Utilization of Augmented Reality for Enterprise Architecture Decision-Making – An Empirical Investigation

DISSERTATION

zur Erlangung des akademischen Grades

Dr. rer. pol.

der Fakultät für Wirtschaftswissenschaften

der Universität Duisburg-Essen

vorgelegt

von

Kevin Rehring

aus Moers, Deutschland

Betreuer:

Prof. Dr. Frederik Ahlemann

Lehrstuhl für Wirtschaftsinformatik und Strategisches IT-Management

Duisburg, 2021

Gutachter

Prof. Dr. Frederik Ahlemann, Universität Duisburg-Essen

Prof. Dr. Fabian Beck, Universität Duisburg-Essen

Tag der mündlichen Prüfung:

06.07.2021

DOI: 10.17185/duepublico/75263
URN: urn:nbn:de:hbz:464-20220104-121150-4

Dedicated to all those who were told their goals were out of reach.

Abstract

Enterprise Architecture Management (EAM) is a management discipline that deals with constant organizational change and the alignment between business and IT in organizations. EAM develops, maintains, and refines Enterprise Architectures (EAs), which are time-dependent high-level representations of an organization's business and IT structure and how these relate to each other. These insights are visualized in the form of text, numbers, tables, graphs, models, and diagrams to support stakeholders in decision-making processes. Particularly in the current era of business process digitalization and the rapid pace of technology innovations, which in turn require a variety of capabilities and adoption measures, EAM plays a significant role in managing digitalization efforts by providing decision-makers and subject-matter experts with fact-based rational arguments. Yet despite theory and practice substantiating and demonstrating EAM's relevance for today's organizations, the successful application of EAM artefacts remains moderate.

This cumulative dissertation is composed of a set of five articles with the overarching research objective of shedding light on current challenges in EAM in practice, and that propose artefacts to overcome these challenges. Based on a comprehensive review of the literature on the goals, decision-making tasks, and employed EA artefacts in organizations, this dissertation suggests a positive influence of Virtual Reality (VR) and Augmented Reality (AR) affordances on the quality of EA decision-making, and hence, on EAM effectiveness. This claim has been supported by developing two 3D EA visualizations in the form of a three-layer EA model and an EA city model. In-depth evaluations with business experts and decision-makers in the form of case studies, structured interviews, and comprehensive usability testing resulted in sophisticated EA artefacts that can be applied in practice. The results indicate especially that less experienced EA decision-makers benefit the most from these innovative EA visualizations. Finally, this dissertation further prepares the ground for future comparability evaluations by providing a taxonomy for this purpose.

All in all, this work is part of the efforts to further develop the EAM discipline by investigating empirically the application of AR in EA decision-making scenarios. Consequently, the results contribute to research by both providing conceptual and empirical insights. The designed artefacts provide insights and recommendations into how organizations can utilize AR for EA decision-making to increase EAM effectiveness in real-world settings.

Keywords: *Enterprise Architecture Management, Enterprise Architecture Decision-Making, Augmented Reality*

Preface

Like never before, we are living in an exciting time, where we can experience the emergence of new technological possibilities virtually in real time. I have always been interested in researching new technologies and using them in a meaningful way. Not surprisingly, I was very happy about the opportunity to independently and intensively examine technologies and their use in the context of a dissertation - without having realized in advance that again I would have to reinvent myself on this exiting journey. Creating new knowledge requires extensive methodical knowledge, a very good understanding of the research domain, and the ability to think positively and to see setbacks as an opportunity. I have been very fortunate in my life that many people have supported me with these challenges not only during my doctoral thesis but also far in advance. It will not be possible for me to mention all the supporters adequately, but I would like to take the opportunity to explicitly thank some of the personalities who have had a significant influence on me.

First and foremost, I would like to thank Prof. Dr. Hans-Werner Gessmann. He encouraged me to pursue an academic career when I was a high school student. I had no contact with the scientific community until then, but he believed in my abilities and supported me as best as possible. Without his support I probably would not have gone to university.

Second, I thank Prof. Dr. Frederik Ahlemann not only for the chance to conduct a PhD at his chair but also for his enlightening supervision. His demanding and supportive nature helped me to challenge my ideas and intendent approaches as well as get research submissions done. The many fruitful academic and personal discussions with him have helped me a lot along my way about which I am very grateful. My sincere thanks also go to Prof. Dr. Fabian Beck for inspiring discussions and kindly accepting to be the second supervisor of my thesis.

Third, I also thank all my coworkers, especially David Hoffmann, Peder Bergan, Malte Greulich, Stefan Reining, Helge Schmermbeck, Matthias Werner, and Anna Khodijah for the many enjoyable moments in our offices and delighting and often constructive discussions. An addition, I received great support by Léonie Hackemann, Tim Brée, and Laurenz Bredenfeld, who greatly supported me and who were always ready to discuss new ideas.

Lastly, I also thank all those who helped me along the way, most importantly, my wife Katharina. Her support and backing during this challenging time have contributed significantly to the completion of this dissertation. A special thank also goes to my friends, particularly Jens and Angelina, for their patience and encouragement. I thank you all from my heart for your enormous support.

Duisburg, December 2020 Kevin Rehring

Table of Contents

List of Publications

Preceding work or earlier versions of essays included in this thesis have been published as full paper in conference proceedings.

	Essay 1	Essay 2	Essay 3	Essay 4	Essay 5
Title	Put your glasses on: Conceptualizing affordances of mixed and virtual reality for enterprise architecture management	Let's Get in Touch - Decision Making about Enterprise Architecture Using 3D Visualization in Augmented Reality	Conceptualizing EA cities: Towards Visualizing Complex Enterprise Architectures as cities	Evaluation of an Augmented Reality Prototype for Enterprise Architecture	Comparing EA Visualization and Visualization Technologies – A Taxonomy for the Development of Research Designs
Published at (Level[1])	MKWI, Conference (D)	HICSS, Conference (C)	ECIS, Conference (B)	WI, Conference (C)	/
Related references	Rehring, Hoffmann & Ahlemann (2018)	Rehring, Greulich, Bredenfeld & Ahlemann (2019)	Rehring, Brée, Gulden & Bredenfeld (2019)	Rehring & Ahlemann (2020)	/
Method[2]	Literature analysis	Case study, qualitative research	Literature analysis, qualitative research	Qualitative research	Literature analysis
Coauthors	David Hoffmann, Frederik Ahlemann, Mohamed Nassar	Malte Greulich, Laurenz Bredenfeld, Frederik Ahlemann	Tim Brée, Jens Gulden, Laurenz Bredenfeld	Frederik Ahlemann	/
Assistance[3]	/	/	Frederik Ahlemann	Tim Brée	Frederik Ahlemann
Own major contribution	Idea generation, research design selection, literature analysis, artefact design, writing manuscript manuscript review, management research process	Idea generation, research design selection, literature search & analysis, artefact evaluation, writing manuscript manuscript review, management research process	Idea generation, research design selection, data analysis, writing manuscript manuscript review, management research process	Idea generation, research design selection, literature collection & analysis, data collection & analysis, writing manuscript manuscript review, management research process	Idea generation, research design selection, literature collection & analysis, data collection & analysis, writing manuscript manuscript review, management research process
Language check: Prof. Christine Anthonissen					

[1] VHB JQ3 ranking: https://vhbonline.org/vhb4you/vhb-jourqual/vhb-jourqual-3/gesamtliste

[2] According to the classification provided by Palvia et al. (2004, p. 529)

[3] Refers to additional assistance that did not qualify for co-authorship in the dissertation's included version (Deutsche Forschungsgemeinschaft, 2013, p. 29)

Publications included in this thesis

Rehring, K., Hoffmann, D., & Ahlemann, F. (2018). Put your glasses on: Conceptualizing affordances of mixed and virtual reality for enterprise architecture management. In *Multikonferenz Wirtschaftsinformatik* (MKWI), Lüneburg, Germany.

Rehring, K., Greulich, M., Bredenfeld, L., & Ahlemann, F. (2019). Let's Get in Touch-Decision Making about Enterprise Architecture Using 3D Visualization in Augmented Reality. In *Proceedings of the 52nd Hawaii International Conference on System Sciences* (HICSS). Maui, Hawaii, USA.

Rehring, K., Brée, T., Gulden, J., & Bredenfeld, L. (2019). Conceptualizing EA Cities: Towards Visualizing Complex Enterprise Architectures as Cities. In *Proceedings of the 27th European Conference on Information Systems* (ECIS). Stockholm, Sweden.

Rehring, K., & Ahlemann, F. (2020). Evaluating the User Experience of an Augmented Reality Prototype for Enterprise Architecture. In *15th International Conference on Wirtschaftsinformatik* (WI). Potsdam, Germany.

Publications not included in this thesis

Bergan, P., Mölders, A., Rehring, K., Ahlemann, F., Decker, S. & Reining, S. (2020). Towards Designing Effective Governance Regimes for Smart City Initiatives: The Case of the City of Duisburg. In: *Proceedings of the 53rd annual Hawaii International Conference on Systems Science* (HICSS). Hawaii, USA.

Jung J., Hacks S., de Gooijer, T., Kinnunen, M. & Rehring, K. (2021). Revealing Common Enterprise Architecture Debts: Conceptualization and Critical Reflection on a Workshop Format Industry Experience Report. In *IEEE 25th International Enterprise Distributed Object Computing Workshop* (EDOCW). Gold Coast, Australia.

Brandt, N., Ahlemann, F., Reining, S. & Rehring, K. (2021) Internet of Things in Product Lifecycle Management – A Review on Value Creation through Product Status Data. In: *Americas Conference on Information Systems* (AMICIS). Online. 2021.

Muschkiet, M., Kühne, B., Jagals, M., Bergan, P., Rehring, K. & Ahlemann, F. (2022). Making Data Valuable for Smart City Service Systems – A Citizen Journey Map for Data-driven Service Design. In: *Proceedings of the 54th annual Hawaii International Conference on Systems Science* (HICSS) (forthcoming). Hawaii, USA.

References

Deutsche Forschungsgemeinschaft. (2013). *Sicherung guter wissenschaftlicher Praxis*. Weinheim, Germany: Wiley-VCH.

Palvia, P., Leary, D., Mao, E., Midha, V., Pinjani, P., & Salam, A. (2004). Research Methodologies in MIS: An Update. *Communications of the Association for Information Systems*, *14*(1), 24.

I

INTRODUCTION TO "UTILIZATION OF AUGMENTED REALITY FOR ENTERPRISE ARCHITECTURE DECISION-MAKING – AN EMPIRICAL INVESTIGATION"

Abstract

Organizations today are confronted with changing technologies and rapidly developing digital innovations. Especially large organizations implement enterprise architecture management (EAM) as an approach to change its underlying IT landscape toward a sustainable and cost-effective enterprise architecture (EA). However, many organizations struggle to implement, as well as to adapt to, EAM's methods and processes. Even though the benefits of applying EAM are widely known, one major concern lies in decision-makers' limited use of EA-provided information. This introduction provides an overview of this projects' research context, introducing relevant concepts and presenting problems prevailing in practice and research. Based on this overview, the overarching research problem, as well as the dependent research questions, are introduced. The applied research methods and the corresponding philosophical position are discussed in more detail. An overview of the dissertation's structure, as well as a summary of the individual research papers and their most important results, concludes the introduction.

Keywords: *Motivation, Research Domain, Research Design, Research Process*

Table of Contents

List of Figures

List of Tables

1 Introduction

Since the 1950's, organizations have been employing *Information Technology* (IT) for data processing purposes to enhance the organizational effectiveness, increase its flexibility, and develop new business models to stay competitive in a constantly changing environment (Campbell-Kelly, 2018, p. 97; Korhonen & Halén, 2017, p. 349; R. Winter, Legner, & Fischbach, 2014, p. 1). The increasingly turbulent and dynamic markets spurred by ongoing globalization, more regulations, the rapid development of faster development cycles in new technologies, as well as altered customer needs, have forced businesses to transform themselves into innovation-driven and sustainable organizations (Ross, Weill, & Robertson, 2006, p. 11; Stolterman & Fors, 2004, p. 689; Van de Wetering, 2019, p. 1). A common approach in addressing these challenges is to invest in IT assets and *Information Systems* (IS) and to integrate these into simultaneously adjusted or new organizational structures, processes, and capabilities (Ahlemann, Stettiner, Messerschmidt, & Legner, 2012, p. 5; Van de Wetering, 2019, p. 1), the details of which depend on whether the expected organizational change is characterized by an incremental change (optimization) or fundamental change (transformation) (Aier, Kurpjuweit, Saat, & Winter, 2009, p. 36). Due to the growing complexity of key elements and their relations to an enterprise, well-planned, systematically conducted, and holistic actions are needed to support organizational changes (Aier et al., 2009, p. 36; R. Winter et al., 2014, p. 1). However, many organizations are not fully aware of their business and IS landscapes, nor of their dependencies (Niemi & Pekkola, 2019, p. 1).

A suitable approach to understanding the entire organization and its various relations from a business and IT perspective, in order to manage its complexity, drive transformation projects, and support innovation, is the application of *Enterprise Architecture Management* (EAM) (Lange & Mendling, 2011, pp. 5–6). EAM provides a set of methods, tools, principles, and standards (Ahlemann et al., 2012; D. Simon, Fischbach, & Schoder, 2014) to establish, develop, and maintain so called *enterprise architectures* (EA), which are holistic views on enterprises encompassing business and IT aspects (Tamm, Seddon, Shanks, & Reynolds, 2011, p. 142; The Open Group, 2009, p. 411; Aier, Gleichauf, & Winter, 2011, p. 645). EAs describe organizations from a time-specific perspective, which can be past, current, and multiple future states, as well as a domain-specific perspective that could refer to infrastructure assets, applications, data, business processes, and the overall company strategy (Tamm et al., 2011, p. 142; The Open Group, 2009, p. 411). With this overview of the key components of enterprises, EAs offer a consistent basis for decision-making about, for instance, business-IT alignment, complexity reduction, or future planning of organizations (Tamm et al., 2011, p. 142). This fact-based foundation provides rational arguments about EAs (van der Linden & Van Zee, 2015, p. 28), and facilitates better and timely decision-making for a variety of EA stakeholders (Ahlemann et al., 2012, pp. 39 & 44; Olshannikova, Ometov, Koucheryavy, & Olsson, 2015,

p. 19). EAs are accessible through, e.g., texts, matrix views, layer perspectives, bar charts, pie charts, and 2D and 3D models (Roth, Zec, & Matthes, 2014, p. 46).

Although EAM is considered to be a promising management approach for achieving and maintaining the efficiency and effectiveness of IS in organizations (Boucharas, Steenbergen, Jansen, & Brinkkemper, 2010, p. 76; Schmidt & Buxmann, 2011, p. 181; Tamm et al., 2011, pp. 149–156), the low usage of EAs in decision-making in practice is still widely reported (Niemi & Pekkola, 2019, p. 2; Shanks, Gloet, Asadi Someh, Frampton, & Tamm, 2018, pp. 139–140; Lange, Mendling, & Recker, 2016, p. 412; Kotusev, Singh, & Storey, 2015, p. 1; D. Simon et al., 2014, p. 6; Hauder, Roth, Schulz, & Matthes, 2013, pp. 2–4; Lucke, Krell, & Lechner, 2010, p. 9). Consequently, by addressing the design and application limitations of EAs in organizational settings the study meaningfully contributes to the body of EAM knowledge.

Following the cumulative tradition in IS research (Hirschheim & Klein, 2012, p. 218), this thesis consists of five research papers of which each examines a separate research question. This introduction presents the general research topic, frames the overarching research goal, describes the research methods, and summarizes the final contributions. Section 2 introduces the basic terminology and details the research problem, research goal, and research questions. Section 3 provides an overview of the research design, including the underlying epistemological assumptions, the overall research process, and the research methods applied to answer the research questions. Section 4 presents the main contribution of each individual research paper, and furthermore, shows how the papers fit into the stated research design. Finally, section 5 briefly discusses the main contribution and limitations of this thesis.

2 Theoretical Foundation

2.1 Enterprise Architecture Management

Besides its maturity, research has not achieved a common understanding of Enterprise Architecture (EA), nor of Enterprise Architecture Management (EAM) (Niemi & Pekkola, 2019, p. 2; Löhe & Legner, 2014, p. 103; Schönherr, 2009, p. 400). Below I shall present the basic concepts of EA and EAM in order to introduce the terminology used in the remainder of this thesis.

Most researchers define EA based on the ANSI/IEEE Std 1471-2000 standard (K. Winter, Buckl, Matthes, & Schweda, 2010, p. 2; Aier, Fischer, & Winter, 2011, p. 637) or, respectively, ISO/IEC/IEEE 42010 (2011, p. 2), describing architectures as "fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution." Besides this rather generic and technical definition of EA, Kaisler et al. (2005, p. 1) consider the structure of organizational components and their relationship to the organization's information systems as part of an EA. They also include a description of how these components work together to support business processes and achieve business objectives. Tamm et al. (2011, p. 142) also define EA as a high level representation of business processes and the relationship to its underlying IT components, but they further focus on the extent to which these processes and systems are shared inside the enterprise, for example, in each division or department (R. Winter & Fischer, 2007, p. 1). Many publications attend to business and IT aspects in giving EA definitions. For example, Aier et al. (2011, p. 645) define EA as a description of a company or government agency's fundamental structure intended to bridge the gap between business and IT. Winter and Schelp (2008, p. 548) refer to business-related artefacts like goals, productions, markets, or competitors as part of EA. They argue that including these artefacts leads to effective business and IT construct alignment. Winter and Fischer (2007, p. 2) argue that EA could also include external partners, customers and suppliers. They also identified five common layers that describe the fundamental structure of an organization: business architecture, process architecture, integration architecture, software architecture, and technology (or infrastructure) architecture. However, more layers could be possible. Besides describing business processes and their link to the IT infrastructure, Ross et al. (2006, p. 9) define EA as reflecting the company's operating model which standardizes and integrates business processes. Ahlemann et al. (2012, p. 16) extend this view by adding design rules to the EA definition to ensure consistency in components' use and their relationships. Moreover, many researchers claim that EA describes not only the current state of organizational artefacts, but also multiple future states (Korhonen, Hiekkanen, & Lähteenmäki, 2009, p. 2), which emphasizes EA's long-term perspective on organizational development (Ross et al., 2006, p. 9). The current state of an EA is often described as "as-is" or "baseline architecture," and the future states are called "to-be" or "target architecture" (Tamm et al., 2011, p. 142). Comparing the baseline to the target architecture enables the development of roadmaps that provide a plan for achieving the desired EA future state (Tamm et al., 2011, p. 142).

Similar to EA, we currently find differences in definitions of EAM (K. Winter et al., 2010, p. 2). Following Aier et al. (2011, p. 645), EAM aims to establish and develop an organizations' EA. Based on an architectural perspective, we consider planning and controlling activities that bring business change to be a part of EAM, which, according to Hanschke (2016, p. 8), underlines the systematic and holistic approach EAM takes. For Hanschke (2016, p. 8) EAM is a process organizations use to understand, design, plan, and communicate within their professional and technical structures. According to Löhe and Legner (2014, p. 104), EAM provides clear guidelines using plans, roadmaps, principles, and standards to support the enterprise's transformation. In the same vein, Ahlemann et al. (2012, p. 20) focus on developing an EA supported by architectural principles, guidelines, and a formulated governance regime. The goal is to be compliant with the EAM's architectural vision and business strategy. Wijeya and Gregory (2012, p. 2) support this view, arguing that EAM is closely linked to business strategy. Tamm et al. (2011, p. 142) apparently share a similar view, while emphasizing the nature of strategy implementation; however, their definition refers to EA instead of EAM. In a broader sense, Simon et al. (2014) describe EAM not only from a process perspective, but also considering methods and tools, and highlighting the need for assigning responsibilities when building EAs.

In view of the above, and according to Rahimi et al. (2017, p. 125), we postulate a distinction between EA and EAM. Thus, we understand Enterprise Architecture as a time-dependent high-level representation of the structure of an organization, which comprises business and IT components and the relationship between them. Enterprise Architecture Management, then, is a business strategy driven management discipline that establishes, maintains, and develops an Enterprise Architecture.

Over the last decade, EAM built up a reputation as a business and IT management instrument (Lange et al., 2016, p. 412), but it is not a new management process (Ahlemann et al., 2012, p. 20). EAM provides new information and management methods that support existing management processes and enable informed architectural decision-making (Ahlemann et al., 2012, p. 20; D. Simon et al., 2014, p. 32). However, the main purpose of EAM is to limit the organizational design freedom of affected stakeholders (Weiss, Aier, & Winter, 2013, p. 2). For example, EAM confronts IT infrastructure heterogeneity by applying technology standards intended to reduce the number of permitted platforms or to standardize the communication between applications through defining standard protocols (Boh & Yellin, 2006, p. 13). Another example lies in EA principles which are derived from high-level business strategies and guide concrete design decisions such as "reuse as much as possible" or "application should be decoupled" (Proper & Greefhorst, 2010, p. 6). Unsurprisingly, these design limiting approaches must be enforced; hence, they affect many business processes, like strategy development, project prioritization, budgeting, and project implementation (Ahlemann et al., 2012, p. 39).

2.2 Real, Mixed, and Virtual Reality

To get a clear understanding of Mixed Reality (MR) and Virtual Reality (VR) technologies, we follow the proposed Milgram et al. (1994) Reality-Virtuality continuum. As presented in Figure I-1 their approach describes a spectrum of environments ranging from completely real to completely unreal, i.e., virtual environments. One finds mixed environments, which define a combination of real and virtual environments, either side of the continuum (Milgram et al., 1994, p. 283). To fit the scope of our research, we describe Augmented Reality (AR) and Augmented Virtuality (AV) as two forms of mixed environment, as well as VR as a form of virtual environment.

