics have a strong influence on connected domains. The so-called value-added-services (VAS), describing activities and tasks the logistics service provider takes over from manufacturers or other parties of the supply chain (e.g., assembling of products, assembling and filling of merchandise displays, or management of returns and quality control), have become valid products for the logistics domain (Soinio et al. 2012).

The discovery of head-mounted displays goes back to the late 1960s (Sutherland 1968). The Google Glass started a new era in AR technology as the first popular and broadly available mobile head-mounted display that augmented the user's reality with the provision of unobtrusive information. When first introduced in 2012, the Google Glass faced manifold adoption barriers. Two such barriers were a lack of useful usage scenarios, and a poor predisposition in public. Due to societal concerns, specifically of involuntarily being photographed or filmed by Google Glass users, the overall impression and connotation of the Google Glass quickly turned negative in terms of acceptance and privacy issues (Koelle et al. 2015). As a consequence, Google withdrew their product from the market in 2015 (Google Inc. 2015a). A revised version of the product was then presented exclusively to the B2B market under high restrictions in 2017. So the lesson learned from this incident was to focus on technology acceptance as a key aspect for the adoption of disruptive products. To cross the chasm into mass market, acceptance must be integrated into the design phase of innovative solutions (Kim 2015). To achieve this, research toward a sufficient design theory for AR glasses-based systems is inevitable. Due to the novelty of AR glasses, only a few experts and real-life implementations to build upon exist (Niemöller et al. 2017a). As we aim to structure the problem space of successful AR glasses implementation and derive respective design solutions, we apply an explorative approach with a cyclical attempt to generate satisficing solutions. AR glasses-based systems have a high potential to support service delivery in industries (Elder and Vakaloudis 2015) such as logistics services (Niemöller et al. 2017b), health care (Klinker et al. 2017) and technical customer service (Niemöller et al. 2017a). However, the available solutions lack maturity and prescriptive knowledge about AR glasses-based system design is scarce (Hobert and Schumann 2017). Due to the missing experience, the implementation of these systems is associated with high risks.

We contribute to the knowledge base with a framework for the design and implementation of AR glasses-based information systems (IS). Novel and validated artifacts are integrated into the design framework. We build on relevant theories of IS design (Hevner et al. 2004; Österle et al. 2011) and AR system design (Metzger et al. 2016), as well as including problem domain perspectives. The research is embedded in a consortium research project that investigates the comprehensive support of intralogistics services with an AR glasses-based information system. The intralogistics domain encompasses the flow of physical goods along the entire supply network (Lars Nagel and Moritz Roidl 2004) and therefore is responsible for handling, storing, picking and supporting services such as packaging. So far, as an increasing factor along with the overall digitalization, the flow of information is managed analogously to physical goods. As a collaborative endeavor, our research is informed by practice and science. Two cases of logistics service providers give practical input. Applying a design science research (DSR) approach, we address impediments in the adoption of AR glasses and include respective measures and solutions in a design-oriented project. The initial problem is to identify these impacts and implement a corresponding system successfully and sustainably. Our research aims to address this unresolved issue in four research questions, stated in Table 1. Following the line of argumentation by Baskerville and Pries-Heje (2014), we focus on the projectability of our solutions, rather than the generalization of our artifacts, to provide descriptive design knowledge about systems based on AR glasses and implementation guidelines.

To answer the research questions, the paper is structured as follows: First, we give an overview of the theoretical background of AR glasses as a digital innovation and their usage in logistics services in Sect. 2. In Sect. 3, we describe the methodological approach we applied in the

Table 1 Research questions

RQ 1	What are beneficial use cases for AR glasses in intralogistics services?
RQ 2	How can AR glasses-based information systems for intralogistics services be implemented?
2.1	Which requirements exist for the AR glasses-based system?
2.2	How should the AR glasses-based system be designed?
RQ 3	How can adoption and diffusion of AR glasses-based systems be supported?
RQ 4	Which general implications result from the implementation of AR glasses-based information systems?

course of our research. The resulting artifacts are presented in Sect. 4 as an instantiation of AR glasses-based systems in intralogistics services. Initially, we derived use cases (UC) for AR glasses in intralogistics services (cf. Sect. 4.1) and analyzed stakeholders' requirements (cf. Sect. 4.2). The design knowledge of the successively designed and developed prototypes are explicated in design principles. To outline our method approach and path of knowledge, we describe the design process (cf. Sect. 4.3) and instantiation of two exemplary prototypes (cf. Sect. 4.4) from our research project. In the design process we integrate influencing factors of AR glasses-based systems' diffusion and impact (cf. Sect. 4.5). We outline the findings of the formative evaluation, which is a major input into the design and implementation process (cf. Sect. 4.6). To inform the knowledge base of AR glasses-based systems design, we postulate a design framework for following projects that is based on our experiences in Sect. 5. The design solutions and their limitations are discussed in Sect. 6. In Sect. 7, we summarize the main findings and give an outlook on future research issues.

2 Augmented Reality Glasses as Digital Innovation

Technical innovation (Schumpeter 1934) and digital innovation (Yoo et al. 2010a) are defined as the new combination of already existing technical, respectively digital, and physical product parts to a new consumer product. Fichman et al. (2014) describe digital innovation as a "fundamental and powerful concept" to transform organizations to digital and innovative market leaders and conceptualizes it in four key stages: *discovery*, *development*, *diffusion* and *impact* (Fichman et al. 2014). The thorough assessment of these four stages is essential for a sustainable implementation of digital innovations, as only after all stages have been completed the innovation itself can be understood in terms of expectations and actual needs by users and markets.

After the last prominent examples of disruptive technologies (e.g., ERP-systems or the Internet), the next waves of technical innovations are currently approaching the markets (Fichman et al. 2014). In combination with the maturation of connected products and services, trends such as smart devices are about to shake up traditional industries (Porter and Heppelmann 2014; Ives et al. 2016). Promising wearable devices are AR-products. With these devices, digital innovations are offered to consumers in B2C-markets, primarily in the gaming industry, and to business customers in B2B-markets, e.g., in production and logistics, to optimize their work processes. AR as a concept is described by the addition/superposition of information or other visual elements directly to the field of vision, while the user is still able to perceive the "actual" reality. AR glasses integrate this technology into head-mounted objects such as spectacles. When looking through AR glasses, the digital objects coexist with the real world and the user is able to interact with virtual elements in real-time. Moreover, a virtual object can be fixed in a defined position of the user's field of vision by using surface detection (Azuma 1997; Ma et al. 2011; Mehler-Bicher and Steiger 2011). We refer to an AR glasses-based system as the integration of AR device hardware, the application software, the interaction with the user, and the architecture of the system for integration into an existing environment.

AR glasses are struggling simultaneously in three of the digital innovation concept stages, published by Fichman et al. (2014). The hardware is still under ongoing development and has often not reached market readiness [cf. Google glasses 1, (Google Inc. 2015a); Intel Vaunt, (Bohn 2018)]. Beneficial use cases for the diffusion of the products are still scarce and the impact of this innovative technology is criticized for acceptance problems and privacy invasion (Koelle et al. 2015; Rauschnabel and Ro 2016; Metzger et al. 2017). This lack of usability is further curbing the digital product and service innovation (Nylén and Holmström 2015; Berkemeier et al. 2017b). Therefore, the successful implementation and diffusion of AR glasses as a digital innovation requires an interdisciplinary and dynamic approach that engages design and implementation knowledge.

Although AR glasses as a hardware platform are struggling to enter the market, their introduction reveals great potential for developing new and innovative work

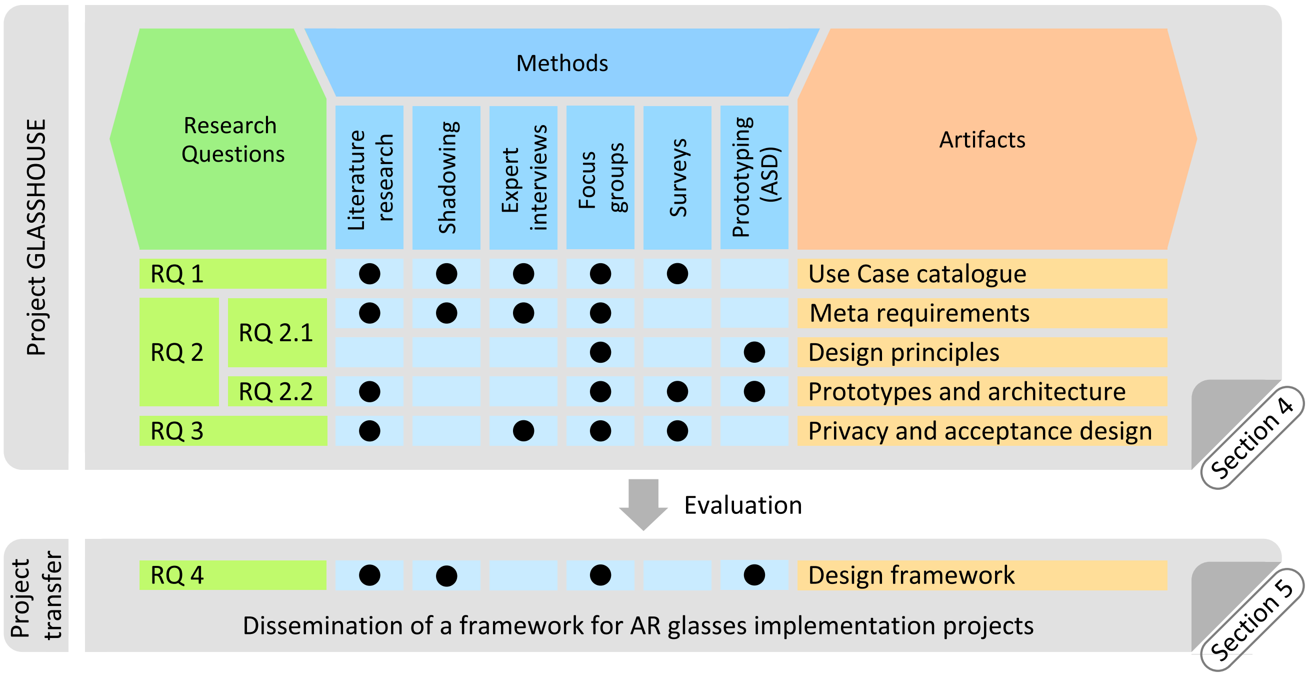

Fig. 1 Design-oriented research approach

UC	Description	UC	Description	UC	Description	UC	Description
01	Monitoring/Process capturing	10	Support streaming [A]	19	Automated monitoring of advertisment displays	28	Show precess related warnings and security notices
02	Show monitoring analysis	11	Guide working steps via remote control (Internal support)	20	Automated control of object state	29	Capture location [A]
03	Show reward symbols	12	Guide working steps via remote control (External support)	21	Automated control of hazardous goods	30	Find object
04	Prioritize employees by process metrics	13	Support video communication with customers (VAS)	22	Identify objects [A]	31	Show information for stacking
05	Show current workload	14	Document process execution	23	Scan barcodes and QR-codes [A]	32	Measure and document objects
06	Translate notifications and text	15	Document damages	24	Show object information	33	Show optimal storage area
07	Show operating instructions [A]	16	Recognize and show input errors	25	Navigation instructions (static)	34	Show and control packing list
08	Support learning phase with instructions	17	Support automated control functions [A]	26	Real-time traffic information (dynamic)	35	Show loading optimization
09	Show inspection plan (Value Added Services)	18	Automated control of consignment	27	Show object related warnings and security notices	36	Automated inventory gathering

Fig. 2 List of 36 use cases for AR glasses in intralogistics services

processes and services. Until now, this technology has only been investigated experimentally with regard to individual scenarios (Ernst et al. 2016; Hein and Rauschnabel 2016; Rauschnabel and Ro 2016). A systematic literature research has shown that the logistics domain has multiple promising use cases for AR glasses-based systems, but the deployment is still mainly limited to discussions in practice-oriented specialist magazines (Niemöller et al. 2015).

With the ongoing development of AR glasses as a hardware platform, and the options to interconnect that standardized operating systems possess, new digital innovations have reached the market. The automotive company Volkswagen is testing AR glasses for human–system communication in the production environment (Volkswagen 2015). The automotive supplier Schnellecke has implemented first prototypes for multi-order picking tasks (Ubimax GmbH 2015). Syncreon, one of the first companies to deploy AR glasses in the logistics domain, has increased the overall picking performance and reduced the rate of errors (Ubimax GmbH 2017).

3 Research Strategy

3.1 Research Approach

AR glasses have the potential to improve service delivery (Metzger et al. 2016), but knowledge about system development and adoption, as well as about their impact on users, organizations and society as whole is scarce. A direct consequence of the lack of sustainable implementations of AR glasses is the absence of design theories. This research gap can be bridged through the collaboration of science and practice. To develop a domain-specific solution for intralogistics services, we have designed and developed an AR glasses-based system in a consortium research project with two logistics services providers. The first global contract logistics company selected (case A) offers a broad spectrum of applications in the field of storage and transport concepts. These range from sea and air freight to delivery by train and truck with more than 20 million shipments per year. The second company is a medium-sized logistics service provider (case B) for the field of fashion that is an expert in picking and value-added services. We follow a design oriented research paradigm (Österle et al. 2011) in order to integrate input from the problem domain and to assure strong practical relevance of our results. We have applied a DSR theory that supports an iterative approach to ensure relevance and rigor (Hevner et al. 2004). Figure 1 shows an overview of the methods applied and the corresponding artifacts that can be seen as our research output. To ensure a comprehensive understanding of our research approach, we assigned the research questions to methods and artifacts. Section 3.2 provides a more detailed overview of the research methods applied.

