Evaluating the User Experience of an Augmented Reality Prototype for Enterprise Architecture

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Abstract. Enterprise architecture (EA) visualizations like text, diagrams, and models are commonly displayed on 2D screens and are manipulated with a computer mouse and keyboard. The additional application of augmented reality (AR) promises improvements in terms of understanding complex architectural relationships and enables more natural manipulation of visualizations, ultimately leading to better decision-making. As part of a Design Science Research (DSR) project, we report on an empirical evaluation of user experience of an EA visualizing prototype deployed on an optical see-through head-mounted display (HMD) with 13 practitioners. The examined prototype displays a three-layer model that allows the analysis of randomly generated EAs. The participants performed 13 tasks which differed in complexity and context. In this study we qualitatively observe users' behavior. Our results indicate that AR is suitable to analyze EA. In particular those stakeholders less experienced with EA can benefit from utilizing EA visualizations in AR.

Keywords: Enterprise architecture visualization, augmented reality evaluation, head-mounted display, evaluating user experience

1 Introduction

Recent technological improvements have led to the development of high-performing optical see-through head-mounted displays (HMDs) [1]. These special forms of HMDs superimpose three-dimensional virtual objects over the real-world view of its operator [2] enabling interaction in a so-called augmented reality (AR) [3]. Recent publications indicate that AR systems are capable of presenting large amounts of information [4] that can be accessed and manipulated by using gestures [3]. This can reduce a user's cognitive load [5, 6], also due to exploiting humans' spatial imagination capabilities, which subsequently can enable a better overall understanding of complex causal relationships [5–7] and, hence, can lead to quicker decision-making processes [8]. In addition and despite virtual reality (VR) applications which immerse users in a fully virtual environment and disconnect them from the real world [9], AR still enables face-to-face communication in a real-world setting with less reported motion sickness [10, 11] – which is favorable for practitioners. These characteristics have resulted in various AR HMD

15th International Conference on Wirtschaftsinformatik,
March 08-11, 2020, Potsdam, Germany

https://doi.org/10.30844/wi_2020_i3-rehring

implementations, e.g. in the area of medicine [12], teaching [13], and software development [14].

Motivated by these benefits and facing the relatively low use of enterprise architecture (EA) visualizations for decision-making in organizations [15, 16], we followed the Design Science Research (DSR) paradigm and, in an earlier research project, developed an AR HMD-based prototype. EAs, which represent time-dependent structures of and relationships between business and IT landscapes [17, 18] in the form of text, graphs, charts, and 2D and 3D models [19], were represented in AR in the shape of a three-layer model. Our goal in this previous study [20] was to take advantage of the above-stated AR characteristics so that we could simplify visualizations of EAs in terms of accessibility, manipulability, as well as analyzability. Based on our findings, we argue that especially less EA-experienced stakeholders benefit from utilizing EA visualizations in AR due to the intuitive way in which information is represented in the real world, and how the content can be manipulated [20]. As a result, we assume that this approach may address confront the low usage of EA visualization for EA-related decision-making in organizations [20].

In order to test these claims, we conducted another DSR round to evaluate the user experience of an updated EA visualizing AR HMD prototype for a broad audience of EA-experienced participants from multiple industries. In this paper, our objective is to understand to what extent, from a user's point of view, the three-layer EA visualization represented in AR using an HMD can support possible EA-specific tasks. We sought to study how the users understood the EA visualization, to elaborate the interaction with the EA visualization, and to uncover promising opportunities for future research. We followed the guidelines for evaluating user experiences by Lam et al. [21] and conducted a usability test. This method seemed suited to our objectives, since it can be applied in evaluating working prototypes to "measure or predict how effective, efficient and/or satisfied people would be when using the interface to perform one or more tasks" [22]. Consequently, we aim here to assess users' performance, as well as to observe how such users interact with the EA visualization. For this, we invited 13 EA-experienced participants and tracked the time participants needed to successfully complete 13 EA tasks. Further, we evaluated the users' experience based on feedback, questionnaires, and observations, which we had audio and video recorded.

With our paper, we contribute to the sparse body of research about the development of AR HMD-based visualization prototypes by providing an empirical-based, in-depth analysis of such a prototype's usage. We discuss how the unique characteristics of AR instantiated by the prototype support users in analyzing EAs, and examine shortcomings and technological as well as operational hurdles. Further, in doing so, enrich the existing visualization approaches in EA itself.