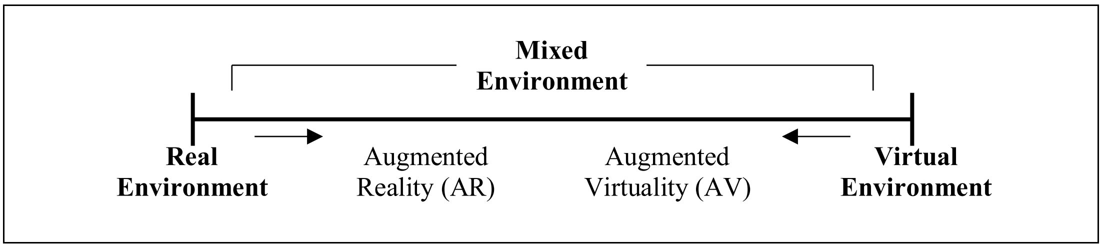


Figure I-1. Reality-Virtuality (RV) continuum proposed by Milgram et al. (1994)

As a part of the mixed environment, AR enriches the real world environment with virtual objects, and therefore, lies close to the the real environment on the RV-continuum (Milgram et al., 1994, p. 284). Users can see and experience the real world, while AR adds or even removes objects from it (Azuma, 1997, p. 2). Some scholars find AR relies on more than only the sense of sight (e.g. Azuma, 1997, p. 9), although a recent review of AR applied in workforce information systems identified that, as yet, only visual characteristics of AR are in focus when organizations implement these projects (Lušić, Fischer, Bönig, Hornfeck, & Franke, 2016, p. 1117).

Generally speaking, there are two classes of AR definitions (Ohta & Tamura, 1999): The first largely builds on a broad understanding, giving a technology-independent definition of AR (Ohta & Tamura, 1999). Azuma (1997, p. 2) 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." In contrast, the second class of AR definitions mainly focus on AR displays which are technology-related (Ohta & Tamura, 1999). Most commonly, this includes so-called head-mounted displays (HMD) (Azuma, 1997, p. 10) that distinguish between optical and video see-through displays (Sherman & Craig, 2002, p. 128). Head-mounted optical see-through displays allow users to see the real environment through a display medium (Azuma, 1997, p. 10; Milgram et al., 1994, p. 284). A variation of this is a handheld AR display where a small screen shows virtual objects which react to changes of the real environment (Sherman & Craig, 2002, p. 140). Alternatively, 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 (Azuma, 1997, p. 12).

Augmented Virtuality (AV) is also part of the mixed environment, though in close proximity to the virtual environment on the RV-continuum (Milgram et al., 1994, p. 285). In contrast to AR, AV is more virtual, even if it includes real objects like a user's hand (Milgram et al., 1994, p. 285). Currently, there is considerably less research on AV than on AR, mainly because we lack feasible consumer devices (McGill, Boland, Murray-Smith, & Brewster, 2015, p. 2143). However, new room-wide motion detecting devices that capture the position of objects, gestures, and other physiological measures could increase the applicability of AV (McGill et al., 2015, p. 2152).

A virtual environment (VE) consists completely of computer generated virtual objects (Milgram et al., 1994, p. 287) and is commonly called Virtual Reality (VR) (Azuma, 1997, p. 2). As a result of different past understandings and interpretations, we have multiple definitions of VR (Sherman & Craig, 2002, p. 6; Zhou & Deng, 2009, p. 319). Many scholars define VR based on the nature of its technology, describing the devices, computers and methods that are needed to create an interactive simulation (Zhou & Deng, 2009, p. 319f). Others highlight the immersive experiences with VR (Azuma, 1997, p. 2), or add human imagination to the definition as a key concept (Burdea & Coiffet, 2003, p. 3). Many agree that VR technology addresses all human senses (Burdea & Coiffet, 2003; Walsh & Pawlowski, 2002, p. 298) and that sensory feedback is an important aspect of it (Sherman & Craig, 2002, p. 10). Considering all these facets, we follow Biocca and Delaney (1995, p. 63) 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."

Common VR output devices are occlusive HMDs (Biocca & Delaney, 1995, p. 59; Sherman & Craig, 2002, p. 86). These displays rely on head-centered motion and its capability of binocular disparity (Biocca & Delaney, 1995, p. 59). In contrast to AR, occlusive HMDs suppress the real world to the benefit of the VR, while using small screens (Sherman & Craig, 2002, p. 135f). A variation of these HMDs are virtual retinal displays (VRD) that present images directly onto the retina of a users' eye (Sherman & Craig, 2002, p. 152; Walsh & Pawlowski, 2002, p. 300). Monitor-based 'fishtank' VRs (Sherman & Craig, 2002, p. 140) are alternative VR output devices that track the position of the users' head, and the VR then responds to the head movement (Sherman & Craig, 2002, p. 140f). Movement and user input are important characteristics of immersive virtual reality experiences (Sherman & Craig, 2002, pp. 111 & 120). Position tracking (e.g. the user's location, 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 instruments with which users can interact with a virtual world (Sherman & Craig, 2002, p. 89).

2.3 Problem Statement and Research Questions

Even though poorly coordinated organizational changes frequently lead to heterogeneous, isolated, costly, and incompatible EAs (Ahlemann et al., 2012, p. 5; Niemi & Pekkola, 2019, p. 1), the successful application of EAM remains moderate (Niemi & Pekkola, 2019, p. 2; Shanks et al., 2018, pp. 139–140; Lange et al., 2016, p. 412; Kotusev et al., 2015, p. 1; D. Simon et al., 2014, p. 6; Hauder et al., 2013, pp. 2–4; Lucke et al., 2010, p. 9). Without EAM, implementation projects miss relevant organizational viewpoints, such as strategic planning, process improvement, IT governance, and program management "as they lack the holistic picture and the "glue" that holds the transformation together" (Niemi & Pekkola, 2019, p. 2). Missing realization of expected business value and competitiveness is one symptom of uncoordinated organizational change (Mithas & Rust, 2016, p. 223). There are various reasons for not-considering EA information in decision-making, which range from, e.g., limited institutionalization (Weiss et al., 2013, p. 2), missing strategic considerations (D. Simon et al., 2014, p. 6), challenging implementation (Löhe & Legner, 2014, p. 104), and lack of acceptance due to weak documentation and presentation (Kotusev et al., 2015, pp. 3–4).

This thesis focuses on the low use of EA in decision-making processes in organizational change projec*ts* as research to date generally dedicates minimal attention to this (Abraham, 2013, p. 2; Hiekkanen et al., 2013, p. 296; Löhe & Legner, 2014, p. 116; Banaeianjahromi & Smolander, 2017, p. 25; Carvalho & Sousa, 2014, p. 7; Kotusev et al., 2015, pp. 3–4). Potential reasons for the limited application of EA documentation are manifold: stakeholders perceive EA visualizations to be exceptionally complex as EA components include various stakeholders and many kinds of organizational aspects, including their relations to one another (Löhe & Legner, 2014, p. 115; van der Raadt, Schouten, & Vliet, 2008, p. 20). Similarly, oversized EAs composed of hundreds of elements hinder effective communication and limit the identification of errors (Buckl, Ernst, Matthes, & Schweda, 2009, p. 4; Lucke et al., 2010, p. 8). Communicating EAs is also limited when architectural information is outdated, of poor quality, or does not address stakeholders' specific needs (Löhe & Legner, 2014, p. 115). Although in some cases stakeholders require detailed architectural descriptions (e.g. for implementation projects), many others require a more abstract level of description; thus, an inappropriate level of abstraction becomes another reason for not using EAs (Nowakowski et al., 2017, p. 4854;

Vieira, Cardoso, & Becker, 2014, p. 245). Frequently, some EAM teams develop EA models, not to address specific business problems or stakeholder concerns, but simply for the sake of developing EAs, which lead to the perception of the EA function as an ivory tower (Hobbs, 2012, p. 85). Finally, decision-makers complain about insufficient EA tool support, as they demand a variety of features such as capturing, visualizing, planning, and analyzing. These are often not afforded in a stakeholder or business-value oriented way (Nowakowski et al., 2017, p. 4854; Lucke et al., 2010, pp. 8–9; Lux & Ahlemann, 2012, p. 163). All in all, the literature indicates that stakeholders often find the added value of EA visualizations for decision-making to be rather low. They perceive EA visualizations as either complex, oversized, or simplified, with the EA represented in a way that neither prioritizes stakeholder needs, nor gives adequate tool support. This is surprising, as EAM research and practice have developed a broad range of EA visualizations and EA tools, all intended to present and communicate the complexity and dependencies of EAs (consider e.g. Roth et al., 2014).

This thesis states that the above-mentioned limitations are the result of unsuitable visualizations of EAs for EA-specific decision-making tasks. This study follows the cognitive fit theory (CFT) (Vessey, 1991b) that states a missing fit between a visualization on the one hand and a task on the other, leads to inefficient problem-solving processes in human mind. As presented in Figure I-2, the CFT explains that if the problem presentation and problem-solving tasks emphasize the same type of information, similar problem-solving processes automatically occur, eventually forming a consistent mental representation that leads to an effective problem-solving performance (John & Kundisch, 2015, p. 4; Vessey & Galletta, 1991, p. 67; Weiss, Aier, & Winter, 2012, p. 6). Drawing on these claims, this study's overarching research problem is defined as follows:

RP: *Due to a poor fit between EA visualizations and EA decision-making tasks, many stakeholders struggle to process EAs; this situation manifests in low EA visualization use in decision-making tasks.*

It is important to consider that visualizations are created with and transported by technology (John & Kundisch, 2015, p. 4), which can be pen and paper, 2D and 3D printers, as well as a computer. Assuming high maturity in potentially relevant types of EA visualizations (e.g. Roth et al., 2014), this thesis focuses on the applied technology used to communicate EAs. To achieve this, the advantage of recent technological improvements in the form of high-performing optical see-through HMDs is used (Kortekamp, Werning, Thomas, & Ickerott, 2019, p. 1). The special HMDs immerse users in an AR in which three-dimensional virtual objects are superimposed onto the individual real-world view (Milgram et al., 1994, p. 284; Azuma, 1997, p. 357). Concrete implementation of AR HMD aimed at visualizing complex information is

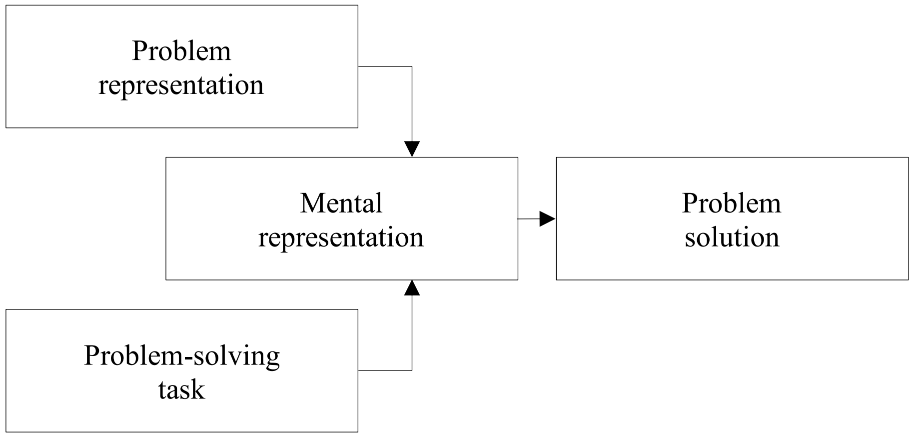


Figure I-2. Model of the cognitive fit theory by Vessey (1991b)

already in use in the areas of, e.g., medicine (Meola et al., 2017), teaching (Lee, 2012), and software development (Merino, Bergel, & Nierstrasz, 2018). Such AR HMDs afford unique characteristics that are suitable for supporting problem-solving processes in the context EAs' decision-making processes. First, AR can present large amounts of data in a three-dimensional real-world environment which users can easily interpret due to humans' natural spatial imagination capabilities (Dunleavy, Dede, & Mitchell, 2009, p. 17; Olshannikova et al., 2015, p. 21; Sommerauer & Müller, 2014, p. 67; Wang, Love, Kim, & Wang, 2014, p. 13). Exploiting the user's spatial ability can reduce cognitive load, and thus enable a better overall understanding of complex causal relationships (Dunleavy et al., 2009, p. 17; Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014, p. 3; Sommerauer & Müller, 2014, p. 67; Wang et al., 2014, p. 13). Second, instead of commonly used keyboards and computer mice, interaction in AR is realized by using gestures, voice control (Azuma, 1997, p. 357), and body movements (Henderson & Feiner, 2008, p. 211) which reduce users' need for interaction capabilities. Without external control hardware users can directly interact with visualized content, thus navigating a situation intuitively and naturally (Ohta & Tamura, 1999, p. 224). Such AR potential can improve EA decision-makers' understanding of EAs and increase users' willingness to consider EAs in decision-making processes. Third, business meetings are dominated by face-to-face meetings as the co-presence of the human body is important to provide realistic facial features, sound, and body movement (Strengers, 2015, p. 604). AR supports this meeting approach as it still enables face-to-face communication in a real-world setting (Wu, Lee, Chang, & Liang, 2013, p. 44). This contrasts with VR technologies, which also employ HMDs but immerse users completely in a fully virtual environment that is disconnected from the real world (Steffen, Gaskin, Meservy, & Jenkins, 2017, p. 4) and often leads to motion sickness (Vovk, Wild, Guest, & Kuula, 2018, p. 6). In sum, we assume that interacting with EA visualizations in AR using HMDs increases decision-makers' information processing capacity, thereby enhancing the understandability of EAs, which, in turn, increases the use and eventually the effectiveness of EAM in organizations. Thus, this thesis aims to address the limitations mentioned above by *developing and evaluating an interactive, easy to use, and understandable visualization of EAs in AR using an HMD for decision-making tasks without discounting the current complexity of organizations*. Following Nguyen et al.'s (2019, p. 15) guidelines for designing DSR research questions, the overarching research questions of this thesis are:

RQ1: *How is Enterprise Architecture Management applied in practice?*

RQ2: *How can we design an Augmented Reality Head-Mounted Display prototype for decision-making about Enterprise Architectures?*

RQ3: *How can we use an Augmented Reality Head-Mounted Display prototype for decision-making about Enterprise Architectures?*

3 Research Design

3.1 Meta-Theoretical Assumptions

Every scientific outcome is based on a set of epistemological assumptions that influence the basic understanding of concepts like validity, reliability, quality, and rigor of research (Becker & Niehaves, 2007, p. 198). Different fundamental assumptions about how knowledge can be captured influence the focus of research, the definition of research questions, and the analysis of results (Becker & Niehaves, 2007, p. 209). Especially IS research's cumulative nature (Hirschheim & Klein, 2012, p. 218) and methodical pluralism (Orlikowski & Baroudi, 1991, pp. 3 & 24; Recker, 2013, p. 65) fosters each researcher's explicit epistemological positioning to ensure mutual understanding among researchers and readers (Becker & Niehaves, 2007, p. 198) and support researchers to "understand the implications of their research perspective choice, and act in ways that reflect that knowledge" (Orlikowski & Baroudi, 1991, p. 24).

The IS discipline is mainly characterized by the two distinct epistemological paradigms positivism and interpretivism. The positivistic stance is particularly widespread in the US (Chen & Hirschheim, 2004, pp. 207 & 210). The positivist and interpretivist paradigms can briefly be differentiated on three aspects. First, from an ontological perspective, positivistic researchers believe that the world exists objectively and, thus, independent of human cognition and experience (Chen & Hirschheim, 2004, p. 201; Becker & Niehaves, 2007, p. 202). This underpins the view that phenomena can be interpreted independent of researcher subjectivity. Materialism, an extreme form of positivism, assumes that everything in the world refers exclusively to matter, material forces, and physical processes (Stack, 1998). In contrast, interpretivists assume that reality is socially-constructed and depends on social interaction processes and human consciousness (Chen & Hirschheim, 2004, p. 201; Becker & Niehaves, 2007, p. 202). Hence, interpreting research results depends on the researcher's experience.

Second, from an epistemological perspective, positivists focus on repeatedly verifying or falsifying theories, as well as inductively generalizing observations. They assume causal explanations of phenomena that can be objectively tested (Orlikowski & Baroudi, 1991, pp. 6 & 9; Chen & Hirschheim, 2004, p. 201). Interpretivists, however, acknowledge multiple states of truth as they depend on the researcher's perspective and the context in which the phenomena are being analyzed (Orlikowski & Baroudi, 1991, p. 6; Chen & Hirschheim, 2004, p. 201). They focus on understanding human and social interactions in a natural setting.

Third, from a methodological perspective, positivists aim to test hypothetic-deductive theories with objective measurements from an independent position. They commonly apply quantitative methods where they can change research design parameters throughout data collection and analysis (Orlikowski & Baroudi, 1991, p. 9). Typical quantitative research methods make use of surveys and lab experiments (Recker, 2013, p. 66). Contrastively, interpretivists believe in subjectivity, and thus personally engage in a research setting which they are investigating (Orlikowski & Baroudi, 1991, p. 14). While studying the social processes to better understand a social group's meanings, beliefs, and intentions (Orlikowski & Baroudi, 1991, p. 14), interpretivism typically employs qualitative research methods like case studies, action research, or grounded theory (Recker, 2013, p. 88).

Following here, I discuss this study's philosophical assumptions which are supported by Becker und Niehaves's (2007, p. 202) epistemological framework, consisting of five aspects of relevance. Table I-1 presents the research framework, including my own philosophical assumptions.

Table I-1. Becker and Niehaves's (2007, p. 202) epistemological framework

I. What is the object of cognition? (Ontological aspect)	**Ontological realism** A world exists independently of human cognition, for instance, independent of thought and speech processes.	**Ontological idealism** The 'world' is a construct which depends on human consciousness.	**Kantianism** Entities exist that are independent of the human mind (noumena), while others are dependent on it (phenomena).
II. What is the relationship between cognition and the object of cognition?	**Epistemological realism** Objective cognition of an independent reality is possible.		**Constructivism** The relationship between cognition and the object of cognition is determined by the subject.
III. What is true cognition? (Concept of truth)	**Correspondence theory of truth** True statements are those which correspond to 'real world facts.'	**Consensus theory of truth** A statement is true (for a group), if it is acceptable to the group.	**Semantic theory of truth** A condition for truth is the differentiation of an object from a metalanguage term.
IV. Where does cognition originate?	**Empiricism** Cognition originates in the senses. Such experience-based knowledge is called *a posteriori* or empirical knowledge.	**Rationalism** Cognition originates in the intellect. Such non-experience-based knowledge is referred to as *a priori* knowledge.	**Kantianism** Both experience and intellect are sources of cognition. Thoughts are meaningless without content; cognitions are blind if not linked to terms.
V. By what means can cognition be achieved? (Methodological aspect)	**Inductivism** Induction is understood as the extension from individual cases to universal phases, thus to generalization.	**Deductivism** Deduction entails deriving the individual from the universal.	**Hermeneutics** Understanding a certain phenomenon is influenced by the pre-understanding of the whole/context.

Becker and Niehaves's (2007) first question encompasses the ontological aspect of the philosophical stance, and refers to the question whether or not a real world (existence and nature of reality) exists beyond human cognition (Niehaves, 2007, p. 3; Becker & Niehaves, 2007, p. 201f). This thesis takes a Kantianism perspective to overcome the hard binary distinction between an objective and subjective, i.e. a socially constructed, perception of how the real world exists. Truly, visualizations of EAs in AR can form different mental models and depend on human understanding (phenomena) of, e.g., architectural models in general, as well as business processes, data values, and platforms in particular. However, some entities of EAs exist independent of the human mind (noumena), e.g. technical infrastructure assets like computer hardware or head-mounted displays.

The second question focuses on the relationship between a subject and an object. It considers "whether entities beyond human thoughts and speech can, at least in principle, be recognized as objective" (Becker & Niehaves, 2007, p. 203). In short, epistemological realism assumes an objective reality in which the existence of objects is independent of the human mind (positivist subject-object relationship stance), whereas constructivism describes a subjective subject-object relationship that needs to be interpreted by a subject (interpretivist subject-object relationship stance) (Becker & Niehaves, 2007, p. 203). In this thesis, I take a moderate constructivist perspective, as I am convinced that cognition of an objective reality can and has to be interpreted in conducting IS research. The scope of my thesis obliges such an assumption, as it considers stakeholders' subjective interpretations of reality which are themselves influenced by unique cultural conditions, as well as individual and historical experiences (Patomäki & Wight, 2000, p. 224).

The third question refers to the concept of truth and the extent to which accurate knowledge can be gathered and assessed (Becker & Niehaves, 2007, p. 203f). Following the correspondence theory of truth, true knowledge is found when a statement and a fact that is objectively assessed as correct, validly correspond. The consensus theory of truth assumes a statement is true if a group of people considers it to be true. The semantic theory of truth aims to achieve clarity and precision of argumentation by assuming that if a meta language positively assesses the validity of an objective language based statement, truth is established (Becker & Niehaves, 2007, p. 204). Considering the scope of this research, the assumptions underpinning this thesis build on a consensus-oriented truth perspective, as humans experience and evaluate the design artefacts. The tested prototypes and the corresponding design principles are taken to be true when a considerable proportion of the group agrees on the stated principles.

The fourth question deals with the origin of knowledge. Empiricism refers to knowledge obtained through humans' experience, while rationalism is based on their non-experience-based conceptual efforts. Kantianism provides a third space, as it includes both empirical and rational aspects as valid origins of valuable cognition (Becker & Niehaves, 2007, p. 205). In my research, I focused on participants' experiences, but also on their intellectual considerations, hence, this thesis follows the Kantian perspective.

The fifth and last question of Becker und Niehaves's (2007) epistemological framework examines the ways in which knowledge can be acquired. A common approach in natural science is induction or generalization, where the explanation for an observed individual case is transferred to having universal validity. Contrastively, knowledge can be gained through deduction, thus derived as logical conclusion, where an individual case is explained by a universal explanation. Hermeneutics refers to obtaining new knowledge through a cyclic approach based on previous understanding (Becker & Niehaves, 2007, p. 205f). This thesis follows the pluralistic character of IS research (Orlikowski & Baroudi, 1991, pp. 3 & 24; Recker, 2013, p. 65), including inductive as well as deductive approaches to knowledge acquisition. Combining the two methods delivers richer research results, however, it comes at the price of higher difficulty levels of method execution and data analysis (Mingers, 2001, p. 249). Hence, as a fundamental methodology, this thesis applies a hermeneutic approach in which several research stages enhance our understanding of the phenomenon itself.