In a first step, we wanted to collect information about designing an AR glasses-based system from the field of intralogistics services. We initially analyzed current business processes with the two logistics service providers mentioned above and identified 36 suitable use cases for AR glasses that could be employed to address research question 1. To answer research question 2, these use cases were individually designed and implemented in iterative and reciprocal design cycles. Each use case shares the same modular architecture and is integrated into a comprehensive system for the support of intralogistics service processes. In our initial analysis, we applied five different research methods. In order to complete our findings, the analysis of the research questions and the artifacts generated were based on several research methods. The various research methods were applied multiple times in the course of our research. The actual production of our concepts and models as prototypes served as a further method of evaluation (Sonnenberg and vom Brocke 2012). During the design and development of the system, we faced issues that had an impact on the design of the solution, such as privacy and acceptance, and that could impede the adoption and diffusion of AR glasses. Therefore, we included respective measures from the beginning in our system design (research question 3). The design knowledge gained from each iterative development cycle was externalized in the design principles (cf. Sect. 4.2) and solution elements (cf. Sect. 4.3 and Appendix I, available online via http://www.springerlink.com) for AR glasses-based systems.

In a second step, we came up with a design framework for our AR glasses-based system design as a nascent design theory (Vaishnavi and Kuechler 2015). The results and insights gained during the research and design of the system entered into the design framework that addresses research question 4. As we examined each use case, we were able to collect knowledge for the design of AR glasses-based systems and improved our design framework with every new cycle. The following section describes the methods applied in this approach.

3.2 Applied Research Methods

3.2.1 Literature Research

The problem space was structured by way of systematic literature reviews (Webster and Watson 2002; Fettke 2006). The selected publications were analyzed to identify design knowledge and existing solution components for the design and development of our systems. We conducted two systematic literature reviews (cf. Appendix A): the first review was used in the initial phase of the project in order to understand the research community (Vaishnavi and Kuechler 2015) and identify practicable use cases. The second literature review focused on the acceptance and use of technology in order to prevent the system from being rejected by our target users. We calibrated our findings with the help of supporting literature from the DSR and Service Systems research community throughout our research.

3.2.2 Shadowing

If detailed information about processes in logistics services was required, we used shadowing (Myers 2009) to document and analyze state-of-the-art business processes and work places. Researchers were present as neutral observers to document the processes and actions in intralogistics services, without interfering with workers. The current state of such processes was documented during the exploration of research questions 1 and 2. The resulting process models formed the basis for discussions in focus groups and the foundation for the deduction of information needs and workflows in the requirements engineering.

3.2.3 Expert Interviews

We expanded our findings from literature with insights from expert interviews (Myers and Newman 2007). Aiming at a narrative-generating interview, the guideline was semi-structured to include follow-up questions (cf. Appendix B). We conducted two interviews with domain experts to complete the use case catalogue and elicit requirements from them. Later, another expert interview was conducted to include the user's point of view on the acceptance-based solution components.

3.2.4 Focus Groups

We discussed our findings and the iterations of our artifacts in focus groups (Misoch 2015) with the research consortium and associated researchers (cf. Appendix C). In these groups, we presented insights and artifacts resulting from the other methods. In doing so, we discussed, evaluated and extended our findings. We discussed and enhanced the results from the other methods in the focus groups in order to integrate the researchers' and practitioners' point of view into the artifact design. Throughout our project, focus groups calibrated, evaluated and provided knowledge for the analysis of our research questions. In order to provide a technical evaluation, one focus group differed from the open discussion (cf. Appendix D). Based on the results, we prioritize the 36 use cases for design and implementation (research question 2).

3.2.5 Surveys

We used online questionnaires to collect standardized data and assess our findings (Oates 2006). While exploring research question 1 (cf. Sect. 4.1), we validated and completed the use case catalogue by means of an online survey. Yet another survey was conducted during the instantiation of use case 15, in order to evaluate the acceptance and usability of the product at an early stage of development (cf. Appendix E). The results from these surveys provided us with feedback for the ongoing system development and gave us new insights into impediments in the design and implementation process.

3.2.6 Prototyping

To design and develop the AR glasses-based system, we applied the concept of agile software development for prototyping (Paetsch et al. 2003). Prototyping was a major source of knowledge for answering research question 3 (cf. Sects. 4.3. 4.4). Characteristic for this iterative approach is the early involvement of users, which was realized through a formative evaluation (Venable et al. 2016), described in Sect. 4.6. The assessment was conducted as soon as a prototype was both presentable and usable, resulting in an enhanced version of the application by directly incorporating user feedback and the assessment results.

3.2.7 Analogical Transfer

Analogical thinking describes the transfer of problem solving knowledge from one domain or industry to another (Kalogerakis et al. 2010). Yoo et al. (2010b) recommend the conduction of multidisciplinary research and the transfer of knowledge between analogical contexts. Hence, we discussed our findings in multidisciplinary focus groups with associated researchers and independently compared our design solutions and artifacts. To complement our research and transfer our findings to other industries, we exchanged knowledge with teams working on similar research projects. These projects provided us with cross-industry insights into the development of AR glasses-based systems for technical customer service (Metzger et al. 2017, 2018) and health care (Klinker et al. 2017) on the one hand. On the other hand, results from mobile process guidance systems for technical customer services (Matijacic et al. 2013) provided cross-technology insights. This helped us design useful artifacts that are not necessarily limited to a use in logistics services and can be of benefit to future AR glasses-based projects. A detailed overview of the insights that were transferred to our project or vice versa is provided in Appendix F.

4 How to Implement AR Glasses: Evidence from the Design and Development in Intralogistics Services

4.1 Defining Suitable Use Cases

Initially, we faced restraints to identify beneficial application scenarios for AR glasses (RQ1), besides pick-by-vision as an already known field of use. To push the innovation, we analyzed existing knowledge, explored the technical possibilities and examined business processes to determine potential processes to be supported with AR glasses (cf. Appendix G). Processes are possible application scenarios, if (1) users need to keep their hands free during information-intensive tasks, and if (2) processes require context-sensitive information to guide the user through work steps (Metzger et al. 2016). The identified application scenarios were transformed into use cases for AR glasses in logistics services to support an agile software development. We derived a catalogue of 36 use cases to determine the system's scope as stated in Fig. 2. When we described the use cases, communication problems between

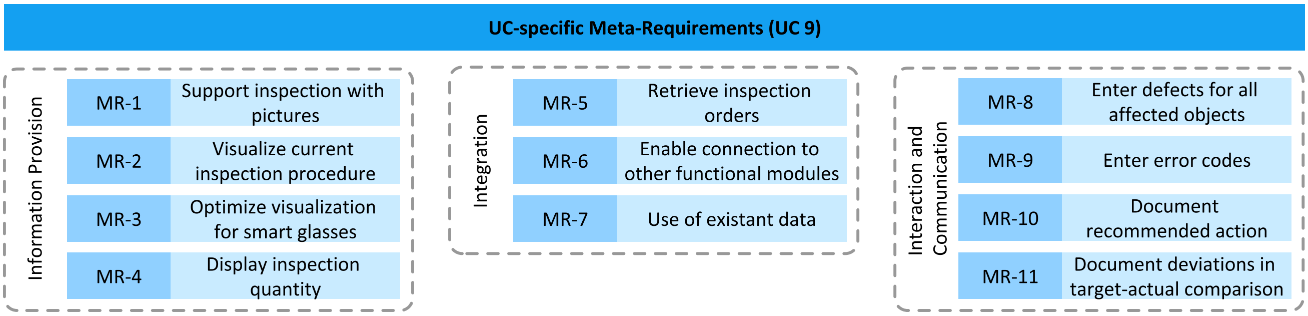

Fig. 3 Use case-specific meta-requirements for UC 9: process guidance

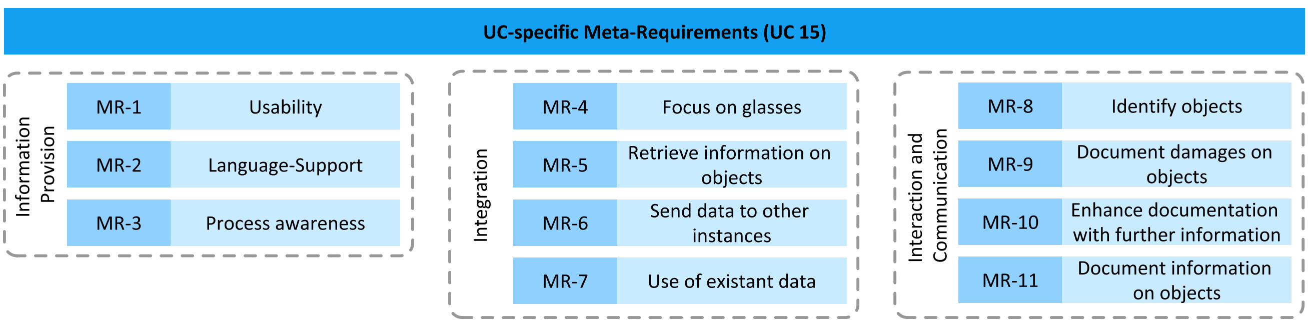

Fig. 4 Use case-specific meta-requirements for UC 15: damage documentation

domain and technical experts arose. The domain experts presented task-based use cases, which make up the majority of the catalogue. The technical experts derived less complex use cases that pointed towards microservices (cf. Sect. 4.3). The latter were integrated into the use case catalogue as assisting (A) use cases. To examine the implementation of AR glasses-based systems in logistics services (RQ 2), we designed and instantiated the use cases one after the other. In the following requirements analysis (cf. Sect. 4.1) the use case catalogue was a beneficial base for communication between domain and technical experts as well as between the scientific and the practical perspective.

Therefore, the project consortium prioritized the use cases according to their technical feasibility (cf. Appendix D) and usefulness (cf. Appendix E). In consultation with domain experts, we chose two use cases from this catalogue for first instantiations: *a general process guidance* (*UC9*) and a tool for *the documentation of damages on incoming containers or goods* (*UC15*). Both are characterized by being highly useful and technically feasible.

4.2 Requirements for System Design

Use cases capture the stakeholder's requirements (Jacobson et al. 2011), which refine them in respect to the technical implementation. One challenge during requirement engineering was to design a system that does not solely present a specific solution for a single company. We gathered and progressed the design requirements for the two representative use cases in multiple steps. At first, we deducted requirements from the processes currently in use at the two companies, which we aimed to enhance and support through AR glasses. Afterwards, a target process was defined and the set of requirements adjusted. We enhanced the use case-specific requirements by means of literature, expert interviews with process experts, and focus groups with the project consortium (cf. Appendix C). In a focus group with representative domain experts from both companies and scientists from the field of IS and logistics services, we aggregated the design requirements to generalized meta-requirements in order to address more than one company or a specific workflow. The process guidance prototype was developed on the base of 11 use case-specific meta-requirements, postulated in Fig. 3. We clustered them following the functionalities of AR glasses in the categories *information provision*, *system integration*, and *interaction and communication* (Niemöller et al. 2016).

In order to create a system that documents damages to incoming containers or goods (UC15), we were able to collect 21 specific requirements. Since these were too

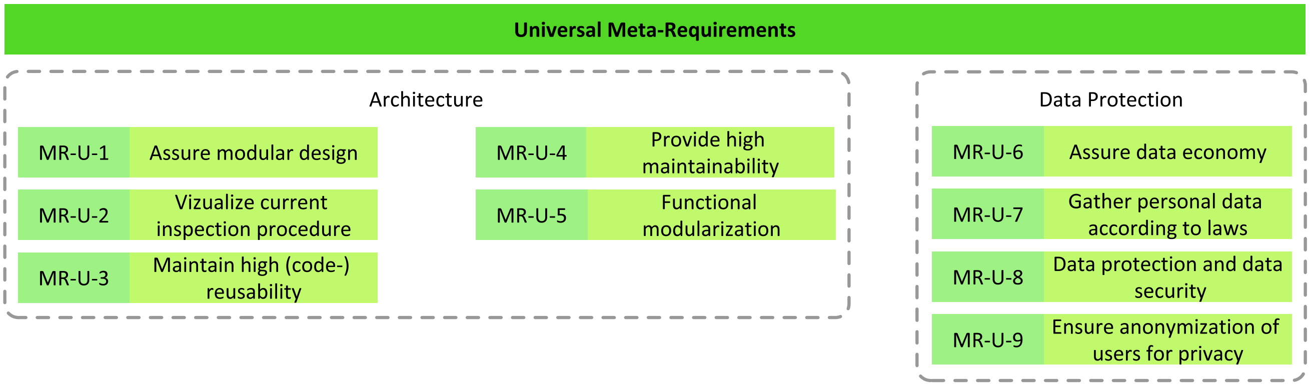

Fig. 5 Universal meta-requirements

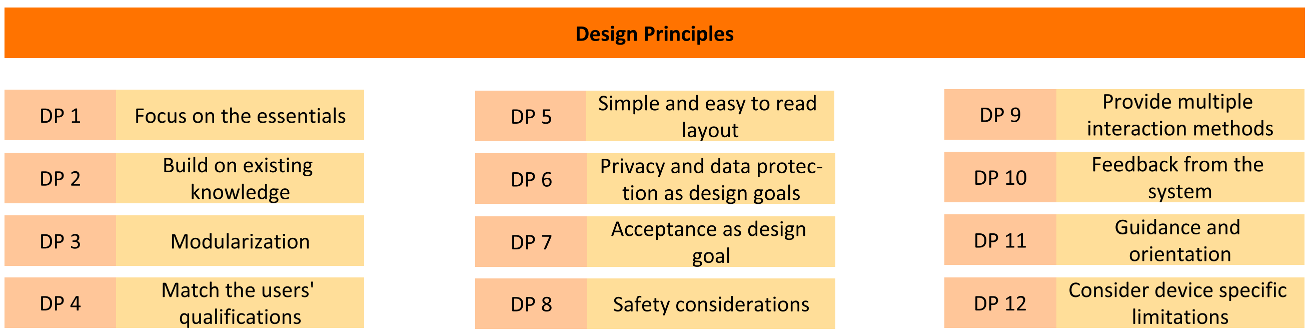

Fig. 6 Design principles for the design of AR glasses-based systems

process-specific and contained a strong business perspective, we again derived 11 use case-specific meta-requirements for implementation (cf. Fig. 4).

