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Let's Get in Touch - Decision Making about Enterprise Architecture Using 3D Visualization in Augmented Reality

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Abstract

Making informed decisions about historically grown and often complex business and Information Technology (IT) landscapes can be particularly difficult. Enterprise Architecture Management (EAM) addresses this issue by enabling stakeholders to base their decisions on relevant information about the organization's current and future Enterprise Architectures (EAs). However, visualization of EA is often confronted with low usefulness perceptions. Informed by the cognitive fit theory (CFT), we argue that decision-makers benefit from interacting with EA visualizations using Augmented Reality (AR), because it enables a consistent task-related mental representation based on the natural use of decision-makers' visual-spatial abilities. The goal of this paper is to demonstrate ARs suitability for EA-related decision-making. We follow the design science research (DSR) approach to develop and evaluate an AR head-mounted display (HMD) prototype, using the Microsoft HoloLens. Our results suggest that EA-related decision-making can profit from applying AR, but users find the handling of the HMD device cumbersome.

1. Introduction

Advances in Information Technology (IT) enable organizations to enhance enterprise effectiveness, increase flexibility, and develop new business models [18]. At the same time, the complexity of IT landscapes has grown considerably in recent years [51], thereby making a vast impact on many firms' Enterprise Architectures (EAs). EAs represent the fundamental structure of and relationship between business and IT landscapes and provide domain-specific descriptions (i.e. of infrastructure assets, business applications, business processes) and time-specific descriptions (i.e. as-is versus to-be) of the organizations [41, 42]. Hence, EAs offer a consistent basis for decision-making about, for instance, business-IT alignment, complexity reduction, or future planning of organizations [41]. This fact-based foundation provides rational arguments about EAs [21] and therefore facilitates better and timely decision-making for a variety of EA stakeholders [2]. EAs can be made visual as i.e. texts, matrix views, layer perspectives, bar charts, or pie charts [37], which support decision-makers' understanding of EA descriptions [29]. The establishment, maintenance, and development of EAs and corresponding EA visualizations are the main outcomes of Enterprise Architecture Management (EAM) [2, 3]. Companies that do not employ EAM could face significant challenges in terms of increased operational risks, gained complexity costs, and distraction from core business problems [2].

However, research indicates low use of EAs for decision-making in organizations [1, 15, 22], in particular for visualizing and, hence, understanding complex IT landscapes [8, 27, 46]. Potential reasons for this include the limited perceived usefulness of EA visualizations, which are often characterized by their complexity [32], lack of focus [8], an inappropriate level of abstraction [27, 46], or insufficient tool support [27]. In sum, this inhibits the effective use of EAs for decision-making [6], so that stakeholders often find the added value of EA visualizations to be rather low [15, 32].

Drawing on cognitive fit theory (CFT), we take it that efficient problem-solving processes depend on an individual's mental fit between the problem presentation and the characteristics of the problem-solving task [17, 45, 49]. We thus seek to improve the presentation of EAs by employing an interactive, easy-to-use, and comprehensible visualization for EA decision-makers. In particular, we argue that

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Augmented Reality (AR) is a suitable technology for addressing the above-mentioned issues by enhancing decision-makers' understanding of EAs and related problem-solving processes. Researchers promote AR as a technology that presents virtual 3D objects in a real-world environment [5, 28]. By interacting with these 3D objects, AR takes the user's spatial ability into account, which can reduce cognitive load and thus enable a better overall understanding of complex causal relationships [9, 16, 39, 48]. Moreover, due to the natural integration of the virtual objects into the real world [28] and the use of hand gestures [5], AR requires less skills for interacting with these objects in a real-world environment, which results in potentially low to moderate individual learning effort. In contrast, Virtual Reality (VR) users are so completely immersed that they become disconnected from the real environment [40]. Decision-makers who use AR can still perceive the real world [5, 28], engage in face-to-face collaboration [52], and experience almost no motion sickness [47], all of which can increase decision-makers' willingness to use such a technology. These benefits have been considered very little in practice, however, some companies applied 3D printing to visualize the current state of their EA and, furthermore, plan to use AR for a dynamic view on EAs [10]. In addition, market research firms like Gartner claim that AR can change how customers and employees interact with the organization, thus, leading to higher business performance [12].