3.2 Research Process and Applied Methods

As mentioned in section 1, this thesis is focused on addressing the low use of EA visualizations for EA-related decision-making in organizations, by employing augmented reality technology. Hence, the overall research design addresses an organizational problem. Not only do the stated research questions refer to influencing adequate research process design and suitable research methods selection; the meta-theoretical assumptions discussed in section 3.1 contribute as well (Gregor, 2006, p. 634).

Given the need for designing new artifacts, the Design Science Research (DSR) (Hevner, March, Park, & Ram, 2004; Peffers et al., 2006) is used as a guide. Applying the DSR fits the general research objective, as it aims to solve specific human-made organization-related and practical problems (Hevner et al., 2004, pp. 76, 83; March & Smith, 1995, p. 254) by designing and developing meaningful IT artifacts (Hevner et al., 2004, p. 82). DSR is motivated by the goal to improve the environment by introducing and building new and innovative artifacts (Hevner, 2007, pp. 2 & 3; H. A. Simon, 1996). Artefacts can be any kind of output, e.g. constructs, models, methods, and instantiations (Hevner et al., 2004, p. 77). This approach is rooted in the understanding that IT-related research deals with an artificial rather than a natural phenomenon (March & Smith, 1995, p. 262). Design science, which attends to utility for practice, and natural and behavioral sciences which describe truth, are complementary and therefore are inseparably connected. This connection supports researchers not only in designing artifacts, but also in testing and evaluating artifacts to solve specific, identified organizational problems (Hevner et al., 2004, pp. 77 & 80; March & Smith, 1995, p. 253). DSR supports this research project by providing principles and procedures to identify an organizational problem and also to assist in designing, developing, demonstrating, evaluating, and communicating an artefact (Peffers et al., 2006, pp. 89–93).

Each DSR project consists of three cycles, identified as rigor, relevance, and design (Hevner, 2007, p. 2; Hevner et al., 2004, p. 80). The rigor cycle provides the research project with an encompassing body of knowledge on existing theories, artefacts, analogies, metaphors, or additional sources of creative insights. The relevance cycle provides a practical application context in which a given problem occurs or could occur in the future. This cycle relies on people, organizational systems, and technical systems that interact in working toward a goal. In the design cycle, concrete research activities develop, evaluate, and finally refine an artifact incrementally (Hevner et al., 2004, p. 90).

This thesis defines five phases (or rounds) in which each phase consists of performing the rigor, relevance, and design cycles (except for phase 1 and 5). Each phase states its own contribution by addressing a specific aspect of the overall research objective. The outcome of a phase is the input to the subsequent phase. Figure I-3 gives an overview of the five DSR phases the study went through. The following section describes the applied research methods in detail.

(1) Literature review: In the first phase, a systematic literature review revealed the current state of research on EAM. In view of the research objective to examine the application of AR in visualizing EAs for decision-making, the first phase also consists of affordances that mixed reality technology provide. Following Webster and Watson’s (2002) and vom Brocke et al.’s (2015) guidelines and recommendations, we identified 24 research papers describing the EAM function in 32 organizations. The results shed light on the practical application of EAM and support the adjustment to requirements for designing an AR HMD prototype as defined in the research goal. We further conducted another literature review in the last phase to develop a taxonomy for further comparison studies. 12 considered research papers supported the design of a four-dimensions encompassing taxonomy.

(2) Action research: The second phase entailed a single case study that would allow an in-depth analysis of an application of the EAM function, and especially also the use of EA information for architectural decision-making in practice (Recker, 2013, pp. 95–99). The organization in this case is a medium to large-sized municipal utility company in Germany. Due to its heterogeneous business model, the company is characterized by a rather complex EA. It manages over 12.000 users and 1000 applications running on almost 2600 servers. The stakeholders, top-level decision-makers, as well as three main customers in the business areas of transport, energy production, and government services, supported the case study. Several

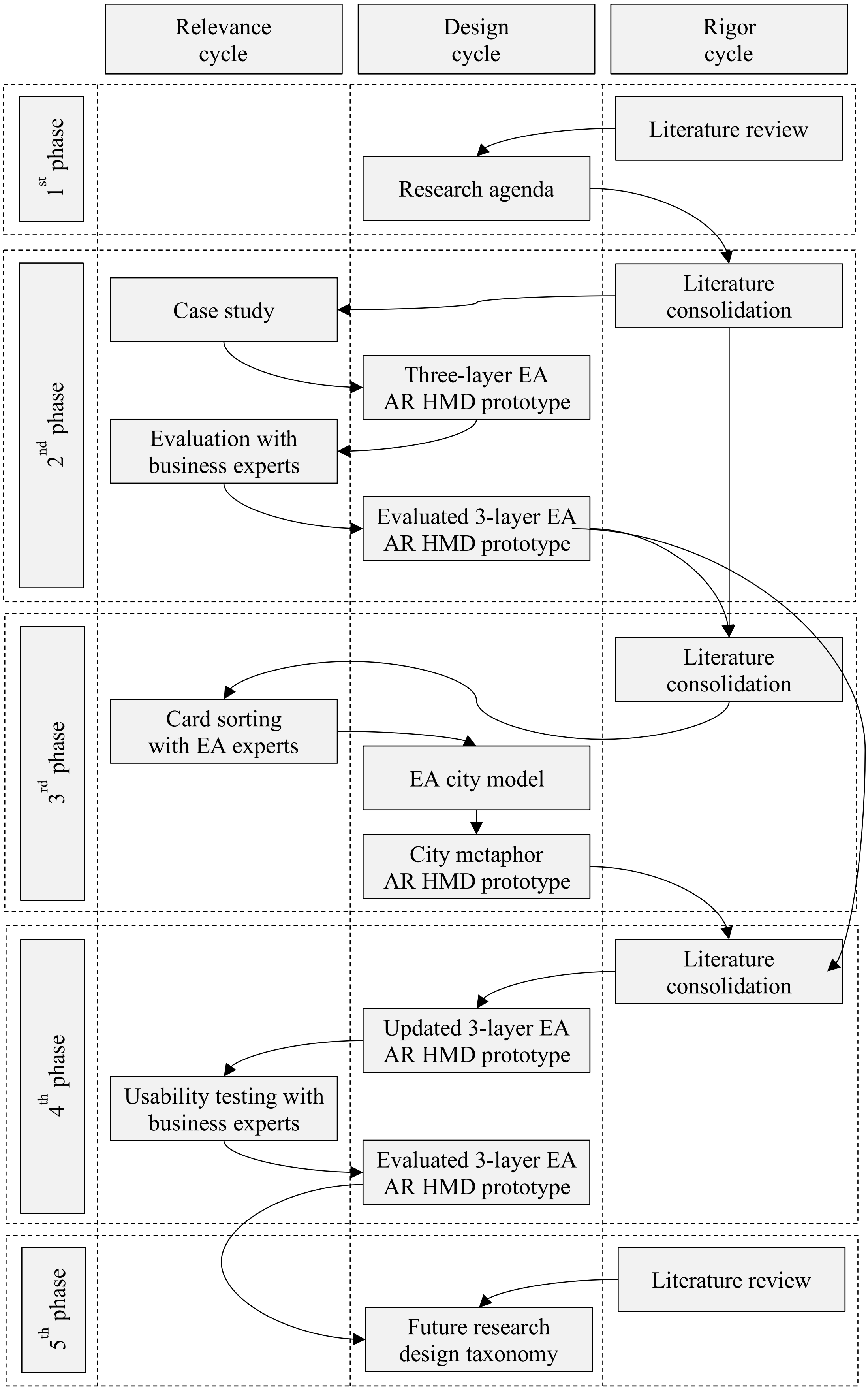


Figure I-3. Overview of the design science phases discussions with stakeholders and decision-makers as well as two workshops enabled our examination of current EA visualizations and practices. The results emphasize the need for more comprehensive EA visualization approaches. The results further supported the research objectives and were used to derive design goals which specify the scope and purpose of the envisaged outcome (Gregor & Jones, 2007, p. 320). The enterprise architect supported the research by not only permitting access to the EA repository, but also providing an anonymized copy of the entire EA data set. This repository then became the data foundation for the following prototype developments. At the conclusion of the case study I gave feedback, presenting the results to top-level IT decision-makers.

(3) Prototype development: The second, third, and fourth phases consisted of developing an AR HMD prototype to visualize EAs following a three-layer model (second and fourth phases), as well as a city metaphor (third phase). Prototypes are considered to be an artefact in DSR (Hevner et al., 2004, p. 82). The requirements for the prototypes were gained from literature, the single case study, and the feedback of each evaluation. Each phase consisted of several development iterations, which fundamentally followed the scrum methodology (Schwaber, 1997). After each iteration, testing and bug fixing helped to confirm the usability of the prototype in a real-world application. Colleagues gave support in validating the prototype's functionality.

(4) Card sorting: Informed by literature and the feedback of the second phase evaluation, the third phase aimed to develop another form of possible EA visualization using AR support. Based on Baker et al.'s (2009, p. 540) assumptions about individual sensemaking, this phase addressed shortcomings in supporting analogical reasoning by employing metaphors. The city metaphor was selected as an exemplary spatial metaphor as it utilizes AR capabilities and is well-known in the EA community, e.g., in the context of software code visualization (Wettel & Lanza, 2007; Merino et al., 2018). Further, this use case has not been implemented before, although some have mentioned its applicability (e.g. Panas, Berrigan, & Grundy, 2003, p. 5). Addressing how context is often arbitrarily or inexplicably derived via the development of metaphors in literature, this study applied the card sorting technique as a promising approach to derive meaning empirically (Moore & Benbasat, 1991; Schaffer & Fang, 2018, p. 1). Acknowledging that every person perceives the concept "city" differently, the card sorting method was considered a suitable research method for (a) exploring people's mental models (Schaffer & Fang, 2018, p. 1) of perceiving a city by describing EAs, and (b) developing a generally acceptable representation of EA in the form of a city. Finding EA represented as a city, was the goal in this phase. Three rounds of open card sorting delivered eleven classes of EA objects mapped to city elements. The derived mappings are used in a following AR prototype implementation.

(5) Usability test: We updated the prototype based on the gained experience gathered in the second and third phase. As DSR aims to solve specific organizational problems (Hevner et al., 2004, pp. 76, 83; March & Smith, 1995, p. 254), evaluating developed artefacts is a key step in DSR (Peffers et al., 2006, pp. 89–93). Specifically, this thesis aims to evaluate the usability of an AR-based EA visualization using an HMD for EA decision-making. Hence, usability testing was chosen as a suitable research method to “measure or predict how effective, efficient and/or satisfied people would be when using the interface to perform one or more tasks" (Greenberg & Buxton, 2008, p. 111). The usability test performed in the fourth phase involved measuring the time business experts needed to successfully complete individual EA-related tasks, as well as appraising how the users experienced the prototype. For this, as proposed by Liam et al. (Lam, Bertini, Isenberg, Plaisant, & Carpendale, 2012, p. 1529f), we considered participants’ feedback, the results of questionnaires, and observation notes.

(6) Taxonomy development: In the last phase, we particularly considered the comparability of EA visualizations and EA visualization technologies. We faced the problem of limited comparability between technologies due to their different characteristics, especially when dealing with various visualization devices and the associated input devices. In order to identify the relevant aspects of such comparability studies and to structure possible future research scenarios, we decided to develop a conceptual model in the form of a taxonomy. We applied Nickerson et al.’s (2013, pp. 342–347) iterative taxonomy development method, which is frequently used in the IS discipline. It is a step-by-step approach that guides researchers in developing useful taxonomies. Drawing on a literature review and strengthened by EA visualization research discussed in this thesis, the proposed taxonomy consists of four categories with 11 dimensions and a set of associated characteristics.

4 Thesis Structure and Summary of Research Papers

This cumulative thesis consists of five individual research papers, which four have been published in highly accepted IS conferences. This approach was chosen for several reasons: First, it helped me to join the IS community. Submitting research papers to conferences opens opportunities to present research ideas and personally discuss them with experts. It gives increased opportunities to meet new scholars who conduct research in the same or related research areas and, additionally to collaborate in future research. Second, through conference submission every publication in this thesis underwent a double-blinded peer-review process. Such research submission reviewing by three or four experts in this narrow field is very attractive to PhD students, as conferences usually provide feedback within two to three months compared to journal submissions which can take months, and sometimes even years (Recker, 2013, pp. 116–117). The expert feedback I received, significantly increased not only the quality of every research manuscript, but also enhanced my research skills along the way. Moreover, as the scope of each paper is limited, it is more pragmatic to receive specific feedback from other scholars and colleagues, and also easier to follow. Discussing the entire research project from beginning to end could have been overwhelming for reviewers and thus brought less voluntary feedback. Third, submitting papers in response to conference calls is attractive in that the review cycles are relatively short, especially compared to journal submissions. Admittedly, journal submissions accept higher word counts, possibly provide more valuable feedback. Publication in scholarly journals possibly ensures higher acceptance of researchers in the IS community, compared to publication in conference proceedings. However, during my doctoral program I was keen to learn quickly and comprehensively how to conduct research professionally, therefore my publication strategy included receiving rapid expert feedback which could increase my research skills and challenge my research ideas at an early stage and onwards. I also found the conference submission deadlines highly motivating as they forced me to continue and progress, and more importantly, to write up research results as they appear, rather than collecting results and write a monograph at the end of the larger project. It helped me in developing writing skills, which the reader will hopefully notice. The limited text space of conference proceedings helped me to focus on key facts, rather than counterproductively increasing the scope of the thesis. Furthermore, the short publication cycles achieved by conference publications enabled contributions to the existing body of knowledge, as new insights are available to interested readers faster than would have been possible if the work had been submitted to a journal.

As mentioned in 3.2 above, this thesis follows the DSR paradigm, with each essay reporting on one iteration of the DSR process. After this general thesis introduction including a brief discussion, in which the general findings, the theoretical and practical contributions, as well as the outlook are presented, the following chapters present the extended versions of each research paper. Following here, I introduce the main content of each research paper. The structure of the thesis is visualized in Figure I-4.

UTILIZATION OF AUGMENTED REALITY FOR ENTERPRISE ARCHITECTURE DECISION-MAKING - AN EMPIRICAL INVESTIGATION

Overall guiding approach: Design Science Research

Introduction & motivation & summary

Essay 1	**Put your glasses on: Conceptualizing affordances of mixed and virtual reality for enterprise architecture management**	Affordance theory; Community of Practice Literature review; Conceptual development	Review literature on EAM and mixed and virtual reality and development of research agenda.
Essay 2	**Let's Get in Touch - Decision Making about Enterprise Architecture Using 3D Visualization in Augmented Reality**	Cognitive fit theory Case Study; Prototype development; Qualitative evaluation	Motivating the selection of AR for EA decision-making and development and evaluation of a three-layer representing EA AR HMD prototype.
Essay 3	**Conceptualizing EA Cities: Towards visualizing complex Enterprise Architecture as Cities**	Individual sensemaking; Information processing Card sorting, Formal language dev.; Prototype development	Introducing the city metaphor for EA visualization and development of an empirical-based EA city model implemented in AR.
Essay 4	**Evaluation of an Augmented Reality Prototype for Enterprise Architecture**	Information processing Prototype development; Qualitative evaluation with usability test	Qualitative evaluation of a three-layer EA visualizing AR HMD prototype to test how the prototype support EA-specific tasks.
Essay 5	**Comparing EA visualization and visualization technologies – A taxonomy for the development of research designs**	Literature review; taxonomy development	Developing a taxonomy that aims to design future research settings to compare EA visualization and EA visualization technologies.

Figure I-4. Structure of this thesis

Essay 1: Put your glasses on: conceptualizing affordances of mixed and virtual reality for enterprise architecture management

The first paper collected and analyzed the current body of literature on Enterprise Architecture Management (EAM), as well as on mixed and virtual reality affordances. This paper's goal is to discuss the idea of applying mixed and virtual reality technology in Enterprise Architecture (EA) related decision-making. Research shows limited effectiveness of EAM, especially due to EA artefacts being considered less often in decision-making (e.g. Kotusev et al., 2015). Although EA artifacts are the fundamental resource for EA-related decision-making, business and IT staff often consider them as inflexible, difficult to understand, or focused on the wrong level of abstraction (Hauder et al., 2013; Löhe & Legner, 2014). In this paper, Mixed Reality (MR) and Virtual Reality (VR) are discussed as promising approaches to solving these shortcomings in information processing. The paper argues that these technologies might enable higher acceptance of EA artefacts for decision-making, because they allow natural interaction with data (Ohta & Tamura, 1999), higher manageability of vast amounts of data, as well as increased analytical skills due to involving users' natural spatial and visual abilities (Greenhalgh & Benford, 1995). Based on the theoretical lens of affordances (Chemero, 2003; Pozzi, Pigni, & Vitari, 2014; Stendal, Thapa, & Lanamaki, 2016), this paper develops a conceptual model based on a literature review about EAM use in practice, and derives hypotheses of how users might perceive and use MR and VR technology to perform EAM-related tasks. This paper further contributes to research in claiming that MR and VR could have a positive impact on the effectiveness of EAM and set the ground for future research in this research area.

Essay 2: Let's Get in Touch: Decision-Making about Enterprise Architecture Using 3D Visualization in Augmented Reality

The second paper presents a case study to assess the need for suitable EA visualizations, examining data from a medium to large-sized German municipal company with 2000 employees, operating in the energy and transportation industry. Regarding their EA visualization design and use, the company faces four major challenges, which are the need for easily accessible EA visualizations, stakeholder-specific EA visualizations, EA analysis functionalities, and an approach to intuitively and playfully interact with EA visualizations for stakeholders. Informed by the cognitive fit theory (CFT) (Vessey, 1991a, p. 221), this paper presents the development and evaluation of an AR head-mounted display (HMD) prototype that visualizes an exemplary EA in the form of a frequently applied layer model.

The underlying theory is helpful, as it 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, it frames a consistent mental representation (John & Kundisch, 2015, p. 4; Vessey & Galletta, 1991, p. 67; Weiss et al., 2012, p. 6). Further, 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 an effective problem-solving performance. This paper thus argues that decision-makers benefit from interacting with EA visualizations using AR, because such interaction can enable a consistent task-related mental representation based on taking the user's spatial ability into account. This can reduce cognitive load and thus enable a better overall understanding of complex causal relationships (Dunleavy et al., 2009, p. 17; Ibáñez et al., 2014, p. 3; Sommerauer & Müller, 2014, p. 67; Wang et al., 2014, p. 13). Moreover, due to naturally integrating virtual objects into the real world (Ohta & Tamura, 1999, p. 224) and using hand gestures (Azuma, 1997, p. 357), AR requires less skills for interacting with these objects in a real-world environment, which results in potentially low to moderate individual learning effort. To test this claim, six participants' evaluations revealed that EA-related decision-making can profit from applying AR; but the participants find the handling of the specific HMD device cumbersome.

Essay 3: Conceptualizing EA Cities: Toward visualizing complex Enterprise Architecture as Cities

The third research paper presents a novel AR-based visualization technique to represent exemplary EAs. Common EA visualizations are represented in the form of text, numbers, tables, graphs, models, and diagrams (Roth et al., 2014, p. 46), and they consist of EA objects like business processes, applications, and infrastructure assets (The Open Group, 2018). Informed by Baker et al. (2009, p. 540), I followed the idea that in individual sensemaking of complex information, the use of metaphors might be beneficial for information processing. Especially spatial metaphors are able to activate cognitive capabilities of the human mind that enable spatial orientation and a sense of bodily movement, as well as the perception and understanding of conceptual meaning (Johnson & Lakoff, 1999; Lakoff, 1987). This way of conveying knowledge is highly efficient, as it allows for much faster and parallel cognitive processing of sensual impressions than language use does (consider e.g. Humphreys & Bruce, 1989 for an excellent discussion). Following these benefits, this paper presents an approach to visualizing EAs using a city-building metaphor. This metaphor has already been used in several related areas, such as software code visualization (Wettel & Lanza, 2007; Merino et al., 2018), representation of the Internet (Dieberger & Frank, 1998; Sparacino, Wren, Azarbayejani, & Pentland, 2002), multimedia files (Derthick et al., 2003; Chiu, Girgensohn, Lertsithichai, Polak, & Shipman, 2005), application architectures (Soares, 2008), or IS governance rules (Guetat & Dakhli, 2015). Hence, this paper addresses the question of how EAs can be modeled using the city metaphor. For this, the paper presents a novel approach to develop a city model based on card sorting. Considering the existing body of knowledge on EA objects implemented in organizations, as well as on discernible city elements, we applied card sorting to investigate people's mental models of how they would perceive a city describing EAs. Fourteen EA-experienced participants developed a comprehensive model containing eleven classes of EA objects and equivalent city elements. To evaluate its suitability, we further implemented the described EA city in an AR-based prototype. Thus, the paper contributes to research in providing a terminology for describing EAs using commonly known concepts from the city metaphor. Further, the paper proposes a method for collecting data through card sorting, and develops a formal language that describes the results.

Essay 4: Evaluation of an Augmented Reality Prototype for Enterprise Architecture

This research paper describes the qualitative empirical evaluation of a three-layer EA representation in AR using an optical see-through HMD with 13 business professionals from multiple industries. The goal was to take advantage of AR characteristics so that EA visualizations were simplified in terms of accessibility, manipulability, and analyzability. Based on randomly generated EAs from real-world data, the participants conducted 13 exemplary EA tasks which differed in complexity and context. For this, we followed Lam et al. (Lam et al., 2012, pp. 10–11) and conducted a usability test. This method seemed well-suited to the above-stated objectives, as 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" (Greenberg & Buxton, 2008, p. 111). We evaluated the users' experience based on feedback, questionnaires, and observations which we audio and video recorded, while tracking the time participants needed to successfully complete the tasks. The results indicate an agreement using AR for EA analysis, but this is limited to high level tasks of which the purpose is to communicate with specific stakeholders. We further derived design requirements for similar AR prototype developments.

