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A REFERENCE ARCHITECTURE FOR A WORKFLOW MANAGEMENT SYSTEM FRONT END DESIGNED FOR AUGMENTED REALITY HEADSETS

Research Paper

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Abstract

A well-known approach to managing and controlling workflows in organizations is the workflow management system (WFMS). Recently, approaches utilizing augmented reality headsets as WFMS front ends have been discussed, enabling higher efficiency, effectiveness, and usability for certain application scenarios. However, existing design-oriented approaches lack tangible guidance for implementation. A well-known approach to address such knowledge gaps is a reference architecture, which inter alia reduces development times and risks and facilitates collaboration between developers. Based on an existing tentative design theory for an augmented reality-based WFMS front end, we contribute a reference architecture containing an extended design theory, user interface design, and UML models for use cases, components, classes, and sequence flows. The reference architecture was successfully operationalized in a prototype and positively evaluated via a survey of respective users.

Keywords: Augmented Reality, Workflow Management System, Design Theory, Reference Architecture.

1 Introduction

A well-known tool for collaboration, coordination, and communication within organizations is the workflow management system (WFMS) (Reijers *et al.*, 2016). Modern implementations of WFMS have evolved much from older understandings as "organizationally aware groupware" (Ellis, 1999). Still, the well-known definition by the Workflow Management Coalition (1995) of a WFMS as a system that defines, interprets, instantiates, and manages the execution of workflows with software, integrates external applications, and interacts with human workflow participants, still applies (Damarowsky and Kühnel, 2022). Recently, approaches have been discussed to interact with WFMSs by using augmented reality (AR) technology, which combines and aligns real and virtual objects with the real environment for users to interact with in real-time (Azuma *et al.*, 2001). A wide array of applications is discussed, e.g., spatial AR for healthcare (Böhmer *et al.*, 2022), assembly (Wang *et al.*, 2016b), or medical operations (Katić *et al.*, 2013). Although a large empirical base has not yet been established, existing evidence suggests tangible benefits of AR-based workflow execution support, e.g., with AR task instructions. Increased task efficiency, i.e., reduction of error rates, execution times, cognitive loads, or required training, was observed in the domains of collaborative planning, assembly, service, maintenance, warehouse picking, process training, and process modeling (Hanson *et al.*, 2017; Lampen *et al;* Seiger *et al.*, 2021; Jetter *et al.*, 2018; Sääski *et al;* Hofmann *et al.*, 2019; Wang *et al.*, 2016a).

While these AR-enabled task efficiency gains benefit organizations and employees alike, the management and control of workflows via WFMSs is another vector for improvement, i.e., using AR to enhance WFMS front ends. Recent research, however, shows that contemporary approaches only enable very limited and isolated workflow management and control functions (Damarowsky and Kühnel, 2022) e.g., advancing backward and forward through a workflow's tasks or switching to a task of a different workflow (Berkemeier *et al.*, 2019; Mourtzis *et al.*, 2019; Makris *et al.*, 2013). In contrast, the well-known reference architecture (RA) for WFMSs by the Workflow Management Coalition describes a much greater variety of workflow control and management functions, e.g., instantiating, pausing, canceling, and generating filtered lists of workflow instances (Workflow Management Coalition, 1995).

To address this research gap, we followed a design science research (DSR) approach (Vaishnavi and Kuechler, 2015) to develop *HoloWFM*, a WFMS front end designed for AR headsets that supports the entire range of WFMS user interactions, as defined for a workflow client application in the WFMS RA by the Workflow Management Coalition (1995). We developed and evaluated a tentative UI design and design theory (DT), consisting of 4 design requirements (DR) and 9 design principles (DP) (Damarowsky and Kühnel, 2022). However, a summative evaluation with two focus groups revealed a new user requirement for HoloWFM, the seamless integration of AR task support with the HoloWFM application, which we could not properly address without first understanding the software architecture necessary to operationalize a HoloWFM. To systematically bridge this abstraction gap between abstract DT and specific software prototypes and thus properly address the newly raised user requirement, we initiated a second DSR cycle (Vaishnavi and Kuechler, 2015; Meth *et al.*, 2015). This cycle aims to develop an RA for HoloWFM, including, inter alia, an extension of the DT with less-abstract design features and multiple UML class diagrams. By chaining the operationalizable UML diagrams upwards to the increasingly abstract DFs, DPs, and finally DRs, we systematically bridge the abstraction gap and thus can properly address the raised user requirements in the abstract DPs. Also, well-known advantages of RAs, e.g., reduced development time, risks, and improved collaboration via a better common understanding of problem domains, systems, and software (Cloutier *et al.*, 2009; Martinez-Fernandez *et al.*, 2015; Nakagawa *et al.*, 2011), become available for HoloWFM developers, which profit less from the DT than IS and AR researchers. Consequently, we define our research question (RQ) as:

RQ: *What are the models, model elements, and textual descriptions of a system reference architecture for a workflow management system front end designed for augmented reality headsets, providing the full range of workflow user interactions?*

To answer the question, we implement a second design cycle, whose methodological foundations are described in Section 2. In Section 3, we briefly discuss the theoretical background of RAs. The main contributions of this paper are presented in Section 4: a reference architecture description, including an extended DT and multiple UML diagrams. In Section 5, we present the evaluation of the results, including a prototype instantiation. We elicit the implications of our results for theory and practice in Section 6. Finally, Section 7 concludes this article and reflects on our research.

Our study shows that's it possible to implement a WFMS front end with comprehensive functionalities in an AR headset. We thus extend the IS community's prescriptive knowledge base by providing abstract and tangible design knowledge for this novel type of WFMS front end. Methodically, we demonstrate how to bridge the abstraction gap between DTs and software architectures and utilize the system architecture description standard ISO/IEC/IEEE 42010:2011 to document the design knowledge. The operationalizable HoloWFM RA supports especially AR practitioners during development.

2 Research Method

We continue the DSR approach in Damarowsky and Kühnel (2022), which is based on Vaishnavi and Kuechler (2015) and involves five steps: awareness of problem, suggestion, development, evaluation, and conclusion. Compared to alternative DSR approaches (cf. Venable *et al.*, 2017b), the framework by

Vaishnavi and Kuechler (2015) explicitly focuses on the development of theoretically sound DRs and DPs to guide IS development, as these DRs and DPs are the unconditional prerequisites for an RA (Oussalah, 2014). The research approach features two design cycles, each addressing the five steps of Vaishnavi and Kuechler (2015) (Figure 1).

The first cycle was dedicated to the gathering of DRs and conceptualization of a tentative DT. A complete DT is constituted of two types of elements: DRs and DPs, which together embody a general design solution for a class of problems (Baskerville and Pries-Heje, 2010). The DRs describe the general objectives of the DT and function as meta-requirements for the software artifact (Baskerville and Pries-Heje, 2010; Walls *et al.*, 1992). The DPs can be descriptive or – as for HoloWFM – prescriptive, stating how an artifact should be instantiated to fulfill the DRs (Fu *et al.*, 2016). To support the prototype development we followed the *supportive approach* by Möller *et al.* (2020) and defined the DPs prior to development instead of deriving them from the development (*reflective approach*).