In addition to the requirements engineering conducted with specific use cases in mind, many aspects of generic character appeared throughout the course of research. We were able to deduct nine meta-requirements that are not task-related in order to address all use cases. As stated in Fig. 5, these meta-requirements are grouped as either *architecture* or *data protection* with respect to privacy compliance (cf. Sect. 4.5).

4.3 Software Design and Architecture

The software design and architecture was informed by the experience from the AR glasses implementation project in technical customer service (Metzger et al. 2018), which is similar to our project in terms of choice of technology and development approach. The transfer of valuable experience regarding the multiple method approach in requirements engineering and the actual design of the application in terms of UI and navigation built a starting point for our course of action. The actual design of the support system for intralogistics services is based on the meta-requirements derived in collaboration with the domain experts (cf. Sect. 4.2) the design knowledge was calibrated and reinforced by the reuse in the design and development of the different prototypes (cf. Sect. 4.4 for the instantiation in intralogistics service). We explicated the implicit design knowledge from the development of the prototypes as we transformed the lessons learned and best practices into a first set of design principles. These 12 principles are proposed in Fig. 6 and provide general guidance for the design and implementation of AR glasses-based systems. The following descriptions of the design, development and instantiation include the foundation and explanation of this knowledge.

One of the most critical aspects of enterprise application development is the evaluation and choice of the underlying technical architecture. In order to apply requirements such as a high reusability of source code, good maintainability and modular design, we conducted different focus groups with the choice of a technical architecture in mind. Guiding the implementation process, we decided on the development of microservices, which increases reusability supporting the implementation of further use cases. The technical architecture is based on two main parts, the frontend and the backend. The user, i.e., the employee working with the support of the AR glasses, only has access to the frontend client system. AR glasses are used to depict information or retrieve input from the user. To tackle privacy concerns as well as the General Data Protection Regulation (GDPR), a privacy gate ensures that a user can only use the software and hardware components required to fulfill the assigned tasks, leaving all other functionality deactivated (e.g., the glasses' camera or voice recognition). Through a desktop-based modeling system, the user can change the current or add a new process without needing programming expertise. Thus, the system can be dynamically adapted to changing external effects without having to hire a developer or technical expert. If process models for the implementation of workflows on the glasses already exist, they can easily be transferred into the system as content to be displayed on the device. Additionally, the achieved reusability of processes supports the system's sustainability. Both the glasses and the modeling system are connected to the project system, including the main processing modules of the application. With a backend API, different backend services can be used and accessed. If needed, the system can establish an internet connection via the external communication service, e.g., for external or proprietary modules such as voice control. Additionally, the system contains an authentication system, integrated by an authentication service, securing the use by valid users via input and output measures. Authentication can be conducted via unique barcodes, passwords, and other means. All data is stored in system-specific databases. The core system is planned to be hosted in a cloud infrastructure. Thus, the system's modules and functions can be reached by mobile devices independent of their position, as long as network connectivity is established. In most cases, information, inquiries or other types of data have to either be retrieved or uploaded from and into the client system (typically the leading warehouse management system of the user's company). This backend of the client is accessible through the core system, making use of the microservices architecture. Our architecture can be seen in Fig. 7.

In applying this architecture, we opt for creating a pleasant user experience by respecting six design rules and best practices that we generated from experiences as well as by means of focus groups with development experts. Our design considers (A1) privacy compliance, (A2) economic use of memory, (A3) adoption of existing knowledge, (A4) adaptability for the usage context, (A5) modular customizability, and (A6) scalability. To implement (A1) privacy as a design goal, we conceptualized our architecture in compliance with the GDPR. We achieved this specifically through integrating a privacy filter between the backend, with access to all subsequent systems and databases, and the user, respectively the AR glasses. By doing this, we opt for both privacy by design and privacy by default, as well as for a transparent data collection, mitigating concerns for privacy issues or legal risks (Berkemeier et al. 2017a, b). A user is provided only with the functionality (e.g., camera access) that is needed to fulfill the assigned tasks. This gate allows us to deactivate the display or specific functions in order to reduce distraction caused by the glasses, e.g., while a user is walking from one workplace to another. With fewer distractions, accident probability can be decreased, thus tackling safety concerns.

Moreover, as AR glasses only have very limited memory capacities, another focus lies on the (A2) economic and efficient use of limited hardware resources. Through our instantiation, we improved the hardware requirements of the systems we developed by scaling down all images that were used and by trying to avoid unnecessary elements and activities. These steps helped to achieve more efficient RAM usage and a longer battery life. Nevertheless, depending on the use case, a different balance between data plan usage (e.g., by not saving anything locally and hence being dependent of mobile data coverage) and memory utilization (e.g., through syncing only once to keep a database-image on local memory, increasing connection safety but needing more memory and a more complex syncing algorithm) may prove to be most suitable. Community work and a fast pace are characteristics of today's agile software development. Hence, every development project should (A3) try to benefit from the very active community and standard solutions. This is specifically true for mobile or web development, as a variety of different frameworks and libraries have been established in recent years. By carefully choosing a development framework and applying standard solutions from the domains of mobile app and web development, systems can be instantiated faster and more efficiently. This also holds true regarding endeavors to (A4) adapt the solution for its usage context, both in terms of the system itself, and its development process and architecture.

Through the (A5) modular design of the system, the development process ensures safety from risks of being "overengineered", instead of creating a sufficient solution. By opting for a high degree of code reusability and a clear definition of system components, development overheads can be eliminated. Furthermore, system use will become faster and more privacy-compliant by deactivating unnecessary modules when in use. In addition, the (A6) scalability of a solution must be guaranteed nowadays. This ensures the system's ability to be maintainable and expandable in order to meet a potentially increasing demand, and to keep pace with further technical evolutions. Hence, it will be possible to maintain and expand the

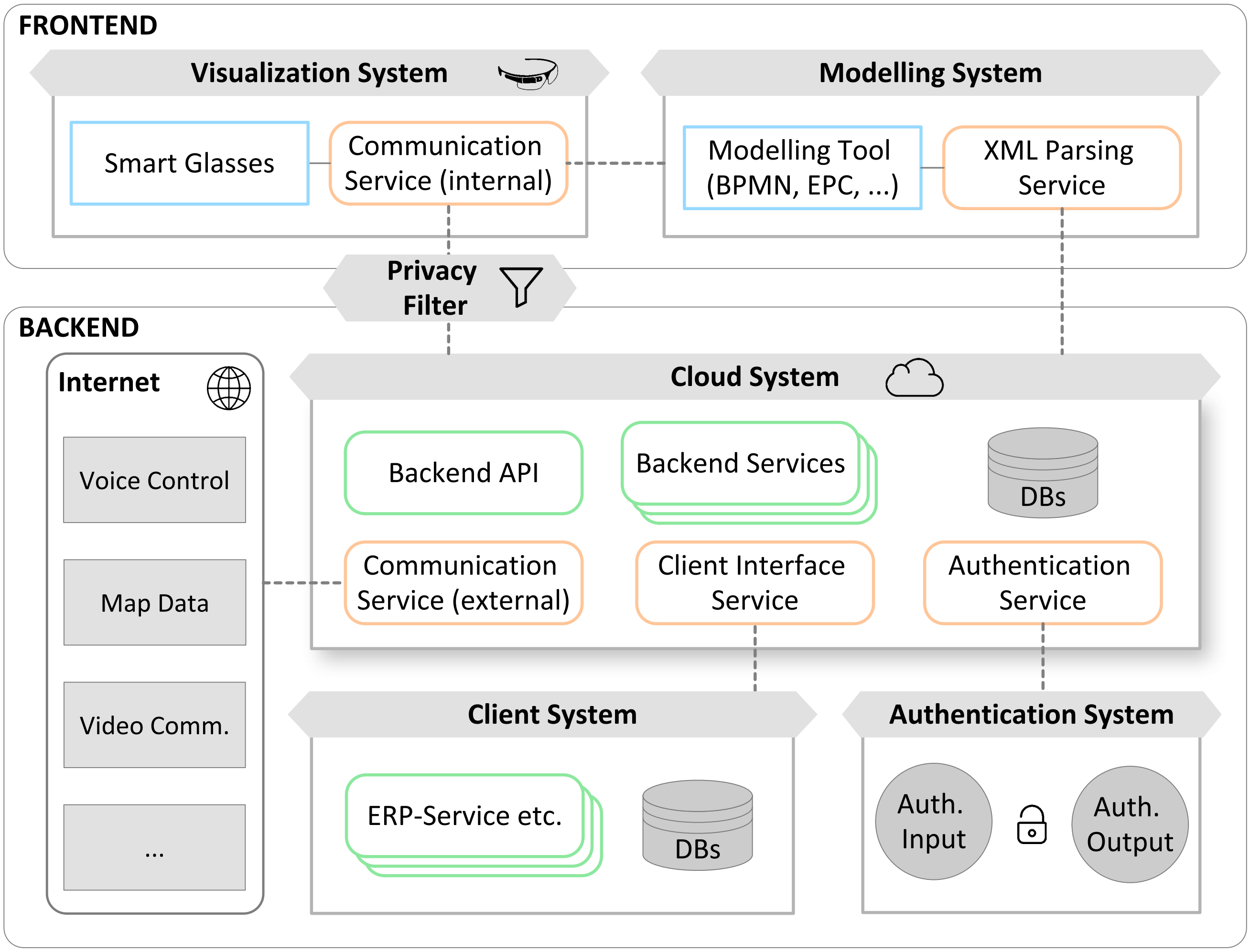

Fig. 7 Architecture of a modular AR glasses-based system for intralogistics services

system to meet a potentially increasing demand and to keep pace with further technical evolutions.

The design of the user interface follows three major design rules and best practices: (UI1) simple and consistent layout, (UI2) advanced perceptibility, and (UI3) customizable interface. A (UI1) simple and consistent layout is necessary, as complex and dynamic layouts impede usability and an ergonomic design. The screen always has a status bar at the top. As the standard Android version is too small and detailed, we developed an individual bar that includes time, the status of voice control and battery, and an icon for connection errors that fades in/out in these specific situations. The navigation bar is located at the bottom of the screen (Google Inc. 2015b). Navigation objects such as toggles or buttons contain voice commands following the principle "say what you see." The mandatory input is selected by default to reduce navigation within the system. The major information object is placed in the lower center of the screen (Tanuma et al. 2011). As the inner part of the screen is easier to read and perceive than the outer one (Google Inc. 2015b), we place the core information in a split screen sidewise in the inner part. For example, a process guidance for an experienced employee would display pictures and icons in the inner part and textual explanations in the outer part because he is used to the workflow and the pictographic indications. The use of recognizable icons can reduce the cognitive load and complexity, compared to textual explanations.

Additionally, an (UI2) advanced perceptibility is required as the user interacts with a limited screen size that should merge unobtrusively into the field of vision. To avoid irritations and reduce the cognitive load, a maximum of three different colors should be applied on a dark background (Tanuma et al. 2011; Google Inc. 2015b). A marked contrast to the background and the suitability for the usage context need to be considered (Tanuma et al.

2011; Meta Company 2017). A choice of themes (e.g., night mode, outdoor mode) for color and brightness can improve the display's legibility. The choice of font size and style should be appropriate for the usage context (Sony Corporation 2017). Sans serif fonts are preferable to optimize the readability of textual elements. To meet individual demands a (UI3) customizable interface is beneficial. Brightness, colors and text style should be customizable, as well as the positioning of information objects. For example, inexperienced employees might be more dependent on textual explanations than on pictographic information objects and should be able to switch between the screen sides. A split screen also needs to change if the user places the monocular display in front of the other eye.

Interaction methods vary among the different types of AR glasses. We applied four design rules during the course of implementation. To use the full potential in process support and ensure good usability, (I1) a simple and hands-free interaction is favorable. We chose button control as the primary input method, but to keep both hands free for bimanual tasks voice control is inevitable. The commands for the voice control are easy to access if a preselection is given, following the "say what you see" principle. The ease of use is supported by (I2) a reciprocal and dynamic interaction with the system. As the voice control requires time for processing, the status should be displayed. The interaction methods can be expanded by an (I3) interoperability with peripheral devices and telemetry sensors.

Furthermore, a central question to be answered during the application development is the selection of the optimal information provision method. Information overload, cognitive stress, confusion and losing track of the workflow are impediments for acceptance and usability. Again, we followed three design rules from the existing design knowledge and best practices: (IP1) focus on the essentials, (IP2) match the user's qualification, and (IP3) avoid unexpected behavior of the application or screen sequences. The key to (IP1) focusing on the essentials is to provide information in an way that is as minimal and contextually adaptive as possible. For process guidance, every step should be addressed with one main screen that only contains relevant information for the corresponding specific action (Niemöller et al. 2017a). If additional information is required, this must be appear on new screens or deployed as pictures and videos (Niemöller et al. 2017a). Long and complex text structures should be avoided on monocular displays (Sony Corporation 2017). To keep track of the workflow, complex processes and navigation hierarchies are counterproductive. Linear processes and a progress bar support the orientation within the workflow. To create a positive user experience, the depth of detail should (IP2) match the user's qualification. An employee can access multiple degrees of detail of the process guidance in accordance to individual qualification. This supports a positive user experience and motivates the user during task completion. Beside an appropriate depth of information, it is important to (IP3) avoid unexpected experiences and information provision. Guidance and orientation within the process (e.g., progress bar or milestones) support the user's information retrieval. Icons need to be recognizable and intuitive (Sony Corporation 2017). If additional information is provided, the user should always return to the step shown last to keep track of the process (Niemöller et al. 2017a). To improve the system and the process guidance, the user should be enabled to provide direct feedback to every step (Niemöller et al. 2017a). These design principles for the UI design and information provision are instantiated in two AR glassed-based systems described below.