Essay 5: Comparing EA visualization and visualization technologies – A taxonomy for the development of research designs

The last research paper describes the development of a conceptual model in the form of a taxonomy that intends to support researchers in designing future research settings when comparing various EA visualizations and EA visualization technologies. This paper refers to the limited comparability of various visualization technologies that differ in terms of their unique characteristics, e.g., in how users apply the associated interaction devices or how immersive users perceive the visualizations to be. The outcome of our research endeavor is influenced by Nickerson et al.'s (2013, pp. 342–347) iterative taxonomy development method and Brocke et al.'s (2015) literature review recommendations. The resulting 11 dimensions of our taxonomy provide the relevant aspects that should be considered when conducting comparability studies. Two examples illustrate its applicability. Our artefact can further be applied as a conceptual model to synthesize existing literature.

5 Summary of Results

This thesis aims overall to address the low use of EA visualizations in decision-making processes in organizational change projects. Although EAM research provides a variety of suitable EA visualizations, literature indicates that stakeholders often perceive EA visualization as complex, oversized, simplified, represented in a way that detracts from their needs, and also not adequately supported by tools (Abraham, 2013, p. 2; Hiekkanen et al., 2013, p. 296; Löhe & Legner, 2014, p. 116; Banaeianjahromi & Smolander, 2017, p. 25; Carvalho & Sousa, 2014, p. 7; Kotusev et al., 2015, pp. 3–4). Underpinned by the cognitive fit theory Vessay (1991a) introduced, this thesis assumes a missing fit between EA visualizations available to stakeholders and individual EA-related decision-making tasks with which stakeholders are confronted. Despite the developed body of knowledge on EAM in general (e.g. Ahlemann et al., 2012, p. 3) and EA visualizations in particular (e.g. Roth et al., 2014), the commonly applied EA visualizations seem to be limited to represent the dependencies of heterogeneous business and IT aspects of enterprises. This thesis argues that EA visualizations as well as EA decision-making tasks are spatial in nature as they mainly focus on assessing relationships in data, e.g. visualizing and analyzing dependencies between processes and applications or strategy and infrastructure implementation. Then, achieving a fit between spatial visualizations and spatial decision-making tasks could lead to a better overall understanding of EA visualizations and conceivably higher use of EA visualization in decision-making processes. Moreover, literature suggests that taking the user's spatial ability into account can reduce cognitive load and thus enable a better overall understanding of complex causal relationships (Dunleavy et al., 2009, p. 17; Ibáñez et al., 2014, p. 3; Sommerauer & Müller, 2014, p. 67; Wang et al., 2014, p. 13). This ultimately will simplify stakeholders understanding and analysis of EA visualizations. A promising technology for visualizing and interacting with spatial representations which is considered in the context of this thesis, is AR-enabled HMDs. In order to investigate whether this technology is deemed suitable considering the above-mentioned limitations, this thesis sought to develop and evaluate an interactive, easy-to-use, and understandable visualization of EAs in AR using an HMD for decision-making tasks without dismissing the complexity of contemporary organizations. To fulfill this goal, three key research questions were separately addressed and published in stand-alone research papers that are framed in an overall DSR process. In general, this thesis describes the current state of the art in EAM in practice and, in accordance with a case study at a municipal company in Europe, it derives exemplary requirements for an AR HMD prototype. Based on these design goals, two artefacts were developed: A three-layer EA visualization as well as an EA visualization employing a city metaphor. Two rounds of evaluation revealed that users perform well using these prototypes. In the following section, I briefly answer the stated research questions. Detailed answers can be found in the corresponding essays.

RQ1: *How is Enterprise Architecture Management applied in practice?*

A literature review in the first essay, as well as the presented case study in the second essay, give answers to the first research question. The literature review provides a broad overview of the current state-of-the-art of EAM in organizations. For this, 24 research papers describing EAM functions in 32 organizations worldwide were identified and analyzed. The results highlighted various EAM aspects that organizations consider, and indicate a remarkable variety in EAM maturity. In the second essay a case study in an exemplary municipal company which is characterized by a highly heterogeneous and interrelated EA, extends the view on how EAM is applied in practice. Both findings answered to the research goal as they describe the relevance and rigor required in the design and evaluation of an AR HMD prototype.

RQ2: *How can we design an Augmented Reality Head-Mounted Display prototype for decision-making about Enterprise Architectures?*

The requirements for exemplary AR HMD prototypes are derived from the literature as well as the conducted case study described in the second essay. As literature indicates an established use and acceptance of the three-layer model in EAM practice, the second essay describes how such an EA visualization can be designed in AR. This EA visualization encompasses a business information system, as well as an infrastructure layer that connects these elements. The essay describes which features this three-layer model EA visualization provides and what it looks like. Further, AR's unique characteristics reduce cognitive load by means of the visualizations. In order to exploit these benefits, the study designed another exemplary EA visualization type, working with the city metaphor as described in the third essay Motivated by increased use of the city metaphor in software development, this proposed experimental EA visualization pictures EAs in the form of a city, with EA objects' connections to city elements being mapped by using an empirically employed card sorting technique.

RQ3: *How can we use an Augmented Reality Head-Mounted Display prototype for decision-making about Enterprise Architectures?*

Studying individuals' and organizations' use of information technology and its impact, is of interest in information system research in general (Recker, 2013, p. v), and a key DSR activity DSR in particular (Hevner et al., 2004, p. 83). The empirical investigation's focus on the actual use of AR HMDs, relied on the three-layer model, as this EA visualization appeared to be the most commonly known and accepted EA visualization method in practice. Essay two describes a short evaluation, as essay four presents a longer, more detailed one. The results indicate that users generally accepted the EA visualization and perceived it as useful; however, the less EA experienced users seemed to benefit more from this AR HMD prototype.

All five essays in this thesis contribute to answering the initially stated research questions given in section 2.3. Whereas the first essay lays the foundation for further research, essays two and three present two possible implementations of an AR HMD prototype. Based on these findings, the final essay which includes the evaluation of a three-layer EA-representing AR HMD prototype, demonstrates the applicability of the prototype in a practical setting. Hence, all essays contribute to reflecting on the overarching research problem as described in 2.3:

RP: *Due to a poor fit between EA visualizations and EA decision-making tasks, many stakeholders struggle to process EAs; this situation manifests in low EA visualization use in decision-making tasks.*

Taking all research results into account, this thesis provides a theoretically grounded and empirically justified understanding of why and how AR is deemed suitable for visualizing and analyzing EAs. The thesis emphasizes that AR can be employed in complex analyses in which heterogeneous objects are connected and are subjects of interest for business analysts like EA-related stakeholders. The results show what EA visualizations in AR can look like, and how they can be used, while well-aware that different styles of visualization could be more efficient than those proposed here, depending on contextual specifics. Rather than suggesting a one-size-fits-all solution, the evaluations revealed that some stakeholders benefit more from this visualization and data analysis technique than others. Decision-makers should be requested to frame their specific information needs to ensure that using AR for EA visualization is a helpful visualization method for them. Hence, this study states that the developed prototype does not replace, but rather extends existing EA visualizations.

This research makes a twofold contribution. First, practitioners who follow it, will benefit from an advanced visualization technology that is suitable for representing manifold relationships between various EA features. Instead of narrowing down complex relationships into simplified visualizations or, vice versa, applying simplified visualizations to represent complex relationships, this research proposes engaging humans' spatial imagination when organizations analyze EAs. The results suggest that especially less EA-experienced employees benefit from AR-based EA representations, as it allows intuitive and interactive access to EAs which eventually leads to increased consideration of EAs in decision-making tasks and therefore also increased effectiveness of the EAM function. Experienced EA experts, conversely, did not benefit from this new visualization technique as they were used to the existing EA visualizations, and saw no need for an AR-represented EA visualization.

Second, researchers will benefit from the discussion and application of the unique characteristics of AR in the area of EAM and, in particular, in the visualization of EAs for organizational decision-making. This thesis also contributes to the sparse body of research on the development of AR HMD-based visualization prototypes by providing an empirically based, in-depth analysis of such a prototype's usage. Further, the existing body of knowledge on the cognitive fit theory benefits from another instantiation in AR and EAM. In addition, the developed visualizations pave the way for more detailed research, especially for applying the city metaphor and the three-layer model for describing EAs. It contributes to research in that it claims AR could have a positive impact on EAM effectiveness.

In spite of the mentioned contributions, this thesis is not without its limitations. These suggest directions for future research. This thesis is a first step toward applying AR in visualizing EAs to support decision-making processes in organizations. Vessey's (1991a) cognitive fit theory is used as a theoretical lens to describe and explain the poor fit between the range of existing EA visualizations and their limited use in practice. Although the cognitive fit theory provides an appropriate grounding of the argumentation in this thesis, it is not in the scope of this manuscript to empirically evaluate or conduct a clinical test of stakeholders' mental fit while they consider EA visualizations during EA-related decision-making processes. The results indicate that respondents quickly understood the content of the developed EA visualizations; in turn, this pointed to a high degree of mental fit between an EA task and a corresponding EA visualization. However, operationalizations of the concept 'mental fit' as well as quantitative statements about the actual degree of mental fit are not postulated here. Future research could add value by considering this.

This limitation is in line with other potential criticism that would call for quantitative and qualitative comparisons between various EA visualization types, such as 2D or 3D charts, models, and diagrams, as well as technologies like AR, VR, desktop apps, mobile apps, 3D printouts, and hand-drawn EA visualizations. Comparing various visualization types and technologies in terms of, e.g., their effectiveness or efficiency in pre-defined decision-making scenarios would be a beneficial research project in order to compare the performance of various approaches and to derive further practitioner-oriented research outcomes. In doing so, interested researchers should consider the manifold differences between the technologies, e.g., in respect of the approach of interacting with visualizations on the basis of a stakeholder's existing level of experience and knowledge, as well as of the immersive effect to be achieved. This study's stated research objectives, however, aim to prepare the ground for initially designing and developing AR-based EA visualizations to address the limited use of EA visualizations in decision-making processes. Following through by quantitatively measuring users' performance in their use of different EA visualization types and technologies in future projects would be desirable and could produce interesting research results.

This study focused on exploiting the possibilities provided by the characteristics of AR, rather than optimizing the software code to increase the performance of each prototype. This explains why an in-depth discussion of the considered software architecture of the prototypes that have been developed is not given in this thesis. While following this pragmatic approach, it was clear that the prototypes have bottlenecks in the provision of the EA visualizations. Especially, loading the 3D objects and the EA repository takes a great deal of time. Also, all prototypes are based on the same core software code that has over time frequently changed, and has at times negatively affected existing prototypes. New prototypes, in contrast, work nicely. Future research could address these concerns by comparing different software architectures such as fully-client-based vs. server-client vs. microservice-based architectures. In doing so, future AR-based EA visualizations should integrate existing visualizations like standard reports containing, e.g., KPIs, diagrams, and charts. Many participants who took part in the evaluations reported that that they missed such integration in this research project.

Although this thesis contains two empirical-based evaluations of the use of AR-based EA visualization prototypes, the findings cannot be generalized beyond the considered population group. The first evaluation described in the second essay consists only of participants from the case company, while the second evaluation encompasses thirteen participants from various industries. The evaluations were detailed and comprehensive; however, the considered sample size does not reflect the broad population of all industries and decision-makers. Currently, the use of AR-HMDs generally, and the application of AR-based EA visualizations specifically, represent a new approach for most people, which limits potential research success when quantitative research methods are used to generalize findings to a broad audience. Also, as discussed in the fourth essay, due to the novelty of the technology this study examined, there was a tendency among some participants to be overly positive in their assessment of the prototype's usefulness. This can negatively impact the results of quantitative research projects. In this study's case, results indicate that the existing knowledge of architectural thinking and the EA-experience of stakeholders influence the perceived usefulness of AR-based EA visualizations in decision-making processes, and not the special conditions in industries. Face-to-face workshops, interviews, and lab experiments with stakeholders from different EA-backgrounds might be a useful and promising approach for the further development of AR-based EA visualizations. Longitudinal research projects as part of an action design study (Sein, Henfridsson, Purao, Rossi, & Lindgren, 2011, p. 3), in which the researchers design, develop, implement, and monitor the use of such EA visualizations in practice, can also derive relevant insights.

Regarding the decision-making scenario, this thesis attended to the individual use of EA visualizations using an AR-HMD. In practice, EA decisions are commonly made based on teamwork in which business and IT experts collaborate. AR characteristics allow decision-makers to view and manipulate EA visualizations simultaneously. A study investigating the mechanism of decision-making in AR about EAs, as well as a study about the systematic procedure can be a further promising research avenue.

References

Abraham, R. (2013). Enterprise Architecture Artifacts as Boundary Objects-A Framework of Properties. *ECIS 2013 Proceedings*.

Ahlemann, F., Stettiner, E., Messerschmidt, M., & Legner, C. (2012). *Strategic Enterprise Architecture Management: Challenges, Best Practices, and Future Developments*. Berlin ; New York: Springer.

Aier, S., Fischer, C., & Winter, R. (2011). Construction and evaluation of a meta-model for enterprise architecture design principles. *Wirtschaftsinformatik Proceedings 2011*.

Aier, S., Gleichauf, B., & Winter, R. (2011). Understanding Enterprise Architecture Management Design - An Empirical Analysis. *Proceedings of the 10th International Conference on Wirtschaftsinformatik*, 645–654. Zurich, Switzerland.

Aier, S., Kurpjuweit, S., Saat, J., & Winter, R. (2009). Enterprise Architecture Design as an Engineering Discipline. *AIS Transactions on Enterprise Systems*, *1*(1), 36–43.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355–385.

Baker, J., Jones, D., & Burkman, J. (2009). Using visual representations of data to enhance sensemaking in data exploration tasks. *Journal of the Association for Information Systems*, *10*(7), 533–559.

Banaeianjahromi, N., & Smolander, K. (2017). Lack of Communication and Collaboration in Enterprise Architecture Development. *Information Systems Frontiers*. https://doi.org/10.1007/s10796-017-9779-6

Becker, J., & Niehaves, B. (2007). Epistemological perspectives on IS research: a framework for analysing and systematizing epistemological assumptions. *Information Systems Journal*, *17*(2), 197–214. https://doi.org/10.1111/j.1365-2575.2007.00234.x

Biocca, F., & Delaney, B. (1995). Immersive Virtual Reality Technology. In *Communication in the Age of Virtual Reality* (p. 401). Routledge.

Boh, W. F., & Yellin, D. (2006). Using Enterprise Architecture Standards in Managing Information Technology. *Journal of Management Information Systems*, *23*(3), 163–207. https://doi.org/10.2753/MIS0742-1222230307

Boucharas, V., Steenbergen, M. van, Jansen, S., & Brinkkemper, S. (2010). The Contribution of Enterprise Architecture to the Achievement of Organizational Goals: A Review of the Evidence. *Trends in Enterprise Architecture Research*, 1–15. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-16819-2_1

Buckl, S., Ernst, A. M., Matthes, F., & Schweda, C. M. (2009). How to make your enterprise architecture management endeavor fail! *Proceedings of the 16th Conference on Pattern Languages of Programs*. Presented at the Proceedings of the 16th Conference on Pattern Languages of Programs, Chicago, Illinois, USA.

Burdea, G. C., & Coiffet, P. (2003). *Virtual reality technology*. John Wiley & Sons.

Campbell-Kelly, M. (2018). *Computer: A History of the Information Machine*. Routledge.

Carvalho, J., & Sousa, R. D. (2014). Enterprise Architecture as Enabler of Organizational Agility – A Municipality Case Study. *Twentieth Americas Conference on Information Systems*, 11. Savannah.

Chemero, A. (2003). An outline of a theory of affordances. *Ecological Psychology*, *15*(2), 181–195.

Chen, W. S., & Hirschheim, R. (2004). A paradigmatic and methodological examination of information systems research from 1991 to 2001. *Information Systems Journal*, *14*(3), 197–235.

Chiu, P., Girgensohn, A., Lertsithichai, S., Polak, W., & Shipman, F. (2005). MediaMetro: browsing multimedia document collections with a 3D city metaphor. *Proceedings of the 13th Annual ACM International Conference on Multimedia*, 213–214. Singapore.

Derthick, M., Christel, M., Hauptmann, A., Ng, D., Stevens, S., & Wactlar, H. (2003). A Cityscape Visualization of Video Perspectives. *Proceedings of the National Academy of Sciences Arthur M. Sackler Colloquium on Mapping Knowledge Domains (Unpublished)*, 1–2. Irvine, CA.

Deutsche Forschungsgemeinschaft. (2013). *Sicherung guter wissenschaftlicher Praxis*. Weinheim, Germany: Wiley-VCH.

Dieberger, A., & Frank, A. U. (1998). A city metaphor for supporting navigation in complex information spaces. *Journal of Visual Languages and Computing*, *9*(6), 597–622.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, *18*(1), 7–22. https://doi.org/10.1007/s10956-008-9119-1

Greenberg, S., & Buxton, B. (2008). Usability evaluation considered harmful (some of the time). *Proceeding of the Twenty-Sixth Annual CHI Conference on Human Factors in Computing Systems - CHI '08*, 111. Florence, Italy: ACM Press. https://doi.org/10.1145/1357054.1357074

Greenhalgh, C., & Benford, S. (1995). MASSIVE: a distributed virtual reality system incorporating spatial trading. *Proceedings of 15th International Conference on Distributed Computing Systems*, 27–34. https://doi.org/10.1109/ICDCS.1995.499999

Gregor, S. (2006). The nature of theory in information systems. *MIS Quarterly*, *30*(3), 611–642. (3B25375520CE30B4C1257205002E4342).

Gregor, S., & Jones, D. (2007). The Anatomy of a Design Theory. *Journal of the Association for Information Systems*, *8*(5), 313–335.

Guetat, S. B. A., & Dakhli, S. B. D. (2015). The Architecture Facet of Information Governance: The Case of Urbanized Information Systems. *Procedia Computer Science*, *64*, 1088–1098.

Hanschke, I. (2016). *Enterprise Architecture Management-einfach und effektiv: Ein praktischer Leitfaden für die Einführung von EAM*. Carl Hanser Verlag GmbH Co KG.

Hauder, M., Roth, S., Schulz, C., & Matthes, F. (2013). *An Examination Of Organizational Factors Influencing Enterprise Architecture Management Challenges.* 175.

Henderson, S. J., & Feiner, S. (2008). Opportunistic Controls: Leveraging Natural Affordances As Tangible User Interfaces for Augmented Reality. *Proceedings of the 2008 ACM Symposium on Virtual Reality Software and Technology*, 211–218. New York, NY, USA: ACM. https://doi.org/10.1145/1450579.1450625

Hevner, A. R. (2007). The Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*(2), 87.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75–105.

Hiekkanen, K., Korhonen, J. J., Collin, J., Patricio, E., Helenius, M., & Mykkänen, J. (2013). Architects' Perceptions on EA Use – An Empirical Study. *2013 IEEE 15th Conference on Business Informatics*, 292–297. https://doi.org/10.1109/CBI.2013.48

Hirschheim, R., & Klein, H. K. (2012). A glorious and not-so-short history of the information systems field. *Journal of the Association for Information Systems*, *13*(4), 188.

Hobbs, G. (2012). EAM governance and organisation. *Strategic Enterprise Architecture Management: Challenges, Best Practices, and Future Developments*.

Humphreys, G. W., & Bruce, V. (1989). *Visual Cognition: Computational, Experimental and Neuropsychological Perspectives*. Hove, UK: Lawrence Erlbaum Associates Ltd.

Ibáñez, M. B., Di Serio, Á., Villarán, D., & Delgado Kloos, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers & Education*, *71*(Supplement C), 1–13. https://doi.org/10.1016/j.compedu.2013.09.004

ISO/IEC/IEEE 42010:2011(E). (2011). *Systems and software engineering - Architecture description*.

John, T., & Kundisch, D. (2015). Why fit leads to surprise: An extension of cognitive fit theory to creative problems. *ICIS*. Presented at the Fort Worth. Fort Worth.

Johnson, M., & Lakoff, G. (1999). *Philosophy in the Flesh : The Embodied Mind and Its Challenge to Western Thought*. New York, NY: Basic Books.

Kaisler, S. H., Armour, F., & Valivullah, M. (2005). Enterprise Architecting: Critical Problems. *Proceedings of the 38th Annual Hawaii International Conference on System Sciences, 2005. HICSS '05*, 224b–224b. https://doi.org/10.1109/HICSS.2005.241

Korhonen, J. J., & Halén, M. (2017). Enterprise Architecture for Digital Transformation. *Business Informatics (CBI), 2017 IEEE 19th Conference On*, *1*, 349–358. IEEE.

Korhonen, J. J., Hiekkanen, K., & Lähteenmäki, J. (2009). EA and IT governance- A systemic approach. *European Conference on Leadership, Management and Governance*.

Kortekamp, S.-S., Werning, S., Thomas, O., & Ickerott, I. (2019). THE FUTURE OF DIGITAL WORK - USE CASES FOR AUGMENTED REALITY GLASSES. *ECIS 2019*. Presented at the Sweden. Sweden.

Kotusev, S., Singh, M., & Storey, I. (2015). Investigating the Usage of Enterprise Architecture Artifacts. *ECIS 2015 Research-in-Progress Papers*.

Lakoff, G. (1987). *Women, Fire, and Dangerous Things*. Chicago, IL: University of Chicago Press.

Lam, H., Bertini, E., Isenberg, P., Plaisant, C., & Carpendale, S. (2012). Empirical Studies in Information Visualization: Seven Scenarios. *IEEE Transactions on Visualization and Computer Graphics*, *18*(9), 1520–1536. https://doi.org/10.1109/TVCG.2011.279

Lange, M., & Mendling, J. (2011). An Experts' Perspective on Enterprise Architecture Goals, Framework Adoption and Benefit Assessment. *2011 IEEE 15th International Enterprise Distributed Object Computing Conference Workshops*, 304–313. Helsinki, Finland. https://doi.org/10.1109/EDOCW.2011.41

Lange, M., Mendling, J., & Recker, J. (2016). An empirical analysis of the factors and measures of Enterprise Architecture Management success. *European Journal of Information Systems*, *25*(5), 411–431. https://doi.org/10.1057/ejis.2014.39

Lee, K. (2012). *Augmented Reality in Education and Training*. *56*(2), 9.