The following section provides an overview of AR and EA visualizations. Section 3 describes the performed usability evaluation. The results are presented in section 4, which are discussed along with general design recommendations in section 5. The last section summarizes the main findings, mentions limitations, and suggests further research opportunities.

https://doi.org/10.30844/wi_2020_i3-rehring

2 Foundation

2.1 Augmented Reality

Following Azuma's [3] extensively cited definition, AR superimposes virtual objects onto the real environment and, hence, combines the real and virtual world. Virtual objects react to the user's behavior in real time, which creates an immersive and interactive environment. There are various devices that provide users with AR capabilities. In general, AR devices come as either head-mounted or handheld displays. HMDs can be either optical or video see-through displays. Today's optical see-through HMDs use mirrors, cameras, and further sensors to enable the user to see his or her real-world surroundings augmented by virtual objects [2]. Video see-through HMDs do not allow a direct view on the real world, but run a software that manipulates live pictures captured by a camera to project virtual content onto the real environment [2]. Both types of HMDs provide a hands-free AR experience which allows users to interact with virtual objects with two-handed gestures, voice control, body and head movement [1, 3]. In comparison, smartphones or tablets are handheld AR displays, which use cameras to overlay real and virtual objects on a screen [5, 13]. These devices also provide various interaction techniques. However, their disadvantage is that users have to hold the device in one hand, and thus have only one hand free for interaction.

2.2 Visualizing Enterprise Architecture

Today's EAs are commonly visualized using e.g. text (tag clouds, textual descriptions), charts (pie chart, line chart, bar chart), models based on modelling languages (ArchiMate, BPMN, UML), maps (geographic maps, tree maps), and many more such instruments [19]. The great variety of EA visualization types enables stakeholders to "communicate and analyze complex information, promote stakeholder involvement, or increase transparency" [19] with the aim of achieving "coherent and goal-oriented organizational processes, structures, information provision and technology" [23]. Depending on the organization and the requested analysis, achieving these goals usually requires a combination of multiple data sources and visualization types. The presented AR-based EA prototype in this paper visualizes a well-known layer representation.

3 Research Design

This paper aims to explain the extent to which, from a practitioner's point of view, an AR HMD-based prototype visualizing an exemplary EA supports specific EA-related tasks. Following Lam et al. [21], we invited practitioners to evaluate an EA

https://doi.org/10.30844/wi_2020_i3-rehring

visualization prototype by observing how the participants interact with it. In the following sections, we describe how we set up the evaluation, how we executed it, and how we analyzed our data quantitatively by time tracking and qualitatively by means of feedback mentioned during the evaluation, conducted questionnaires, and unique observation.

3.1 Evaluation Setup

Our evaluation setting is based on a common EA scenario. We assume that an EA stakeholder considers making use of a visualization instrument, first, to get an overview of a corresponding EA and, second, to further analyze the present EA visualization.

We previously developed an AR HMD-based EA visualization prototype [20] which visualizes the frequently applied three-layer model consisting of a business, an information system, and an infrastructure layer. The model is based on the well-applied TOGAF meta model [18] and the well-known ArchiMate notation [24] to ensure high acceptance by practitioners. Overall, the prototype affords visualization, analysis, and filter capabilities. Users can move, rotate, and zoom in or out of the visualization, as well as analyze the EA using tools that show the connection between EA objects, or that change the objects' appearance in terms of size and color. If necessary, filter functions enable users to remove all non-relevant layers and objects through keywords or specific selections. Readers are encouraged to consider our previous paper for a detailed description of the prototype's capabilities [20].

The prototype is based on pseudonymized real world company data from a large-sized German municipal company that contains a variety of EA objects on all but the data layer. To prevent data bias that results from using the same data sets repeatedly, we randomized the data for each evaluation. For this, we randomly selected between 10 and 50 EA objects per type (e.g. server, applications, processes) to generate different EAs each time. Further, an algorithm connects these EA objects randomly to other EA objects following the TOGAF meta model [18]. This algorithm also assigns each EA object a grading between low, middle, and high by chance in terms of risk, business know how, etc. In doing so, this approach reduces the risk of data-optimized evaluations, but it generates less realistic EAs as well.