4.4 Development and Instantiation in Intralogistics Services

The prioritized use cases were instantiated by implementing two prototypes of AR glasses-based systems. Both prototypes are based on the respective artifacts previously presented. For implementation, we used Java as native Android development language in combination with Android Studio. We structured the design of the prototype according to existent design knowledge, such as the recommendation to preferably use dark backgrounds with bright text providing high contrast, and to restrict the displayed information to a minimum, using a combination of pictographic and textual visualizations (Tanuma et al. 2011; Uchiyama et al. 2013). The first prototype (documentation of damages) was evaluated on the Vuzix M100 as well as the newly introduced Vuzix M300. Both devices are monocular AR glasses with a look-around display and information provision on a closed display in the user's field of vision. The second prototype (process guidance) was primarily used on the Vuzix M300.

4.4.1 Instantiation of Use Case 9: Process Guidance

The latest prototype consists of an AR glasses application guiding the user through the process of assembling and equipping a promotional display (as a typical specialized logistics service from the value-added-service range). After starting the app, a promotional display can be selected for assembly. An initial overview-screen is presented to the user for each display setup, containing information on the expected duration of assembly. Following voice commands the app jumps from step to step. The app leads the user through one main process, usually containing different sub-processes. In the presented example, these sub-processes include the assembly of individual parts, the assembly of the display itself, and equipping the display with different

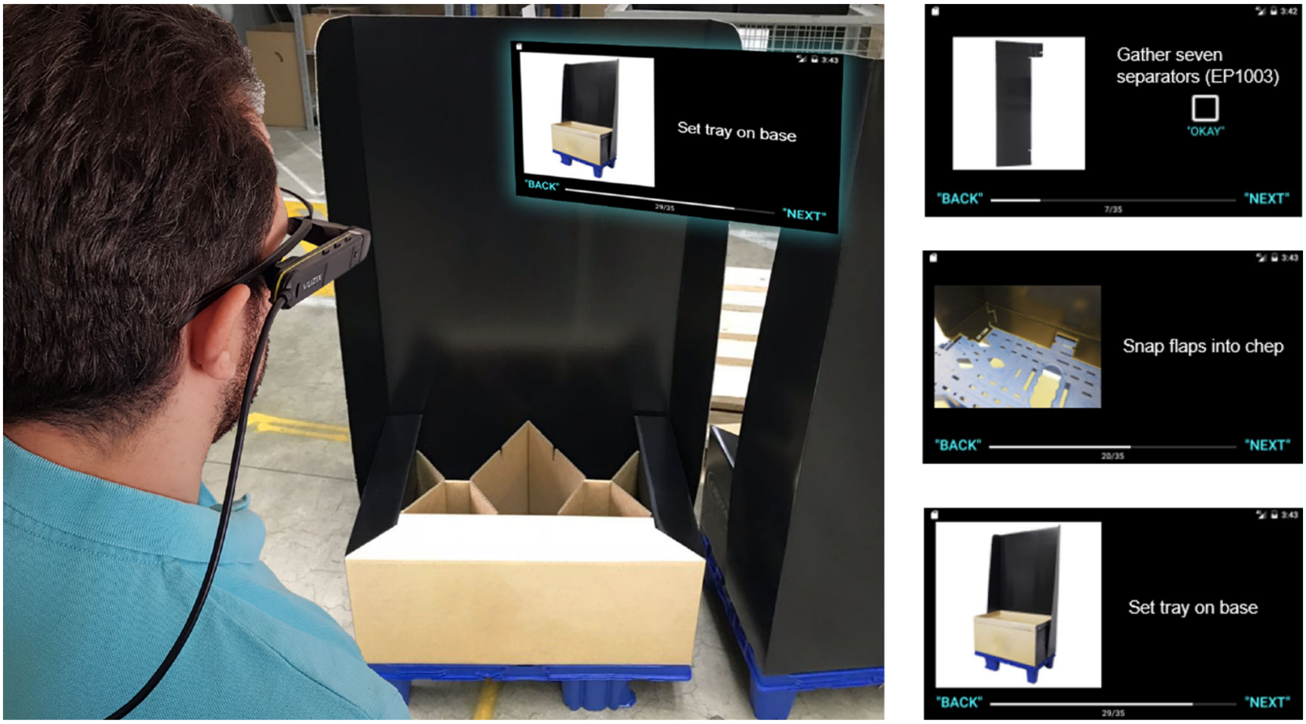

Fig. 8 Instantiation of the process guidance system

products. In case the display has already been assembled before and is ready for equipping, the user can jump directly to the first equipping step. The system ensures that the individual steps have been performed correctly by prompting the user to compare the progress with images. If the task was done correctly, a checkbox can be activated and the system jumps to the next step. If something was wrong, and the user does not confirm via checkbox, the app jumps back to the first step of the current sub-process. The screens of the system, along with an exemplary depiction of its use, are shown in Fig. 8. From the screen after the overview, the current progress is shown at the bottom of the screen. Visualization of most steps is divided into the left part of the screen (pictures, photographs, illustrations) and the right part (textual information, inquiries or checkboxes). The process guidance is developed for expert users who primarily request a picture that shows the final object per task.

4.4.2 Instantiation of Use Case 15: Documentation of Damages

The application provides an eight point documentation plan to identify potential damages or errors. The user compares the product with a photo of a correctly mounted product visualized on the display the AR glasses by following a pre-defined set of test steps. In case of deviation or apparent damages, these will be documented using the installed camera. Generated images are stored and linked to the corresponding object and process step. When the damage protocol is completed, the image is transferred to a database for further processing (e.g., for the initiation of a repair job). For this prototypical instantiation, the product to be checked for damages is represented by a wooden locomotive. The guiding process for the damage documentation is shown in Appendix H. The entire user interface follows a uniform design and a consistent structure. The application is controlled by buttons on the top side of the AR glasses. The initial task and object identification can be by the built-in camera reading barcodes.

4.5 Influences on Diffusion and Impact of AR Glasses in the Design and Development Stage

Ethical issues and the problem of a controversial social image arise in conjunction with the usage of AR glasses (Hofmann et al. 2017). The diffusion of this digital innovation is impeded by ergonomic issues, missing utility, privacy issues, data protection gaps and a lack of usability (Koelle et al. 2017). During design and implementation, we struggled with impediments and limitations concerning the acceptance, usability and user experience, ergonomic design, safety, as well as with privacy and data protection. While focusing on first implementations it soon turned out that is it quite difficult to distinguish between hardware and software in the course of analysis and evaluation. The deduced phenomena often address intertwined functions such as navigation with control buttons. On the one hand, the software design influences the navigation time and effort. On the other hand, the hardware provides limited haptic interaction interfaces, which can result in uncomfortable navigation options. The privacy invasion which AR glasses present are – along with a lack of acceptance among potential users – amid these phenomena indicated as major impediments for the AR glasses adoption (Koelle et al. 2015), and were addressed as critical concerns by the two case companies. Therefore, we endeavored to tackle these issues with our system design from the beginning. Actual design knowledge about privacy and acceptance of AR glasses-based systems and usage experience among the target groups are scarce. Consequently, the problem space is fuzzy and solution designs are not available at this point. Due to the vagueness of the design requirements prior to the actual implementation of an AR glasses-based system, we embedded privacy and acceptance in the initial problem space as design problems.

In contrast to findings of pre-market studies, which state no influence of privacy concerns on the acceptance of AR glasses (Rauschnabel and Ro 2016), the results of our evaluation indicate that privacy affects the acceptance and adoption of AR glasses in business contexts. Granting privacy is primarily a legal concept and, building on its complexity, manifests itself in the user's trust (Zhou 2012). To ensure compliance, a legal evaluation of the usage of AR glasses-based systems is necessary, but it was our aim to already integrate privacy as a central design goal to achieve the user's trust (Bélanger and Crossler 2011; Berkemeier et al. 2017a). We structured the problem space in line with the leading principles of the European General Data Protection Regulation (GDPR). It addresses both privacy and data protection. The concepts of the GDPR are not design-oriented and do not provide specific guidance for legally compliant software development (Koops and Leenes 2014). To transform the legal requirements into applicable solution components, we collaborated with researchers from legal studies. Together, we analyzed the legal base and deduced corresponding technical and organizational design elements as a privacy-by-design concept for AR glasses-based systems (cf. Appendix I). First, constitutional requirements of the German Basic Law were determined. The next step was a description of the legal requirements of GDPR. In the following steps, we derived specific criteria for the implementation of this new technology in a business context. In accordance with these criteria, technical design elements were formulated. The resulting design guidelines in principle follow the privacy-by-design paradigm (Langheinrich 2001).

Furthermore, technology acceptance describes the success of an implementation in terms of the intention to use the evaluated technology from organizational as well as individual levels (Hein and Rauschnabel 2016). As an established theory in IS research, several models and theories are applied to explain and measure the acceptance of potential and actual users. Due to the small number of cases, the factors influencing the acceptance of AR glasses are not fully understood (Segura and Thiesse 2015), and the actual usage is not a sufficient indicator. To support the diffusion of AR glasses-based systems, acceptance has to be integrated into the design process (Berkemeier et al. 2018).

To inform our research, we initially conducted a literature review on acceptance and adoption of AR glasses and wearable technology (cf. Appendix A). The majority of the identified publications used acceptance models to frame the research and applied descriptive statistics to analyze the results. The Technology Acceptance Model (TAM) by Davis et al. (1989) was used in nine publications and another eight applied individual concepts to measure and explain acceptance in a structural equation model. This approach requires a large number of participants, who require experience in the usage of AR glasses. Unfortunately, most potential users have a lack of experience as it is not a common device. This is contrary to our research where field tests are required because we design and develop an expert system in collaboration with practitioners. Even in an agile approach it was not possible to deploy the necessary tests with a sufficient number of participants.

We utilized the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al. 2003) to identify major problem areas in the system development and diffusion. The constructs and items from established acceptance models are a sufficient framework to structure the problem space acceptance in our research process. The identified design problems are addressed in our system design. We gained design knowledge through prototyping (cf. Sect. 4.4) and further insights from the formative evaluation of the prototypes (cf. Sect. 4.5). Enabled by the close communication between system designers and potential users, we derived design elements for the acceptance of AR glasses-based systems as indicated in Appendix I.

4.6 Formative Evaluation in Intralogistics Services

So far, we apply a formative evaluation in a naturalistic setting to provide constant feedback and enhance our artifacts during design and implementation. Novelty and utility of the artifacts as well as effectiveness and effectivity provided by the use of the artifacts are main targets of the evaluation (Rai et al. 2017). Given the barriers of AR glasses adoption, our main goals when evaluating are to achieve technology acceptance, (privacy) compliance and usefulness of our artifacts. Therefore, our evaluation is structured and applied following the FEDS framework by Venable et al. (2016).

The evaluation is planned in four steps: (1) the objectives calibrating our evaluation are the utility and usability of the prototype as well as the technology acceptance and user experience perceived by the user. (2) As the acceptance of AR glasses is a barrier for its diffusion, the main design risks are user oriented. An evaluation in the real context is made possible by the engagement of the case companies and inevitable to assure practical relevance of the results. Thus, we follow a human risk and effectiveness evaluation strategy (Venable et al. 2016). (3) We defined acceptance and the realization of the design requirements as major properties of our evaluation. Further properties are compliance with privacy and safety regulations, usefulness and usability. (4) The individual episodes planned for the evaluation of the prototypes are scheduled for every implementation milestone and consist of either (a) expert interviews, (b) focus groups, (c) laboratory tests, (d) field tests or (e) online questionnaires (cf. Appendix J for fuller planning of the evaluation). Due to the barriers detected in the history of AR glasses market diffusion we identified the actual prototypes as the artifacts with the highest risk to be rejected by the users. The system architecture, the requirements and design principles are manifested in the prototypes. Table 2 presents the contribution of our evaluation cycles broken down by our artifacts.

Table 2 Evaluation cycles and feedback

Evaluation setting				Feedback
1: UC 15 focus group and survey in lab				
2: UC 9 focus group and survey in lab				
3: UC 9 focus group on site				
4: UC 9 focus group in lab				
1	2	3	4	
x				Improve navigation in-between the screens
x				Improve process guidance on the prototype
x				Implement clear feedback after completing a step
x	x			Improve readability of information on the screen
	x			Improve speed of the application
		x		Adapt order according to current workflows
		x		Add missing steps
		x		Rather use simplistic illustrations instead of photos
		x		List various products with their ID and color-coding
		x		Include sub-step numbering in the instructional texts
	x	x		Separate the workflow into sub-processes, with inquiry at the start, enabling division of labor
x		x	x	Implement different proficiency levels and hide details accordingly
		x		Evaluate technical feasibility of color recognition via camera
		x		Maintain balance of the structure through side-alternations when equipping
		x		Evaluate technical feasibility of checking products automatically instead of visually
x		x		Evaluate additional mounts (such as headbands)
		x	x	Evaluate technical feasibility of integrating inventory systems
			x	Focus on improving process quality instead of runtime

5 Toward a Design Framework for AR Glasses-Based Information Systems

5.1 Structuring the Design and Development of AR Glasses-Based Information Systems

The successful design and instantiation is not simply a matter of software engineering. It depends on the selection of beneficial usage scenarios, organizational implementation, content management and user's acceptance. To support the diffusion of AR glasses, a comprehensive approach is required for design and instantiation. The design and instantiation presented in Sect. 4 demonstrates design novelty and validity in the domain of intralogistics services. Implicit design knowledge is formalized in a design framework for AR glasses-based systems. The application of this framework guides and supports AR glasses-based system development. Adapting the artifacts in various domains and settings promotes the generation of design knowledge, which can be integrated into the framework. Following Gregor and Hevner's (2013) line of argumentation, it is a first step toward a design theory for AR glasses-based systems.