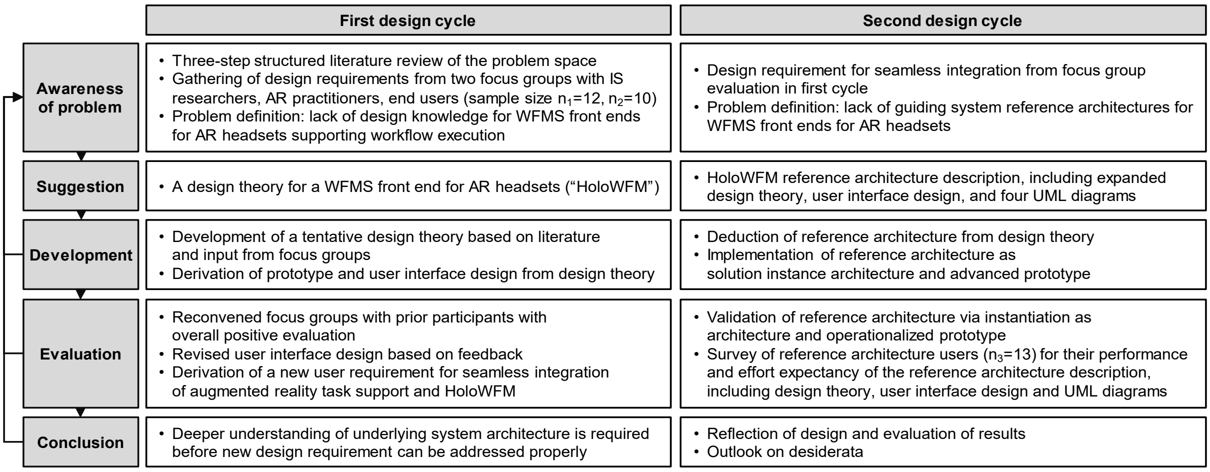


Figure 1. Design Science Research Cycles for HoloWFM.

As we concluded in the evaluation of the first cycle, to rigorously address the newly raised user requirement for seamless integration of AR task support and the HoloWFM application, a deeper understanding of the system architecture is required applies (Damarowsky and Kühnel, 2022). Consequently, the second design cycle addresses this challenge by presenting an RA for a WFMS front end designed for AR headsets that provides the full range of workflow user interactions. Thus, the RA addresses the question of how to successfully implement a HoloWFM, which was raised at the end of the first design cycle. We interpret the user requirement for seamless integration of AR task support and the HoloWFM application, raised in the evaluation of the first design cycle, as a DP rather than a DR, as this will enhance user satisfaction (DR1) and efficiency (DR2) of a HoloWFM. As part of the suggestion phase in Section 4, we consequently update the original DT with an additional DP.

To provide reference design knowledge on how to instantiate the DPs into a software artifact, we also derive design features (DFs) to address the established DPs. Even though it is not a required part of a DT (cf. Baskerville and Pries-Heje, 2010), DFs can be utilized to document how DPs could be implemented in a specific instance (see, e.g., Meth *et al.*, 2015, Böhmer *et al.*, 2022). The DFs then serve as a foundation to systematically develop UML diagrams and textual descriptions for the RA, in line with the supportive approach by Möller *et al.* (2020), followed in the first design cycle.

3 Theoretical Background: Reference Architectures

An RA is an architecture that distills the essence of existing architectures for a certain problem domain and provides a template and guidance to develop solution architectures for specific problem instances in the same domain. As the *problem instance environment* differs, e.g., for different companies, the RA gets adopted into a unique *solution instance architecture*, also based on the specific *stakeholder* *requirements*, e.g., end-user requirements. The solution instance architecture then finally gets implemented into a *solution instance system* (Figure 2) (Cloutier *et al.*, 2009; Martinez-Fernandez *et al.*, 2015; Nakagawa *et al.*, 2011; Oussalah, 2014). An RA can contain multiple elements, e.g., models, figures, or text. When utilized for collaboration, an RA can improve the common understanding of problem domains and systems by providing a common lexicon and terminology. Important concepts are clarified. Functions and qualities above the system level, the relevant context, and consequent design decisions are documented to foster a common understanding and ease the application of the RA for specific problem scenarios. With improved communication, interoperability between systems and organizational units can improve as well. The RA itself facilitates a common architectural vision by functioning as a focal point for information exchange, which in turn focuses and aligns the efforts of multiple people and teams. As RAs capture past experiences, lessons learned, and best practices, their utilization generally reduces development risks and time, helps spread best practices, and can serve as instruments of knowledge management in organizations (Cloutier *et al.*, 2009; Martinez-Fernandez *et al.*, 2015; Nakagawa *et al.*, 2011; Oussalah, 2014).

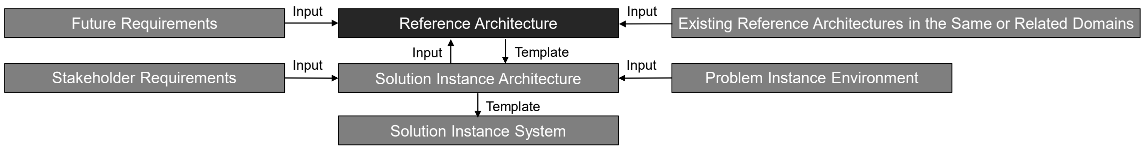


Figure 2. Reference architecture inputs. Based on OASD/NII (2010), Cloutier et al. (2009).

A standard for describing architectures is provided by ISO/IEC/IEEE 42010:2011(E) *Systems and software engineering — Architecture description* (ISO, 2011). Hence, a RA description (RAD) should include: 1) a RAD identifier ("HoloWFM reference architecture"), 2) overview information, 3) the RADs stakeholders and their concerns, 4) a definition for each RA viewpoint, i.e., the target audience's perspective, in the RAD, 5) exactly one RA view for each defined RA viewpoint, possibly containing multiple models, 6) RAD correspondence rules, RAD correspondences, and known inconsistencies among the RAD's content, and 7) rationales for architecture decisions made. These components are presented in Section 4 in the above order. Notably, ISO/IEC/IEEE 42010:2011(E) does not specify which models or modeling languages must be utilized to constitute an RA view. Therefore, DTs, reference UI designs, and UML diagrams are appropriate contents for an RA view.