The prototype runs on a first-generation Microsoft HoloLens head-mounted display with a 1268x720 resolution, 60 Hz refresh rate, and enables users 30^{o} horizontal and 17.5^{o} vertical field of view. Even though the prototype supports voice control, we limit the evaluation to the pre-developed gestures only. Hence, for interaction, users can look at objects and perform any action by raising the index finger and then briefly pressing on the thumb. This behavior is called air tap and it functions like a mouse click on a regular computer. Further, users can use both hands in performing air taps to move, rotate, and zoom the model. See Figure 1 for an example of such visualization.

https://doi.org/10.30844/wi_2020_i3-rehring

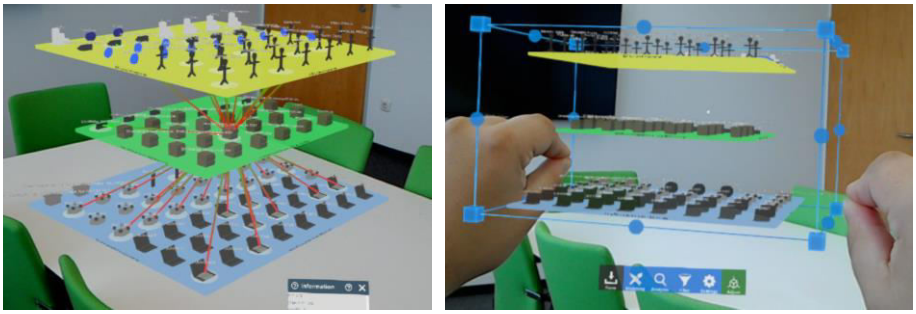

Figure 1. *Left*: 3-layer EA visualization showing connections between EA objects *Right*: Rotating the 3-layer EA visualization using two hands

3.2 Participants

To achieve our research objectives, we required the participation of EA-experienced practitioners. These would be people familiar with EAs and decision-making situations in organizations where other considerably less EA-experienced stakeholders participate. Based on our personal networks as well as via social media, we invited participants with a background in architecture modelling and analysis as well as from different industries for higher validity of results. Overall, we evaluated user experiences with 13 participants, of which 2 were women and 11 men. Their average age was 37,3 years. For the evaluation, we selected those whose job title indicated an understanding of enterprise architectures. Further, we asked each candidate to give a definition of enterprise architecture, as well as to describe what kind of EA visualization they work with. These preliminary questions helped us to assess broadly whether the participants' EA maturity was appropriate for our evaluation. We settled on 13 candidates after recognizing during the evaluation that new candidates were repeating answers of those before them. Thus, we assumed a point of saturation and stopped inviting more participants. On average, the participants had 9 years of experience with EAs, which was widely distributed across a range of between one year and 40 years of experience. Also, some of the participants had already worked with a Microsoft HoloLens (7 out of 13), but only four of them rated themselves as having a medium to good knowledge of the device, giving a median of 2 on a 5-step Likert scale. We did not pay the participants for taking part. Asking about their motivation to participate in this evaluation, most mentioned a special interest in this topic (11 participants) or in the device itself (4). Further answers on motivation signaled that they missed tools for EA visualization (3), with a focus of reducing communication barriers (2). Also, participants wanted to know what advanced EA visualization approaches exist besides standard business reports (2). The evaluations were conducted between May and July 2019. Table 1 provides an overview of the participants.

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3.3 Evaluation

We conducted all evaluations in a similar environment, taking six of the appraisals at our university and seven on a company's premises. We put two tables together, so that the participant faced the moderator. The presenter was always the same person. We ensured that the practitioners could walk around the tables freely or stay seated if they wished to. We also assured similar lighting in the rooms to enhance the comparability. Further, the video signal of the HMD was presented on a 65" screen right next to the table that allowed the moderator to follow the participants' actions. As the HMD was connected wirelessly, no further electronic set up was necessary.

We followed the same procedure. First, we explained the overall goal and the research approach to the participants. Next, we asked the participants to sign a data privacy statement, which allows us to gather, store, and analyze the data. Based on this, we did not store the participants' names, but created a randomly assigned ID for each one. The participants were then asked to answer a pre-evaluation questionnaire consisting of general demographic questions and specific questions to assess the

Table 1. Overview of participants

ID	Industry	Role	Years of EA experience	AR HMD experience [1-5]
1	Energy production	Software Architect	9	4
2	Plant construction	Head of IT Architecture	6	3
3	Retail	IT Systems Engineer	1	1
4	Power supply	Junior Application Developer	1,5	1
5	Power supply	Quality Management Representative	4	1
6	Power supply	Process Manager IT	10	2
7	Utilities industry	IT Architect	40	2
8	Energy service	IT Emergency Manager	4	2
9	Retail	Software Service Architect	1	1
10	Technology Consulting	IT Architect	6	1
11	Professional Services	Architecture Responsible	15	1
12	Consulting	Strategic Business Development and Research Innovation	5	4
13	Consulting	Software Engineer	15	3

maturity of their EA knowledge. We already knew from previous evaluations that interacting with the HMD needs practice as users have to learn the gestures and to understand how the device responds [20]. Hence, we requested the participants to complete a tutorial with the official training app on the HMD. This app supported the practitioners in setting up the device to fit their individual needs, and trained them in using the gestures. After the tutorial had been finished successfully, we started with the evaluation of the prototype. For this, we prepared three classes of EA-related tasks