Based on the insights from the design and instantiation of AR glasses-based systems, we developed the design framework presented in Fig. 9. The framework provides guidance for projects and teams with the target of successful and rapid implementation of AR glasses-based systems. The design and implementation of an AR glasses-

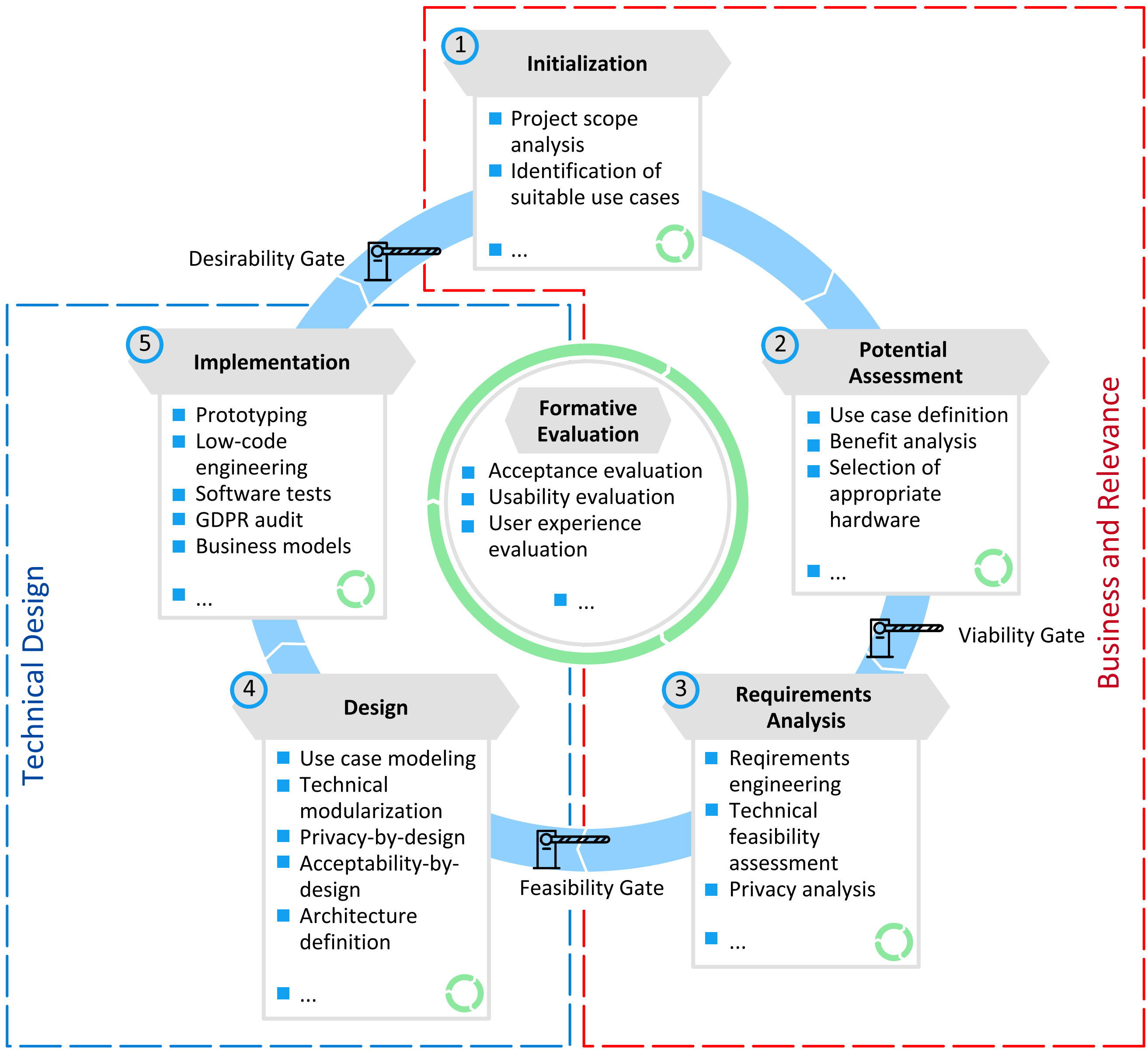

Fig. 9 Framework for AR glasses implementation

based system is executed in six 'phases.' The five project phases (1) *initialization*, (2) *potential assessment*, (3) *requirements analysis*, (4) *design*, and (5) *implementation* form a cycle to support an iterative procedure. The phase *formative evaluation* serves as constant support and a standard of alignment, allowing multiple projects (or use cases) to run simultaneously while providing ongoing feedback to improve the solutions. The phases address the three layers of digital innovation. The development of the product is supported and connected to reciprocal progression of the business processes. New and modified business models can be either integrated as a result of new processes, or trigger evolvement in the other layers in terms of adjustment to market demand. These phases are not limited to AR glasses as a specific digital innovation, but the six phases are enriched with AR glasses-specific artifacts. The following sections provide an overview of the framework, respective artifacts, and support for adaption and deployment of the artifacts in other projects. Thereby, we support a successful diffusion of this digital innovation.

Connecting the business perspective and technical design has proven to be the main challenge during the implementation of AR glasses-based solutions. As an immature technology, expectations of AR glasses instantiations and implementation potentials differ. The framework dictates which phases are shaped by process specialists (1: initialization, 2: potential assessment, 3: requirements analysis), and which phases are shaped by technical experts (4: design, 5: implementation). A collaboration is beneficial during the course of the project, but the main perspective should be retained. Furthermore, we address the uncertainty during the design and implementation of digital innovation projects with technology-related gates. Building on Design Thinking (Vaishnavi and Kuechler 2007), innovation combines three components: economic viability, technical feasibility, and human desirability. Our framework suggests three gates seeking to find positive answers to the respective component. Only projects or use cases that prove to have potential toward a beneficial solution will pass the viability gate. Through requirements analysis, technical feasibility can be assessed. Lastly, human desirability can be best evaluated through initial implementation efforts, a process that presents solution artifacts to the user.

5.2 Initialization of AR Glasses Implementation Projects

The initialization phase prepares the definition of suitable use cases, which is inevitable for AR glasses use in business contexts. A holistic approach is required to both identify use cases and provide suggestions and support for the implementation (Niemöller et al. 2017b). Based on the problem statement, the initialization phase aims to keep track of the environment and background of the project or use case. To analyze the problem statement, we suggest visualizing the actual process to be refined using AR glasses. Existing process models can be utilized, otherwise the process needs to be modelled. We applied shadowing, as described by Myers (2009), to collect the necessary data and used BPMN as a standardized modelling language. Capturing key performance indictors provides a base for ex-post cost-effectiveness analysis. An inspection of the actual process and process environment facilitates brainstorming and provides the participants with a uniform understanding of the process.

Prior to the inquiry, it is important to obtain an overview of the design and implementation knowledge base. We applied a systematic literature review, but literature on digital innovations such as AR glasses is often scarce. It is beneficial to include reports on tests and pilot projects, or include design knowledge from related technologies. Design knowledge about virtual objects can be drawn from virtual reality (VR) projects and insights into the interaction and ergonomic design from earlier versions of HMDs.

5.3 Potential Assessment of AR Glasses-Based Information Systems

The use cases identified in the initialization phase must be further validated and consolidated into a catalogue of aggregated use cases. By comparing our logistics services use case catalogue with results from researchers who implemented AR glasses-based information systems in other industries (e.g., machinery and plant engineering, health care), we identified 11 cross-industrial use cases (Table 3). In order to be prepared for the viability gate, the benefit or usefulness of the use cases should be assessed along with the functional and organizational effort in the case of implementation. Based on this, the implementation of the use cases can be prioritized. Prioritizing highly useful and technically feasible use cases supports system acceptance and allows the implementer to gain experience in AR glasses-based system design and development. Use cases that are not viable in terms of usefulness or technical feasibility need to be excluded from the implementation process. From our instantiation of this phase, we have learned that a very careful selection and thorough exploration of potential use cases is required throughout to avoid misleading designs or faulty implementations at the end of a project cycle. At this point, differentiating between a technical and domain perspective, and a business perspective is an important action. Evolving requirements on both sides of the process need to be considered in order to properly meet challenges in the engineering of microservices. The deducted use cases should sufficiently describe uses of AR glasses in the new system from a business perspective, not the IT expert's perspective. The use cases need to be on a similar abstraction level. If separate

Table 3 Cross-industrial application areas for AR glasses-based systems

Application area	Description
Communication	Helps to get or send information to the operation location
Documentation	Provides the possibility to document processes on the fly
Process guidance	Provides guiding information
Education	Use smart glasses to teach employees
Alerts	Attract user attention for urgent information or warning
Data visualization	Shows helpful augmented information in situ
Automatic control	Reduces error rates in error-prone processes
Inventory management and automatic ordering	Automatically keeps track of objects and resources to enable optimized consumption, usage and re-ordering
Resource allocation	Distributes and manages limited capacities, e.g., time and staff
Text handling	Helps users generate or interpret written language
Navigation	Supports the user by providing routes and action sequences

technical use cases are defined, interdependencies should be analyzed to avoid redundant developments.

In addition to the use case definition, hardware, or devices, should be preselected. Depending on the device type (e.g., monocular vs. binocular AR glasses), the subsequent requirements engineering outputs can differ significantly. We learned that there should be a strong focus on ergonomics in respect to the selected hardware used in an industrial setting, therefore, when deciding on different devices, these should be suitable for being used (and worn) for up to 8 h. There are three major criteria in hardware selection. The primary criterion is (1) the wearing comfort to ensure usability and an ergonomic design. Current devices cause discomfort due to the unbalanced or inflexible positioning of the display. A lightweight and stable device supports the wearing comfort, especially during movement. Clip-on solutions are especially favorable for spectacle wearers, but also and more importantly necessary in working environments that require safety equipment such as helmets or goggles. In this case, they can be mounted on custom products. The (2) suitability for an industrial purpose is a decisive criterion. Industry standards, such as IP protection class, indicate the robustness of the device.

Moreover, a flexibly mounted camera facilitates an ergonomic working place, contrary to a fixed camera, which forces the user to move his head into the right position in order to take pictures and videos, or to scan a barcode. Not all use cases require the whole spectrum of functionalities, such as a built-in camera. A (3) minimalistic and customizable hardware design has a positive influence on acceptance, privacy and safety, usability, as well as the ergonomic design. Functionalities should match the usage context to avoid unnecessary privacy invasion options, and to reduce the weight of the hardware. Computing power and batteries placed on the user's head cause discomfort due to weight and heat generation. Environmental effects such as diffused light conditions can compromise the legibility of AR glasses. Excellent legibility (4) has a positive influence on the ergonomic design, usability and user experience. Key factors are high display resolutions and, specifically applying to look-through devices, a wide field of view. The brightness and depth have to suit the individual user and the usage environment. If used outside, a protection against solar radiation and light diffusion should be provided.

While deciding on potential use cases and devices, as well as during the other cycles, AR glasses do not necessarily have to be the perfect solution for all scenarios. As the number of Internet-of-Things (IoT) devices and technology knowledge increase, IoT architectures or clients can expand selection criteria to connected devices, e.g., for use as communication device. Additionally, a combination of peripheral hardware is always better than complex software applications or self-developed hardware extensions.

5.4 Requirements Analysis for AR Glasses Use Cases

The use cases capture the requirements of the system's stakeholder. We derived meta-requirements as properties for implementation in logistics services. Apart from the differentiation between functional and non-functional requirements, we formed granular categories focusing on the technical design for the application of AR glasses in an intralogistics scenario: (1) *architecture*, (2) *data security*, (3) *information provision*, (4) *system integration*, (5) *interaction and communication* (cf. Sect. 4.2). These categories can be used as a foundation for the requirements engineering in the development of AR glasses-based systems. Methods applied during requirements engineering should foster creative thinking and focus on the user to ensure useful scenarios and acceptance. By means of a focus group with both technical and domain experts, we discussed and evaluated the technical feasibility of potential use cases by assessing the technical capabilities of AR glasses and the effort needed to implement the necessary modules to realize a use case.

Furthermore, privacy regulations must be considered from the beginning to ensure legal compliance with the GDPR; this includes information privacy and data security regulations. Table 4 shows the privacy status of the AR glasses functionalities (range, function, functional characteristics), which were identified by Niemöller et al. (2016), following a traffic light logic. Functionalities marked as green can be deployed in an industrial context without special measures, such as the measurement of the ambient temperature. Red lights indicate functionalities that cannot be deployed in most industries, as they harm the user's privacy. AR glasses' functionalities marked as yellow can be deployed, but require measures to ensure the protection of the user's privacy. After having completed the requirements analysis, feasible scenarios pass the feasibility gate and are conceptualized and designed further in the next phase.

5.5 Design of AR Glasses-Based Information Systems

In the design phase, the actual business processes of the corresponding use cases must be reviewed and new target processes should be defined – preferably standardized reusable processes (use case modeling). To bring the system perspective forward into the use case, the technical feasibility evaluation has to be analyzed, interdependencies between the UCs must be identified, and missing system components have to be added to reach derived modular components, called system modules.

Table 4 Privacy status of AR functionalities based on functional characteristics by Niemöller et al. (2016)

Range	Function	Functional characteristics	Privacy status			Measures
			Green	Yellow	Red	
Device range (sensors)	Tracking	Temperature gauge	x			
		Health tracking			x	No collection of special personal data
		GPS navigation		x		Restriction of data storage
						No processing of special personal data
						Individual registration voluntary and personal
	Glasses interaction	Hands-free content navigation	x			
		Voice recognition		x		Restriction of data storage
		Gesture recognition		x		No processing of special personal data
		Eye tracking		x		
		Head tracking		x		
Close range (environment)	Environment identification	Identification of objects	x			
		Identification of people	x	x		Restriction of data storage
						No processing of special personal data
		Night/thermal vision	x			
	Picture and video	Pictures and videos		x		Restriction of data storage
						Individual registration voluntary and personal
Far range (internet)	Information provision	Search information	x			
		Contextual information	x			
		Real-time statistics		x		Restriction of data storage
						Individual registration voluntary and personal
		Information overlay/ application	x			
	Advanced communication	Textual communication		x		Restriction of data storage
		Video conferencing		x		
		Real-time translation		x		
		Live streaming		x		Restriction of data storage
						Comprehensive data security measures

A cloud-based architecture is desired, in order to embrace the connected characteristics of AR glasses and to keep processing on the device itself low. The current devices suffer from short battery life and significant heat production if used intensively by the software. Based on a structured architecture, prototyping of less complex (sub-) use cases is helpful to generate running applications in a short time (cf. Sect. 4.3). Additionally, all interaction possibilities of the AR glasses should be considered, e.g., speech recognition and gesture control. An application running on AR glasses should also be sensitive to the knowledge level of the user (expert and beginner views).