As we found in an extensive structured review of the literature in Damarowsky and Kühnel (2022), no RA for a HoloWFM is available. Additionally, very few architectures are provided by recent studies for AR-based IS supporting workflow execution, management, or control. Of these, most are highly abstract or do not utilize documentation and modeling standards (e.g., Barenkamp and Niemoller, 2020; Berkemeier *et al.*, 2019; Wang *et al.*, 2016a).

4 Reference Architecture Description

4.1 Identification and Overview information

The purpose of the "HoloWFM reference architecture" is to support HoloWFM developers, i.e., IT and AR architects and developers, in designing and building a HoloWFM. A HoloWFM aims to enable end-users to manage and control workflows, e.g., to generate filtered lists for specific workflows and workflow tasks, to control the status of workflows, or to interact with the user tasks by filling out forms and checkboxes or reading information. These management and control functions are provided for end users during the usage of AR headsets, and therefore the UI of HoloWFM is entirely presented with AR elements. To enhance the user experience, efficiency, and effectiveness of HoloWFM, it is designed to be context-aware, i.e., it reacts to contextual environmental information, e.g., a user's location or when a certain object is in the headset camera's field-of-view. To process this context, information *context reasoning workflows* are defined by administrators.

4.2 Stakeholders and Stakeholder Concerns

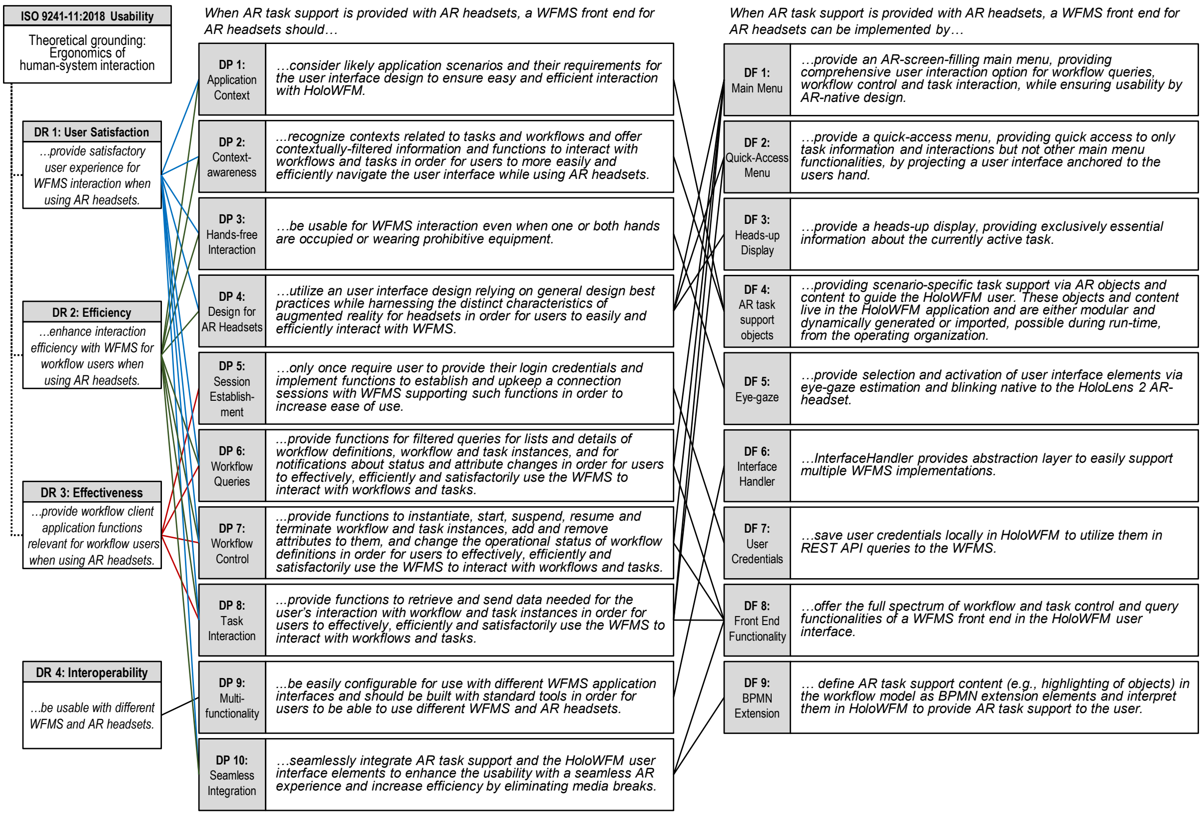
Two stakeholders are of preeminent importance to the HoloWFM RA. First and directly, HoloWFM developers, i.e., IT Architects, software, and AR developers, are concerned with the RA, as it should support them in developing and deploying a HoloWFM instantiation in real organizations. Therefore, we evaluate the expected effort for and performance of HoloWFM with a corresponding target audience in Section 7. The second important stakeholders are HoloWFM end users. Their concerns refer to the efficiency, effectiveness, and usability of HoloWFM, as our qualitative studies in the first design cycle found and are systematically addressed by the DT, DP, and DF, respectively.

4.3 Reference Architecture Viewpoint "HoloWFM Developer" Definition

Consequently, the herein-considered RA viewpoint is that of the *HoloWFM developer*. This viewpoint is concerned with guidance provided by the RA during the actual design and development of a HoloWFM instantiation for an organization. Abstract design knowledge is helpful as it can apply to many different organizations. DTs are, therefore, appropriate in this viewpoint. Tangible architectural knowledge, however, is also important to shorten and ease development cycles (cf. Section 3). Hence, UML diagrams in lower levels of abstractions are appropriate for the *HoloWFM developer's* viewpoint.

4.4 Reference Architecture View "HoloWFM Developer"

4.4.1 Extended Design Theory for HoloWFM



Note. AR = augmented reality, API = application interface, BPMN = business process model and notation, REST = representational state transfer, WFMS = workflow management system.

Figure 3. Extended design theory.

To formalize the update to our tentative DT from the first design cycle and to bridge the gap in abstraction between DPs and an RA, we add one DP and nine novel DFs to the original DT. For an in-depth explanation of the original DT, see Damarowsky and Kühnel (2022), pp. 4-6. The complete DT, with the names and short descriptions of the DRs, DPs, and DFs is depicted in Figure 3.

