Put your glasses on: Conceptualizing affordances of mixed and virtual reality for enterprise architecture management

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Abstract. Enterprise Architecture Management (EAM) is recognized as a valuable management discipline for dealing with and developing contemporary IT landscapes. However, research shows that the effectiveness of EAM differs from one organization to the next. One reason for this lies in the insufficient use of EA artifacts. A promising approach towards solving this problem, is to use Mixed Reality (MR) or Virtual Reality (VR) devices that allow intuitive and immersive interaction with IT and business architectures. These technologies enable intuitive interaction with data, higher manageability of vast amounts of data, as well as greater analytical skills due to involving natural spatial and visual ability. This paper explores the potential benefits of MR and VR for EAM from an affordance perspective. We have developed a conceptual model based on the notion of core IT affordances, and we discuss future research opportunities.

Keywords: Mixed Reality, Virtual Reality, Enterprise Architecture Management, Affordances

1 Introduction

Regardless of their size, organizations have for decades been facing a rapidly changing business environment [1]. Fast-changing IT requirements and the steadily growing complexity of the IT landscape have become a major challenge for them [1, 2]. Shadow IT organizations, redundant IT systems, and increasing risk of IT-failure are some examples of rapidly developing IT consequences [3]. An approach that could assist in overcoming these challenges and drive organizational change lies in the application of Enterprise Architecture Management (EAM) [1, 4]. EAM is a business strategy driven management discipline that establishes, maintains and develops an Enterprise Architecture (EA) through methods, tools, principles, and standards [3, 5, 6]. It supports managers in the alignment of business processes with corporate strategy, while considering the overall IT landscape [4].

Nevertheless, the successful application of EAM remains moderate [7]. One reason for this lies in the insufficient use of EAM outcomes [7], which are defined as EA artifacts [8]. Even though EA artifacts are the key resource for EA-related decision-making, business and IT staff often consider them as inflexible, difficult to understand, or being focused on a wrong level of abstraction [4, 9]. One approach to overcome these

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visualization challenges might lie in the application of Mixed Reality (MR) and Virtual Reality (VR) technologies. These technologies enable a natural interaction with data [10], higher manageability of vast amounts of data, as well as greater analytical skills due to natural spatial and visual ability being involved [11]. Therefore, we assume that interacting with EA artifacts provided by MR or VR increases the information processing of decision-makers that enhances the quality of decision-making, which, in turn, increases EAM effectiveness. Considering the novelty of this approach, the aim of this paper is to investigate how MR and VR can improve EAM effectiveness.

We apply the theoretical lens of affordances, as this allows us to study possible relationships between human users and technology [12–14]. This is deemed suitable because we can examine how users might perceive and use the afforded features of MR and VR devices to perform EAM-related tasks. We adopt three technology affordances that draw on the notion of Community of Practices. Moreover, we state propositions and develop a conceptual model that show the influence of EAM affordances on decision-making quality and, hence, on EAM effectiveness. This paper contributes to research in that it claims that MR and VR could have a positive impact on the effectiveness of EAM. It prepares the ground for future research in this area.

The paper proceeds as follows: Section 2 presents the theoretical foundation. In section 3, we present our conceptual model. We conclude our paper in section 4, with suggestions on future research opportunities.

2 Theoretical Foundation

This section provides an overview of the basic definitions and assumptions we work with in the paper. To our knowledge, due also to the novelty of this approach, there is, as yet, no comparable research on VR/MR and EAM. For this reason, we give the following detailed exposition.

2.1 Enterprise Architecture and Enterprise Architecture Management

In spite of high maturity in some aspects of the research on EA as well as EAM, there is still no commonly agreed understanding and distinction of these terms [1, 4, 15]. As clear definitions are crucial to our research project, we will give a brief overview of both terms.

Most researchers define EA based on the ANSI/IEEE 1471-2000 standard [16, 17] or, respectively, on the ISO/IEC/IEEE 42010 [18], whereas architectures are "fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution" (p. 2). Winter and Fischer [19] identify five common layers that describe the fundamental structure of an organization: Business, process, integration, software, and technology architecture. Ahlemann et al. [3] extend this view by adding design rules to EAs definition in order to ensure architectural consistency. Moreover, EA describes not only the current state ("as is") of organizational artifacts, but also multiple future states ("to be") [20, 21], which emphasizes EA's long-term view on organizational development

[22]. Comparing the baseline and target states enables the development of roadmaps that provide a plan for how to achieve the desired EA future state [21].