User interface guidelines provided by the hardware suppliers are an important source for addressing the chosen device's specific requirements. Nevertheless, these guidelines are limited to the usability of the developed software and do not provide guidance for the development of a comprehensive system. Building on our design experience, we propose 12 major design principles for AR glasses-based systems. These are enriched with design elements to ensure acceptance and privacy, which influence the design and implementation. We include findings on the privacy compliant design of AR glasses-based systems from a collaboration between information systems researchers and researchers from legal studies, to identify design problems for AR glasses-based systems (Berkemeier et al. 2017a). Design problems regarding the acceptance of AR glasses-based systems are derived on the basis of the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al. 2003) and of insights from the collaboration with potential users. The deduced design elements are proposed as a privacy-by-design and acceptance-by-design approach in Appendix I. By respecting and applying these components, the very important factors of privacy and data security, and acceptance, can be considered from the start. All of these factors are essential for a valid industrial AR glasses implementation.

5.6 Implementation of AR Glasses-Based Information Systems in Business Context

Lastly, after reaching the desirability gate, the implementation cycle can start. Through prototyping, the previously defined system modules and the modelled architecture are implemented in the target augmented reality system. Building on general principles of agile software development, frequent user and stakeholder feedback can be gathered by applying fast and short iteration cycles. In order to provide testable prototypes and system modules, software and developer tests must be conducted frequently and continuously. Low-code engineering enables easy implementation and process integration into the system, and empowers the users to exchange or alter the system's content in case of external alterations. Hence, improvements in the organizational workflow of a use case can be integrated into the system without the need to change the programming code or hire a software developer. The use of non-proprietary implementation frameworks can help to build on an already approved knowledge base and to assure platform independencies.

Furthermore, successfully implemented modules should be tested for their compliance with privacy and data protection regulations at this point. By employing GDPR-audits, the application of such regulations can be validated and documented. After having reached evaluable systems or prototypes, the desirability gate can be passed once a solution is evaluated by the potential users as desirable.

5.7 Formative Evaluation of AR Glasses-Based Information Systems in the Field

The evaluation of the artifacts contributes to their continuous improvement. The implementation of the corresponding artifacts' respective input, such as requirements for system development, is verified and the results are validated. Since long-term implementations and empirical values of AR glasses-based systems are scarce, it is unclear whether existing evaluation models are suitable for this new technology. Field tests are advantageous as potential users continuously get involved in system design. In this way, the user-friendliness of the system is ensured, and the participation of the users supports the acceptance of a system implemented for long-term use. The evaluation also allows the users to gain experience in the interaction with the device. This may result in changing requirements for the system. There are various reservations with respect to AR glasses, so in an evaluation, human-centered aspects such as acceptance, usability and ergonomics should be taken into account. It is beneficial to use short iterations in the design and open a dialogue with potential users. We applied different acceptance and usability theories on AR glasses-based systems and experienced difficulties with the full integration of hardware and software. As the users are unfamiliar with the hardware, it is a challenge to receive separate feedback on the software design. We recommend to engage participants in multiple evaluation cycles and to determine their experience with the technology.

6 Discussion

While the focus of our research project is the creation of solutions for a domain-specific design problem, we aim to reflect on executed design processes and evidence from practical instantiations toward a theory for the design and implementation of AR glasses-based systems. Our work is motivated by the identified gaps in research and practice (cf. Sects. 1, 2). As a part of that, AR glasses face barriers in diffusion and concerns about the devices' impact on users, organizations, and society (Koelle et al. 2015). Furthermore, beneficial usage scenarios have so far been limited. Finally, research toward a sufficient design theory for AR glasses-based systems was inevitable, and only a few real-life implementations exist (Niemöller et al. 2017a) to build upon. To address identified gaps, we contribute to theory (especially design theory) by providing design principles and a design framework for AR-glassed based systems. Along with this, acceptance and privacy were confirmed as key drivers for successful instantiations and therefore have a central position in the proposed design framework.

Due to the domain restriction (intralogistics service), we faced the risk of performing solution engineering rather than conducting design science research. To ensure that our artifacts are transferable within the domain, we included two different logistic service providers as real business cases. Despite the risk of performing solution engineering, DSR was proven as a sufficient paradigm to structure issues in terms of development, diffusion and impact of digital innovations. However, both logistics service providers (cases A and B) were struggling with the deployment of the introduced design principles without having a prototype as demonstrator.

During the research project we identified prominent acceptance models providing statistical evidence on the potential user's attitude towards the technology (cf. Appendix E and Niemöller et al. 2017a). However, quantitative measures require a sufficient number of participants. To include acceptance in a formative evaluation, a qualitative approach is preferential to ensure dynamic and flexible design cycles. By measuring acceptance of AR glasses-based systems, we found that the survey of acceptance requires actual user experience during evaluation. As digital innovations are based on new concepts enabled by digitization, it is hard to imagine the impact of the resulting solution.

The practical relevance is provided by the introduced design framework, with an emphasis on design principles and elements for privacy protection and acceptance, enabling logistic providers, along with software solution implementers, to successfully design and instantiate AR glasses-based systems for intralogistics services. Moreover, the use cases catalog is not only the foundation of system design, it provides sufficient application scenarios to support companies in determining if AR glasses are viable to support their business processes. With a detailed look at AR glasses as a hardware platform for AR glasses-based systems, we addressed hardware issues and the need for non-invasive mounting mechanisms, as well as recommendations for hardware selection (cf. Sect. 5.2).

We are aware that our research has limitations. The data provided does not refer to long-term implementations. While following the introduced design framework, differentiated feedback addressing hardware and software is challenging, but must be strictly executed, regardless of difficulties. Although they knew that our framework primarily aims to support the development of software for AR glasses, users demanded hardware optimization, such as ergonomic design and customization options during evaluation. Along with this, software performance is constrained even with the latest hardware capacities (processing capacity). Overall, the derived design framework focuses on, but is not limited to, AR glasses. Although an extension to digital innovation projects has not yet been accomplished, it is probable that this potential exists.

7 Conclusion and Outlook

Concluding our research, we applied a DSR approach to design and develop AR glasses-based systems in intralogistics services, and formalized our knowledge in a design framework. Our research aims to merge design knowledge with real life implementation in order to enable valid and accepted AR glasses-based systems as innovative products and services. The research questions are addressed in five main findings: Answering research question 1, useful and beneficial use cases for AR glasses are proposed. Respectively, in research question 2 (RQ 2.1), we derived requirements for AR glasses-based systems and (RQ 2.2) design principles, along with best practices for the design of AR glasses-based systems. To address research question 3, design elements were deduced to integrate acceptance and privacy into system design, as key drivers for practice-ready AR glasses-based systems. Aggregating this design knowledge, we answered research question 4 with the introduction of a complementing design framework that supports following implementation projects with AR glasses. The provided design framework (incl. design principles, privacy status) aims to close the identified gap in research. AR glasses-based systems come to light as a valid digital innovation. Instantiated prototypes (cf. Sect. 4.4), the introduced framework (cf. Sect. 5) and derived design principles (cf. Sect. 4.3) mainly address the digital innovation layers (1) products and (2) processes, while designed AR glasses-based systems, following the proposed framework, enable new (3) business models e.g., the introduction of the customer into the returns processing. Although we faced the risk of performing solution engineering, DSR was proven to be a sufficient paradigm to examine AR glasses in terms of development, diffusion and impact. The design-oriented approach is beneficial to structure the problem space and to create satisficing solution components. While looking at the design knowledge about AR glasses-based systems, acceptance and privacy are identified as key drivers for productive implementations.

Further research on AR glasses is required in order to understand the three layers of this digital innovation: product, process, and business model. Latest withdrawals of AR glasses confirm the still existing need for suitable AR glasses (hardware-platforms) and design principles for market-ready AR glasses-based systems. An ongoing issue in literature and practice is the definition of AR glasses. With the Microsoft HoloLens introduced to the market as a mixed reality (MR) technology, the categorization of the established mixed reality continuum (Milgram and Kishino 1994) was undermined. As a result, the definition of and differentiation between AR and MR is vague, and the categorization of different devices like monocular and look-around combinations such as Vuzix and Intel Vaunt remains unclear. This further results in communication problems in science and practice.

Moreover, the product is still evolving, as new classifications are required for displaying technology that interacts with the perceived reality of the user. New innovations in the field of AR glasses lead to alterations of the introduced design framework. The presented set of artifacts is a result of a consortium research project located in the intralogistics domain. A transferability to other industries is presumed but not yet confirmed. Instantiations in other industries with a broader range of devices are necessary to improve the projectability. To provide knowledge about organizational change in long-term deployment of AR glasses-based systems, further insight into success and risk factors is required. A sustainable implementation in a business context also requires a detailed concept for data security. To address the economic perspective of digital innovations, concepts are required that cover cost structures and economic benefits, such as business management performance figures and key performance indicators of AR glasses-based systems. Respectively, an inquiry into new business models for AR glasses could provide further insights about the market and user expectations. On the other side, health risks of AR glasses need to be examined, especially in a long-term application.

Additionally, AR glasses as a stand-alone solution do not suffice to solve a broad range of usage scenarios. We expect that a combination of AR glasses and other wearables such as smart watches could be expedient to create a comprehensive support for business processes. As concepts of the Internet of Things are gaining attention in the market and business environments become more and more digitized, AR glasses can interconnect with other smart devices and infrastructure, which support the user in an intelligent and context-sensitive manner. Following this line of argumentation, the use of AR glasses-based systems in smart services is a future research topic.

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Engineering of Augmented Reality-Based Information Systems – Design and Implementation for Intralogistics Services

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Appendix (available online via http://link.springer.com)

Appendix A

The systematic literature reviews were conducted in four steps: (1) definition of search terms, (2) extraction of a search hit list, (3) identification of relevant literature, (4) a forward and backward search. Publications were included as relevant in the review, if (a) development of AR glasses-based systems, (b) information systems in intralogistics or other knowledge intense services or (c) general phenomena regarding AR glasses or wearables in general were addressed.

The first literature review was conducted in the initial phase in order to structure the problem space. It was conducted in 2015, when the research projected started. The search terms were comprised of two dimensions: technology ("Smart Glasses", "Datenbrille", because the Google Glass was implemented in first industrial settings at that time) and domain ("logistics", "Logistik"). The terms were applied in English and German. We identified 56 relevant publications. These publications were used to explore research question 1 and 2.

We conducted a second systematic literature review during the exploration of research question 3, focusing on acceptance and adoption of wearable technology. Wearables were included into the search term as the generic product concept of these AR glasses. We identified 28 relevant publications after eliminating duplicates; title, abstract and full-text scans, and the addition of further publications applying forward and backward search. We identified eleven articles that specifically focus on AR glasses and 17 publications that refer to wearables in general.

Table 5: Systematic literature reviews

Searchterm	Database	Hits	Duplicates	Relevant publications
„Smart Glasses" AND Logistics	AIS electronic Library	1		
	Ebscohost	10		
	Science Direct	9		
	SpringerLink	19		
	Google Scholar	178		
	WISO	27		
	Total	**245**	**4**	**9**
Datenbrille AND Logistik	AIS electronic Library	0		
	Ebscohost	0		
	Science Direct	0		
	SpringerLink	38		
	WISO	227		
	Google Scholar	174		
	Total	**439**	**11**	**47**
(„technology adoption" OR „technology acceptance model") AND (wearbles OR „mobile information system")	AIS electronic Library	91		
	Ebscohost	11		
	Science Direct	116		
	SpringerLink	219		
	Total	**437**	**8**	**28**

Appendix B

As a part of the requirements engineering in the exploration of research question 1 (cf. section 4.1), we conducted two expert interviews with logistics experts from an international contract logistics company, one business system consultant for IS Solutions and one business system analyst. Aiming at a narrative-generating interview, the guideline was semi-structured to include follow-up questions. The interview guideline contained four questions:

- What does the current support with mobile information systems look like?
- What are beneficial use cases for a service support with AR glasses in the intralogistics domain?
- How can AR glasses be used to support intralogistics services? and

- Which use cases or processes would you exclude from an AR glasses-based support?

To identify major problem areas in the system development and diffusion (cf. section 4.5) and exploit research question 3, we utilized the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al. 2003). The UTAUT takes mandatory use into account and has a manageable complexity to use it as a guideline in focus groups and expert interviews. We enriched our findings through an interview with a member of a workers council in logistics services in the early stages of system design. The interviewee was initially informed about the acceptance factors from the UTAUT and was asked to assess whether these factors are relevant for the acceptance of AR glasses-based systems in an intralogistics setting. Afterwards the interviewee received a list with functionalities of AR glasses (Niemöller et al. 2016) in order to evaluate the impact of each function on the acceptance. If the interviewee evaluated an acceptance factor or function as problematic, he was asked to think of possible solutions to address the respective problem. Again, we used a semi-structured interview guideline, structured as follows:

- In your experience, what is the influence of *perceived usefulness* on the acceptance of AR glasses-based support systems?
    - Can you state examples from already implemented systems?
- How does *GPS navigation* influence the acceptance of AR glasses-based support systems?