First, **DP 10** *Seamless Integration* addresses both user satisfaction and efficiency by ensuring that the task support via AR content and the AR UI of HoloWFM are integrated such that no media breaks occur, i.e., the same application provides the HoloWFM UI and task support. In contrast, an alternative approach could start or send a message to a second application in the AR headset, which – after the user switches applications – provides the appropriate task support. Second, to lower the level of abstraction, provide an example instantiation, and systemically derive the RA from, we define a set of DFs. To operationalize DP 4 for an AR headset-native design and provide workflow management and control functionalities (DP 6-8), we propose a *main menu* (**DF 1**), *quick-access menu* (**DF 2**), and *heads-up display* (**DF 3**). The consideration of the relevant application context (DP 1) is inherently realized in *AR task support objects* (**DF 4**), which are also context-aware (DP 2). As the Microsoft HoloLens offers native *Eye-gazing* (**DF 5**) features, we define this solution to operationalize DP 3 for one-handed and hands-free modes of interaction. To maximize interoperability with different WFMS and AR headsets, we utilize an *Interface Handler* (**DF 6**) as an abstraction layer for WFMS functions. To enable session establishment (DP 5), the *User Credentials* (**DF 7**) can be saved in HoloWFM. Since not all UI elements in DF 1-3 enable all functionalities, we define **DF 8** to ensure full *WFMS Front End Functionality*. In addition to DF 8, we utilize a *BPMN Extension* (**DF 9**) to realize the seamless integration of AR UI and AR task support. In particular, workflow elements link to AR task support content via BPMN extension elements. The AR task support objects themselves live in the HoloWFM application.

4.4.2 Reference UML Use Case Diagram

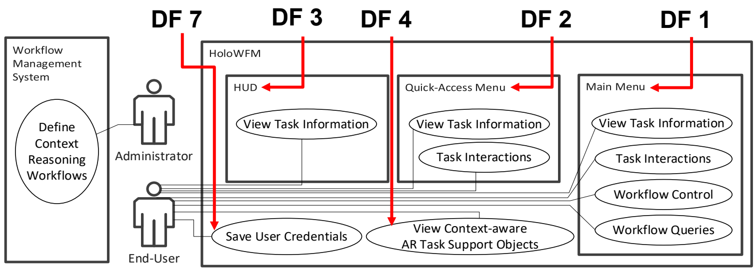


Figure 4. Reference UML use case diagram, with corresponding design features indicated.

The use case diagram depicted in Figure 4 visualizes how two roles, *administrators* and *end users*, can interact with HoloWFM. Their possible actions refer to the DFs and subsequently also to the DPs. DFs 5 and 6 don't apply to the use case diagram. *Administrators* also define context reasoning workflows, i.e., workflows that calculate how to process identified contextual environmental information. Interactions of the *end user* with the organization's workflows aren't depicted.

4.4.3 Reference User Interface Design

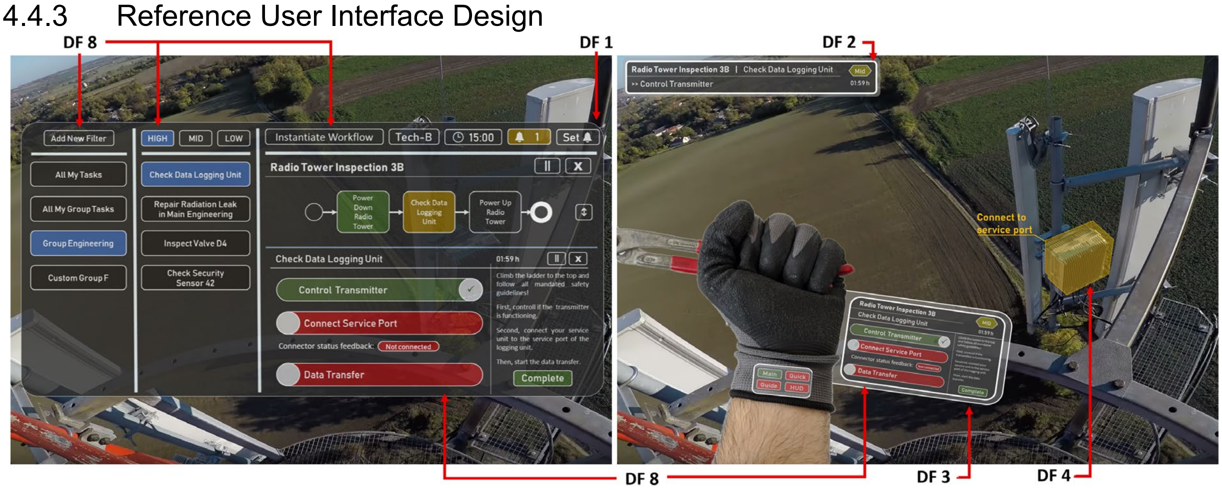


Figure 5. Reference design for main menu (5a), heads-up display, and quick-access menu (5b).

Figure 5 depicts the reference UI design (Damarowsky and Kühnel, 2022) and the corresponding DFs. The DFs 5-7 and 9 don't apply to the UI design. In Figure 5a, the main menu offers two levels to filter tasks on the left and a full, more detailed view of the currently selected user task on the right. In this menu, the user can also switch tasks or workflows and access advanced management and control functions. In Figure 5b, the heads-up display is depicted in the upper left corner, visualizing some minimalistic information about the currently active task. Attached to the wrist and hand is the quick-access menu, which provides users with task interactions and access to the main menu. The context-aware recognition and highlighting of an object identified as relevant for the action "connect to service port" (visible in the quick-access menu) is shown on the right.

4.4.4 Reference UML Component Diagram

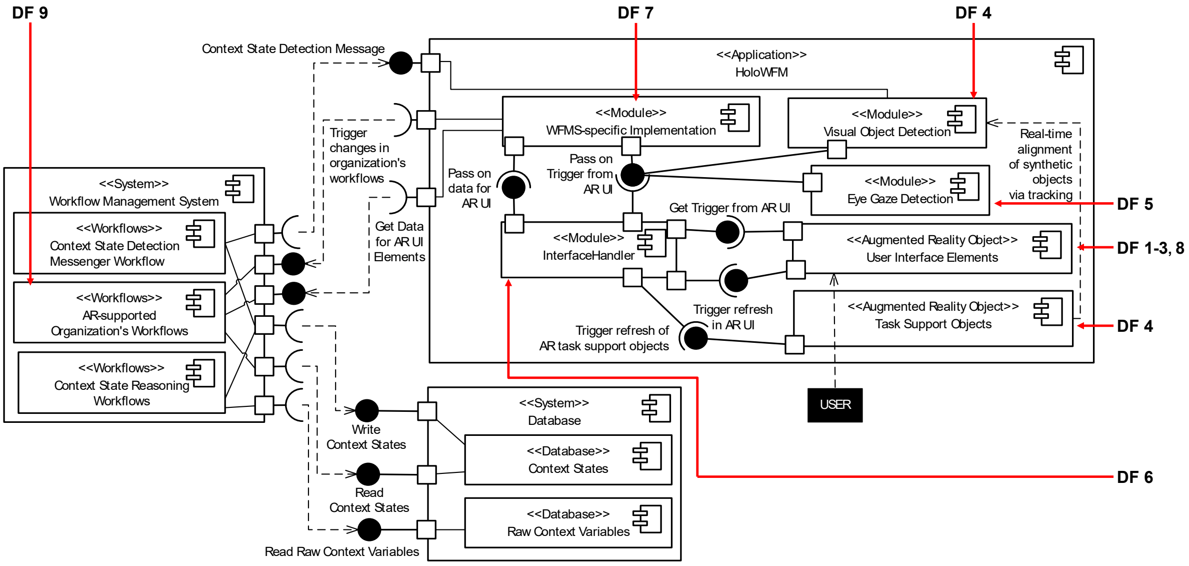


Figure 6. Reference UML component diagram, with corresponding design features indicated.