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that, in all, can be completed in approximately 30 minutes. The tasks were influenced by the extent of EA data the municipal company provided, and considered general EA tasks in day-to-day businesses. Participants had to use the EA *visualization* (in creating, moving, rotating, zooming), *analyze* the EA (by finding dependencies and comparing objects), and *filtering* the appearance (by disabling layers and objects, searching for keywords). Table 2 gives an overview of all tasks. We went through the tasks one-by-one, first reading out the task aloud and immediately after that telling the participants which gestures they had to use to answer the question. We tracked the time they spent to finish the task and noted remarkable reactions to or usage of the prototype, so that during the evaluation we could ask individual questions, to help us understand how the participants worked with the visualization. Finally, all participants completed a post-evaluation questionnaire. For this, we followed Lam et al. [21] and used open-questions in asking about participants' first impression of the prototype, which features they considered useful, which features were missing, how features could be revised to improve work processes, and whether the tool was understandable and easy to learn. Finally, we also asked them how they had experienced the interaction.

Table 2. Selected exemplary EA-related tasks

ID	Capability	Task description
1	Visualization	Create a new EA model
2		Rotate the EA model
3		Zoom into the EA model
4		Move the EA model to another location
5	Analysis - Find dependencies	Show the dependency of any application on other EA objects
6		Select any application and hide any objects that are not associated with the selected application
7	Analysis - Compare objects	Identify a high-risk EA object
8		Find the application used by most users
9		Determine the EA objects with a high strategic fit to business goals
10		Identify an EA object with a high level of business process know-how
11	Filter	Deactivate the view on the "Business" layer
12		Deactivate the view on "Roles," "Databases," and "Servers"
13		Display all EA objects associated with the term "SAP"

3.4 Data Analysis

During the evaluation, we audio recorded everything that was said, to ensure we would not miss any important statement. Afterwards, we transcribed the audio files. In combination with the pre- and post-evaluation questionnaires as well as our notes from the evaluation, we inductively coded all data supported by the tool ATLAS.ti in order to qualitatively analyze the user experience.

Moreover, we recorded the video stream of the HMD for each participant. This enabled us to analyze the specific use of the EA visualization from a user point of view. In addition, we quantitatively analyzed the data in terms of median, minimum, and maximum completion time, and calculated the respective standard deviation. This helped us to quickly identify obstacles in applying the prototype and, combined with the qualitative analysis, to understand how these obstacles emerged.

4 Results

4.1 User Performance

Using the video recordings, we measured the completion time from the point at which the participant started interacting with the system until he or she had completed all the tasks' instructions. The results are shown in Figure 2. In the following, we explain how the users performed in each class of EA task: visualizing, analyzing, and filtering.

Visualization: How the participants are able to interact with the EA visualization influences how they understand it. Overall, the participants had difficulties in applying the gestures when they started, but after using it for a short while they learned how to

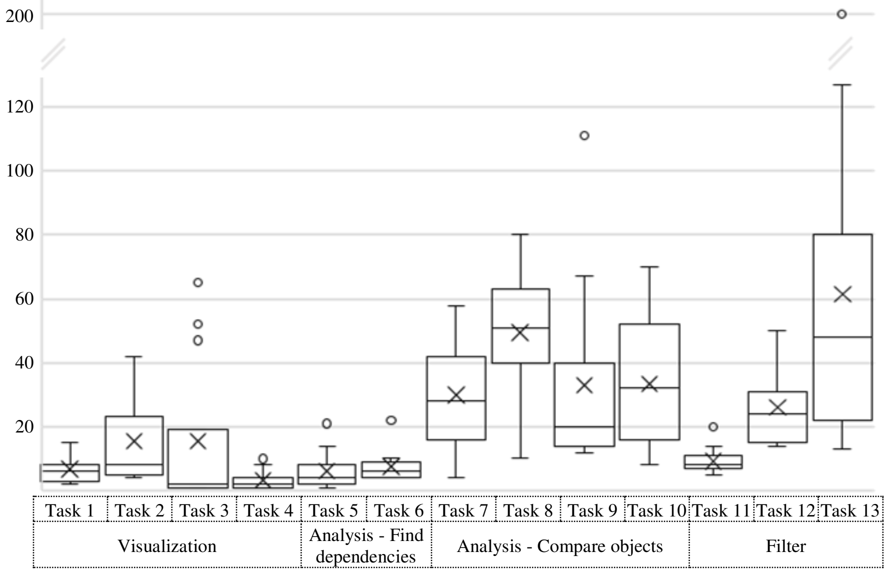

Figure 2. Completion time in seconds for each task represented in a box-plot chart