In the same manner as EA, a variety of EAM definitions exist [16]. Following Aier et al. [5], EAM aims to establish and develop an organization's EA. Based on an architectural perspective, business changing planning and controlling activities are considered to be a part of EAM. According to Löhe and Legner [4], EAM provides clear guidelines using plans, roadmaps, principles, and standards to support the transformation of the enterprise. In the same vein, Ahlemann et al. [3] highlight the need for a formulated governance regime. This view is supported by Wijeya and Gregory [23] who argue that EAM is closely linked to business strategy. In a broader sense, Simon et al. [6] describe EAM not only from a process perspective; they also highlight the need for assigning responsibilities when building an EA.

In view of all that has been mentioned so far and in line with Rahimi et al. [24], we postulate a distinction between EA and EAM. Thus, we understand Enterprise Architecture as a time-dependent representation of the structure of an organization, which comprises business and IT components and the relationship between them [18, 19]. Enterprise Architecture Management is a business strategy-driven management discipline that establishes, maintains and develops an Enterprise Architecture [3, 5, 6, 23].

2.2 Mixed Reality and Virtual Reality

In this paper, we want to investigate the potential influence of MR/VR on EAM effectiveness. To get a clear understanding of MR and VR technologies, we follow the proposed Reality-Virtuality continuum of Milgram et al. [25]. As presented in Figure 1, their approach describes a spectrum of environments ranging from completely real to completely unreal, thus, virtual environments. Mixed environments, which define a combination of real and virtual environments, exist on either side of the spectrum [25]. Due to the scope of our research, we describe AR and Augmented Virtuality (AV) as two forms of Mixed Environment, as well as VR as a form of Virtual Environment.

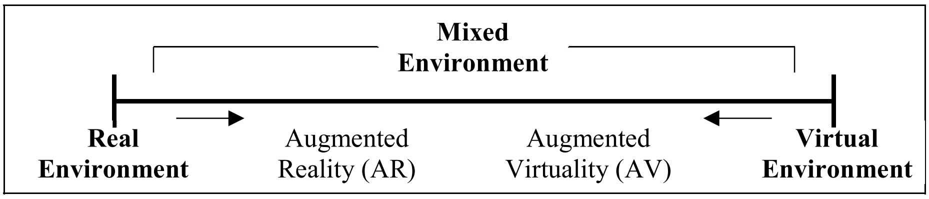

Figure 1. Reality-Virtuality (RV) continuum proposed by Milgram et al. [25]

As part of the Mixed Environment, **Augmented Reality** (AR) enriches the real world environment with virtual objects and, therefore, lies close to the Real Environment on the RV continuum [10, 25]. A user can still see the real world [26], while AR adds or even removes objects from it [26]. Some authors mention that AR does not only rely on the sense of sight ([e.g. 26], although a recent review identified only visual aspects that constitute AR [27].

Generally speaking, there are two classes of AR definitions [10]: The first class focuses largely on a wide-ranging understanding and technology-independent definition of AR [10]. Azuma characterizes AR as any system that "(1) combines real and virtual world, (2) is interactive in real time, and (3) is registered in three dimensions" [26].

In contrast, the second class of technology-related AR definitions mainly focus on AR displays [10]. Most commonly, this includes so-called head-mounted displays (HMD) [26] that distinguish between optical and video see-through displays [10, 28]. Head-mounted optical see-through displays allow the user to see the real environment through a display medium [25, 26]. A variation of it is in handheld AR displays where a small screen contains virtual objects, which react to changes of the real environment [28]. In contrast, head-mounted video see-through displays remove the user's direct vision of the real world, so that it becomes visible through a video camera [26].

Augmented Virtuality (AV) is also part of the Mixed Environment, but lies close to the Virtual Environment on the RV continuum [25]. In contrast to AR, AV is rather more virtual, but it includes real objects like a user's hand [25]. Currently, there is considerably less research on AV than on AR, mainly due to the absence of feasible consumer devices [29]. However, new room-wide motion detecting devices that capture the position of objects, gestures, and other physiological measures could increase the applicability of AV [29].

A Virtual Environment (VE) consists completely of computer generated virtual objects [25] and is commonly called **Virtual Reality** (VR) [26]. Multiple definitions of VR exist as a result of different past understandings and interpretations [28, 30]. Many authors define VR based on its technology nature, describing the devices, computers and methods that are needed to create an interactive simulation [30]. Other authors highlight the immersive experiences with VR [26], or add human imagination as a key concept to the definition [31]. Many agree that VR technology addresses all human senses [31, 32] and that sensory feedback is an important aspect of it [28]. Considering all these facets, we follow Biocca and Delaney who state that "Virtual Reality can be defined as the sum of the hardware and software systems that seek to perfect an all-inclusive, immersive, sensory illusion of being present in another environment, another reality; a virtual reality" [33].