This paper's objective, therefore, is to develop and demonstrate ARs suitability for EA decision-making using an AR-based prototype. Based on insights gained from a large municipal company in Germany, we followed the Design Science Research (DSR) paradigm to identify problems in practice, derive suitable design goals, and develop and evaluate a head-mounted display (HMD) AR prototype. As an exemplary EA visualization, we chose a commonly known three-layer-model and evaluated the importance, accessibility, and suitability of the prototype through six semi-structured interviews. Our main contribution is twofold: First, we successfully developed an AR-based EA prototype and evaluated it in a practical setting. Second, this extends the body of knowledge about CFT, by having employed it in the context of EAM and AR.

This paper proceeds as follows: Section 2 presents the theoretical background. In section 3, we describe our research approach and in section 4 the identified problems and requirements for the AR prototype. Section 5 then describes the developed prototype, and section 6 summarizes the results of the evaluation. We conclude our paper in section 7, providing avenues for future research.

2. Conceptual background

In what follows, we provide an overview of possible EA-related decision tasks (section 2.1) and suitable forms for visualizing EAs (section 2.2). Next, we explain the CFT, which allowed us to jointly consider these two aspects (section 2.3), and we briefly introduce AR (section 2.4).

2.1. Use cases of EA-based decision-making

EAM can support strategic decision-making by providing relevant information on the current and future state of EAs [2, 19, 49]. Decision-makers are business or IT representatives in an organization, who design or use EAs [7]. Typical decision-makers would be enterprise architects, board members, business project managers, business project analysts, or application managers [4, 32]. They consider EAs for communication, analysis, and decision-making [19].

According to Khosroshahi et al. [4], most upper management EA stakeholders recognize EAM to be a relevant strategic tool that provides meaningful information about the organization [4]. High-level strategic decisions can draw on EAs, which therefore, have a strong impact on the future development of the organization [23, 27, 33]. Examples include feasibility analyses for implementing new products, identifying market offers depending on the existing IT landscape, or discovering redundant processes [35]. In a similar way, EA stakeholders make decisions on business structuring to plan and guide the implementation of strategic initiatives [31, 33]. This could affect not only IT-related aspects, but also the design of business processes and information assets [33]. The selection and prioritization of IT projects can be based on project-related EA information [33]. This includes, for instance, the consideration of standards [4], the results of risk analyses, and EA project proposals [23]. IT standards can ensure IT projects' compliance [35] and help to avoid implementing redundant technologies [23]. IT investment or IT portfolio decisions could consider EA requirements like capabilities, qualities, and cost of technologies [31]. Application replacement or retracting decisions could depend on the applications' lifecycle, or other organizationally relevant assessment dimensions like the number of application users [23, 27, 35].

In sum, we conclude that the above-mentioned decision tasks view EAs from various perspectives and different hierarchy levels. Hence, in our view, a main characteristic of EA-related decision tasks is their ability to jointly assess numerous data points.

2.2. EA visualization types

EAs describe the current (as-is) or multiple future states (to-be) of an organization [41, 42]. To name a few examples, EAs can be visualized in the form of business strategies, process models, principles, standards, logical data models, network diagrams, or roadmaps [19]. Researchers claim that visualizing EAs can improve decision-making, and finally enable better-informed decisions [15, 41]. This claim is based on the assumption that visualizing EAs provides a holistic fact-based view of an organization from both the business perspective and the IT perspective [41].

Current EA tools support, for instance, a wide range of matrices, tables, charts, diagrams, gauges, tree maps, tree views, as well as specialized modelling languages and geographic maps to visualize EAs [37]. More sophisticated visualizations combine a number of elements to form tables or various kinds of visualization: clusters, dependencies, portfolios, life-cycles, or roadmaps [13]. Figure 1 shows a matrix visualization and a dependency visualization, two commonly used EA visualizations. The former (left) typically presents current or future states of information systems (IS) in relation to two assessment dimensions, namely responsibilities and business processes. The latter (right) depicts the dependencies between IS across a business process [13].