interact with the visualization. We identified three obstacles: First, the HMD only allowed gestures within a specified frame, but some participants did not stay within the frame while making the gestures. Second, some participants did not perform the air tap correctly, e.g. the distance between the index finger and the thumb was too

https://doi.org/10.30844/wi_2020_i3-rehring

close. Third, some participants did not air tap with both hands at the same time, which led to moving the model instead of rotating or zooming. This unintended application of the gestures resulted in longer completion time for task 2 (rotating; M=8sec; SD=14sec) and less time for task 3 (zooming; M=2sec; SD=23sec). Task 4 (moving; M=2sec; SD=3sec) posed no difficulties at all, mainly because only one air tap was needed. Notably, we observed that most participants instantly tried to move the model and fix it onto the table. However, in some cases, the model dropped below the table which resulted in higher completion times as this forced the users to look for and find that model again.

Analysis: Finding connections between EA objects was the easiest task for the participants, hence, the completion times were generally low (Task 5: M=4sec; SD=6sec & Task 6: M=6sec; SD=5sec). Visualized by straight lines between objects, the participants quickly identified the dependencies between EA objects (see Figure 1). In cases where the names of the objects, which were placed as text elements above each object, were hidden behind other objects, the participants took advantage of the AR capability to adjust their perspective on the model by moving their head sideways, walking around the model, or rotating the model using gestures. The practitioners found it more time consuming and challenging to compare the results of a specific analysis (e.g. task 7: compare low and high-risk EA objects) for three reasons. First, it involved more user interaction. The participants needed to hit two buttons in a pop-up menu to activate a specific analysis. Second, the participants successfully identified the different colors, however, due to a missing legend (discussed later), some participants had difficulties understanding the results of the analysis. This is also because we did not provide proper definitions of each analytic function. The practitioners might have had different understandings of what risk (Task 7: M=28sec; SD=18sec), strategic fit (Task 9: M=20sec; SD=30sec), or business knowhow (Task 10: M=32sec; SD=21sec) in the context of EA means, consequently it took a longer time for them to interpret the results. Third, the users did not immediately identify the different sizes of objects used for task 8 properly (M=51sec; SD=19sec). Some practitioners needed a considerable amount of time to recognize the different object sizes, which was mainly due to missing audio, visual, or haptic feedback from the prototype. Hence, in all three circumstances the tasks were challenging due to missing features of the evaluated prototype.

Filter: Filtering the EA visualization, including disabling and enabling visualized objects and layers, led to mixed results. Deactivating layers was not a problem at all (Task 11: M=8sec; SD=5sec). Task 12 took more time, as the participants needed to interact more with the user menu (M=24sec; SD=11sec). However, using the virtual keyboard for task 13 posed considerable difficulties for most participants (M=48sec; SD=53sec). Depending on the users' perspective on the model, or due to the perceived low resolution of the keyboard, the keyboard was either too small, too far away, or both too small and too distant, which meant the practitioners mistyped the search value.

4.2 User Experience

In this section, we will provide further insight on the perception of the users while they were performing the task. Our insight is based on the statements that the participants mentioned, on our notes during the evaluation, as well as on open questions that we asked after the evaluation. For precision, we mark in parenthesis participants' statements with reference to the IDs of those who made the points.

Overall assessment: In general, most participants assessed visualizing EAs in AR as being a "good idea" (12 of 13 respondents) and many claimed that it provided a comprehensive overview of the EA (*3,4,7,8,12*). The visualized EA was also perceived as being "touchable" (*2,5,7,9*), which could have enhanced the understandability. Four participants explicitly mentioned that the 3D visualization might be useful for communicating EAs to non-EA stakeholders, e.g. to customers, departments, or other groups of people (*2,5,7,11*). One participant stated that it might be a useful tool to introduce EAs within a company (*2*). However, the evaluated prototype might not be relevant for enterprise architects, as they need more detailed analysis capabilities (*2*). Looking to the future, another participant commented that collaborative work on EAs can be positively influenced by the application of the evaluated prototype (*11*). Only one participant was convinced that a 3D visualization of the EA yields no benefit (*3*).