The component diagram and corresponding DFs are depicted in Figure 6. It contains three systems: 1) a WFMS, 2) a database system, and 3) the HoloWFM application. The database system contains two databases for a) *raw context variables* directly from the sensors. e.g., a temperature data point of 42° Celsius ("42"), and b) *context states*, which are calculated from the raw context variables, e.g., "hot" or "cold" (cf. DP 2). The organization's data, e.g., for workflows, is not depicted. The WFMS contains three sets of workflows. Reading from the database's *raw context variables* are the *context state reasoning workflows*, which calculate context states from the raw data and write these to the *context states* database accordingly. Reading from the context states are the *AR-supported organization's workflows*, i.e., the organization's workflows that are supported with AR and are managed and controlled via HoloWFM. These workflows utilize BPMN extension elements to link corresponding AR *Task Support Objects*, e.g., object highlights. The third type of workflow is the *context state detection messenger workflow*, which is triggered by the *visual object detection* module of the HoloWFM application. E.g., when a certain object is within the field-of-view of the headset camera, the context state "objectVisible" is set to 1 in the context state database. The visual detection module might be natively implemented in the utilized IDE, e.g., *Unity*. The organization's workflows also interact with the *WFMS-specific implementation* module of HoloWFM, which can trigger changes in workflow definitions and instances, and read data from these for display in the AR-based UI of HoloWFM. The *WMFS-specific implementation* contains all the methods, data formats, and communication protocols necessary to communicate with specific WFMSs, e.g.*, Camunda (see Figure 8)*. Abstracting from these implementations is the *interfaceHandler* module. Leaning on the Model-View-Controller software architectural pattern, the *interfaceHandler* sends triggers from and receives data for the AR UI from the

WFMS-specific implementations and receives, and vice versa sends them to the *user interface elements*. It also triggers refreshes of AR *task support objects*, which are not part of the UI but, e.g., highlight task-relevant objects directly. These objects are also tracked with the visual object detection module to align AR objects in real-time. The *interfaceHandler* thus integrates the user experience of AR task support objects and HoloWFM UI, addressing DP 10 raised at the end of the first design cycle. Finally, the end user's points of contact with HoloWFM are the AR-based UI elements.

4.4.5 Reference UML Sequence Diagram

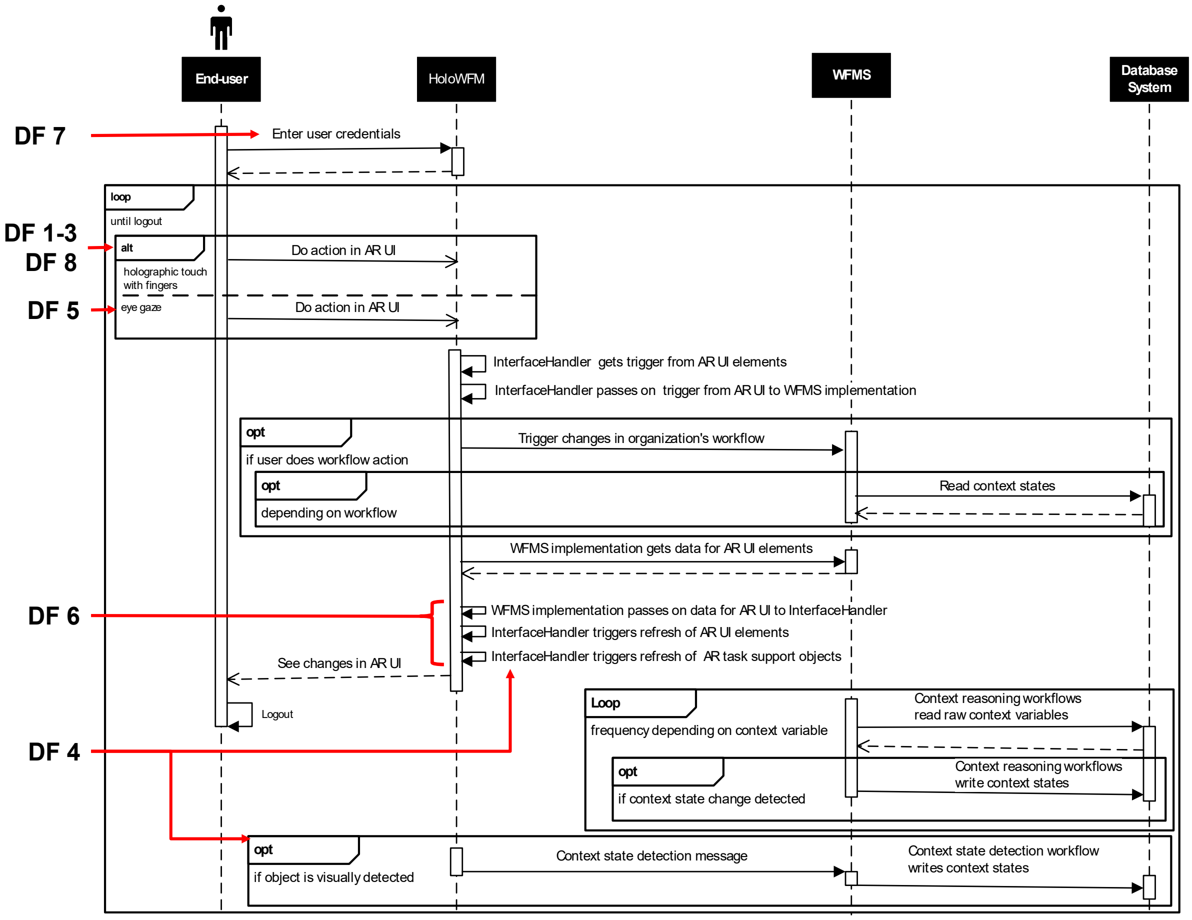


Figure 7. Reference UML sequence diagram, with corresponding design features indicated.

The UML sequence diagram in Figure 7 depicts the flow of information and actions between those components logically and chronologically, which have been depicted as a static UML component diagram in Figure 6. The main action starts with the end user's lifeline, interacting with the AR UI either via holographic touch or eye gaze (first *alt* box). Afterward, HoloWFM processes the input and may forward the user’s actions to the WFMS or read from the database system. After processing possible responses, HoloWFM finally updated the AR UI for the end user. Independently from these user interactions, a loop runs to read and check for updates of the context variables and states (small *loop* box). Also, if the sensors of HoloWFM recognize a known object, a context state might be changed for that (last *opt* box).