Common VR output devices are occlusive HMD [28, 33]. These displays have the advantage of head-centered motion and its capability for binocular disparity [33]. In contrast to AR, occlusive HMDs suppress the real world to the benefit of VR [28]. Usually, small screens are used [28]. A variation of these HMDs are virtual retinal displays (VRD) that present images directly onto the retina of a users' eye [28, 32]. Monitor-based 'fishtank' VRs [28] are alternative VR output devices that track the position of the users' head, and the VR then responds to the head movement [28]. Movement and user inputs are important characteristics of immersive virtual reality experiences [28]. Position tracking (e.g. location of user, muscular movement), body tracking (e.g. posture and gestures, head, hand and fingers), and further physical input devices (e.g. controls, speech, requisites, platforms) are ways in which users can interact with a virtual world [28].

2.3 IT Affordances

As highlighted by Stendal et al. [14], affordances are gaining research interest in the IS discipline. James J. Gibson, an ecological psychologist who introduced the concept of affordances, claims that animals and people perceive surrounding physical objects as potential offers for action [34]. For instance, a tree affords climbing, or a ball affords kicking. Many authors follow Chemero's definition of affordances [12] which understands them as "relations between the abilities of organism and features of the environment" (p. 189).

The IS discipline applies the lens of affordances to study the relationship between technology and its users [14]. Following Chatterjee et al. [35], "IT affordances reflect the user's goals and how the user appropriates the IT capability to realize those goals" (p. 161). Stendal et al. [14] identified two major perspectives on affordances in the IS context, namely design vs. use. On the one hand, affordances can be designed on purpose to provide specific features to users with reference to their individual goals and capabilities. On the other hand, affordances are understood as emerging utilities that occur over time while interacting with a technology.

3 Conceptual development

3.1 Research context

To explore the influence of MR and VR technologies on EAM effectiveness, we deductively derive the involved constructs and propositions from IS literature. We focus our review on affordances provided by MR and VR technology to a group of employees (such as enterprise architects, business managers, and project managers [36]) who repeatedly examine and analyze existing EA artifacts for decision-making in organizations. We understand IT affordances in this context as intendedly designed EA artifacts visualized with MR (optical or video HMD; handheld AR displays) and VR (HMD) devices that provide action possibilities to employees. Whereas IT capabilities address the right and/or the possibility to execute a set of actions [37], the notion of IT affordances allows us to study the relationship between MR/VR devices and users [14] based on provided action possibilities [38].

In order to derive meaningful and suitable affordances, we focus on knowing and learning in organizations, as this encompasses EAM's characteristic to provide a holistic view on the enterprise as a basis for decision-making. A useful perspective for this is seen in the concept of Community of Practice (COP) [39]. Following Wenger [39], we consider a group of employees interacting with EAM as a COP, as they share the same concerns, interact regularly, and develop a joint repertory of experiences. In the following, we explain the applicability of the perspective of COP to EAM with the three key features of organizational COPs identified by Chatterjee et al. [35]. First, COPs are built on a joint knowledge base that captures the collective learning of each COP member. All EAM COP members share the same concerns as they are part of establishing, maintaining and developing an EA [3, 5, 6, 23]. They store EA resources and assets in an EA repository [36], which can be seen as a knowledge base. Second, a crucial aspect of COPs is collaboration that is characterized by regular interactions and collective learning. This applies to EAM through periodic discussions (e.g. in architectural boards) and activities (e.g. workshops, project participation) [3]. Third, COPs retain knowledge by developing, sharing, aligning, exploring, and exploiting mechanisms to support organizational processes. In EAM, this is enabled through a joint repertory of experiences (e.g. through projects), tools and methods (e.g. EA analysis tools) [36]. Based on the above mentioned key characteristics of COPs, we follow Chatterjee et al.'s [35] derivation of the three IT affordances, namely collaborative affordances, organizational memory affordances, and process management affordances, and we apply them using MR and VR technology in the EAM context. In the following section, we discuss the corresponding constructs and propositions.

3.2 Constructs and propositions

Decision-making quality

EAM supports the process of informed decision-making on EAs [3, 21] by providing knowledge about the inherent structure and relationship of EA components [18, 21]. EAM affords a variety of analysis methods, like impact evaluation approaches to new projects [4], EA component dependency analyses [19], or inefficiencies identification throughout the organization [21]. We argue that EAM analytic methods enable COP members for high quality decision-making as long as EA data are accurate.