Löhe, J., & Legner, C. (2014). Overcoming implementation challenges in enterprise architecture management: a design theory for architecture-driven IT Management (ADRIMA). *Information Systems and E-Business Management*, *12*(1), 101–137. https://doi.org/10.1007/s10257-012-0211-y

Lucke, C., Krell, S., & Lechner, U. (2010). Critical issues in enterprise architecting – a literature review. *Proceedings of the 16th Americas Conference on Information Systems (AMCIS 2010)*. Presented at the Lima, Peru. Lima, Peru.

Lušić, M., Fischer, C., Bönig, J., Hornfeck, R., & Franke, J. (2016). Worker information systems: state of the art and guideline for selection under consideration of company specific boundary conditions. *Procedia CIRP*, *41*, 1113–1118.

Lux, J., & Ahlemann, F. (2012). Embedding EAM into the project life cycle. *Strategic Enterprise Architecture Management: Challenges, Best Practices, and Future Developments*, 141–168.

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*(4), 251–266. https://doi.org/10.1016/0167-9236(94)00041-2

McGill, M., Boland, D., Murray-Smith, R., & Brewster, S. (2015). A dose of reality: Overcoming usability challenges in vr head-mounted displays. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2143–2152. ACM.

Meola, A., Cutolo, F., Carbone, M., Cagnazzo, F., Ferrari, M., & Ferrari, V. (2017). Augmented reality in neurosurgery: a systematic review. *Neurosurgical Review*, *40*(4), 537–548. https://doi.org/10.1007/s10143-016-0732-9

Merino, L., Bergel, A., & Nierstrasz, O. (2018). Overcoming issues of 3D software visualization through immersive augmented reality. *2018 IEEE Working Conference on Software Visualization (VISSOFT)*, 54–64. Madrid, Spain.

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies*, *2351*(11), 282–292.

Mingers, J. (2001). Combining IS research methods: towards a pluralist methodology. *Information Systems Research*, *12*(3), 240–259.

Mithas, S., & Rust, R. T. (2016). How Information Technology Strategy and Investments Influence Firm Performance: Conjecture and Empirical Evidence1. *MIS Quarterly*, *40*(1), 223–246.

Moore, G. C., & Benbasat, I. (1991). Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information Systems Research*, *2*(3), 192–222.

Nguyen, H. T., Drechsler, A., & Antunes, P. (2019). Construction of Design Science Research Questions. *Communications of the Association for Information Systems*, 332–363. https://doi.org/10.17705/1CAIS.04420

Niehaves, B. (2007). On epistemological diversity in design science: New vistas for a design-oriented IS research. *Proceedings of the 28th International Conference on Information Systems, Montreal, Canada: Association for Information Systems*.

Niemi, E., & Pekkola, S. (2019). The Benefits of Enterprise Architecture in Organizational Transformation. *Business & Information Systems Engineering*.

Nowakowski, E., Farwick, M., Trojer, T., Häusler, M., Kessler, J., & Breu, R. (2017). Enterprise Architecture Planning: Analyses of Requirements from Practice and Research. *Proceedings of the 50th Hawaii International Conference on System Sciences*.

Ohta, Y., & Tamura, H. (1999). *Mixed Reality: Mergin Real and Virtual Worlds*. Springer Berlin Heidelberg.

Olshannikova, E., Ometov, A., Koucheryavy, Y., & Olsson, T. (2015). Visualizing Big Data with augmented and virtual reality: challenges and research agenda. *Journal of Big Data*, *2*(1), 1–27.

Orlikowski, W. J., & Baroudi, J. J. (1991). Studying Information Technology in Organizations: Research Approaches and Assumptions. *Information Systems Research*, *2*, 1–28.

Palvia, P., Leary, D., Mao, E., Midha, V., Pinjani, P., & Salam, A. (2004). Research methodologies in MIS: an update. *Communications of the Association for Information Systems*, *14*(1), 24.

Panas, T., Berrigan, R., & Grundy, J. (2003). A 3D metaphor for software production visualization. *Proceedings on Seventh International Conference on Information Visualization, 2003. IV 2003.*, 314–319. London, UK: IEEE.

Patomäki, H., & Wight, C. (2000). After Postpositivism? The Promises of Critical Realism. *International Studies Quarterly*, *44*(2), 213–237.

Peffers, K., Tuunanen, T., Gengler, C. E., Rossi, M., Hui, W., Virtanen, V., & Bragge, J. (2006). The Design Science research process: a model for producing and presenting information systems research. *Proceedings of the First International Conference on Design Science Research in Information Systems and Technology*, 83–106.

Pozzi, G., Pigni, F., & Vitari, C. (2014). Affordance theory in the IS discipline: A review and synthesis of the literature. *AMCIS 2014 Proceedings*.

Proper, E., & Greefhorst, D. (2010). The roles of principles in enterprise architecture. *Trends in Enterprise Architecture Research*, *70*, 57–70.

Rahimi, F., Gøtze, J., & Møller, C. (2017). Enterprise Architecture Management: Toward a Taxonomy of Applications. *Communications of the Association for Information Systems*, *40*(1).

Recker, J. (2013). *Scientific Research in Information Systems - A Beginner's Guide*. Heidelberg, Germany: Springer.

Ross, J. W., Weill, P., & Robertson, D. C. (2006). *Enterprise architecture as strategy: Creating a foundation for business execution*. Boston, Massachusetts, USA: Harvard Business School Press.

Roth, S., Zec, M., & Matthes, F. (2014). *Enterprise Architecture Visualization Tool Survey 2014*. Germany: epubli GmbH.

Schaffer, O., & Fang, X. (2018). What Makes Games Fun? Card Sort Reveals 34 Sources of Computer Game Enjoyment. *AMCIS 2018 Proceedings*, 1–10. Association for Information Systems.

Schmidt, C., & Buxmann, P. (2011). Outcomes and success factors of enterprise IT architecture management: empirical insight from the international financial services industry. *European Journal of Information Systems*, *20*(2), 168–185.

Schönherr, M. (2009). Towards a common terminology in the discipline of enterprise architecture. In *Service-Oriented Computing – ICSOC 2008 Workshops* (pp. 400–413). Berlin, Heidelberg: Springer.

Schwaber, K. (1997). SCRUM Development Process. In J. Sutherland, C. Casanave, J. Miller, P. Patel, & G. Hollowell (Eds.), *Business Object Design and Implementation* (pp. 117–134). London: Springer London. https://doi.org/10.1007/978-1-4471-0947-1_11

Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., & Lindgren, R. (2011). Action design research. *MIS Quarterly*, *35*(1), 37–56.

Shanks, G., Gloet, M., Asadi Someh, I., Frampton, K., & Tamm, T. (2018). Achieving benefits with enterprise architecture. *The Journal of Strategic Information Systems*, *27*(2), 139–156. https://doi.org/10.1016/j.jsis.2018.03.001

Sherman, W. R., & Craig, A. B. (2002). *Understanding Virtual Reality: Interface, Application, and Design*. Elsevier Science.

Simon, D., Fischbach, K., & Schoder, D. (2014). Enterprise architecture management and its role in corporate strategic management. *Information Systems and E-Business Management*, *12*(1), 5–42. https://doi.org/10.1007/s10257-013-0213-4

Simon, H. A. (1996). *The sciences of the artificial*. Cambridge, MA: MIT Press.

Soares, L. (2008). Using Metaphors for Visualizing Enterprise Architectures. *SAC'08*, 1–5. Fortaleza, Ceará, Brazil: ACM.

Sommerauer, P., & Müller, O. (2014). Augmented reality in informal learning environments: A field experiment in a mathematics exhibition. *Computers & Education*, *79*, 59–68. https://doi.org/10.1016/j.compedu.2014.07.013

Sparacino, F., Wren, C., Azarbayejani, A., & Pentland, A. (2002). Browsing 3-D spaces with 3-D vision: body-driven navigation through the internet city. *Proceedings. First International Symposium on 3D Data Processing Visualization and Transmission*, 224–231. Padova, Italy: IEEE.

Stack, G. J. (1998). *Materialism*. Retrieved February 12, 2020, from https://www.rep.routledge.com/articles/thematic/materialism/v-1

Steffen, J., Gaskin, J., Meservy, T., & Jenkins, J. (2017). The Missing Framework for Virtually Assisted Activities. *Thirty Eighth International Conference on Information Systems*. Presented at the Seoul. Seoul.

Stendal, K., Thapa, D., & Lanamaki, A. (2016, January). *Analyzing the Concept of Affordances in Information Systems*. 5270–5277. IEEE. https://doi.org/10.1109/HICSS.2016.651

Stolterman, E., & Fors, A. C. (2004). Information Technology and the Good Life. In B. Kaplan, D. P. Truex, D. Wastell, A. T. Wood-Harper, & J. I. DeGross (Eds.), *Information Systems Research* (Vol. 143, pp. 687–692). Boston: Kluwer Academic Publishers.

Strengers, Y. (2015). Meeting in the Global Workplace: Air Travel, Telepresence and the Body. *Mobilities*, *10*(4), 592–608. https://doi.org/10.1080/17450101.2014.902655

Tamm, T., Seddon, P. B., Shanks, G., & Reynolds, P. (2011). How does enterprise architecture add value to organisations. *Communications of the Association for Information Systems*, *28*(1), 141–168.

The Open Group. (2009). *TOGAF® Version 9*. Van Haren Publishing.

The Open Group. (2018). *The TOGAF® Standard, Version 9.2* (11th ed.). van Haren Publishing.

Van de Wetering, R. (2019). Enterprise Architecture Resources, Dynamic Capabilities, and their Pathways to Operational Value. *ICIS 2019 Proceedings*.

van der Linden, D., & Van Zee, M. (2015). Insights from a Study on Decision Making in Enterprise Architecture. *In Short Paper Proceedings of the 8th IFIP WG 8.1 Working Conference on the Practice of Enterprise Modeling (PoEM)*, 21–30.

van der Raadt, B., Schouten, S., & Vliet, H. van. (2008). Stakeholder Perception of Enterprise Architecture. In R. Morrison, D. Balasubramaniam, & K. Falkner (Eds.), *Software Architecture* (pp. 19–34). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-88030-1_4

Vessey, I. (1991a). *Cognitive fit: A theory-based analysis of the graphs versus tables literature*. *22*(2), 219–240.

Vessey, I. (1991b). *Cognitive Fit: A Theory-Based Analysis of the Graps Versus Tables Literature*.

Vessey, I., & Galletta, D. (1991). Cognitive Fit: An Empirical Study of Information Acquisition. *Information Systems Research*, *2*(1), 63–84. https://doi.org/10.1287/isre.2.1.63

Vieira, R., Cardoso, E., & Becker, C. (2014, September). *A Traceable Maturity Assessment Method Based on Enterprise Architecture Modelling*. 245–253. IEEE. https://doi.org/10.1109/EDOCW.2014.44

vom Brocke, J., Simons, A., Riemer, K., Niehaves, B., Plattfaut, R., & Cleven, A. (2015). Standing on the Shoulders of Giants: Challenges and Recommendations of Literature Search in Information Systems Research. *Communications of the Association for Information Systems*, *37*(1).

Vovk, A., Wild, F., Guest, W., & Kuula, T. (2018). Simulator Sickness in Augmented Reality Training Using the Microsoft HoloLens. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 209. ACM.

Walsh, K. R., & Pawlowski, S. D. (2002). Virtual Reality: A Technology in Need of IS Research. *Communications of the Association for Information Systems*, *8*(1).

Wang, X., Love, P. E. D., Kim, M. J., & Wang, W. (2014). Mutual awareness in collaborative design: An Augmented Reality integrated telepresence system. *Computers in Industry*, *65*(2), 314–324. https://doi.org/10.1016/j.compind.2013.11.012

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS Quarterly*, *26*(2), xiii–xxiii.

Weiss, S., Aier, S., & Winter, R. (2012). Towards a reconstruction of theoretical foundations of enterprise architecture management. In *Information systems: crossroads for organization, management, accounting and engineering* (pp. 461–468). Springer.

Weiss, S., Aier, S., & Winter, R. (2013). INSTITUTIONALIZATION AND THE EFFECTIVENESS OF ENTERPRISE ARCHITECTURE MANAGEMENT. *Association for Information Systems*. Presented at the 34th International Conference on Information Systems, Milan, Italy.

Wettel, R., & Lanza, M. (2007). Visualizing software systems as cities. *2007 4th IEEE International Workshop on Visualizing Software for Understanding and Analysis*, 92–99. Banff, Ont., Canada: IEEE.

Widjaja, T., & Gregory, R. (2012). Design Principles for Heterogeneity Decisions in Enterprise Architecture Management. *ICIS 2012 Proceedings*.

Winter, K., Buckl, S., Matthes, F., & Schweda, C. M. (2010). *Investigating the state-of-the-art in enterprise architecture management methods in literature and practice*.

Winter, R., & Fischer, R. (2007). Essential layers, artifacts, and dependencies of enterprise architecture. *Journal of Enterprise Architecture*, *3*(2), 7–18.

Winter, R., Legner, C., & Fischbach, K. (2014). Introduction to the special issue on enterprise architecture management. *Information Systems and E-Business Management*, *12*(1), 1–4. https://doi.org/10.1007/s10257-013-0221-4

Winter, R., & Schelp, J. (2008). *Enterprise architecture governance: the need for a business-to-IT approach*. Presented at the 23rd Annual ACM Symposium on Applied Computing.

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*(Supplement C), 41–49. https://doi.org/10.1016/j.compedu.2012.10.024

Zhou, N.-N., & Deng, Y.-L. (2009). Virtual reality: A state-of-the-art survey. *International Journal of Automation and Computing*, *6*(4), 319–325. https://doi.org/10.1007/s11633-009-0319-9

II

PUT YOUR GLASSES ON: CONCEPTUALIZING AFFORDANCES OF MIXED AND VIRTUAL REALITY FOR ENTERPRISE ARCHITECTURE MANAGEMENT

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 natural 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, which is based on 37 case studies of EAM applied in practice. 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*

This article was co-authored with David Hoffmann and Frederik Ahlemann. An earlier version of this article was published in Multikonferenz Wirtschaftsinformatik (MKWI):

Rehring, K., Hoffmann, D., & Ahlemann, F. (2018). Put your glasses on: Conceptualizing affordances of mixed and virtual reality for enterprise architecture management. Multikonferenz Wirtschaftsinformatik 2018.

Table of Contents

List of Figures

List of Tables

1 Introduction

Regardless of their size, organizations have for decades been facing a rapidly changing business environment (R. Winter, Legner, & Fischbach, 2014, p. 1). Fast-changing IT requirements and the steadily growing complexity of the IT landscape have become a major challenge for them (R. Winter et al., 2014, p. 1). Shadow IT organizations, redundant IT systems, and increasing risk of IT-failure are some examples of rapidly developing IT consequences (Ahlemann, Stettiner, Messerschmidt, & Legner, 2012, p. 6). An approach that could assist in overcoming these challenges and drive organizational change lies in the application of Enterprise Architecture Management (EAM) (Löhe & Legner, 2014, p. 103; R. Winter et al., 2014, p. 1). EAM is a business strategy driven management discipline that establishes, maintains and develops an Enterprise Architecture (EA) through methods, tools, principles, and standards (Ahlemann et al., 2012, p. 20; Aier, Gleichauf, & Winter, 2011, p. 645; Simon, Fischbach, & Schoder, 2014, p. 32). It supports managers in the alignment of business processes with corporate strategy, while considering the overall IT landscape (Löhe & Legner, 2014, p. 104).

Nevertheless, the successful application of EAM remains moderate (Kotusev, Singh, & Storey, 2015, p. 1). One reason for this lies in the insufficient use of EAM outcomes (Kotusev et al., 2015, p. 3), which are defined as EA artifacts (Rouhani, Mahrin, Shirazi, Nikpay, & Rouhani, 2015, p. 51). 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 (Hauder, Roth, Schulz, & Matthes, 2013, pp. 2–4; Löhe & Legner, 2014, p. 116). One approach to overcome these visualization challenges might lie in the application of Mixed Reality (MR) and Virtual Reality (VR) technologies. These technologies enable a natural interaction with data (Ohta & Tamura, 1999), higher manageability of vast amounts of data, as well as greater analytical skills due to natural spatial and visual ability being involved (Greenhalgh & Benford, 1995, p. 27). 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. We base our argumentation on a comprehensive literature review that shows how the EAM function is applied in practice. Our analysis of 37 case studies will reveal the intended goals for implementing EAM in organizations, the decision-making tasks that are linked to the EAM function, as well as what artefacts are produced that are eventually used in decision-making processes. Considering the novelty of this approach, the aim of this paper is to understand the status quo of EAM in practice, investigate how MR and VR can improve EAM effectiveness, and to set the ground for further research.

We apply the theoretical lens of affordances, as this allows us to study possible relationships between human users and technology (Chemero, 2003; Pozzi, Pigni, & Vitari, 2014; Stendal, Thapa, & Lanamaki, 2016). 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 (CoP). 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. The status quo of EAM in practice is presented in section 4. Section 5 proposes the above-mentioned conceptual model. A brief development of future research opportunities is presented in section 6. We conclude our paper in section 7, 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 (Buckl, Schweda, & Matthes, 2010; Löhe & Legner, 2014; R. Winter et al., 2014). 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 (K. Winter, Buckl, Matthes, & Schweda, 2010; Aier, Fischer, & Winter, 2011) or, respectively, on the ISO/IEC/IEEE 42010 (2011), 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 (2007) identify five common layers that describe the fundamental structure of an organization: Business, process, integration, software, and technology architecture. Ahlemann et al. (2012) 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") (Korhonen, Hiekkanen, & Lähteenmäki, 2009; Tamm, Seddon, Shanks, & Reynolds, 2011), which emphasizes EA's long-term view on organizational development (Ross, Weill, & Robertson, 2006). Comparing the baseline and target states enables the development of roadmaps that provide a plan for how to achieve the desired EA future state (Tamm et al., 2011).

In the same manner as EA, a variety of EAM definitions exist (K. Winter et al., 2010). Following Aier et al. (2011), 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 (2014), EAM provides clear guidelines using plans, roadmaps, principles, and standards to support the transformation of the enterprise. In the same vein, Ahlemann et al. (2012) highlight the need for a formulated governance regime. This view is supported by Wijeya and Gregory (2012) who argue that EAM is closely linked to business strategy. In a broader sense, Simon et al. (2014) 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. (2017), 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 (ISO/IEC/IEEE 42010:2011(E), 2011; R. Winter & Fischer, 2007). Enterprise Architecture Management is a business strategy-driven management discipline that establishes, maintains and develops an Enterprise Architecture (Ahlemann et al., 2012; Aier, Gleichauf, et al., 2011; Simon et al., 2014; Widjaja & Gregory, 2012).

2.2 Mixed 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. (Milgram, Takemura, Utsumi, & Kishino, 1994). As presented in Figure II-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 (Milgram et al., 1994). 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.

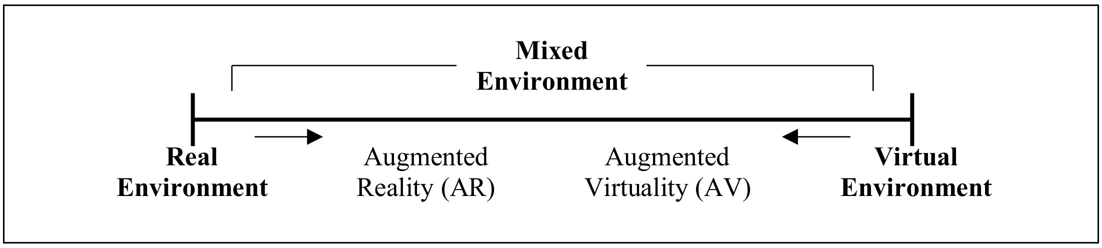


Figure II-1. Reality-Virtuality (RV) continuum proposed by Milgram et al. (1994)

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 (Milgram et al., 1994; Ohta & Tamura, 1999). A user can still see the real world (Azuma, 1997), while AR adds or even removes objects from it (Azuma, 1997). Some authors mention that AR does not only rely on the sense of sight (e.g. Azuma, 1997), although a recent review identified only visual aspects that constitute AR (Lušić, Fischer, Bönig, Hornfeck, & Franke, 2016).

Generally speaking, there are two classes of AR definitions (Ohta & Tamura, 1999): The first class focuses largely on a wide-ranging understanding and technology-independent definition of AR (Ohta & Tamura, 1999). 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" (Azuma, 1997, p. 356).

In contrast, the second class of technology-related AR definitions mainly focus on AR displays (Ohta & Tamura, 1999). Most commonly, this includes so-called head-mounted displays (HMD) (Azuma, 1997) that distinguish between optical and video see-through displays (Ohta & Tamura, 1999; Sherman & Craig, 2002). As presented in Figure II-2, head-mounted optical see-through displays allow the user to see the real environment through a display medium (Azuma, 1997; Milgram et al., 1994). 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 (Azuma, 1997) as shown in Figure II-3. A variation of it is in handheld AR displays where a small screen contains virtual objects, which react to changes of the real environment (Sherman & Craig, 2002).