Some participants have already thought about how to introduce this evaluated prototype in their companies. They stated that the implementation depends on the individual organization (*7*) and especially on the specific architectural processes (*9*), as well as the people working in these organizations (*13*). According to them, an implementation should depend on a solid cost-benefit-analysis (*8,13*). Some remarked that integration into an existing EA repository is mandatory (*2,7*), otherwise deploying such a visualization would be too expensive (*2,3*). A mix between existing 2D EA standard reports and a 3D visualization of the EA was deemed to be a realistic business scenario (*11,12*), as the 2D visualizations were already known (*11*). Also, further visualizations should be included (*11*). Architectural reviews, e.g. for security issues (*13*) or the assessment of the model's robustness (*10*), might increase the application area for such a prototype (*13*). One expert claimed that there should be an industry standard that regulates the use of HMDs in the business context, which is not in place (*2*). The usability in large offices should be tested first (*11*).

Visualization: The presented three-layer model was perceived as being suitable for visualizing the EA (*7,11*) and for enabling quick identification and understanding of different pieces of information (*1,4,6*). The participants perceived the 3D visualization as more visually appealing and compact compared to common 2D architectural presentations and considerably better suited to present connections than doing so using, e.g., network plans or listings (6,*7,8,11*). One practitioner compared the EA visualization to conventional building architecture and concluded that this idea makes it more compelling for users to transfer the notion of city building architecture to EA (*6*). Viewing the architecture from different perspectives was perceived to be helpful (*3,5*). If the user is trained in the modelling language ArchiMate, it will simplify the adoption (*4*). The accompanying main menu is easy to understand (*9,12*).

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Due to the 3D representation of the three-layer model in AR, the perspective from the user's point of view determines the readability of the model itself (*5,11*). Some objects were positioned behind other objects or arrows (*8*) and could only be viewed by moving the user's head, walking around, or by moving and rotating the model. This might explain an assessment that including further EA objects like projects, or increasing the number of objects, can create EAs that overwhelms users (*7,10,11*).

Besides these 3D-related issues, some characteristics of the prototype itself present difficulties. The main menu, as well as the info box which contains further information about specific EA objects, sometimes flowed into the model so that the model brought the content into overlap, which made it difficult to read (*8,11,12*). One participant perceived the distance to the main menu as being too far away (*11*) and another found it too small (*12*). Also, the cursor was not visible on the main menu but highlighted the buttons on it, which confused some participants (*4*). The evaluated prototype did not focus on accessibility, e.g. for color-blind people (*2*), or red-green weakness in particular (*7*), which might hinder the adoption of such a prototype in an organization.

The participants made several suggestions for improvement. Many participants, without prompting, mentioned the idea of applying the EA visualization in AR for communicating and collaborative design of EAs with a group of stakeholders. As it is, the model is displayed on a table and all stakeholder can freely interact with the visualization. For this, changing the view, selecting the analysis feature, or filtering needed objects should be based on a permission management, e.g. to differentiate between moderators and viewers (*2,3,11,12*). If a group of users work together with the HMD, others should be able to see a pointer or cursor on the object of interest (*4*). In order to integrate other existing EA visualizations, the prototype should jump to these visualizations when a user e.g. taps on an EA object in the evaluated visualization (*11*).

Further general concerns apply to the considered prototype. While conducting task 12 (disabling objects), the model quickly disappeared for about one second when disabling and enabling EA objects. Some participants mentioned that the model should be visible without any such interruptions, and should perform smooth transitions (*3,8,12*). Further, the prototype could benefit from adding a navigation that keeps track of the used analysis features and allows a quick return to previous analyses (*7,10,11*). The use of different architecture languages beside ArchiMate might improve users' acceptance (*10*). Changeable style settings concerning e.g. text size, contrast, and colors could improve the convenience of users (*2,3*).

Analysis: Four participants considered the evaluated individual and combined analysis functions of the prototype to be helpful (*2,4,9,13*), but especially the visualization of the connections between EA objects (*3,4,6-13*) was found to be beneficial. The EA visualization displays EA object assessments in terms of different object sizes (small, medium, large) and different colors (green, yellow, red) depending on the kind of analysis. This way of visualizing analysis results was perceived to be supportive and easy to recognize (*4,7,13*). Additionally, filtering the visualization to reduce the amount of visualized EA objects was perceived to be helpful (*3-6,8*).