These decisions, in turn, do not only influence the organization itself but also the effectiveness of the EAM as a management discipline. We understand EAM effectiveness as measureable in terms of the degree to which EAM complies with organization-specific goals [40]. Consequently, we posit:

P4: *High quality of decisions positively influences the effectiveness of EAM.*

EAM collaborative affordances

Collaborative IT affordance describes the ability to share, convey, and integrate knowledge together with people through the use of IT [41, 35]. This can be achieved between two or more users who are working in the same room or are remotely located [35, 41]. Similarly, we define EAM collaborative affordances as the ability enabled by MR and VR technology to share, convey, and integrate three-dimensional EA artifacts.

Stakeholders with different goals use EA artifacts, e.g. for coordinating IT development, risk management, or sourcing decisions [4, 5]. A single EA repository enables an integrated and holistic view on EA data [19], so that all stakeholder-specific EA artifacts are based on the same data and are easy to share with other COP members.

MR and VR technologies support collaboration as they allow users to see and interact with the same virtual EA artefact regardless of where the users are located [42, 43], but depending on their positions [28]. They provide various three-dimensional interactive and, in the case of VR, immersive [26] forms of data visualization, such as diagrams [28, 43], data-driven control panels [42], or multiple occluded layers [44]. This affordance facilitates joint work on the same EA artifact, as users can interact with virtual objects by changing the perspective when moving around as well as slicing, zooming, rotating, or cropping a virtual object [28, 43] with gestures [29]. Therefore, the collaborative ability provided by MR and VR technologies leads to fast and profound knowledge creation as COP members can intuitively work together on the same EA artifacts. We posit:

P1: *The EAM collaborative affordance tendered by MR and VR technologies positively influences the decision-making quality.*

EAM organizational memory affordance

An accessible knowledge base, or organizational memory, that covers the collective learning of COP members is a crucial aspect of COP [35]. Based on [45, 35], we define EAM organizational memory affordance as the ability enabled by MR and VR technology to create, store, transform, refine, access, mobilize, apply, and exploit three-dimensional EA artifacts.

The EA repository contains a variety of diverse EA artifacts such as the meta-model, standards, guidelines, architectural views, or governance activities to just name a few [36]. EA artifacts stored in an EA repository are the result of knowledge creating activities by the COP [21]. The simulation ability of MR and VR technologies [26, 30] assists stakeholders in creating and storing EA artifacts by intuitively combining views and data with gestures to recognize new insights that were previously unknown [3]. Stakeholders can also gain new knowledge by accessing and analyzing existing EA artifacts through MR and VR's transformation and refinement ability [28, 43]. The generated knowledge of the EA supports COPs in addressing some common EAM goals, such as identifying areas of action during strategy implementation [21], planning business change [4, 5], or provide alternative solutions [3]. Overall, these action possibilities allow deep-analysis of the EAs that, in turn, enables high quality decision-making. We therefore posit:

P2: *The EAM organizational memory affordance tendered by MR and VR technologies positively influences decision-making quality*.

EAM process management affordance

Process management affordances enable process analysis, problem identification, business simulations, and hence, optimal allocation of resources [35]. Following Chatterjee et al. [35], we define EAM process management affordance as the ability enabled by MR and VR technology to design, coordinate, implement, and monitor processes with three-dimensional EA artifacts.

Identifying and connecting EA components like processes or information systems throughout its EA layers is a key EAM activity [21, 19, 46] which enables, e.g., business impact analyses of planned changes [4]. EA analyses that involve various EA layers with a wide range of EA components can be performed using MR and VR technology due to their simulation-enabling [30], immersive [26], and human imagination [31] involving abilities. MR and VR can visualize 3D objects that represent all kinds of EA components, such as multiple virtual EA layers or the relationship between EA standards and application components. COPs can interact with these objects to design new or modify existing processes, and then test them in accordance with their surrounding EA components. Besides visualizing dependencies between EA components, MR and VR enable case specific animations such as picturing data flows between processes, present time-dependent shutdown of servers due to system failure, or animate cyber-attacks on the EAs. Moreover, processes can be monitored to track the performance of IS components such as server status, application usage, standards conformity, or project progress. This enables further development of EAM practices and artifacts, as well as enforcement of EA policy [4]. Such in-depth analysis enabled action possibilities by MR and VR technologies facilitates well-grounded decisions. Therefore, we posit:

P3: *The EAM process management affordance tendered by MR and VR technologies positively influences decision-making quality*.