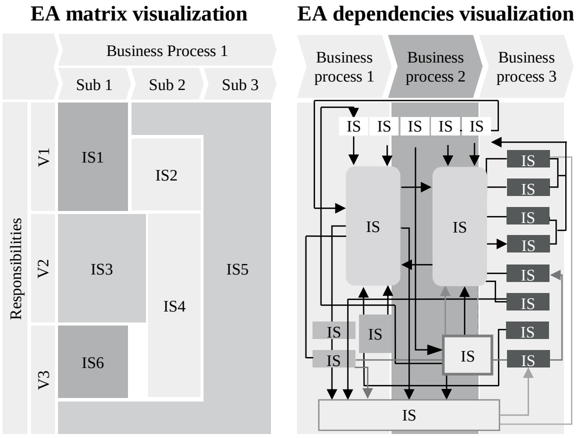

EA matrix visualization **EA dependencies visualization**

Figure 1. Exemplary EA visualizations [13]

These, as other potential EA visualizations, are typically developed with a specific EA stakeholder in mind to ensure a high level of understanding based on the individual information needs [2, 27, 31]. Surprisingly, only a few organizations employ 3D visualizations of EA [37] although 3D is considered beneficial for understanding complex relationships [16, 39, 48]. An in-depth analysis of EA visualizations lies outside of this paper's scope. However, interested readers should consider Roth et al. [37].

2.3. Theory of cognitive fit

The CFT provides a solid theoretical explanation of the interplay between decision-tasks and decision supportive visualizations. It shows the influencing factors leading to an "effective and efficient problem-solving performance" [44]. The theory suggests that whenever the characteristics of problem representation and problem-solving tasks accentuate the same type of information, similar problem-solving processes occur and, hence, frame a consistent mental representation. The mental representation describes how "the problem is represented in human working memory" [44]. Problem-solving tasks are either assessing relationships in data (spatial tasks), which can best be visualized in graphs, or acquiring specific data values (symbolic tasks), which can best be visualized in tables [44]. The corresponding problem representation addresses a structural layer, that describes *how* information is presented, and a content layer, that describes *what* information is presented [17]. In sum, problem solvers, like decision-makers, experience quicker and more accurate decision-making performance if the information presentation format matches the nature of the task description. Absence of such *cognitive fit* can result in slower and inaccurate decision-making [44] because transforming the inadequate information to suit the task requirements requires more mental capacity [17].

Even though some researchers acknowledge the appropriateness of cognitive fit to EAM research (e.g. [49]), this theory has been limitedly considered. Exceptions are Kurpjuweit [20], who concludes that not all EA visualizations fit to every problem, Franke et al. [11] whose empirical results suggest that models have a greater influence on understanding EA than text documents, and Winter [50] who finds that for optimal outcomes business development tools should provide stakeholder-specific visualizations and suitable analysis reports.

Regarding our research objective, the CFT helps us to understand that EA visualizations should be linked to EA decision tasks to achieve good decision-making performance. We found that most EA decision tasks (cf. section 2.1) and visualizations (cf. section 2.2) are spatial in nature, because of EA's purpose to visualize enterprise-wide dependencies from different stakeholder-dependent perspectives. Drawing on the CFT, we further concluded that not only the content of information is important, but also how the information is designed for decision-makers to produce a consistent mental representation and, therefore, accomplish effective problem-solving performance. This paper focuses on the representation aspect. Figure 2 shows the CFT model as applied to the EAM context.