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Even though 12 out of 13 participants immediately understood the different colors while investigating the results of an analysis, many requested a legend explaining the colors and their meanings right next to the model (*1,2,7,8,10,11-13*). The arrows that visualized connections between EA objects caused confusion whenever they went through other non-related EA objects (*6,8,12,13*). We used a color gradient from red to green to tackle this issue; however, this confused some participants (*1,11*). A number of participants quickly identified the different object sizes (*1,2*) and assessed the different object sizes to be more suitable for the representation of the analysis results than colors (*1*); others hardly noticed the different sizes at the beginning (*4,7*) or perceived the small objects as being too small to recognize (*8*). One major drawback of the visualization was that 3D visualization hindered detailed comparisons of different object sizes as this depends on the individual perspective of the user (*10,11*). Users could not always detect slight differences in size between two objects. This claim is supported by another expert who missed concrete data values at each object (*1*).

The prototype does not offer detailed data drill-down, hence, the prototype is perceived as being suitable for addressing high level analysis questions (*2,11*). More details about the EA would have been more desirable (*2,4,11*). Examples of such possibly helpful details are various statistics about each selected EA object (*4*), including standard and well-known EA reports (*2,3*), as well as further information regarding maintenance (*2*) or data security aspects (*13*). The selected analysis function or keyword should be displayed at any place (*7,13*).

Interaction: Overall, many participants mentioned that it was easy to learn to interact with the EA visualization (*1,3,6,7,10,11,13*) and that the HMD was fun to use (*2,5,6,9,10*). Only one participant explicitly asked for a joystick to use instead of gestures (*3*). Regarding interacting with the EA visualization, a large portion of the practitioners agreed that gestures need to be trained first before using an HMD (*2,3,5-10,12*). Participants remarked that the prototype clearly requires practice (*4*) and that an audio-guided tutorial for this prototype might be beneficial (*11*). Some participants asked for more comprehensive gestures (*11,12*), others highlighted the need for standardized gestures across all kinds of AR apps, which should be similar to desktop use (*2*). Notably, two participants mentioned standing to be more comfortable than sitting while interacting with the visualization (*8,12*). This can also be confirmed by the video recordings, which showed that overall the participants stood 79% of the time.

Even though the gestures were accepted, quick to learn, and worked well during the evaluation, some participants had difficulty in performing the air tap at the beginning of the evaluation (*3,4,7,8,10,11*). Most did not stretch their index finger again after the touch, but left their index finger very close to the thumb. In this case, the used HMD could not detect the click movement correctly, resulting in poor zooming and rotating results (*4,10*). According to the practitioners, stretching the index finger before performing an air tap required high effort (*4,6,8,10*). The prototypes' missing feedback after tapping on objects or functions was perceived as problematic (*1,2,6,7,9,11-13*). We did not implement an audio, visual, or haptic feedback after something had been activated, which confused many practitioners as

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they were unsure whether the air tap worked. Another serious issue that led to high completion times was the use of the virtual keyboard. The mixed reality tool kit for unity based keyboard [25] sometimes appeared to be too distant or too small (*6,7,11,12*), which made it difficult for the user to enter keywords and modify the EA visualization in the first place.

The participants made general improvement suggestions for the developed prototype: they recommended adding audio feedback to the prototype to indicate a successful selection, e.g. using a calm click sound (*7,11*). Others highlighted the need for more haptic feedback (*12*), the extensive use of hovering effects like glowing objects, icons, and arrows when looking at it (*2,7,11*), and further interaction techniques besides gestures and voice (*12*). Interactions could also be triggered by looking at objects for few seconds (*12*), or by disabling the adjustment of the model when it does not receive attention for some time (*2*) in order to reduce the number of air taps.

Device: Besides generally being enthusiastic about interacting with the HMD, the practitioners reported several physical issues about the hardware, which influenced their perceptions. Putting on the HMD did not pose major difficulties, except for one expert (*4*). In general, the participants were unsatisfied with the comfort of the device, as they found it to be inconvenient (*3, 8*); one expert said it was unlikely that they could wear the HMD for more than one hour (*10*). The participants reported pain in their necks (*2,4,12*), dry eyes (*3*), pain on the scalp (*12*), and uncomfortable pressure on their nose (*2,5,7*), which was possibly related to the weight of the HMD (*3,10*). Participants seemed to find it challenging to use their hands only within the defined frame of activity that the HMD could capture. This was perceived as inhibiting (*4,9,12*).