4.4.6 Reference Simplified UML Class Diagram

Figure 8 shows the UML class diagram for HoloWFM, with the corresponding DFs, but no methods for attributes for the classes to enhance comprehensibility. The *InterfaceHandler* class acts as an abstraction layer between *AR UI elements* and is attached to the *Unity scene*, where the AR-based task support objects are also implemented for activation. Also, the eye-gazing module is implemented natively in Unity. For each UI component (cf. Section 4.4.3), custom data types are defined. The *interfaceHandler* thus controls, interacts with, and handles the UI and the users' inputs, independently of the WFMS used with HoloWFM: The functionalities of the UI are defined abstractly in *IWFMSMethods*, according to DP 6-8 or DF 8, e.g., starting workflows. This is necessary since every specific WFMS implements these UI functionalities differently and the *interface* IWFMSMethods acts as a contract with the WFMSs to be fulfilled. Because of this necessary abstraction layer, several abstract classes for tasks, workflow instances, workflow definitions, and respective filters are also defined, containing methods and attributes every WFMS must fulfil in order to be compatible with HoloWFM. A WFMS then operationalizes these abstract classes in its *WFMS-specific* manner. For our prototype, we implemented the interface IWFMSMethods and the abstract classes for Camunda 7.15, as shown at the bottom.

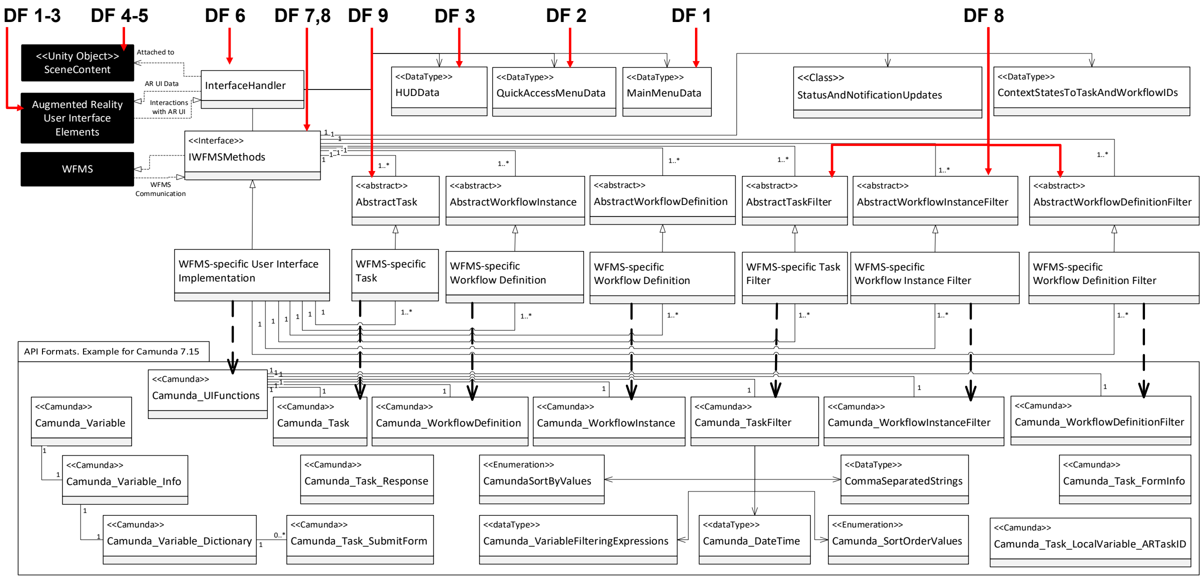


Figure 8. Reference UML class diagram for HoloWFM, with example implementation (bottom).

4.5 Reference Architecture Description Correspondences

The names of elements in the UML diagrams are instructive, i.e., the names and relationships correspond between models. E.g., the *InterfaceHandler* in Figure 6 indicates the same object as in Figure 8.

4.6 Rationales for Architectural Decision

Three key design decisions may be of interest. First, regarding the abstraction layer between UI and WFMS constituted by the *InterfaceHandler* class and *IWFMSMethods* interface. We chose not to include WMFS-specific implementations of methods in the *InterfaceHandler.* Instead, it selects and calls the appropriate *WFMS-specific User Interface Implementation* and passes any parameters to the WMFS-specific implementation of the method. This was done to enhance maintainability and enable better parallel development for multiple WMFS implementations.

Second, we chose to outsource the storage and processing of the *raw context variables* and *context states* from HoloWFM to the *database system* and *WFMS*. This was done to support cases where the amount of context variables collected becomes very large. In these cases, context-state reasoning workflows might also utilize further IT services, e.g., machine learning modules. To enable optimal performance, the context reasoning system was therefore entirely outsourced from the HoloWFM application.

Third, we utilize BPMN extension elements to refer to and pass on parameters to appropriate AR task support objects, which may be stored or dynamically generated in Unity. An alternative approach we explored was to somehow embed AR task support objects directly in the XML underlying the BPMN model. However, this would massively increase the size of the BPMN models and would make them and the AR objects harder to maintain. Instead, in our approach, the AR task support objects need to be somehow imported into the HoloWFM application, in the particular the *Unity scene*. This import could be done during build-time, however, this would require a new build of HoloWFM for each change in AR workflow support. As such, parallel distributed work would be a difficult thing. A better approach, therefore, is to dynamically load or preload AR task support objects into HoloWFM during runtime. Thus, no update of the HoloWFM application itself is needed. The AR task support objects then can be built in a distributed fashion alongside their respective workflows.

5 Evaluation

5.1 Evaluation Strategy

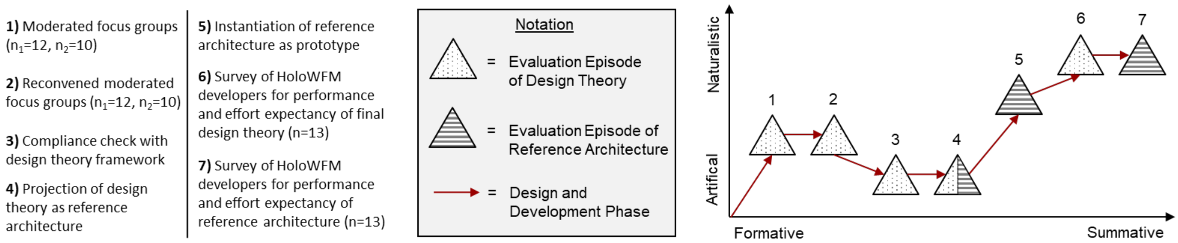


Figure 9. *Evaluations mapped to the evaluation framework by Venable et al. (2017a).*