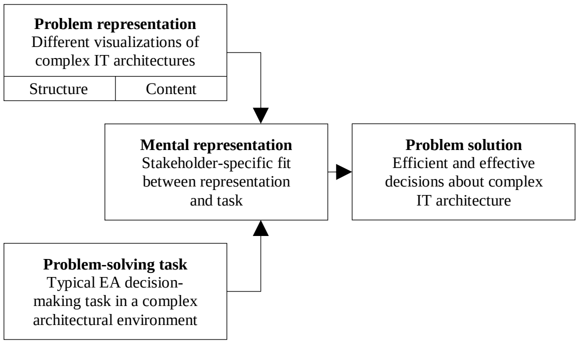


Figure 2. CFT applied to the EAM context

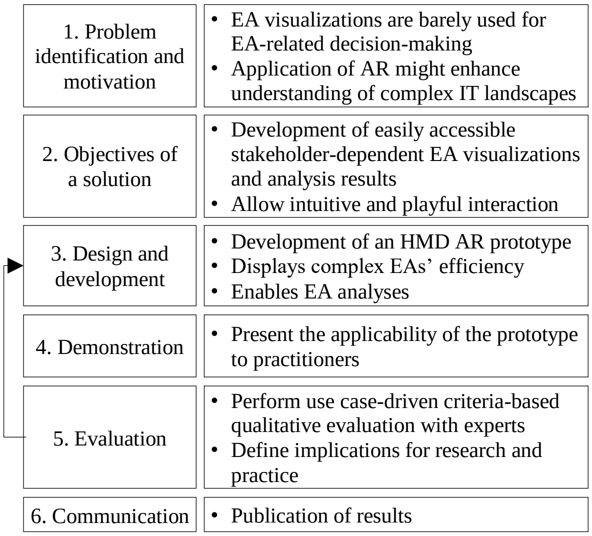
We suggest that EA decision-makers can benefit from the application of AR because it provides an intuitive way of presenting and interacting with (EA) visualizations [5, 28], thus, allowing the formulation of a consistent mental representation. As argued in the introduction, AR can reduce cognitive load, enhance overall understanding of complex causal relationships, [9, 16, 39, 48], decrease individual learning effort, and allow face-to-face collaboration [52].

2.4. Augmented reality

According to Azuma's widely cited definition, AR is characterized by three properties [5]. First, AR is a combination of the real and the virtual world. AR superimposes virtual objects onto the real world by adding or removing objects. Second, AR is interactive in that it reacts to user's gestures or head movements in real time. Third, AR is registered on three dimensions and, therefore, displays virtual objects in correct spatial relation to the user. Common AR devices rely on the sense of sight, as they are optical or video see-through HMDs or handheld displays [28, 38]. Optical see-through HMDs project virtual objects into the real world with the support of mirrors [25], whereas video see-through HMDs present and manipulate a user's view on the real world by using cameras [5]. Handheld AR displays, like smartphones, are small devices that also use cameras to overlay real and virtual objects on a screen [34, 38].

3. Research approach

The goal of this paper has been to develop an AR-based prototype to demonstrate its suitability for stakeholder-dependent EA decision-making. This can be realized with applying Design Science Research (DSR), as it aims to create a meaningful IT artefact, which, in our case, is a prototype [14]. DSR provides principles and procedures to design, develop, and evaluate IT artefacts [30]. From a DSR perspective, IT artefacts should address specific organizational problems [14]. Hence, to acquire in-depth knowledge, we considered existing findings in the literature but also included practical insight from an exploratory single case study to assess its generalizability. We follow the widely-used DSR method proposed by Peffers et al. [30], which is summarized in Figure 3.



1. Problem identification and motivation	• EA visualizations are barely used for EA-related decision-making • Application of AR might enhance understanding of complex IT landscapes
2. Objectives of a solution	• Development of easily accessible stakeholder-dependent EA visualizations and analysis results • Allow intuitive and playful interaction
3. Design and development	• Development of an HMD AR prototype • Displays complex EAs' efficiency • Enables EA analyses
4. Demonstration	• Present the applicability of the prototype to practitioners
5. Evaluation	• Perform use case-driven criteria-based qualitative evaluation with experts • Define implications for research and practice
6. Communication	• Publication of results

Figure 3. DSR process by Peffers et al. [30]