Besides the hardware limitations, the practitioners mentioned various quality issues. The perceived low resolution of the HMD (*1,3,4,10,12*) led to difficulties with reading the text (*3,4,7,8,11,12*). Some participants experienced an unstable model (*1,12*), with a shaky cursor (*3,12*) or text (*5*), that could be corrected by relocating the model to a different place. When placing the model on top of a table, the model sometimes "fell" under the table (*4,5*) which meant that the participant needed to search for it and move it back to top of the table. Also, parts of the model disappeared when the practitioners moved too close to it (*3,4,12*). This prohibited users from standing “inside” the model or getting closer to objects of interest.

5 Discussion

In this paper, we aimed to understand the extent to which an exemplary three layer-based visualization of EAs represented in AR using an HMD support possible EA-specific tasks. In general, the evaluation revealed that the participants learned how to interact with visualization after completing a familiarization phase and, moreover that mostly, they understood the presented analysis results. None of the participants had any difficulties to understand the developed and considered three-layer model, although the ArchiMate-based symbols for each EA object had not been immediately

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accessible. Our observation suggests that participants' quick understanding of the representation was enhanced by the combination of participants' visual spatial abilities, quick head movements, and changing perspectives on the visualization achieved by walking around the model freely in AR. This understanding was positively influenced by the characteristics of AR by having an uninterrupted, detailed view of the entire visualization, unbound by the physical restriction of computer screens, and by the absence of explicit user interaction like clicking or scrolling when viewing the EA. After finishing a familiarization phase, participants adapted the optional user interactions for e.g. creating, moving, zooming, and rotating a model. Participants also adapted the required interactions like showing connections starting from specific objects, or activating analysis features.

What we saw was a difference in how quickly results were interpreted. The average completion time for analyzing connections within an EA - which are depicted as lines connecting objects - was substantially low. We argue that combining lines that are connected to objects throughout several layers in AR are very easy for users to understand and do not require any explanation. In contrast, using colors or different sizes to distinguish between attributes of objects (e.g. low vs. high risk) causes contradicting interpretations if the used colors or sizes are not explained by e.g. a legend, as was the case with the considered prototype.

Hence, we claim that considering the third dimension for EA visualization presented in AR, enables users to view and analyze EAs in an intuitive way. This leads to more comprehensive overall representations without a negative influence on the analytical capabilities of a broad range of observers. Our findings further substantiate the assumption that this form of visualizing of and interacting with EAs could be particularly beneficial for less experienced EA stakeholders and for collaborative decision-making.

6 Conclusion

In this paper, with the aim of supporting EA-related analysis, we have presented an evaluation of an AR-based prototype for visualizing EAs. Based on an already developed prototype [20], we conducted an evaluation of user experience with 13 EA-experienced practitioners, asking them 13 EA-related questions. Overall, most participants were enthusiastic about the developed prototype and many perceived interacting with it as fun and easy to understand. Considering the completion time for each task, the participants learned quickly how to move, rotate, and zoom the model, as well as to identify connections between EA objects. However, interpreting analysis results presented with different object colors and sizes took them longer. Also, the evaluated HMD was perceived as uncomfortable and difficult to use at the beginning.

This research does have a few limitations. First, we only asked practitioners who have experience with EAs. Even though these participants highlighted the suitability of the AR prototype for communicating results to customers and employees in non-IT departments, we did not investigate that possibility here. Second, we could have asked more practitioners to participate in the evaluation. However, we assumed a point of

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saturation due to repeatedly getting the same feedback and answers. Third, we did not question the quality of the underlying EA data that was used for computer-generated exemplary EAs. We excluded a discussion of the difficulties involved in obtaining high quality EA data, also because we worked completely with real-world data. Fourth, we focused on TOGAF as the fundamental methodology, as well as on ArchiMate as the EA describing modelling language only, but we did not incorporate other opportunities. Fifth, we have to assume that some participants might have been overly positive in their assessment due to some form of technology bias. Sixth, we developed a prototype, which is an instantiation of our paper's objectives, hence, our software development influences the evaluation. Different prototypes might come to different results. Lastly, we cannot exclude the absence of acquiescence bias as we did not change moderators.

Future research could aim to extend this work by adding more diverse visualizations to the prototype. Comparing different visualization technologies (e.g. HMD, VR, smartphones, desktop computers, 3D print, pen and paper) for different stakeholders could lead to interesting research about perceived individual or organizational usefulness. Investigating the collaborative use e.g. by conducting a field observation presents a fruitful avenue for further research. As our participants claimed, we should bear in mind that current organizations are used to standardly presented reports containing, e.g., KPIs, diagrams, and charts. In addition, we can apply metaphors that might support stakeholders in developing an understanding of EAs [e.g. 26].

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