Appendix C

Over the course of our three-year consortium research project, we conducted various different focus group sessions. In Table 6, we list the different participant constellations, the number of meetings and which subjects were discussed in these settings. Hence, we conducted 14 meetings where we discussed our use cases and the requirements analysis with the primary project team. The team consisted of researchers from the field of information systems and logistics, representatives and experts from two logistics service providers, as well as technical experts from a software provider specialized in logistics solutions. Additionally, we conducted various smaller focus group meetings, with both the domain experts in logistics and the technical experts on logistics systems. Lastly, we held meetings with a strong research focus with researchers from both mentioned research domains, and one discussion with software developers experienced in developing software for augmented reality hardware.

Table 6: Focus group settings

Participants	Subjects	Number
Project consortium	Use Cases, Requirements Analysis	14
Software developer	Design	1
Associated researchers	Use Cases, Design, Requirements Analysis	4
Domain experts	Workflow, Requirements Analysis	5
Technical experts	Use Cases, Architecture, Workflow	5

Appendix D

In a focus group formed by technical experts and information systems researchers, we assessed the technical effort of each use case's implementation on a scale of 1 (easy) to 3 (difficult). The participants of this system focus group were (1) two experts from the software development of a software and consulting house, (2) one software architect (case A), (3) three software developers (case A), (4) one IT manager (case A) and (5) two research assistants with experience in the design and implementation of AR glasses-based information systems.

The UCs were evaluated using five criteria, on a scale of 1 (easy) to 3 (difficult). The criteria were defined by the focus group as follows: "Time" describes the amount of development time required to implement a software application for the respective UC. The criteria "Interfaces" stands for the amount and complexity of data interfaces, subsystems and data structures that would have to be integrated or developed. The overall extent of the process represented by each UC is evaluated by the "Process" criteria. For example, by the question of whether a process consists of various process layers or the amount of process steps. The criteria “Algorithm” represents the accompanying complexity of required application modules. “Hardware Requirements” describe requirements for technical infrastructure as well as requirements for the smart glasses. If a process requires either large amounts of data to be transferred, or includes complex algorithms that need high processing resources, hardware requirements are rated as 3, making the implementation more difficult. This also holds true for time-critical applications.

Tables 7-9 represent the results of the last focus group meeting, evaluating the development effort for the implementation of each UC sorted by the overall technical feasibility. In addition, the crucial statements causing high or low development effort have been identified and listed. Key drivers for implementation effort were (1) the requirement of implementing a system solely based on smart glasses, without outsourcing all logic to an external Warehouse Management System (WMS), (2) the need to identify an object, (3) the ability to implement navigation and location elements, and (4) hardware constraints due to the architecture of smart glasses (e.g. computing power, camera resolution and bandwidth).

Table 7: Use cases with good technical feasibility

Use case		**Time**	**Interfaces**	**Process/ Function**	**Algorithm**	**Hardware req.**	**Technical feasibility**	**Statements**
1	Monitoring / Process capturing	1	1	1	1	1	**1**	only data-logging, processing excluded
4	Prioritize employees	1	1	1	1	1	**1**	logic location in WMS, interface available
14	Document process execution	1	1	1	1	1	**1**	camera and voice function available (constrained quality)
15	Document damages	1	1	1	1	1	**1**	camera and voice function available (constrained quality)
23	Scan barcodes	1	1	1	1	1	**1**	function available (constrain: distance to object)
24	Show object information	1	1	1	1	1	**1**	logic and information location in WMS, only visualization
27	Show object related warnings	1	1	1	1	1	**1**	logic and information location in WMS, only visualization
30	Find objects	1	1	1	1	1	**1**	logic location in WMS, location system required
33	Show optimal storage area	1	1	1	1	1	**1**	logic and information location in WMS, only visualization
2	Show monitoring analysis	1	1	2	1	1	**1,2**	only visualization of tracked data, interface available
3	Show reward symbols	1	1	2	1	1	**1,2**	only visualization of tracked data, UI design effort
5	Show current workload	1	1	2	1	1	**1,2**	logic location in WMS, UI design effort
16	Recognize and show input errors	1	2	1	1	1	**1,2**	multiple interfaces, only data-comparison
28	Show process related warnings	1	2	1	1	1	**1,2**	process-mapping required, UI restriction
7	Show operating instructions	1	1	2	1	2	**1,4**	process-proposal-mapping required, only visualization
31	Show stacking information	1	1	2	1	2	**1,4**	interface and function available, only visualization
8a	Support learning phase with static instructions	2	1	2	1	2	**1,6**	process-help-mapping required, interface and function available

34	Show and control packing list	2	2	2	1	1	**1,6**	logic location in WMS, interface required

Table 8: Use cases with medium technical feasibility

Use case		**Time**	**Interfaces**	**Process/ Function**	**Algorithm**	**Hardware req.**	**Technical feasibility**	**Statements**
6	Translate notifications and text	2	2	2	2	2	**2**	migration effort for existing translation APIs, bandwidth restriction
10	Support streaming	2	1	2	2	3	**2**	migration effort for existing streaming engine, bandwidth restriction
11	Guide working steps via remote control (internal support)	2	1	2	2	3	**2**	solution available, migration effort, bandwidth restriction
12	Guide working steps via remote control (external support)	2	1	2	2	3	**2**	solution available, migration effort, bandwidth restriction
13	Support video communication with customers (VAS)	2	1	2	2	3	**2**	solution available, migration effort, bandwidth restriction
8b	Support learning phase with dynamic instructions	2	2	3	2	2	**2,2**	process-Help-mapping and workflow system required
9	Show inspection plan (VAS)	2	3	2	2	2	**2,2**	voice control (performance restriction, integration effort)
25	Navigation instructions (static)	3	1	2	2	3	**2,2**	navigation system (migration to SG or back-end system, locating system)
32	Measure and document objects	3	1	3	3	3	**2,6**	development effort for object identification (depth-sensor required)
35	Show loading optimization	3	3	3	2	3	**2,8**	development effort for visualization, data quality in WMS
36	Automated inventory gathering	3	2	3	3	3	**2,8**	development effort for object-identification (accuracy required)

Table 9: Use cases with bad technical feasibility

Use case		**Time**	**Interfaces**	**Process/ Function**	**Algorithm**	**Hardware req.**	**Technical feasibility**	**Statements**
17	Support automated control functions	3	3	3	3	3	**3**	development effort for object-identification (camera resolution/bandwidth)
18	Automated control of consignment	3	3	3	3	3	**3**	development effort for gesture-tracking (depth-sensor required)
19	Automated monitoring of advertisement displays	3	3	3	3	3	**3**	development effort for gesture-tracking (depth-sensor required)
20	Automated control of object state	3	3	3	3	3	**3**	development effort for object-identification (camera res./ bandwidth)
21	Automated control of hazardous goods	3	3	3	3	3	**3**	development effort for object-identification (camera res./ bandwidth)
22	Identify objects	3	3	3	3	3	**3**	development effort for object-identification (learning-engine for new object, angle of view)
26	Real-time traffic information (dynamic)	3	3	3	3	3	**3**	integration to Real-time-location system, data-privacy
29	Capture location	3	3	3	3	3	**3**	real-time-location system (Back-end)

Appendix E

The project consortium prioritized the use cases in respect to their technical feasibility and usefulness. To determine the usefulness, we conducted a personalized online survey among domain experts from the two company cases (21 participants), scientists (7 participants) and implementers for software solutions in logistics services (3 participants). First, a use case is described and illustrated with an example. Second, the participants rated two statements about the usefulness of each use cases on a 7-point Likert scale with the values 1 (strongly disagree) to 7 (strong voice over), as well as "not reasonably answerable": (1) *I rate the innovation content of this use case as high* and (2) *Assuming I had access to smart glasses, I would use them for this application*. The results are presented in Figure 10 .

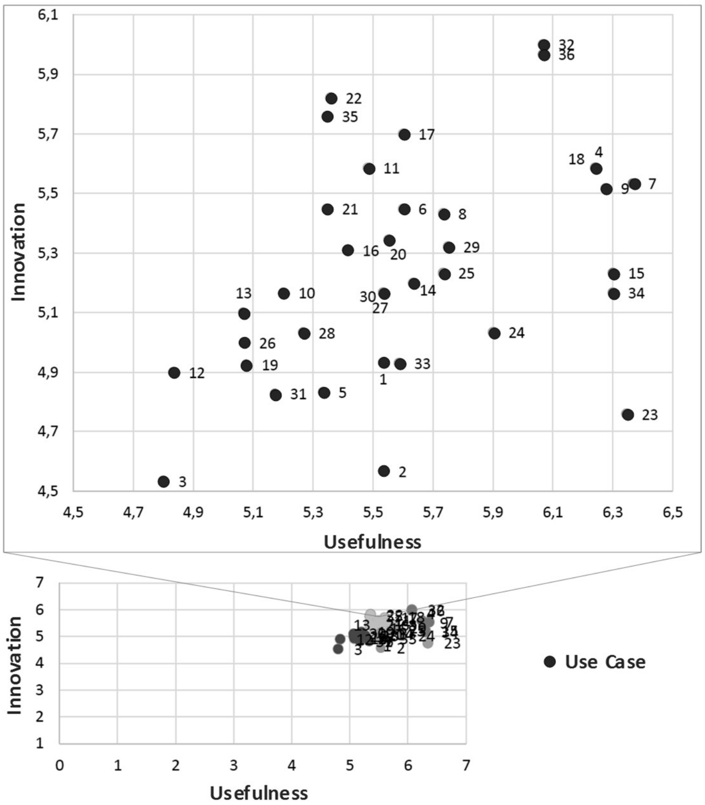

Figure 10: Usefulness and innovation of the 36 use cases

During the agile software development, we evaluated the prototypes with potential users. To evaluate the first prototype, the participants (N = 29) first tested the system and evaluated the acceptance and usability with an online questionnaire that is formed with an adjusted UTAUT (Zhou 2012) and the System Usability Scale (Brooke 1996) (cf. section 4.6). The results were used as feedback for the design and implementation of the target systems (research question 2). The UTAUT was analyzed applying location parameters, because the number of participants(cf. Oates 2006) was not high enough to apply a structural equation model. The data was distributed as stated in Figure 11. The usability, stated in Figure 12 was rated with a median of 60, while a good usability starts at 70. The evaluation of the first iteration implicated a lack of usability and acceptance. We utilized observations made during the experiment, to enhance usability and acceptance in the following design cycle.

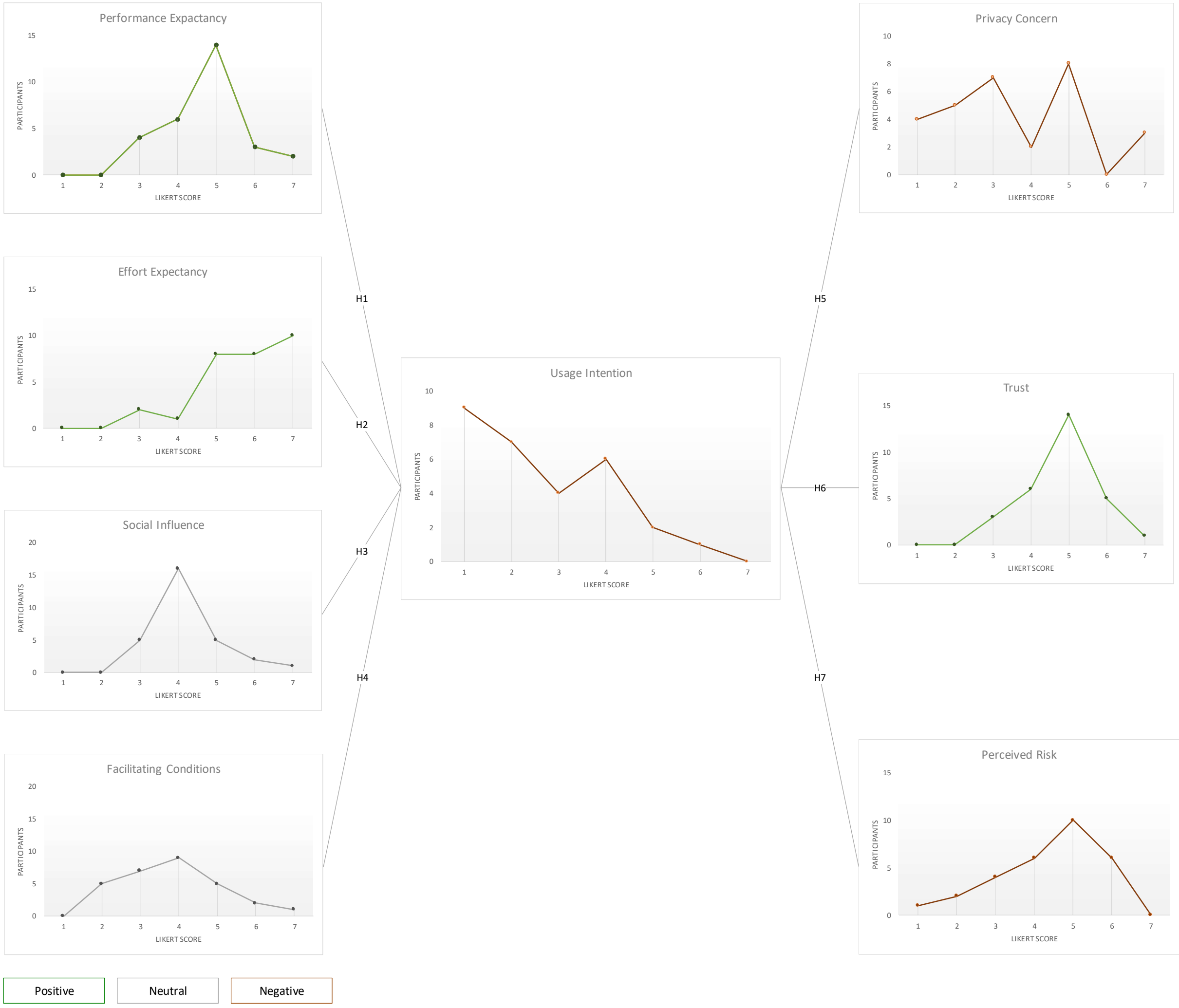

Figure 11: Results from the UTAUT based on Zhou (2012)

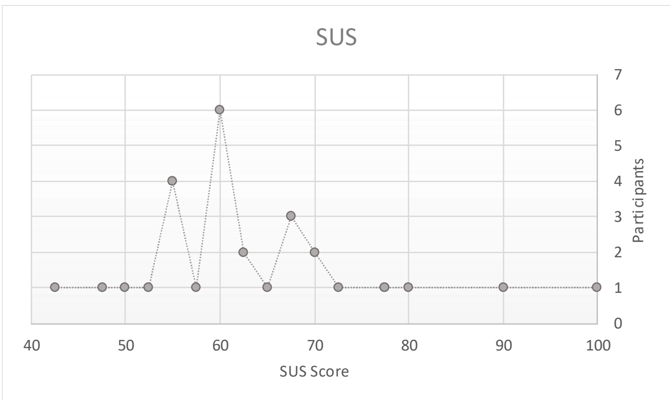

Figure 12: Results from the System Usability Scale

Appendix F

Our research was informed by other industries and our results were transferred via knowledge exchange with complementary research projects. Results from mobile process guidance systems for technical customer services (Matijacic et al. 2013) provided cross-technology insights. The project on mobile process guidance had analogies in that the elicitation of a use case catalog and requirements for mobile systems were generally shown (Däuble et al. 2015). The focus on process guidance was comparable, even though specific results could not be applied from smartphones to AR glasses.