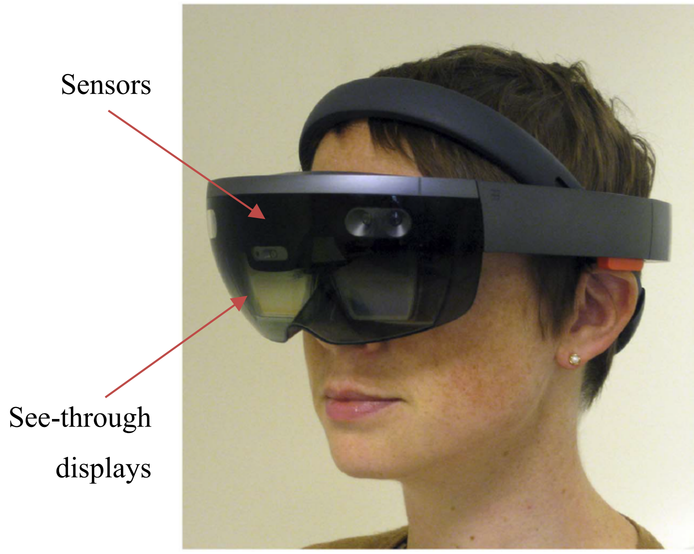


Figure II-2. Example of a head-mounted optical see-through display (Kinateder et al., 2018, p. 2)

Figure II-3. Example of a head-mounted video see-through display (Chair of Human-Machine Communication, 2020)

Augmented Virtuality (AV) is also part of the Mixed Environment, but lies close to the Virtual Environment on the RV continuum (Milgram et al., 1994). In contrast to AR, AV is rather more virtual, but it includes real objects like a user's hand (Milgram et al., 1994) as seen in Figure II-4. Currently, there is considerably less research on AV than on AR, mainly due to the absence of feasible consumer devices (McGill, Boland, Murray-Smith, & Brewster, 2015). However, room-wide motion detecting devices that capture the position of objects, gestures, and other physiological measures could increase the applicability (McGill et al., 2015).

Figure II-4. Example of a head-mounted display in Augmented Virtuality (Stahl, 2015)

A Virtual Environment (VE) consists completely of computer generated virtual objects (Milgram et al., 1994) and is commonly called Virtual Reality (VR) (Azuma, 1997). Multiple definitions of VR exist as a result of different past understandings and interpretations (Sherman & Craig, 2002; Zhou & Deng, 2009). Many authors define VR based on its technology nature, describing the devices, computers and methods that are needed to create an interactive simulation (Zhou & Deng, 2009). Other authors highlight the immersive experiences with VR (Azuma, 1997), or add human imagination as a key concept to the definition (Burdea & Coiffet, 2003). Many agree that VR technology addresses all human senses (Burdea & Coiffet, 2003; Walsh & Pawlowski, 2002) and that sensory feedback is an important aspect of it (Sherman & Craig, 2002). Considering all these facets, we follow Biocca and Delaney who state that VR "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" (Biocca & Delaney, 1995, p. 63).

Common VR output devices are occlusive HMD (Biocca & Delaney, 1995; Sherman & Craig, 2002). These displays have the advantage of head-centered motion and its capability for binocular disparity (Biocca & Delaney, 1995). In contrast to AR, occlusive HMDs suppress the real world to the benefit of VR (Sherman & Craig, 2002). Usually, small screens are used (Sherman & Craig, 2002). An example is presented in Figure II-5. A variation of these HMDs are virtual retinal displays (VRD) that present images directly onto the retina of a users' eye (Sherman & Craig, 2002; Walsh & Pawlowski, 2002, p. 300). Monitor-based 'fishtank' VRs (Sherman & Craig, 2002) are alternative VR output devices that track the position of the users' head, and the VR then responds to the head movement. Movement and user inputs are important characteristics of immersive virtual reality experiences. 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 (Sherman & Craig, 2002).

Figure II-5. Example of a occlusive head-mounted virtual reality device (Lee, Kim, Kim, & Park, 2020, p. 126)

2.3 IT Affordances

As highlighted by Stendal et al. (2016), 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 (Gibson, 1986). For instance, a tree affords climbing, or a ball affords kicking. Many authors follow Chemero's definition of affordances (2003) 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 (Stendal et al., 2016). Following Chatterjee et al. (2015), "IT affordances reflect the user's goals and how the user appropriates the IT capability to realize those goals" (p. 161). Stendal et al. (2016) 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 Research Design

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 (The Open Group, 2011) 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 (Hanseth & Lyytinen, 2010), the notion of IT affordances allows us to study the relationship between MR/VR devices and users (Stendal et al., 2016) based on provided action possibilities (Markus & Silver, 2008).

We base our argumentation on practical insights derived from EAM case studies described in IS literature. This approach aims to gain an in-depth view of implemented EAM functions in real organizations. It helps us to explain our goals, but more importantly, to study the forms of and relationship between EA decision-making scenarios and considered EA artefacts in a real-world setting. This information is crucial for designing the first draft of a conceptual model that describes the possible use of MR/VR devices that intend to improve EA decision-making quality and increase the effectiveness of the EAM function.

In this study, we conducted a systematic literature review following the recommendations provided by vom Brocke et al. (2015). We followed a sequential procedure characterized by (a) gathering literature, (b) analyzing text, and (c) documenting the findings (Levy & Ellis, 2006, p. 181). Our search process relied on seven IS literature databases, which contain highly rated IS journals and conference proceedings, and specifically include peer reviewed IS papers. These databases are IEEE Xplore, Sage Journals, AISel, ACM, MISQ, Web of Science, and Science Direct. We covered various different genres, such as conference papers, journal papers, or white papers, all published between 2006 and 2016 and with a focus on EAM case studies. We chose the keyword search technique to identify relevant papers. The final set of four keywords we used were EAM case study, EA case study, Enterprise Architecture Management case study, and Enterprise Architecture case study. This setting resulted in 273 identified papers, listed in the appendix. We removed 43 duplicate entries, 99 papers that did not mention EAM case studies in their titles or abstracts, and after reading the full texts, another 107 papers that did not describe the characteristics of an EAM case study. A forwards and backward search did not result in more papers to be considered. Figure II-6 provides an overview of the above-mentioned process and its results.

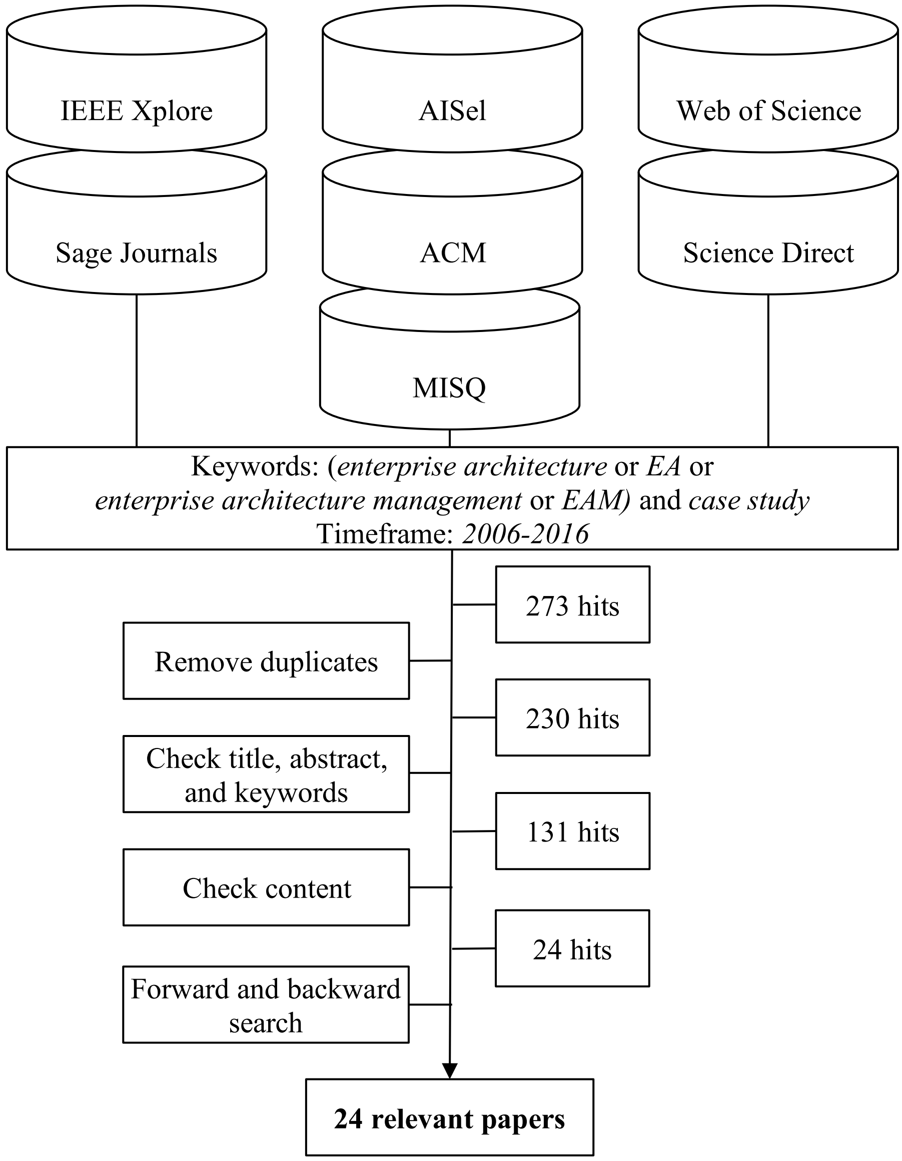


Figure II-6. Literature research process and results

This literature review was intended to identify content relevant to our goals regarding implementing EAM (section 4.1), the reported decision-making tasks (section 4.2), and the employed EA artefacts in organizations (section 4.3). To achieve our goals, we applied a coding technique endorsed by Corbin and Strauss (1990) as one well-suited for qualitative evaluations, to analyze the 24 identified papers. It extracts related concepts from various papers. The three steps that comprise this technique proceed as follows: First, in open coding, two researchers read all papers thoroughly, tagging all words and sets of words that seemed to be relevant, giving each a summarizing description. We continuously changed these descriptions or codes because the goal in such analysis is eventually to produce codes that describe many excerpts. Second, in axial coding, we connected related open codes and then described the new set of connected open codes by new main categories or axial codes. Third, in selective coding, these axial codes were again connected and described by new codes, called selective codes, in order to form a description of 'what happens' in a phenomenon.

4 Status Quo in Enterprise Architecture Management

This paper claims that the effectiveness of EAM can increase when we employ MR and VR technologies, due to their interaction and immersive affordances. To describe the status quo of today's decision-making processes, as well as to identify and address practitioner-relevant goals and challenges, it is crucial to understand how organizations apply EA artifacts in decision-making. Explanations of implemented governance artifacts including decision-making processes regarding EA, increase possible future MR and VR implementation prototypes' applicability. Practical descriptions gathered from case studies is an appropriate source to formalize common EA decision-making tasks and decision-making scenarios that are close to reality. Hence, the following sections reports on 24 identified papers describing 37 EA use cases in practice, focusing on how these organizations employ EA artifacts in decision-making on EAs. The identified use cases are from several places around the world, including Switzerland, Denmark, Germany, South Africa, Finland, China, Norway, Australia, USA, Sweden, Portugal, United Arab Emirates, and the UK. Also, the considered industries that were mentioned in the papers, comprise the insurance sector, finance sector, health sector, energy sector, retail sector, a nonprofit organization, service firm, government, manufacturer, telecommunication, as well as the automobile and supply chain sectors. Most industries were large to very large organizations employing between 20,000 and 368,500 people. However, some smaller businesses encompassing between 35 and 500 employees are also part of the collected data. Table II-1 provides an overview of the considered EA case studies.

All the real-life scenarios we identified describe formal EA decision-making processes, which are opposed to informal organizational EA decision-making. The latter has no defined organizational structures and mechanisms other than ad-hoc reporting to support decision-making processes regarding EAs. In contrast, formal decision-making is predominantly based on problem definitions, goals, processes, artefacts, and institutionalized governances. The following subsections will present these aspects.

4.1 Goals for Introducing EAM in Organizations

Overall EA-related motives for introducing EAM impact how and to what extent EA artefacts are used in decision-making about EAs. Our analysis revealed three classes of goals and benefits we can expect from introducing EAM: overarching goals, business goals, and IT goals. We integrate the concepts of goals and benefits in the following overview as the two are often used synonymously in that goals that are achieved, translate into benefits.

Thirty companies mentioned overarching goals for introducing EAM. We aggregated the goals into the three subclasses shown in Table II-2.

Table II-1. Overview of the considered case studies

Author	Cases	Industry	Country	Size
Aier et al. (2011)	2	Supply Chain	N/A	N/A
		Service firm	N/A	N/A
Alwadain et al. (2016)	1	Government	United Arab Emirates	Large
Andersen et al. (2015)	1	N/A	Denmark	Large
Blomqvist et al. (2015)	1	Finance sector	Nordic	N/A
Bricknall et al. (2006)	2	Supply Chain	Sweden	Large
		Health sector	Sweden	Large
Bui (2015)	3	Government	USA	N/A
		Government	USA	N/A
		Government	USA	N/A
Fallmyr and Bygstad (2014)	4	Government	Norway	Midsize
		Energy sector	Norway	Midsize
		Telecommunication	Norway	Small
		Manufacturer	Norway	Midsize
Haki et al. (2012)	4	Retail sector	N/A	Large
		Automobile	N/A	Large
		Manufacturer	N/A	Large
		Finance sector	N/A	Large
Harris (2008)	1	Government	Australia	N/A
Hjort-Madsen (2006)	1	Health sector	Denmark	Large
Iyamu (2011)	1	Finance sector	South Africa	Large
Kluge et al. (2006)	2	Insurance sector	Switzerland	N/A
		Energy sector	Australia	N/A
Lux et al. (2010)	1	Service firm	Germany	Large
Marques et al. (2011)	1	Manufacturer	Portugal	N/A
Martin (2012)	1	Health sector	UK	Large
Niemi and Pekkola (2013)	1	Government	Finland	N/A
Prem et al. (2011)	1	Non profit organization	Germany	Large
Rijo et al. (2015)	1	Health sector	Portugal	Midsize
Seppanen et al. (2009)	2	Government	Finland	Large
		Government	Finland	Large
Smith and Watson (2015)	1	Insurance sector	United States	Large
Smith et al. (2012)	1	Insurance sector	United States	Large
Tamm et al. (2015)	1	Retail sector	Australia	Midsize
Wang and Zhao (2009)	1	Manufacturer	China	Large
Winter & Schelp (2008)	3	Insurance sector	Switzerland	Large
		Insurance sector	Switzerland	Midsize
		Finance sector	Switzerland	Large

Table II-2. Classes of overarching EAM goals

Alignment of business and IT landscapes	Alwadain et al. (2016, p. 6), Bui (2015, pp. 172 & 174), Haki et al. (2012, p. 7), Harris (2008, p. 611), Hjort-Madsen (2006, p. 4), Iyamu (2011, p. 83), Niemi and Pekkola (2013, p. 58), Rijo et al. (2015, p. 1220), Smith et al. (2012, pp. 78 & 83), Smith and Watson (2015, p. 204), Tamm et al. (2015, p. 187)
Improvement of project management process	Aier et al. (2011, p. 643), Andersen et al. (2015, p. 4093), Fallmyr and Bygstad (2014, p. 3794), Iyamu (2011, p. 85), Lux et al. (2010, p. 7), Niemi and Pekkola (2013, p. 58), Prem et al. (2011, p. 6), Tamm et al. (2015, p. 182), Winter & Schelp (2008, p. 550)
Re-design of organization	Alwadain et al. (2016, p. 10), Blomqvist et al. (2015, p. 45), Bui (2015, p. 174), Fallmyr & Bygstad (2014, p. 3795), Martin (2012, p. 145), Smith and Watson (2015, p. 204), Tamm et al. (2015, p. 182)

A common EAM goal refers to desired improvements in the **alignment of business and IT** aspects in an organization. As Bui (2015, p. 174) mentions, enterprise architects aim to build bridges between business and technology landscapes in order to identify problems, but also improvement opportunities and organizational standardization. Further, this kind of organization management drives a greater focus on how future IT investments serve a specific business purpose and how these investments are linked to marked requirements (Bui, 2015, p. 172). More concretely, an organization Rijo et al. (2015, p. 1220) observed focuses on linking business processes, the related stakeholders, and the applied IT infrastructure for developing problem solving strategies. Haki et al. (2012, p. 7) report on the goal to establish a direct link between business processes and IT systems. Smith and Watson (2015, p. 206) highlight the need for testing strategy development, validating responsibilities, identifying architectural components, deployment reviews, as well as deriving insight from lessons learnt. Hjort-Madsen (2006, p. 4) mentions the need to integrate aspects of EA into strategic goals to deal with a heterogeneous IT environment. Contrastively, Niemi and Pekkola (2013, p. 58) argue that high-level EA artifacts like blueprints should be derived from strategic plans. Harris (2008, p. 611) points out one exemplary organization's aim to increase its associated businesses' acceptance of changes in the service model. Smith et al. (2012, p. 78) highlight the goal of designing artifacts such as reference architectures, models, portfolios, policies, practices, standards, and educational materials based on business strategies. In the same vein, Smith and Watson (2015, p. 204) note that the outcomes of EAM processes are deeply linked to top management decision-making on the design of business architectures. Similarly, Alwadain et al. (2016, pp. 5 & 10) found that the case they observed focused on aligning strategy, business, and technology, as well as architectural standards. The demand management implemented in addition to EAM enabled a rapid response to changing market conditions. An extensive ex-post review of EAs in light of ex-ante strategic decisions, as mentioned by Tamm et al. (2015,

p. 187), enabled the review of “what IT capabilities were delivered as the result of the transformation in support of [the companies’] strategic business objectives and how that would position the business for the future” (Tamm et al., 2015, p. 188). Relating to the goal of aligning business and IT landscapes, Iyamu (2011) and Smith et al. (2012) independently report that implementing EAM facilitated the development of an IT strategy (H. A. Smith et al., 2012, p. 83), or that EAs could be considered as an IT strategy (Iyamu, 2011, p. 83). Together these studies provide important insights into the need for a strategy to derive explicit EA-related artifacts that serve the alignment of business and IT landscapes.

As several authors mentioned, such strategic orientation can archive the goal for a fact-based **re-design of organizations**. In a case study conducted in a US state government institution, Bui (2015, p. 174) reports how the strategy-driven design and provision of EA artifacts like technology roadmaps, performance metrics, and training material supported new IT capabilities being implemented. Smith and Watson (2015, p. 204) found that EAM enabled the design of a discipline-centric organization rather than a line of business-oriented organization. Similar to Smith and Watson (2015), Alwadain et al. (2016, p. 10) mention a transformation of the observed organizational business architecture toward a domain-oriented organization which includes its own service provision. According to Tamm et al. (2015), a major transformation project in a retail company led to a “fundamental change in the company’s business logic and a major overhaul of most of the enabling IT systems” (Tamm et al., 2015, p. 182). According to Fallmyr and Bygstad (2014, p. 3795), reorganization can also lead to a new company culture in which employees accept the constancy of change, which leads to less complaints or resistance. Martin (2012, p. 145) as well as Fallmyr and Bygstad (2014, p. 3794) report that the observed organizations employed EAM as an instrument in centralizing IT-related decision-making processes and bundling services to gain overall business efficiency. Blomqvist et al. (2015, p. 45) observed that centralizing decision-making is also a goal in a company that aimed to strengthen the focus on group performance.

Organizations often value EAM for being supportive in **improving project management processes**. Winter & Schelp (2008, p. 550) describe the goal of employing EAM to support the project portfolio management throughout the project planning processes. Andersen et al. (2015, p. 4093) mention the aim to evaluate projects in terms of which issues are the most critical to the organization. According to Tamm et al. (2015, p. 182), understanding the interdependencies of projects assists in meeting organizational aims of reduced project completion time, more accurate budgeting, and lower costs. Fallmyr and Bygstad (2014, p. 3794) claim that applying EAM has fulfilled the objective of increased project performance due to efficient decision-making processes. Also, one organization Aier et al. (2011, p. 643) observed was able to verify finished projects’ impact on its EA as their goal had been to monitor the project that would ensure organizational transformation. The performance of projects is positively influenced by collecting and using accurate data on EAs. Prem et al. (2011, p. 6) mention the goal of improving overall project execution due to EAM. Iyamu (2011, p. 85) and Lux et al. (2010, p. 7) highlight the importance of uncovering and providing information about the enterprise to enable fact-based decision-making that can be used in implementation projects. Iyamu (2011, p. 85) insists that information on EAs should be acquired, applied, and stored according to a standardized approach. Architectural guidelines, according to Niemi and Pekkola (2013, p. 58), can serve as an instrument in project compliance evaluation. Additionally, Aier et al. (2011, p. 643) mention the goal of increasing communication between stakeholders that can be achieved by distributing EA artefacts in an easily accessible way. Hjort-Madsen (2006, pp. 5 & 8) extends this view by highlighting the need for EA artefacts such as technical and organizational blueprints across an entire organization. Such information, according to Hjort-Madsen (2006, p. 6), could facilitate external collaboration with other organizations.

Business goals that motivate introducing EAM were mentioned for 25 companies. We aggregate the goals into three subclasses that are shown in Table II-3.