In the first step, drawing on prior literature (section 2) and an exemplary single study setting (section 4), we identified the need for alternative approaches to EA visualization. In the second step, we derived suitable design objectives to overcome the organizational problems recognized in our case study. In step three, we designed and developed an AR-based prototype that visualizes an illustrative EA using an EA layer model. Moreover, we chose an HMD, Microsoft HoloLens, as the underlying AR technology because it frees peoples' hands for use in parallel with their voice, while interacting with visualized objects [47]. This moves the focus away from using the technology (e.g. smartphones) toward working with the concrete visualization. Our prototype visualizes an EA in the form of a layer-model, as a commonly used systematic description of EAs [37]. The prototype was developed using the Scrum methodology within six three-week iterations (sprints). To ensure an independent development, we did not involve the case company. In step four, we repeated several rounds of testing and bug fixing to confirm the usability of the prototype in a real-world application. Colleagues supported us in validating the prototype's functionality. In step five, we evaluated our prototype by conducting six semi-structured interviews with EAM decision-makers in the case company to ensure that our prototype suits the information representation needs. For this, we implemented the company's EA data to set up a familiar environment. The interviews lasted between 35 and 45 minutes. We based our evaluation on the three practitioners' relevance criteria proposed by Rosemann and Vessey [36]. They assess the prototype's *importance* in meeting practitioners' EA needs, the research's *accessibility* in achieving understandable research outcomes, and *suitability* in its appropriateness for practitioners. Further, we applied Rosemann and Vessey's applicability check method [36]. This method is suitable as our paper (1) aims to examine theory focused research, (2) is not overly theoretical or mathematic, (3) has developed a prototype which is not influenced by non-researchers, and (4) addresses a real-world problem. We followed all seven steps of the applicability check method, which are planning the applicability check, selecting a moderator, ensuring participants' familiarity with the research objectives, designing the interview guide, establishing an appropriate evaluation environment, conducting the applicability check, and analyzing the data [36]. As the last two participants did not provide any new knowledge, we assumed a point of theoretical saturation. In step six, we documented our prototype development and evaluation.

4. Problem identification

Informed by the literature on EAM introduced in section 2 above, we now delineate the problem of effectively visualizing EAs by looking at a practical case in a real-world environment. In particular, we acknowledge the practice-oriented nature of EAM and briefly elaborate on the case company's use of EAM.

The case company is a medium to large-sized German municipal company with 2000 employees that operates in the energy and transportation industry. The company formally started implementing EAM in 2015, with the main goals of enhancing the architectural transparency, launching strategic initiatives, as well as standardizing and harmonizing the IT landscape. Implementing EAM has progressed considerably in recent years, to the extent that the historically grown IT landscape comprises more than 800 applications for a variety of purposes in different phases of the application life cycle. Hence, the company developed a multitude of EA visualizations.

However, regarding EA visualization design and use, the company faces four major challenges. First, generally, EA documentations are barely used by EA stakeholders. This can be explained by the EAM implementation being a new endeavor in the company, but also by employees' resistance to change. In addition, some do not see any benefit in considering EA visualizations for decision-making. Second, a few decision-makers perceive particular EA visualizations as either too simplistic or too detailed, or as unpleasant and disheartening, which results in low use in daily work. Third, the representation of some EA visualizations seems not to help decision-makers in understanding the relationships and dependencies within the existing IT landscape. An overwhelming number of connections between EA objects contribute to decision-makers' cognitive overload. Last, the available EA visualizations are rather static and do not allow for further interaction with the data (e.g. through drill-down analyses). Decision-makers cannot easily modify the existing visualizations.

In order to cope with these challenges, acknowledged in both academia and practice, we derived design objectives (DO) for the prototype, as summarized in Table 1.

Table 1. Design objectives of the prototype

Design objective	Description
DO1: Develop easily accessible EA visualizations	Provide accessible and low training required visualizations of complex architectures
DO2: Provide analysis functionalities	Provide in-depth analysis capabilities for decision-making
DO3: Enable stakeholder-specific visualizations	Provide EA visualization based on specific information needs
DO4: Allow intuitive and playful interaction with EA representations	Enhance decision-makers willingness to consider EA with interactive and joyful visualizations

5. Design and implementation of the AR EAM prototype

In this section, we briefly describe the architecture and functionalities of the AR EAM prototype. It builds on Microsoft's HoloLens (1st generation), an AR HMD that enables the development and use of AR applications. The HoloLens enables wearers to interact with objects immersed into the real environment using hand gestures and voice control. To address the design objectives explained in the previous section, we specified the four architectural components modeling, analysis, filter, and interaction. Figure 4 provides an overview of the AR EAM prototype's architecture including these components and the underlying database. The data set used for the prototype comprises EA data provided by the case company, complemented with randomized data.