Our overall evaluation strategy follows the framework for evaluation in design science research (FEDS) (Venable *et al.*, 2017a) (see Figure 9). As the goal of the research project was to develop tangible design knowledge for a HoloWFM, the goal of the evaluation was to ensure the utility of the developed DT and RA in real practice, i.e., the developed RA must both be correct and useful for the RAs users: IS and AR architects, practitioners, and researchers. Also, while instantiating a prototype to demonstrate the technical feasibility is relatively cheap, an extensive evaluation with a "polished prototype", e.g. with a high-quality UI, in a real setting with real users would be prohibitively expensive. Therefore, the *Technical Risk & Efficacy* strategy of the FEDS is appropriate for our research project. Three evaluation phases were already performed in the first design cycle, which focuses on the end users. First, two moderated focus groups (MFG) (n_1=12, n_2=10) (Morgan, 1997) established the DRs for HoloWFM. Second, two reconvened MFGs with the same participants (Morgan *et al.*, 2008) confirmed the quality of the tentative DT and UI design. Third, the DT was formally verified by checking its compliance with the framework for DTs by Jones and Gregor (2007). We add to these evaluations with a validation of the DT via projection as an RA, a test of the RA's feasibility via operationalization as a prototype, and evaluations of the RA and DT by HoloWFM developers (n=13).

5.2 Evaluation of Design Theory via Projection as Reference Architecture

We understand the derivation of the RA from the DT in terms of the conceptual framework of *projectability* by Goodman (1955), as recommended by Baskerville and Pries-Heje (2014). According to this, a DT is *actually projected* when it's instantiated. When this *projection* is successful, i.e., no observation in opposition to the DT is made, but not all possible instantiations have been examined, a DT is *projectable*. The more frequently a DT is actually projected, the more entrenched it becomes (Goodman, 1955, pp. 80–81). We, therefore, demonstrated the projectability of the DT by deriving an RA from it as an actual projection. Also, as Fu *et al.* (2016) find, the majority of publications containing DPs lack their validation. By developing the RA, we not only address this common shortcoming but also are in line with other approaches to validation, as by far the most common validation principle is the application of the DPs for the actual design of an artifact (Fu *et al.*, 2016, p. 8).

5.3 Feasibility of Reference Architecture via Operationalization

To evaluate whether the developed design and derived RA are *feasible*, we orient ourselves on the framework by Sonnenberg and Vom Brocke (2012) and perform *evaluation activity 3* via a *demonstration with a prototype* (Sonnenberg and Vom Brocke, 2012, p. 393). We utilized the WFMS *Camunda*, a *MySQL* database, and a *Unity* application running on the *Microsoft HoloLens*. In our prototype, we focused on demonstrating the feasibility of the architecture to ensure utility for *HoloWFM developers*, i.e., if the approaches to structure the components, classes, and sequence logic work. We hence did not implement the full reference UI. In Figure 10 on the right, a tasklist filter for user-specific user tasks via the Camunda API demonstrates the use case "workflow queries" (cf. Figure 4) and displays them as pushable buttons. In the center, a user task is shown with the rendered HTML that Camunda would send to a web browser. The user task is also shown to be moveable. In contrast, the left image shows some AR UI elements, which correspond to workflow variables that are gathered from and sent to the WFMS for an update when the task is completed ("Task beenden"). The text in German is a meaningless placeholder for some task instructions.

Figure 10. Prototype user task with UI elements (left), in HTML (centre) and tasklist (right).

5.4 Summative Evaluation of Performance and Effort Expectancy of Design Theory and Reference Architecture

To ascertain the usefulness of the RA and DT in more general terms, we evaluated the RA's and DT's *performance expectancy* (PE) and *effort expectancy* (EE) via surveying potential HoloWFM developers, i.e., IS and AR architects, developers, and researchers. As PE and EE as constructs are not directly measurable, we drew on the well-known scale items by Venkatesh *et al.* (2003). These are, for PE: usefulness (PE1), quickness (PE2), productivity (PE3), and increased chance of getting a raise (PE4); for EE: clarity (EE1), easiness to master (EE2), easiness to use (EE3), and easiness to learn (EE4). We specified the PE and EE for our application context, i.e., for the development of a WFMS front end for AR headsets. Additionally, we asked the experts about the conciseness (CON), extendibility (EXT), and explanatory power (EXP) of the artifacts, following Nickerson *et al.*'s (2013) approach to subjective ending conditions from their well-known taxonomy development method.

The questionnaire included: 1) an introductory text about the research project, 2) the DT, 3) a prompt to imagine an application scenario for the DT, 4) the statements on the EE, CON, EXT, and EXP, 5) the RA's UML models and descriptions, 6) a prompt to imagine an application scenario for these, 7) the statements on the PE, EE, CON, EXT, and EXP, and 8) some socio-economic questions. For data collection, we used interval-scaled verbal-numeric 7-point Likert-style scales. In choosing the sample size, we considered the so-called "10±2 rule" (Hwang and Salvendy, 2010), which suggests that 8 to 12 respondents are sufficient for our evaluations. Based on an expected response rate of 50 %, we sent the questionnaire by email to a total of 24 experts, whom we identified within our research institute's network as potential HoloWFM developers based on their profession and industry. We received 13 completed questionnaires (actual response rate: 54.2 %). The sending and receiving of the surveys were not done by the authors, and the responses were anonymized before being sent to the authors. The respondents partially fulfilled multiple professional roles and included 1 project manager, 5 project leads, 6 research associates, 3 senior researchers, 2 multimedia developers, and 1 usability engineer, all active in the workflow and AR domain, possessing 1-15 years (median: 3.5, mean: 4.88) of experience in their roles. Among the experts, eleven work in large, and two in micro-sized companies/organizations.

Figure 11 depicts the boxplots of the responses. For both the DT and RA, we received high levels of agreement for all items, with medians of m=6 and m=7. Thus, the sum scores of the PE and EE for the DT and RA with medians of m=26 and m=25 on a 7-28 scale summarize the overall evaluation well.

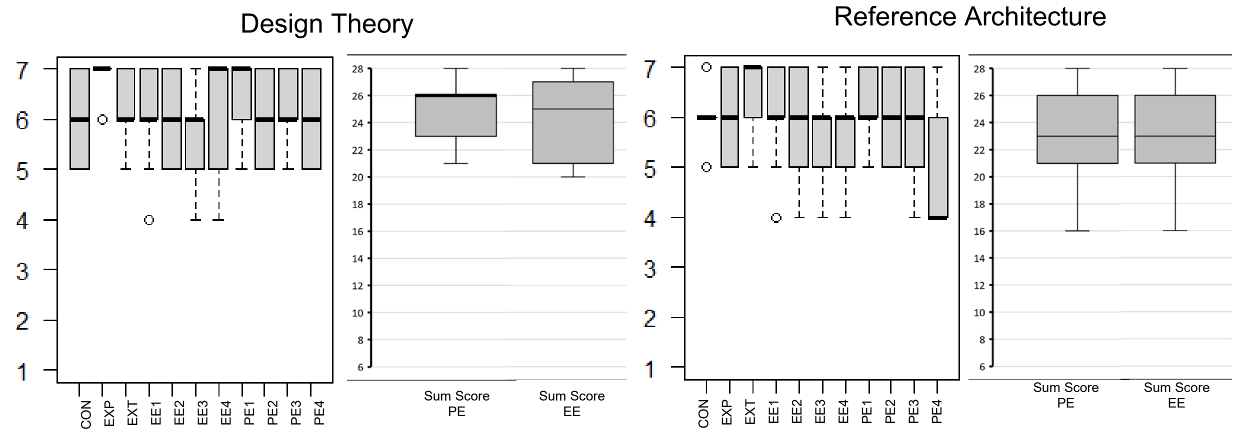


Figure 11. Boxplots for design theory and reference architecture evaluations.