3.3 Conceptual model

We have described the derivation of the three MR and VR EAM affordances, characterized them, and explained the relationship between the constructs through propositions. Figure 2 presents the corresponding conceptual model.

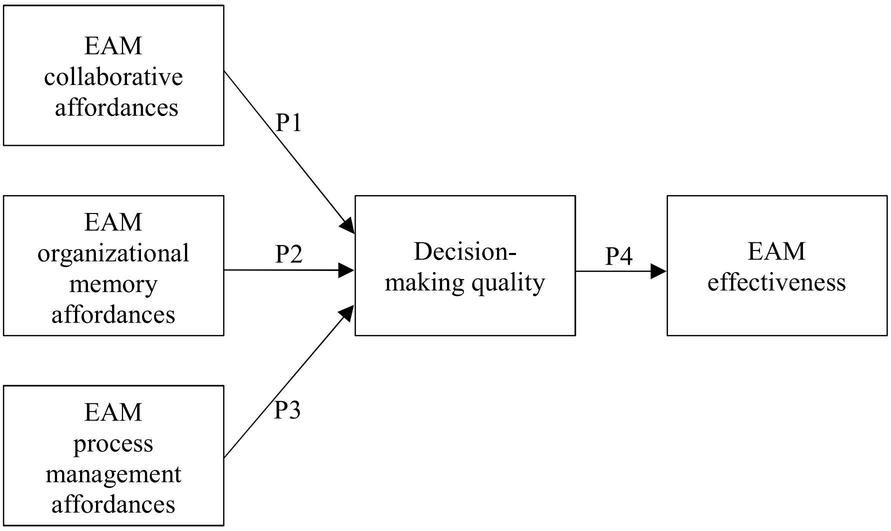

Figure 2: Overview of the conceptual model

4 Development of future research opportunities

We have conceptualized affordances in the area of EAM, tendered by MR and VR technology in order to discuss the influence of these technologies on the effectiveness of EAM. We chose decision-making quality as a moderating variable, because decision-making is an integral part of EAM [3, 6, 7, 21].

Our research has shown that MR and VR's interactive three-dimensional simulation ability offers great opportunities in the context of EAM. In addition to the fact that current EAM tools offer similar features, such as EA visualization and analysis [47], however, MR and VR technologies provide features beyond that. Both technologies track the users' movement and align the view on virtual objects based on the position of the object [26], which enables interactive collaboration with EA artifacts. Research on VR further shows an increased situation awareness, vividness, and media richness during collaborative tasks [43]. Moreover, MR and VR technology processes user inputs through gestures, which allows intuitive interaction with virtual objects [28].

The aim of this paper is to trigger research on MR and VR in the area of EAM. In Table 1 below, we propose a future research agenda.

Table 1: Future research agenda

Research area	*Research thrust*	*Research path*
Benefits	Which benefits do MR/VR provide in EAM?	• Empirical comparison of decision-making effectiveness between contemporary and potentially MR/VR-enabled EAM tools. • Further identification of suitable theoretical explanations about changed information-processing behavior of decision-makers.
Design	How should the user interface look like?	• Development of suitable meta models and EA repositories accounting for simulation requirements. • Development of design proposition for MR/VR interfaces and EA artifacts. • Development of different EA artifact visualizations like city maps, layer models, or bar/pie/etc. charts. • Process model to develop and analyze EA artefacts with MR/VR.
Implementation	How can organizations implement MR/VR for EAM support?	• Development and implementation of prototypes in organizations. • Development of (automatic) EA analysis and improvement capabilities in mixed and virtual environments.
Adoption	How can MR/VR become an accepted EAM tool?	• Comparison of stakeholder adoption rates between VR and MR technologies. • Success criteria for high adoption rates, e.g. in the area of culture or willingness. • Developing a process model for implementing MR/VR in the EAM context. • Solutions for sharing 3D EA artifacts to non-MR/VR users.

5 Conclusion

In this paper, we discussed possible actions of MR and VR technologies in the context of EAM. Our research shows that MR and VR offers affordances that can positively influence the quality of decision-making, and hence, EAM effectiveness. Moreover, we provide a research agenda to trigger more research on EA artifacts development and usage in mixed and virtual environments.

It is beyond the scope of this paper to test our model empirically. We derived the constructs and propositions deductively from relevant existing literature, which seems appropriate for our research goal. Further, we did not explicitly distinguish between MR and VR in our conceptual model even though there are significant differences [26]. As this paper is aimed at being a starting point for further research, we propose that our approach is suitable with regard to our objectives.

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