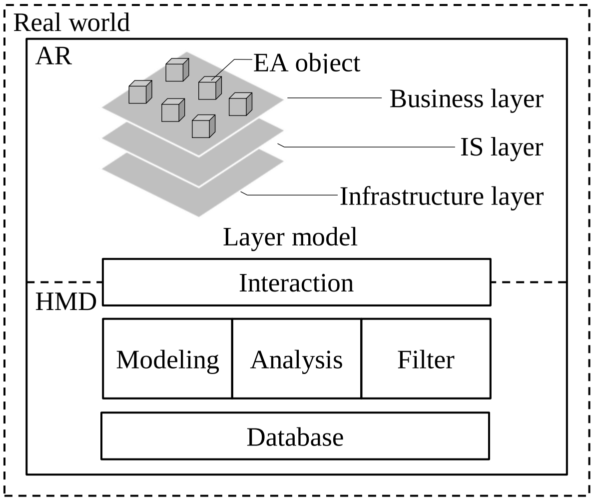


Figure 4. AR EAM software architecture

The first component, *modeling*, focuses on the creation of a comprehensive three-layer model that visualizes an EA (DO1). The model consists of three layers with related EA objects, namely the business layer (i.e., business units, employees, and processes), the IS layer (i.e., applications, and software), and the infrastructure layer (i.e. physical and virtual servers) (cf. Figure 5). Each layer groups similar EA objects to help reduce the cognitive load of working with complex data [29]. This model is projected from the HMD into the AR, making it part of the real world.

We chose the three-layer model for several reasons. First, the CFT highlights the need for spatial visualization because of the underlying EA decision tasks (section 2.3). Second, a layer model is suitable for displaying and clustering various interdependent EA objects [13] needed in most EA decision tasks (section 2.1). Third, the layer representation is well-known in the EAM domain and is widely accepted [37]. To achieve a high acceptance, we based the model on the TOGAF meta model [42] and ArchiMate notation [43] which are also broadly accepted in the community.

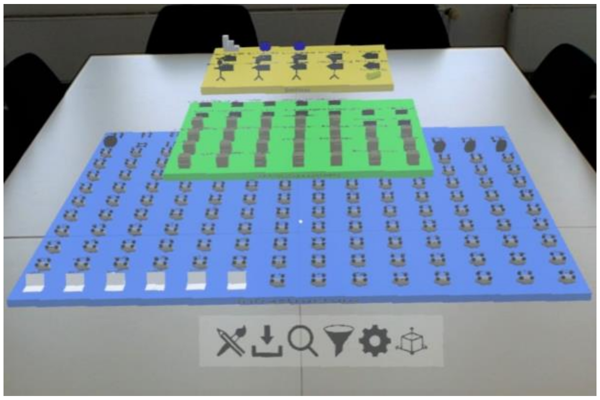


Figure 5. Layer model in the real world

Second, the *analysis component* defines functionalities for analyzing the EA using a set of predefined criteria such as complexity rating, risk assessment, and number of business users (DO2). Based on fundamental cognitive psychology principles of connection, color, and size [29], the entire EA layer model changes its appearance depending on the selected analysis criteria. For instance, once a decision-maker has selected any EA object, lines appear that connect the related EA objects across different layers, which helps to identify relationships. This way, the model depicts only specific relations between EA objects and avoids overloading the model. In addition, changing the color of EA objects helps to draw a decision-makers attention, while a traffic light color scheme indicates positive or negative assessments [26]. In addition, different EA object sizes support the visualizations of e.g. the importance or uses of EA objects. Figure 6 shows an example of a combined analysis visualization.

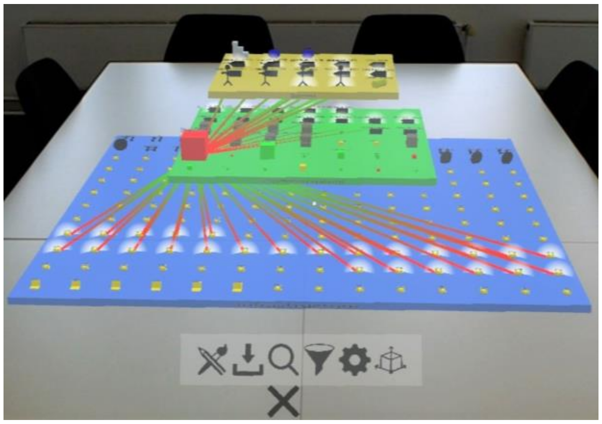


Figure 6. Layer model with analysis functions

Third, the *filter component* allows decision-makers to display individual relevant EA objects, thus reducing the coverage of the layer model (DO3). For instance, a user can show or hide selected layers or EA object types (e.g. server, business processes), switch between past, current, and future states of the EA or search with specific keywords. Moreover, it is possible to select an EA object as a filter criterion to see only other directly or indirectly related EA objects.