Cross-industry results from the development of AR glasses-based systems for technical customer service (Metzger et al. 2017; Metzger et al. 2018) and health care (Klinker et al. 2017) were also transferred. The AR glasses-based system design in technical customer service was very useful for our implementation. It formed the basis to our approach as the system development on the same hardware and was completed at the same time we started our research. The elicited requirements were assimilable and we exchanged experience about the development of a sufficient architecture and system instantiation. This knowledge transfer was a valuable contribution, especially due to the positive results from an acceptance evaluation of the system (Niemöller et al. 2017a). An overview of the different sources of knowledge is given in Table 10.

Table 10: Sources of Knowledge

Source	*Domain*	*Knowledge/ experience transfer*
Metzger, D. and Niemöller, C. and Wingert, B. and Schultze, T. and Bues, M. and Thomas 2017	technical customer service	• applying design science research for AR glasses-based systems • system instantiation
Metzger et al. 2018	technical customer service	• applying design science research for AR glasses-based systems • research method (DSR) well suited for AR glasses-based systems • hardware proposal • system Architecture
Niemöller et al. 2017a	technical customer service	• acceptance evaluation • strategies for the collaboration and evaluation in the field • engage the user in the system design from the beginning
Matijacic et al. 2013	technical customer service	• mobile process guidance systems
Klinker et al. 2017	healthcare	• applying design science research for AR glasses-based systems • strategies for the collaboration and evaluation in the field • engage the user in the system design from the beginning
Däuble et al. 2015	mobile process guidance	• elicitation of use case catalogs for mobile systems • requirement engineering for mobile systems

Appendix G

For better traceability, Table 11 lists the 36 use cases of which two use cases serve as a foundation for the prototypes presented here. As we gathered various insights from systematic literature reviews, expert interviews, shadowing and through focus groups, the use cases come from different sources of evidence. We did not differentiate between first notices or later mentions, hence many use cases come from multiple sources. As some of the focus group sessions took place after having completed all other studies, most of the use cases were discussed in at least one of those sessions.

Table 11: Sources of Use Cases Matrix

Use Cases		**Data Sources**			
#	Name	Literature Review	Expert Interviews	Shadowing	Focus Groups
1	Monitoring / Process capturing	X	X	X	
2	Show monitoring analyses	X	X		X
3	Show reward symbols	X			
4	Prioritize employees by process metrics	X			X
5	Show current workload	X	X		X
6	Translate notifications and text	X			X
7	Show operating instructions				X
8	Support learning phase with instructions				X
9	Show inspection plan (VAS)				X
10	Support streaming				X
11	Guide working steps via remote control (Internal support)		X	X	X
12	Guide working steps via remote control (External support)	X			X
13	Support video communication with customers (VAS)	X	X	X	X
14	Document process execution	X	X	X	
15	Document damages	X	X		X
16	Recognize and show input errors				X
17	Support automated control functions	X			X
18	Automated control of consignment	X			X
19	Automated monitoring of advertisment displays				X
20	Automated control of object state				X
21	Automated control of hazardous goods				X
22	Identify objects	X		X	X
23	Scan barcodes and QR-codes	X		X	X
24	Show object information	X			X
25	Navigation instructions (static)	X	X	X	X
26	Real time traffic information (dynamic)	X			X
27	Show object related warnings and security notices	X	X	X	
28	Show process related warnings and security notices	X	X		X
29	Capture location	X			
30	Find object	X			X
31	Show information for stacking	X	X		X
32	Measure and document objects	X			X
33	Show optimal storage area				X
34	Show and control packing list				X
35	Show loading optimization				X
36	Automated inventory gathering				X

Appendix H

For the damage documentation process presented in this prototype (UC15), the nominal state is shown for each step, including individual images and a description (cf. Figure 13). The actual state of the locomotive is checked by the user based on the individual documentation steps. The user can flag deviations in each and every step including a picture-documentation. If an image was taken, the corresponding documentation step is marked as faulty, and the font color of the process step changes from white to red. The user is always able to jump from step to step, in order to mark them as faulty or damage-free.

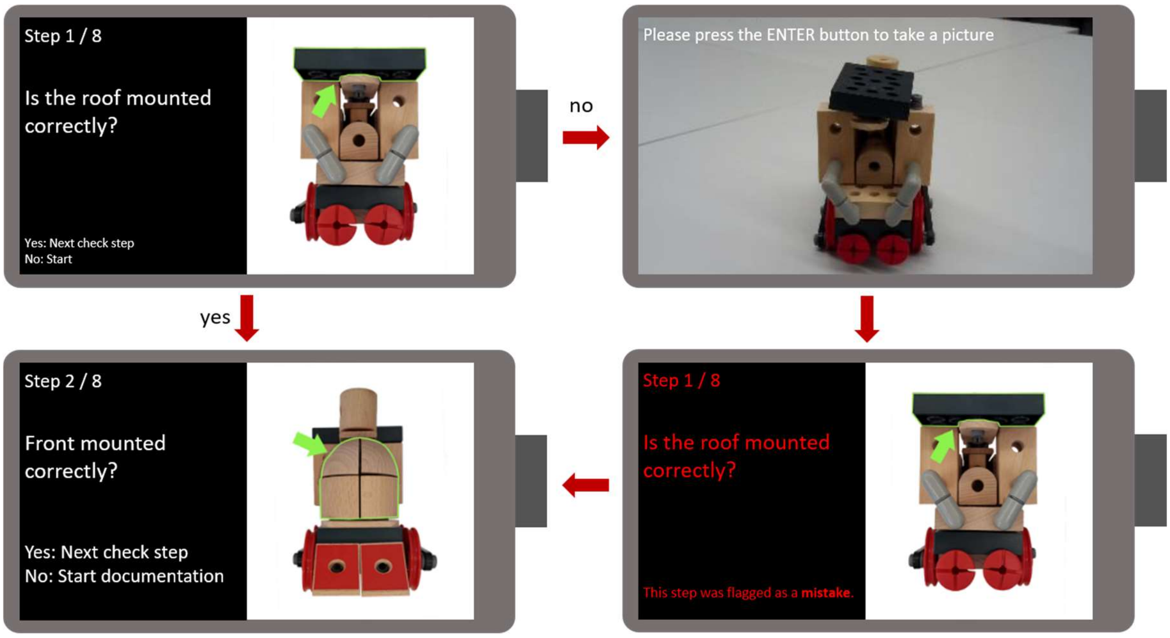

Figure 13: Workflow of the damage documentation system

Appendix I

To be able to comprehensively understand the impacts of innovative technologies, an approach that integrates practitioners' and academic perspectives is expedient. Addressing privacy and acceptance concerns in system design, we deduced solution components based on design problems we particularized from the two problem classes *privacy* and *technology acceptance*, presented in Figure 14.

To address privacy on the functional level, the developer must consider respective solution components for each technical functionality in the system design. Overall, the majority of functions are non-critical if deployed within a transparent system architecture, so the users are aware of which data is collected. Furthermore, the user is not the only focus of our systems. We also address co-workers and customers who get involved with users by solution components such as *(optical) alerts* during data collection.

Figure 14: Privacy solution components

The potential privacy intrusion of innovative technologies, combined with a lack of clarity in data collection and storage, are main acceptance barriers for users and others involved. Hence, we integrated the acceptance perspective into our system design consideration by incorporating solution components based on technology acceptance issues or barriers (Figure 15s). The design problems follow the concepts of acceptance as stated in the UTAUT (Venkatesh et al. 2003). Components such as *gamification* or *non-task related information*, e.g. meal plans or corporate news, aim to engage the user in the workflow. Furthermore, *usability tests* and *trial periods* focus on early user and stakeholder involvement. Nonetheless, these solution components must be designed according to privacy requirements and regulations, limiting components such as *gamification* in terms of data collection. Utilizing KPIs on a personal level according to the *transparent KPI system* in our components requires an agreement of those involved and should not be stored. It is also recommendable to implement such functions only for voluntary use.

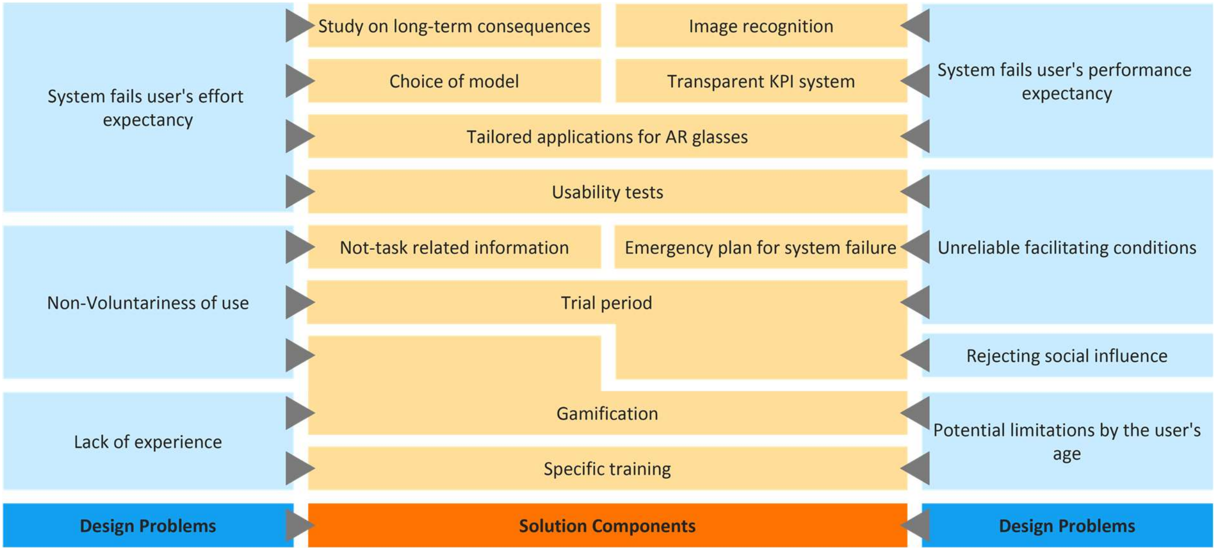

Figure 15: Acceptance solution components

Appendix J

Table 12 presents the main artifacts broken down by the four steps of evaluation design (Venable et al. 2016): (1) evaluation goals, (2) evaluation strategy (3) evaluation properties and (4) planning the individual episodes. We expanded the summary with the methods that were applied in the evaluation episodes.

Table 12: Evaluation of the artifacts following Venable et al. (2016)

Artifact	Goals	Strategy	Properties	Episodes	Method
Use case taxonomy	Generalization of use case catalogue	Quick and simple	Cross-industry use case taxonomy	1. Comparison 2. Abstraction 3. Aggregation	Focus groups (2 with researchers)
Architecture	Compliance	Quick and simple	Compliance with GDRP	4. Ex-post assessment 5. Expansion of privacy measures	Focus groups (3 with technical and domain experts)
(Meta-) Requirements	1. Acceptance 2. Privacy 3. Usability 4. Usefulness	Human risk & effectiveness	Design principles	1. Process modeling 2. Aggregation	3. Focus groups (3 with domain experts) 4. Prototyping 5. Deployment in control case company
Prototype UC 15	1. Acceptance 2. Feedback for implementation	Human risk & effectiveness	3. Acceptance requirement 4. Perceived privacy 5. Usability	2 Prototyping cycles	Laboratory survey (N = 29)
Prototype UC 9	1. User experience 2. Usefulness	Human risk & effectiveness	1. Acceptance requirements 2. Task suitability	3 Prototyping cycles	1. Laboratory test (N = 5) 2. Field test (N = 3) 3. Focus group (2 with domain experts)
Design Principles	1. Acceptance 2. Privacy 3. Usability 4. Usefulness 5. Ergonomic Design	Human risk & effectiveness	Feasibility	1. Application in prototyping after every evaluation 2. Abstraction after every implementation cycle	1. Experience from prototyping 2. Focus groups (6 with prototyping experts) 3. Focus group with 2 experts for AR implementation
Implementation Framework	Usefulness	Human risk & effectiveness	Projectability	1. Abstraction of the research process 2. Discussion	Focus group (1 with prototyping experts, 1 with other researchers)