Table II-3. Classes of business-related EAM goals

Reduction of IT costs	Bricknall et al. (2006, pp. 4 & 9), Bui (2015, p. 173), Haki et al. (2012, p. 8), Harris (2008, p. 614), Hjort-Madsen (2006, p. 6), Kluge et al. (2006, p. 5), Rijo et al. (2015, p. 1218), Prem et al. (2011, p. 6), Smith et al. (2012, pp. 82 & 83), Smith and Watson (2015, p. 198), Tamm et al. (2015, pp. 184 & 186f)
Improvement of processes and services	Aier et al. (2011, p. 643), Bricknall et al. (2006, p. 9), Bui (2015, pp. 171f & 174), Fallmyr and Bygstad (2014, p. 3795), Harris (2008, p. 611), Lux et al. (2010, p. 7)
Improvement in decision-making	Alwadain et al. (2016, p. 6), Fallmyr and Bygstad (2014, p. 3795), Iyamu (2011, p. 85), Lux et al. (2010, p. 7), Smith et al. (2012, p. 83), Tamm et al. (2015, p. 187)

Reducing IT costs and increasing the effectiveness and profitability of IT services are longstanding goals for many organizations. In the case study of a government institution, Harris (2008, p. 614) found that by implementing a solid EAM concept operating costs could be decreased while IT functionality should be increased. Another company Smith et al. (2012, pp. 82 & 83) and Smith and Watson (2015, pp. 198–200) investigated, aims to increase cost-efficient operation of IT services. Operationally, this included integrating application silos, reducing licenses, developing new IT capabilities, reducing the number of technology components, eliminating redundancies of EA components, reducing IT total cost of ownership, and eventually minimizing architectural complexity, while considering business needs throughout. By applying EAM methods and processes, a hospital Rijo et al. (2015, p. 1218) evaluated, focused on cost reduction by improving business operation and enhancing the profitability of existing IT solutions. All four organizations Haki et al. (2012, p. 8) investigated, set the goal of reducing costs through consolidation, standardization, and integration of its EA. Prem et al. (2011, p. 6) mentioned the plan to reduce costs and architectural complexity through standardization. Bricknall et al.'s (2006, p. 9) case study examined the requirement of increasing the IT's cost-effectiveness by avoiding costly ad hoc solutions, reducing business infrastructure, and lowering system operating costs in favor of implementing EA planning processes. Another case study by Bricknall et al. (2006, p. 4) aimed to centralize the application portfolio with the goal of reducing the service management cost globally. In an extensive transformation project, Tamm et al. (2015, p. 187) were able to show that for top management cost saving was a main target. Within a few years, the organization they observed saved millions of dollars by reducing implementation costs, reducing their workforce, providing training, and increasing project delivery – all of which was supported by EA processes and artefacts. Bui (2015, p. 173) identified the goal of increasing the IT cost-effectiveness of the organization under investigation. A new business platform based on agreed IT standards and reusing existing components supported the company in achieving this goal. Hjort-Madsen (2006, p. 6) could point out that the organization he observed aimed to save costs by reducing their EA complexity, e.g. by reducing the number of vendors, cutting IT maintenance costs, and standardizing its application portfolio. Kluge et al. (2006, p. 5) reported on the need to cut IT expenditures in one exemplary organization due to the observed architecture's historically grown complexity.

Some investigated organizations implemented EAM with the purpose of **improving their business processes and services**. Lux et al. (2010, p. 7) note that processes like project management, project portfolio management, service management, and running an operational information system, should be improved by providing new information obtained by EAM processes. Iyamu (2011, p. 85) mentions the goal for optimizing processes through EA principles, standards, and policies. A company supervised by Bui (2015, p. 174), articulated defining and implementing standardized procedures is a goal when to achieve decreasing the runtime of procurement processes. Aier et al. (2011, p. 643) found that EA processes supported by adequate EA tools lead to achieving the goal of increased business performance. Also, Bricknall et al. (2006, p. 9) stated that one of the investigated companies' goal was to reduce time-to-market by deploying IT applications faster and increasing process efficiency; all of this could be supported by EAM processes. Hjort-Madsen (2006, p. 6) observed that the goal of improving business services should be fulfilled by defining common services. These services should guide "the acquiring, outsourcing, integrating, operating, and retiring of the IT-infrastructure" (Hjort-Madsen, 2006, p. 6). As Fallmyr and Bygstad (2014, p. 3795) and Harris (2008, p. 611) noted, other organizations focus on enhancing customer satisfaction, improving customer effectiveness and efficiency by standardization, and deploying new technology.

We found another major subclass of EAM-related business goals naming **improvement in decision-making**. Tamm et al. (2015, p. 187) disclosed one company's objective to establish new EA governance structures and EA processes to identify relevant decision-makers, as well as provide "a more transparent, inclusive and objective basis for IT investment decisions" (Tamm et al., 2015, p. 187). The company's development of EA principles and detailed EA descriptions lay the foundations for in-depth discussions and fact-based decision-making. Similarly, Smith et al. (2012, p. 83) reported on implemented EA processes and architectural standards that pursue the goal of enabling quicker time-to-market decisions by IT and business stakeholders. The rationale is that an EA's general conditions are defined and documented, hence, decision-making can proceed within already existing architectural constraints. Iyamu (2011, p. 85), supervised an organization that supported this view in its aim to promote fact-based debates and comprehensive product and service selection processes which became possible due to available EA information. However, another organization explicitly focused on guiding changes through EA and not documenting decisions made in the course of running projects (Tamm et al., 2015, p. 190). By drawing on the accessibility to comprehensive EA descriptions, Lux et al. (2010, p. 7), Fallmyr and Bygstad (2014, p. 3795), and Alwadain et al. (2016, p. 6) identified the need for such EA information to achieve the goal of quick decision-making, especially in fast changing market conditions. In this context, Alwadain et al. (2016, p. 7) highlighted the explicit need for guidance regarding strategic decision-making in alignment with the local government, while Lux et al. (2010, p. 7) identified the need for improved IS planning decisions as a favorable target state.

Twenty-nine companies mentioned introducing IT-related goals. We aggregated the goals into two subclasses that are shown in Table II-4.

Table II-4. Classes of IT-related EAM goals

Optimizing IT portfolio	Aier et al. (2011, p. 643), Alwadain et al. (2016, p. 10), Andersen et al. (2015, p. 4093), Bricknall et al. (2006, p. 4), Bui (2015, pp. 172 & 174), Haki et al. (2012, p. 8), Hjort-Madsen (2006, p. 5), Iyamu (2011, p. 84), Lux et al. (2010, p. 7), Prem et al. (2011, pp. 6 & 8), Rijo et al. (2015, p. 1218), Smith and Watson (2015, p. 205), Smith et al. (2012, p. 82), Tamm et al. (2015, p. 187)
Improvement of IT performance	Bricknall et al. (2006, p. 9), Harris (2008, p. 614), Smith and Watson (2015, p. 203)

A common IT-related EAM goal throughout the considered organizations was to improve the IT landscape through **IT portfolio optimization**. They addressed the goal in a variety of ways. Many authors identified a historically grown heterogenous IT landscape that limits business performance. Hence, already as far back as 2006, Hjort-Madsen (2006, p. 5) reported the need to transform the current IT landscape to become a homogeneous IT environment. The organization he observed planned to achieve this goal by reducing its technological platforms and IT products (Hjort-Madsen, 2006, p. 6). Similarly, Andersen et al. (2015, p. 4093) mentioned the requirement to migrate 27 existing email systems into one global email system for all departments of the observed organization. Another organization, supervised by Aier et al. (2011, p. 643) standardized its main IT product in order to offer a single IT solution for the same purpose, but with different configurations in different contexts. Prem et al. (2011, pp. 6 & 8) highlight the goal of increasing homogeneity through the use of EAs including the linkage between business applications and applied technologies. Andersen et al. (2015, p. 4093) also referred to such harmonization efforts in reporting that consolidating the application portfolio was the most important objective in the organization they supervised. In the same vein, Haki et al. (2012, p. 8) and Bricknall et al. (2006, p. 4) put forward the requirement of consolidating and standardizing the application and data landscape. Also, according to Tamm et al. (2015, p. 187), data standardization efforts were addressed as an objective to facilitate efficient data sharing. Bui (2015, pp. 172 & 174) mentioned goals for improving the IT landscape through standardizations in three different businesses. One aimed to standardize the entire IT landscape, the other sought to standardize a unique cloud solution, whereas the last organization aimed to apply standardization to promote reusing existing IT components. The latter is also a goal mentioned by organizations Alwadain et al. (2016, p. 10), Haki et al. (2012, p. 8), Iyamu (2011, p. 84), and Smith et al. (2012, p. 82) observed. Prem et al. (2011, pp. 6 & 8) and Rijo et al. (2015, p. 1218) explicitly highlighted the use of synergies as a cost and complexity reducing aspect. They recognized standardization as an approach to minimizing redundant EA components and, hence, reducing the overall complexity of existing IT landscapes. Iyamu (2011, pp. 85 & 87) was able to show that eliminating redundancies and focusing on only necessary IT functionalities decrease the overall complexity of an organization’s EA, thus eventually improving the overall business efficiency. Moreover, implementing a solid EAM is perceived as an objective to “lower the risk of redundant technology use” (Lux et al., 2010, p. 7), to discover and avoid duplication (Alwadain et al., 2016, p. 7; H. A. Smith et al., 2012, p. 82; H. Smith & Watson, 2015, p. 205), as well as being prepared for future EA component changes (Haki et al., 2012, p. 9).

More operationally, some authors mentioned **increasing overall IT performance** as a goal, especially in solving IT problems and in reacting to system failure rapidly. Smith and Watson (2015, p. 203) noted that EAM should deliver business value by assisting in IT problem solving. Harris (2008, p. 614) found that EAM is expected to increase overall system functionality. Bricknall et al. (2006, p. 9) commented on the objective of increasing IT operations’ availability, stability, and reliability.

The studies presented above provide insight on the expected goals organizations described as ones motivating EAM implementation. Considering everything mentioned so far, one can summarize that in all, these objectives seek to improve organizations' overall business performance by utilizing EAM processes and methods. Collectively, these studies outline a critical role for the support of decision-making in organizations. The centralized gathering and analyzing of information on an organization's EA aims to enable business and IT stakeholders' fact-based decision-making in contrast to ad hoc isolated information analysis and interpretation. Many of the stated objectives rely on trusted, maintained, and precise architectural descriptions and analyses. To underline the importance of decision support, the next sub-section addresses this by an exposition of which decision-making tasks we most often found in companies.

4.2 Decision-Making Tasks Related to EA in Organizations

The summary presented in subchapter 4.1, giving the goals organizations have in implementing EAM, has shown that supporting decision-making on EAs is a crucial function in institutions. In what follows, we will take a closer look at the decision-making tasks the companies we examined mentioned. The results not only help us understand what kind of decisions EAM should support, but also explain why these decisions are relevant in organizations. In total, 22 companies mentioned decision-making tasks that EAM should support. We aggregated these tasks into three subclasses that are shown in Table II-5.

Table II-5. Overview of identified decision-making tasks

Define rules	Aier et al. (2011, p. 643), Alwadain et al. (2016, p. 8), Andersen et al. (2015, p. 4092), Haki et al. (2012, p. 9), Iyamu (2011, p. 84f), Kluge et al. (2006, p. 4), Martin (2012, p. 142), Prem et al. (2011, p. 6), Smith et al. (2012, p. 78), Smith and Watson (2015, p. 198), Tamm et al. (2015, p. 185f), Wang and Zhao (2009, p. 228)
Check compliance	Aier et al. (2011, p. 643), Andersen et al. (2015, p. 4093f), Bricknall et al. (2006, p. 10), Iyamu (2011, p. 85), Kluge et al. (2006, p. 5), Lux et al. (2010, p. 6f), Martin (2012, p. 142), Smith et al. (2012, pp. 78f & 82), Smith and Watson (2015, pp. 197 & 199), Tamm et al. (2015, p. 184f), Wang and Zhao (2009, p. 229), Winter & Schelp (2008, p. 551)
Approve EAs	Blomqvist et al. (2015, p. 46), Kluge et al. (2006, p. 5), Martin (2012, p. 142), Smith and Watson (2015, pp. 197 & 200), Tamm et al. (2015, pp. 182 & 184)

A core competence associated with EAM is the **definition of rules,** respectively of the boundary condition, of its EAs. These boundary conditions are usually defined in the form of technological standards and architectural principles. Whereas standards entail concrete instructions of action, e.g. the use of a specific tool in a predefined context, principles represent holistic high-level guidelines, e.g. "how companies want to operate their business and how their resources should interact or be deployed" (Ahlemann et al., 2012, p. 69). Defining such rules is a decision-making task. The outcome supports future decision-making tasks. Unsurprisingly, our literature analysis revealed that many authors identified the need to take decisions regarding rules which vary in terms of scope and characteristics. Smith and Watson (2015, p. 198) noted that principles were defined by the CIO and his team to minimize architectural silos and improve reusage of existing technical solutions. Andersen et al. (2015, p. 4092) found that the head of the IT development established and followed principles without notifying the top management. Tamm et al. (2015, p. 185f) mentioned the application of principles to support the planned business transformation. These principles were decided by an EA team and should ease future decision-making about application, information, and infrastructure decisions (Tamm et al., 2015, p. 186). In addition, Martin (2012, p. 142) noted that an architecture review body is responsible for developing EA standards and policies on a strategic level. Without knowing exactly who decided on principles, Iyamu (2011, p. 84) found that each domain of the organization he supervised followed principles that aim to meet the overall organizational objectives. Further, they were used as evaluation criteria for future EA decision-making. Wang and Zhao (2009, p. 228) stated that their observed organization used clear principles to drive the technological landscape toward a target state. Drawing on the concept of organizational rules, Haki et al. (2012, p. 9) listed several areas of EA standards that guide the organization, e.g. application standards, technological standards, infrastructure standards, as well as data standards. Moreover, Prem et al. (2011, p. 6) mentioned the development of a book of all standards. In contrast to Haki et al. (2012, p. 9) and Prem et al. (2011, p. 6), Smith et al. (2012, p. 78) explicitly explained that an architecture review board should be the main decision-making authority encompassing senior architects from business departments and their company's lead architects. This board is responsible for defining and approving standards that aim to guide the future development of the observed organization. Kluge et al. (2006, p. 4) and Aier et al. (2011, p. 643) observed that guidelines, recommendations, and quality gate criteria are defined to support future decision-making. Some authors further mention that a board reviews new or changed rules annually or on an ad hoc basis. For instance, Tamm et al. (2015, p. 184) suggested a so-called EA standards council as the authority to create, disseminate, and review principles and guidelines. Alwadain et al. (2016, p. 8) and Aier et al. (2011, p. 643) identified an architectural board which evaluates and decides about new or to-be-removed rules, as well as regularly evaluating existing rules.

The above-mentioned rules are considered differently in decision-making processes and are dependent on the overall goal of the EAM initiative (see sub-section 4.1 for an overview). However, **checking the architectural compliance** of projects, demands, and ideas is a major decision-making task organization undertake. For instance, Wang and Zhao (2009, p. 229) found that in one organization a project steering board assessed IT projects by regarding their conformity with EA rules, even though the members of this board did not have a veto right in cases that violated guidelines. In addition, this board assessed the cost, benefits, and risks of projects and supported the strategic prioritization of these projects. An architecture review body that Martin (2012, p. 142) examined, was responsible for reviewing project proposals and confirming compliance with standards and policies. According to Smith and Watson (2015, p. 197), enterprise architects helped projects adhere to architectural rules. They also confirmed compliance with the rules. Further, the chief enterprise architect, as well as senior IT and business leaders of the investigated organization acted as quality gatekeepers by reviewing and deciding on the compliance conformation again (H. Smith & Watson, 2015, p. 199). Tamm et al. (2015, p. 185) indicated that the EA manager consults projects directly and evaluates their compliance with EA rules. Smith et al. (2012, pp. 78f & 82) examined how the architectural governance tracks implementation projects, supports project managers, and evaluates and regularly enforces EA rules. Unlike Tamm et al, Bricknall et al. (2006, p. 10) examined an implemented architecture board that reviewed projects. Similarly, other authors report projects that were evaluated with regard to EA compliance as Iyamu (2011, p. 85), Lux et al. (2010, p. 6f), Wang and Zhao (2009, p. 229), and Aier et al. (2011, p. 643) mentioned. In addition, Kluge et al. (2006, p. 5) found a mandatory assessment process in two organizations that reviews the architectural consequences after implementing a planned IT solution. Also, a corporate steering committee decides about the final organizational project portfolio, change requests affecting the current EA, as well as the final review of projects. Smith et al. (2012, p. 79) have reported a broader perspective, noting that all technologies and applications are regularly reviewed in light of EA rules. Decision-makers can also conclude that violating one or more EA rules will be tolerated. Martin (2012, p. 142) points out the possibility of reviewing and approving exceptions to EA rules. In accordance to Tamm et al. (2015, p. 184), a project architecture review group can "authorize any requests for project level deviations from these [EA] guidelines" (Tamm et al., 2015, p. 184). As Andersen et al. (2015, p. 4094) point out, the decision-making task regarding project conformity with EA can also lead to the conclusion that two or more different solutions can be possible.

Enterprise architects are involved in **approving EAs** to ensure long-term architecture planning. To achieve this, previously presented EA rules and business strategies have to be considered in the development of a target state architecture. In this regard, Blomqvist et al. (2015, p. 46) identified three strategic processes that develop future states of the organization: group strategy processes, annual planning processes, and development planning processes. In one organization Tamm et al. (2015, pp. 182 & 184) noted a change in decision-making rights which promoted all decisions related to application and IT services to a centralized EA team. Moreover, this team defines the overall vision for an envisaged EA. In a company observed by Smith and Watson (2015, pp. 197 & 200) a team consisting of architects in the technical domain decide on a roadmap for managing infrastructure projects “that address current and potential key business EA drivers” (H. Smith & Watson, 2015, p. 200). In contrast, Martin (2012, p. 142) found in one case that even if a target EA has successfully been decided, its implementation is not guaranteed.

4.3 Employed EA Artefacts in Organizations

Various artefacts are produced or used in decision-making processes. EAs are time-dependent and intend to describe current and multiple future state EAs (ISO/IEC/IEEE 42010:2011(E), 2011; R. Winter & Fischer, 2007, p. 2). The results of our literature review suggest that a vast majority of considered EA artefacts in practice are models that conceptually define the characteristics and interdependencies of EAs. Besides, general requirements and constraints in the form of EA principles and standards are defined by EAM processes. In total, 34 companies mentioned in our data referred to EA artefacts. We aggregated these artefacts into two subclasses that are shown in Table II-6. In what follows, we will briefly summarize the identified EA artefacts in practice.

Table II-6. Overview of identified EA artefacts

EA blueprints	Aier et al. (2011, p. 643), Alwadain et al. (2016, pp. 7–10), Bricknall et al. (2006, p. 8), Bui (2015, p. 174), Haki et al. (2012, pp. 7–9), Harris (2008, pp. 611–613), Hjort-Madsen (2006, pp. 4 & 7f), Iyamu (2011, p. 86), Kluge et al. (2006, p. 4), Marques et al. (2011, p. 937), Niemi and Pekkola (2013, p. 58), Rijo et al. (2015, p. 1219), Seppanen et al. (2009, p. 119), Smith et al. (2012, pp. 77 & 82), Smith and Watson (2015, pp. 195 & 200), Tamm et al. (2015, p. 185f),Wang and Zhao (2009, p. 228)
EA requirements and constraints	Aier et al. (2011, p. 643), Alwadain et al. (2016, p. 7), Bui (2015, p. 172), Fallmyr and Bygstad (2014, p. 3793), Haki et al. (2012, p. 9), Harris (2008, p. 613), Iyamu (2011, pp. 84 & 86), Kluge et al. (2006, p. 4), Lux et al. (2010, p. 6), Marques et al. (2011, p. 937f), Martin (2012, p. 142), Prem et al. (2011, p. 7), Smith et al. (2012, p. 78), Wang and Zhao (2009, p. 228)

The conceptual high-level description of EAs is variously labeled as an **EA blueprint** (Alwadain et al., 2016, p. 7; H. A. Smith et al., 2012, p. 82), EA landscape (e.g. Lux et al., 2010, p. 7), EA documentation (e.g. Alwadain et al., 2016, p. 7), EA models (e.g. Haki et al., 2012, p. 8), reference architecture (e.g. Bui, 2015, p. 174), or as-is and to-be architecture (e.g. Kluge et al., 2006, p. 4). In this paper we will consistently stick to the term EA blueprint. EA blueprints are used to describe not only the current but also multiple future states of EAs. As-is EA blueprints aim to depict the current characteristics of an organizational EA, whereas to-be EA blueprints are linked to organizational strategy and describe a vision to which a current EA should be developed (Ahlemann et al., 2012, p. 128; Seppanen et al., 2009, p. 119). Such EA blueprints are considered for planning, governance, decision-making, standardization, and EA assessment processes (Alwadain et al., 2016, p. 7; Prem et al., 2011, p. 10).

Following the considered definition of EA in this thesis, EAs generally describe all aspects of an organization and its relationships. Iyamu (2011) underscores this view giving results from an examined organization, which tend to "define and categorize all information within the organization" (Iyamu, 2011, p. 84). Marques et al. (2011, p. 937) restricted the view of an EA to the point of only modelling core information entities. Smith et al. (2012, p. 82) and Harris (2008, p. 611) were able to show that the organization they observed aims to integrate their views on, e.g., business, applications, data, and technological infrastructure into a single comprehensive EA blueprint. Alwadain et al. (2016, pp. 7 & 8) found a way to collate the EA information related to strategy, business, information system, and technical infrastructure in a unified EA repository. Haki et al. (2012, p. 8) described a similar case, but added the applied framework and the used meta-model to the EA blueprint. At least in one organization, the authors Marques et al. (2011, p. 937) could report the integration of outside relationships including the physical locations in EA blueprints. As Harris (2008, p. 613) suggested, designing a catalog of business terms and relevant definitions should also be included in developing EA blueprints.

EA blueprints are also often applied to describe specific layers of EAs. For instance, Aier et al. (2011, p. 643), Haki et al. (2012, p. 7), and Smith and Watson (2015, p. 200) observed organizations that defined EA blueprints for business, application, software, information, technical matters, and policy architectures. More specifically, Bui (2015, p. 174) reported on very concrete EA blueprints such as "identity and access management, business intelligence, master data management, service-oriented architecture, enterprise application integration, enterprise content management and e-Governance" (Bui, 2015, p. 174). Others, like Hjort-Madsen (2006, p. 8), emphasized the need for modeling the data layer to standardize the language about data in an organization. Similarly, Iyamu (2011, p. 86) noted the importance of focusing on the information flow in an EA blueprint development process. Tamm et al. (2015, p. 185) mentioned the development of an EA blueprint describing a software platform. Harris (2008, p. 613) provided insight on an organization that included their perspective on the application and technological infrastructure in order to integrate both perspectives.

An organization observed by Bricknall et al. (2006, p. 8) took a different approach to documenting the EA blueprint. The business experts visualized their EA as a city in which colored districts represent products (business architecture), buildings represent applications (application architecture), and colored arrows represent information flow (data architecture). In the same vein, Smith et al. (2012, p. 82) report on the development of a city plan which describes the application architecture. These applications are linked to city blocks that represent business capabilities. Both approaches aim to provide an easy-to-understand language for stakeholders.