Lastly, the *interaction component* implements features that enable decision-makers to interact with the layer model in AR (DO4). The interactions are based on user interaction types provided by the HoloLens. The device has a cursor (visualized as white dot), which is centered in its field of vision. By performing an “air tap” (hand gesture) [24], it is possible to navigate through the user menu or interact with EA objects. In addition, the air tap allows the operator to move, rotate, and resize the model, by using either one or two hands. As decision-makers still perceive the real environment and can use both hands, AR facilitates a technology-independent natural-like interaction with the EA model. Alternatively, users can give voice commands to employ any AR EAM features, e.g. by saying “show user analysis” or “rotate left.” Here, decision-makers do not have to say an activation word to apply voice control.

6. Evaluation and discussion

We evaluated the prototype by means of six semi-structured interviews with experts from the case company, to confirm the prototype’s importance, accessibility, and suitability [36]. Table 2 provides an overview of the participants’ roles and EA information needs.

Table 2. Overview of interview partner

#	Role	EA information needs
P1	Enterprise Architect	• As-is documentation of EA • Dependencies between objects
P2	Business Continuity Manager	• Dependencies between objects • Esp. between processes and infrastructure • Identify points of failure
P3	Process Manager	• Used applications • Dependencies between processes and applications
P4	Head of Customer and Quality Management Department	• Any kind of resources associated with customer services • Used applications
P5	Deputy Chief of IT Department	• Overview of entire EA • Esp. dependencies between standards, interfaces, and infrastructure components • Identify responsibilities
P6	IT Architect	• Dependencies between objects • Know possible EA effects before changing anything

To begin with, all participants shared the same understanding of EAM and highlighted its appropriateness for managing and visualizing dependencies between businesses and IT. Overall, the participants agreed that the prototype addresses an important problem in EAM practice, and emphasized the intuitive and accessible representation of EAs and analysis results as a great benefit to EA decision-making. P3 assessed the visualization as interesting and meaningful, while P1 perceived the mass of EA objects to make a much stronger impression and be more manageable than otherwise. P4 and P5 mentioned the support for quickly understanding dependencies within EAs being enormous. Moreover, the visualized analysis results were perceived as being more beneficial than bar charts (P1), spreadsheets (P5), or 2D diagrams (P6) participants currently use. All respondents found the visualized dependencies between EA objects, as well as the changes in size and color of EA objects according to the selected analysis, to be useful. In addition, the participants underlined the usefulness of the prototype’s feature of filtering the model for EA objects that are relevant to the respective stakeholder.

Prior to the actual hands-on use and evaluation, some were skeptical about the prototype’s usefulness and applicability (P1, P2, P6). After having completed three illustrative tasks that highlighted the prototype’s use, the participants understood its purpose, relevance, and scope. P3, P4, and P6 stated that this prototype could in future become state-of-the-art.

Following the interviewees’ experience with the prototype, AR seems to be a suitable supportive technology for EA decision-making, as the intuitive interaction with the EA layer model accelerated the introduction phase and improved the handling and assimilation of the EA information. P4 and P5 highlighted the benefit of moving around and inspecting the model from different perspectives. Using hand gestures to interact with the model seemed to be intuitive as “hand-eye coordination is used in everyday life” (P4). In addition, P2 and P3 mentioned that using voice commands to modify the layer model could reduce the time required to get relevant information and, P6 noted the benefit for physically handicapped users.

However, at the beginning all participants struggled to interact with the device. Some found performing the air tab gesture difficult; others did not perform this gesture within the HMD’s sensors range (e.g. moving on the very right side or below the HMD), or the device recognized their voice commands incorrectly. As the HoloLens does not track eye movement, the interviewees had to move the device’s center to a certain point of interest, which was challenging for one interviewee. In addition, most participants reported that it was hard to physically adjust the HoloLens to their needs, and that it was too heavy and uncomfortable. P3 mentioned that air tapping for several minutes put stress on his right shoulder. P4 and P5 commented on the limited field of view. Nevertheless, all participants emphasized that working with this technology regularly would quickly decrease the above-mentioned issues. Following P3 and P4, this learning phase is comparable to learning how to handle a computer mouse “20 years ago.” Even so, these findings suggest that current technology limitations should be addressed by HMD manufacturers to increase applicability in real life.