Performance Expectancy		Design Theory	Reference Architecture	**Effort Expectancy**		Design Theory	Reference Architecture
Loadings	Usefulness	.554	.712	Loadings	Clarity	.582	.662
	Quickness	.998	.717		Easy to Master	.664	.585
	Productivity	.871	.998		Easy to Use	.655	.904
	Chance of Raise	.426	.435		Easy to Learn	.940	.998
	AVE	.560	.551		**AVE**	.523	.648
	CCR	.822	.820		**CCR**	.809	.876

Note. AVE = average variance extracted, CCR = composite construct reliability.

Table 1. Construct validation.

To validate the quality of the constructs PE and EE, we examine individual *item reliability* (loadings), *composite construct reliability*, and *average variance extracted* (Hulland, 1999). Item reliability is examined by evaluating the loadings of the measured items on their respective construct. We performed a confirmatory factor analysis in *R* for this purpose (Table 1). It is generally known that items with low loadings (rule of thumb: < 0.4) should be carefully scrutinized as they offer little additional explanatory power but attenuate (and thus bias) parameter estimates (Nunnally, 1978; Hulland, 1999). In our models, all item loadings exceed the 0.4 limits. The average variance extracted is a measure to assess the amount of variance captured by the construct, compared to the variance due to measurement error, and should be above 0.5, which is given for all our constructs and artifacts, indicating that the variance captured by the construct is greater than the measurement error (Fornell and Larcker, 1981). Composite construct reliability measures the overall reliability of items loading on a construct and, therefore, the internal consistency of a construct. It should exceed the threshold of 0.7 (Hulland, 1999; Nunnally, 1978), which is given for all our items and artifacts. Discriminant validity was assessed by comparing the average variance extracted with the squared correlation between the constructs (Fornell and Larcker, 1981). To calculate the correlation, the Kendall tau coefficient was used, which is particularly appropriate for Likert-style scales (Jamieson, 2004). The comparison shows that the average variances extracted of PE and EE (see table 1) are each higher than the squared correlations (cor) between PE and EE for both the DT (cor^2=0.480) and the RA (cor^2=0.354). Based on these validity criteria, our measurement models with four items each for the constructs PE and EE are suitable for evaluation. We also consider the PE and EE constructs as well as the underlying items to be valid since we adopted them from Venkatesh *et al.*'s (2003) well-known Unified Theory of Acceptance and Use of Technology (UTAUT) and these have been proven to be effective in numerous further studies.

6 Implications for Theory and Practice

The HoloWFM research project produced and evaluated a DT and an RA for a novel AR-based WFMS front end. From these contributions, implications for theory and practice can be derived. For research, the contributions to the knowledge base of the IS community are threefold (Gregor and Hevner, 2013). First, new descriptive knowledge is added by identifying the research gap for HoloWFM and extending existing contributions to address this gap (cf. Damarowsky and Kühnel, 2022).

Second, methodically, we demonstrate how to bridge the gap between highly abstract DRs and DPs with tangible and operationalizable RA UML diagrams by utilizing DFs and how to utilize the system architecture description standard ISO/IEC/IEEE 42010:2011 to document this developed design knowledge. To the best of our knowledge, this has not been shown previously.

Third, the UML diagrams of the RA add to the prescriptive knowledge base by providing tangible design knowledge since existing studies lack such less-abstract contributions. In line with the known benefits of RAs (see Section 3), researchers (and practitioners) can more easily implement a HoloWFM or similar IS. As many studies use prototype implementations to test certain functions or scenarios, the RA presented herein could provide tangible benefits to other researchers. Also, the RA can be expanded to incorporate new stakeholder requirements and new technologies, thus serving as a basis for future research endeavors. Indeed, research opportunities naturally arise to define different DPs, DFs, and RAs than ours, since a well-known inherent weakness in the development of DFs and RAs is the subjectivity of underlying design and architectural decisions, e.g., the number and partition of DFs, systems and (sub)components. Certainly, not all design decisions must or can be grounded in theory and a degree of creativity is unavoidable and essential in the DSR process (Hevner and Chatterjee, 2010; Baskerville *et al.*, 2016). Further, we derived the DFs from well-built DPs and the RA in turn from these DFs. Yet, each of these steps presents its own challenges and thus future research opportunities.

For practice, the positive survey indicates that generally, the DT and RA can provide valuable guidance to practitioners when developing a WFMS front end that is designed for AR headsets. The UI design provides a tangible template to build on but also can be used as a mockup in further design studies with end users. The requirements and principles of design from the DT guide the overall development process. Since we provide tangible, operationalizable component- and class-level design knowledge in standard notation UML, these models can directly be utilized in system and software development. The documentation of key architectural decisions also saves time and resources, e.g., utilizing an abstraction layer between UI and WFMS, linking AR task support objects via BPMN extensions, and placing the context reasoning system outside the HoloWFM application, are not entirely obvious decisions. Thus, the well-known benefits of RAs (see Section 3) can be realized in practice. Finally, the RA's complexity is not overbearing as Figure 7 summarizes. Thus, the instantiation of a HoloWFM is not prohibitively difficult for companies, the main challenge being the construction of a stakeholder-specific AR UI. With the instantiations of HoloWFMs (or related artifacts) for known application scenarios of ARSs for workflow execution support (cf. Section 1), organizations can benefit from the superior workflow management and control functionalities and thus better integrate ARSs into an existing WFMS infrastructure. End users meanwhile can effectively operate workflows and WFMSs more efficiently while benefiting from AR task support, therefore potentially increasing overall productivity.

7 Conclusion & Outlook

The goal of the HoloWFM DSR project was to conceptualize and design a WFMS front end for AR headsets, supporting the full range of user interactions. Based on the positive evaluations, this has been accomplished. Yet, by their very nature, RAs have a shelf life and need to be updated regularly – or discarded eventually. The implementation of HoloWFMs (or derived artifacts) in practice will create the opportunity to refine and update the RA – which we strive to do in our future research.

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