Based on the exemplary decision use cases outlined in section 2.2, we designed a decision scenario in which a decision-maker was asked to identify the most widely used application in the IT landscape that is technically obsolete and thus due to be replaced. Besides learning how to use the prototype, participants were asked to perform three activities, namely first to identify the dependencies of a single employee to any EA object on the other layers (i.e., business processes, information systems, or infrastructure components). Second, they were to identify the application with the most assigned users and related business processes, and third, by using voice control, to identify all technically obsolete applications that have the most users assigned to it.

Interestingly, the results of the semi-structured interviews indicated agreement among all interviewees in that they immediately knew how to proceed in gathering the required information to fulfil the outlined activities. The only exception was that in three cases the menu icons for analysis and filtering were muddled (P1, P3, P4). We observed that participants needed only a short learning period and quickly became familiar with the EA visualization. All confirmed that they were able to understand the EA data quickly, and P1, P2, P4 and P6 exhibited an improved understanding compared to current EA visualizations. This observation led us to the point where we assumed an appropriate formulation of a consistent mental model as the exemplary tasks seem to fit to the given representation. Especially, the most important features that AR provide seem to be the use of hand gestures and the ability to move around and inspect the model from different angles without losing touch with the real world. Current desktop EA tools cannot provide the same functionality.

Referring to our research objectives and based on our findings, we suggest that our AR prototype can be a suitable starting point for understanding and facilitating EA decision making about complex EAs. Therefore, the results indicate that AR visualization can support quick information gathering and can help to reduce cognitive load. In addition, all participants were convinced that this could be a suitable technology for investigating EAs in a collaborative manner. Being able to see the real world while using the prototype helped the participants to feel engaged with EAs, but at the same time ensured that they did not lose touch with reality. Further, none of the participants reported motion sickness but a general kind of discomfort, which is consistent with the findings of Vovk et al. [47].

7. Summary and outlook

In this paper, we developed and evaluated an HMD AR EAM prototype that aims to facilitate decision making about complex EA landscapes. Using the CFT as a theoretical lens helped us to design stakeholder-dependent EA visualizations for EA decision tasks. We chose AR, a technology-enabled way of visualizing and interacting with virtual objects immersed in the real world, because it can reduce cognitive load during information processing. Our evaluation with six participants from an exemplary case company finds support for the applicability of AR for EA decision-making. In particular, all participants were able to use the Microsoft HoloLens, interact with the presented EA visualization, and make decisions in an exemplary decision scenario. We thus believe that AR EAM can help decision makers to better comprehend EAs.

Overall, our research is not without limitations. First, with a small sample size, caution has to be taken, as our findings might not be transferable to other organizational settings. This research could therefore benefit from large-scale multiple case studies. Second, our intention was not to evaluate and compare how different visualization types can support EA decision tasks. Comparing, for instance, the use of 2D and 3D EA visualizations can be a valuable starting point for future research endeavors. Similarly, testing different AR/VR technologies and platforms (e.g. desktop, mobile, cloud) could further enhance our understanding of the technology’s potential for supporting EAM. Third, we did not include the case company’s EAM maturity and the decision maker’s expertise during our evaluation. Arguably, both aspects can have an impact on the prototype’s perceived suitability and ease-of-use. In addition, this paper did not focus on data quality and data gathering processes, which certainly will be required in a real-life implementation. Besides our focus on the CFT, the task-technology fit theory as well as the theory of cognitive load might also appropriate theoretical lenses for future researches. Our evaluation further revealed performance limitations of Microsoft’s HoloLens that could have been reduced by using a client-server architecture instead of a client-only architecture. Moreover, we encourage future researchers to investigate how using AR technology can enhance collaboration in EA contexts. To this end, investigating cross-platform use with different HMD products or smartphones by using a cloud-based solution might be a relevant direction for future research. Finally, an illustrative organizational implementation and a subsequent longitudinal study might clarify in more detail the specific characteristics of AR that influence its acceptance and continuous use, as well as EAM efficiency.

8. References

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