According to business experts, designing EA blueprints depends on the availability and quality of data. Although data sources are critical to developing EA blueprints, gathering high quality data seems to be demanding (Niemi & Pekkola, 2013, p. 58). Seppanen et al. (2009, p. 119) mentioned that when information regarding the current EA was missing, the experts struggled to design an adequate as-is EA blueprint. Also, their colleagues mentioned that new data sources frequently and unexpectedly emerged, which negatively impacted the overall EA project. Bricknall et al. (2006, p. 8) observed a company in which EA data relied completely on IT-related information. In this case, the data lacked a business perspective on the EA. Bui (2015, p. 174) examined employees' consideration of annual reviews, including all pros and cons of such a data gathering approach.

All authors whose work we have considered in this literature review reported on the development of current or as-is EA blueprints, and many reported on target design, or, to-be EA blueprints. A special form of EA blueprints are so-called roadmaps. According to Kluge et al. (2006, p. 4), organizations apply roadmaps to describe the way in which a particular organization can transform itself from a current to a future state EA. Roadmaps are also used to describe various strategic development opportunities (Kluge et al., 2006, p. 4). Further, comparing the two kinds of EA blueprints enabled organizations to perform several analysis tasks, e.g., they could identify gaps between the current and planned EA (Alwadain et al., 2016, p. 7), as well as review performance, reliability, security, and integrity (Wang & Zhao, 2009, p. 228), to focus on organizational objectives like service orientation (Fallmyr & Bygstad, 2014, p. 3793). As Smith et al. (2012, p. 77) reported, organizations also applied roadmaps to harmonize existing technological infrastructure. In addition, Smith et al. (2012, p. 77) mentioned an application rationalization roadmap used to identify applications that could be either retired or outsourced. Yet another observer organization was shown to define roadmaps in identifying the characteristics of planned application integration (Marques et al., 2011, p. 938). Some organizations further defined a process to ensure the deployment of roadmaps. Tamm et al. (2015, p. 186), illustratively referred to the organization they investigated showing how they first defined the required information and then rolled out the system according to the predefined main functional areas of sales forecasting, pricing and promotions, store replenishment, and warehouse replenishment. Smith and Watson (2015, p. 200) added that roadmaps served as a key element to assess research and development processes in their observed organization. Based on the roadmap, prototypes were developed that supported the implementation of the roadmap to achieve the to-be EA blueprint.

In practice, to model EA blueprints, several tools are in use such as ARIS IT architect (Lux et al., 2010, p. 6), Microsoft Visio (Marques et al., 2011, p. 938), ArchiMate (Rijo et al., 2015, p. 1220), and IBM System Architect (Alwadain et al., 2016, p. 7). Such EA blueprints are published, e.g., on the organization's intranet (Aier, Fischer, et al., 2011, p. 643; Kluge et al., 2006, p. 4) or in a specialized tool available for employees in dedicated areas (Alwadain et al., 2016, p. 8).

Clearly defined **EA requirements and constraints** provide transparent and comprehensive overviews of an organization's current and future general condition. According to Iyamu (2011, p. 84), these requirements can be expressed in the form of principles, standards, policies, and procedures. Defining principles and standards are sometimes considered as the main EAM task (Haki et al., 2012, p. 9). Wang and Zhao (2009, p. 228) highlight the need for documenting technical EA requirements and constraints in detail. Marques et al. (2011, p. 938) added that the organization they observed established not only technical requirements, but also development guidelines . Alwadain et al. (2016, p. 7) and Iyamu (2011, p. 86) mentioned the need for storing and providing access to business requirements as well. Moreover, Kluge et al. (2006, p. 4), Lux et al. (2010, p. 6), Martin (2012, p. 142), and Smith et al. (2012, p. 78) reported on one organization documenting guidelines and recommendations to enable project compliance assessments. Requirements can act as quality gatekeepers to ensure the agreed EA conditions are fulfilled (Aier, Fischer, et al., 2011, p. 643). An organization observed by Bui (2015, p. 172) applied such requirements to support the selection of cloud-based solutions.

Similar to EA blueprints, the EA principles and standards are frequently published on organizations' intranet (Aier, Fischer, et al., 2011, p. 643) or in a standardized form, e.g., a book of criteria (Prem et al., 2011, p. 7) to enable internal use.

Our results did not focus on how to visualize the particular EA artefacts. In fact, we could not determine detailed information on implemented EA visualizations therefore it does not show in our results. However, Roth et al. (2014) created a comprehensive overview of employed EA visualizations in practice in the "Enterprise Architecture Tool survey 2014." In this survey, Roth and colleagues assessed the features of 18 EA tool suppliers and asked 109 EA experts which of these visualization features were being used in practice, and for which purpose. This resulted in Roth et al. (2014) identifying and describing 26 EA artefacts used by EA personnel. They identified the following visualization types: matrixes/tables, cluster maps, timelines, flow diagrams, lists, graphs, ER diagrams, bar charts, BPMN models, UML models, bubble charts, tree views, pie charts, dashboards, radar charts, EPCs, ArchiMate models, line charts, scatter charts, geographic maps, BM canvases, gauges, tree maps, tag clouds, 3D visualizations, and sunburst charts (Roth et al., 2014, p. 46). Figure II-7 provides an overview of these types of visualizations.

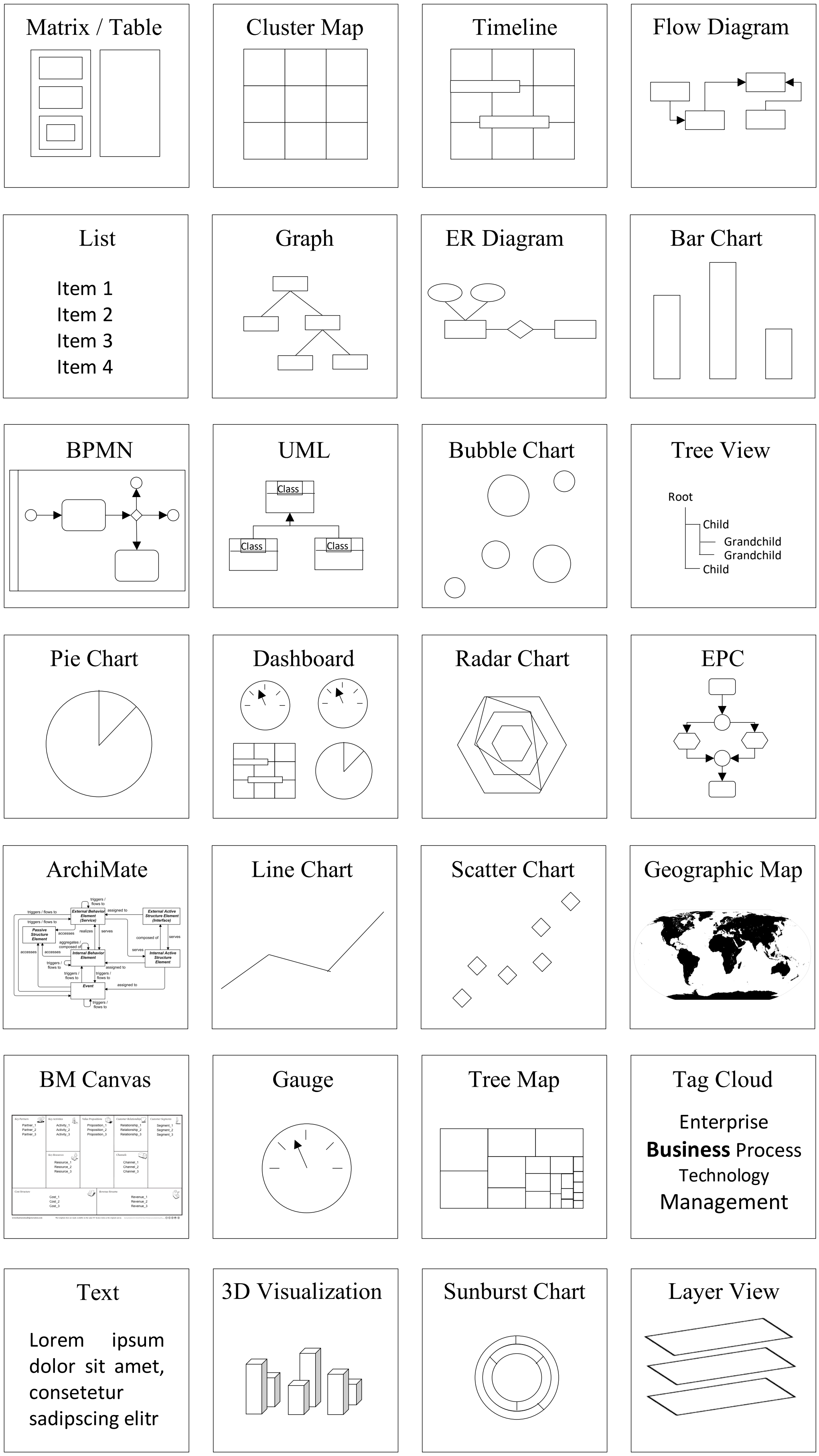


Figure II-7. Common EA visualization types summarized by Roth et al. (2014, p. 46)

5 Proposal of a Conceptual Model

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) (Wenger, 2011). Following Wenger (2011), 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. (2015). 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 (Ahlemann et al., 2012; Aier, Gleichauf, et al., 2011; Simon et al., 2014; Widjaja & Gregory, 2012). They store EA resources and assets in an EA repository (The Open Group, 2011), 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) (Ahlemann et al., 2012). 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) (The Open Group, 2011). Based on the above mentioned key characteristics of COPs, we follow Chatterjee et al.'s (2015) 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.

EAM collaborative affordances

Collaborative IT affordance describes the ability to share, convey, and integrate knowledge together with people through the use of IT (Zammuto, Griffith, Majchrzak, Dougherty, & Faraj, 2007; Chatterjee et al., 2015). This can be achieved between two or more users who are working in the same room or are remotely located (Chatterjee et al., 2015; Zammuto et al., 2007). 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 (Aier, Gleichauf, et al., 2011; Löhe & Legner, 2014). A single EA repository enables an integrated and holistic view on EA data (R. Winter & Fischer, 2007), 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 (Back et al., 2010; Donalek et al., 2014), but depending on their positions (Sherman & Craig, 2002). They provide various three-dimensional interactive and, in the case of VR, immersive (Azuma, 1997) forms of data visualization, such as diagrams (Donalek et al., 2014; Sherman & Craig, 2002), data-driven control panels (Back et al., 2010), or multiple occluded layers (Livingston et al., 2003). 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 (Donalek et al., 2014; Sherman & Craig, 2002) with gestures (McGill et al., 2015). 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 (Chatterjee et al., 2015). Based on (Kane & Alavi, 2007; Chatterjee et al., 2015), 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 (The Open Group, 2011). EA artifacts stored in an EA repository are the result of knowledge creating activities by the COP (Tamm et al., 2011). The simulation ability of MR and VR technologies (Azuma, 1997; Zhou & Deng, 2009) assists stakeholders in creating and storing EA artifacts by naturaly combining views and data with gestures to recognize new insights that were previously unknown (Ahlemann et al., 2012). Stakeholders can also gain new knowledge by accessing and analyzing existing EA artifacts through MR and VR's transformation and refinement ability (Donalek et al., 2014; Sherman & Craig, 2002). The generated knowledge of the EA supports COPs in addressing some common EAM goals, such as identifying areas of action during strategy implementation (Tamm et al., 2011, p. 142), planning business change (Aier, Gleichauf, et al., 2011; Löhe & Legner, 2014), or provide alternative solutions (Ahlemann et al., 2012). 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 (Chatterjee et al., 2015). Following Chatterjee et al. (Chatterjee et al., 2015), 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 (Tamm et al., 2011; R. Winter & Fischer, 2007; Kaisler, Armour, & Valivullah, 2005) which enables, e.g., business impact analyses of planned changes (Löhe & Legner, 2014). 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 (Zhou & Deng, 2009), immersive (Azuma, 1997), and human imagination (Burdea & Coiffet, 2003) 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 (Löhe & Legner, 2014). 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*.

Decision-making quality

EAM supports the process of informed decision-making on EAs (Ahlemann et al., 2012; Tamm et al., 2011) by providing knowledge about the structure and relationship of EA components (ISO/IEC/IEEE 42010:2011(E), 2011; Tamm et al., 2011). EAM affords a variety of analysis methods, like impact evaluation approaches to new projects (Löhe & Legner, 2014), EA component dependency analyses (R. Winter & Fischer, 2007), or inefficiencies identification throughout the organization (Tamm et al., 2011). 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 (van der Raadt, Bonnet, Schouten, & van Vliet, 2010). Consequently, we posit:

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

Initial 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 II-8 presents the corresponding conceptual model.

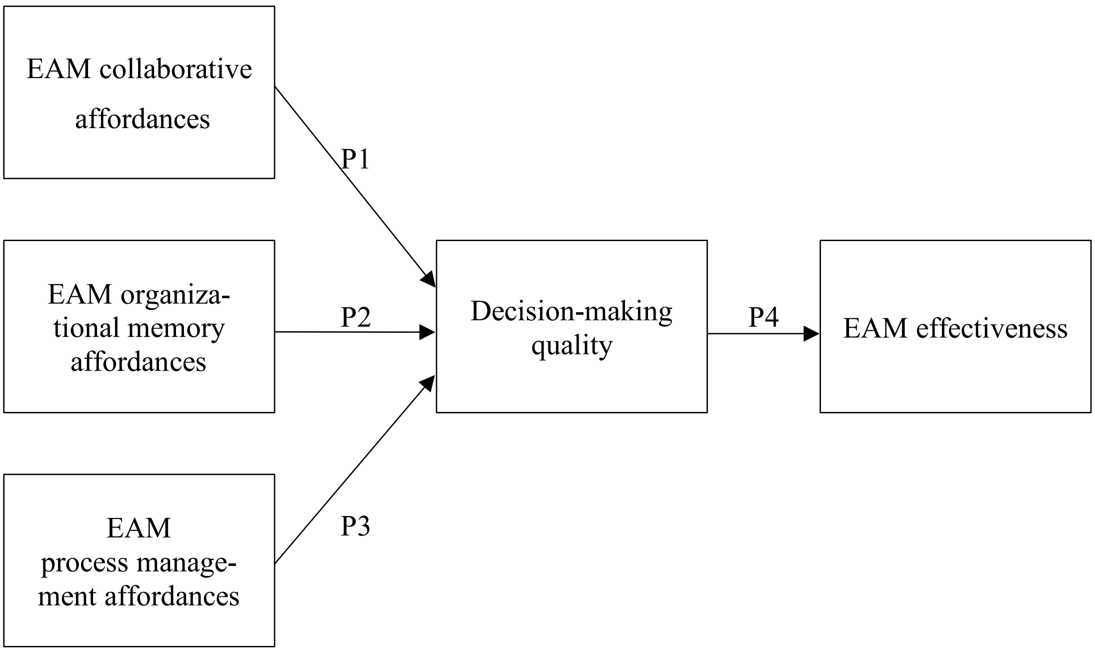


Figure II-8. Overview of the conceptual model

6 Future Research Opportunities and 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. 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 (Ahlemann et al., 2012; Kotusev et al., 2015; Simon et al., 2014; Tamm et al., 2011). Our argumentation relies on practical insights derived from EAM case studies described in IS literature. This approach aimed to gain an in-depth view of implemented EAM functions in real organizations. Based on our results, we provide a research agenda to trigger more research on EA artifacts development and usage in mixed and virtual environments. The research agenda is proposed in Table II-7.

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 (Matthes, Buckl, Leitel, & Schweda, 2008), 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 (Azuma, 1997), which enables interactive collaboration with EA artifacts. Research on VR further shows an increased situation awareness, vividness, and media richness during collaborative tasks (Donalek et al., 2014). Moreover, MR and VR technology processes user inputs through gestures, which allows intuitive interaction with virtual objects (Sherman & Craig, 2002).

It is beyond the scope of this paper to test our conceptual 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 (Azuma, 1997). 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.

Table II-7. 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.

References

Ahlemann, F., Stettiner, E., Messerschmidt, M., & Legner, C. (2012). *Strategic Enterprise Architecture Management: Challenges, Best Practices, and Future Developments*. Berlin ; New York: Springer.

Aier, S., Fischer, C., & Winter, R. (2011). Construction and evaluation of a meta-model for enterprise architecture design principles. *Wirtschaftsinformatik Proceedings 2011*.

Aier, S., Gleichauf, B., & Winter, R. (2011). Understanding Enterprise Architecture Management Design - An Empirical Analysis. *Proceedings of the 10th International Conference on Wirtschaftsinformatik*, 645–654. Zurich, Switzerland.

Alwadain, A., Fielt, E., Korthaus, A., & Rosemann, M. (2016). Empirical insights into the development of a service-oriented enterprise architecture. *Data & Knowledge Engineering*, *105*, 39–52. https://doi.org/10.1016/j.datak.2015.09.004

Andersen, P., Carugati, A., & Sorensen, M. G. (2015, January). *Exploring Enterprise Architecture Evaluation Practices: The Case of a Large University*. 4089–4098. IEEE. https://doi.org/10.1109/HICSS.2015.491

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355–385.

Back, M., Kimber, D., Rieffel, E., Dunnigan, A., Liew, B., Gattepally, S., … Vaughan, J. (2010). The virtual chocolate factory: Building a real world mixed-reality system for industrial collaboration and control. *Multimedia and Expo (ICME), 2010 IEEE International Conference On*, 1160–1165. IEEE.

Biocca, F., & Delaney, B. (1995). Immersive Virtual Reality Technology. In *Communication in the Age of Virtual Reality* (p. 401). Routledge.

Blomqvist, S., Halen, M., & Helenius, M. (2015, July). *Connecting Enterprise Architecture with Strategic Planning Processes: Case Study of a Large Nordic Finance Organization*. 43–50. IEEE. https://doi.org/10.1109/CBI.2015.39

Bricknall, R., Darrell, G., Nilsson, H., & Pessi, K. (2006). *Enterprise architecture: critical factors affecting modelling and management*. Presented at the ECIS 2006 Proceedings.

Buckl, Schweda, C. M., & Matthes, F. (2010). A Design Theory Nexus for Situational Enterprise Architecture Management. *Enterprise Distributed Object Computing Conference Workshops (EDOCW), 2010 14th IEEE International*, 3–8. IEEE. https://doi.org/10.1109/EDOCW.2010.27

Bui, Q. (2015). Increasing the Relevance of Enterprise Architecture through "Crisitunities" in US State Governments. *MIS Quarterly Executive*, *14*(4), 169–179.

Burdea, G. C., & Coiffet, P. (2003). *Virtual reality technology*. John Wiley & Sons.

Chair of Human-Machine Communication. (2020, January 12). Augmented-/Virtual-Reality Lab. Retrieved January 12, 2020, from https://www.ei.tum.de/en/mmk/misc/augmented-virtual-reality-lab/

Chatterjee, S., Moody, G., Lowry, P. B., Chakraborty, S., & Hardin, A. (2015). Strategic Relevance of Organizational Virtues Enabled by Information Technology in Organizational Innovation. *Journal of Management Information Systems*, *32*(3), 158–196. https://doi.org/10.1080/07421222.2015.1099180

Chemero, A. (2003). An outline of a theory of affordances. *Ecological Psychology*, *15*(2), 181–195.

Corbin, J., & Strauss, A. (1990). Grounded theory research: procedures, canons, and evaluative criteria. *Qualitative Sociology*, *13*(1), 3–21.

Donalek, C., Djorgovski, S. G., Cioc, A., Wang, A., Zhang, J., Lawler, E., … Longo, G. (2014). Immersive and collaborative data visualization using virtual reality platforms. *2014 IEEE International Conference on Big Data (Big Data)*, 609–614. https://doi.org/10.1109/BigData.2014.7004282

Fallmyr, T., & Bygstad, B. (2014, January). *Enterprise Architecture Practice and Organizational Agility: An Exploratory Study*. 3788–3797. IEEE. https://doi.org/10.1109/HICSS.2014.471

Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, N.J.: Erlbaum.

Greenhalgh, C., & Benford, S. (1995). MASSIVE: a distributed virtual reality system incorporating spatial trading. *Proceedings of 15th International Conference on Distributed Computing Systems*, 27–34. https://doi.org/10.1109/ICDCS.1995.499999

Haki, M. K., Legner, C., & Ahlemann, F. (2012). BEYOND EA FRAMEWORKS: TOWARDS AN UNDERSTANDING OF THE ADOPTION OF ENTERPRISE ARCHITECTURE MANAGEMENT. *ECIS 2012 Proceedings*.

Hanseth, O., & Lyytinen, K. (2010). Design theory for dynamic complexity in information infrastructures: the case of building internet. *Journal of Information Technology*, *25*(1), 1–19.

Harris, P. T. (2008). Enterprise architecture and its role in solving business issues: Case study of the NSW department of lands. *Computer and Information Technology Workshops, 2008. CIT Workshops 2008. IEEE 8th International Conference On*, 607–615.

Hauder, M., Roth, S., Schulz, C., & Matthes, F. (2013). *An Examination Of Organizational Factors Influencing Enterprise Architecture Management Challenges.* 175.

Hjort-Madsen, K. (2006, January 4). *Enterprise Architecture Implementation and Management: A Case Study on Interoperability*. Presented at the Proceedings of the 39th Hawaii International Conference on System Sciences.

ISO/IEC/IEEE 42010:2011(E). (2011). *Systems and software engineering - Architecture description*.

Iyamu, T. (2011, September). *Enterprise Architecture as Information Technology Strategy*. 82–88. IEEE. https://doi.org/10.1109/CEC.2011.33

Kaisler, S. H., Armour, F., & Valivullah, M. (2005). Enterprise Architecting: Critical Problems. *Proceedings of the 38th Annual Hawaii International Conference on System Sciences, 2005. HICSS '05*, 224b–224b. https://doi.org/10.1109/HICSS.2005.241

Kane, G. C., & Alavi, M. (2007). Information Technology and Organizational Learning: An Investigation of Exploration and Exploitation Processes. *Organization Science*, *18*(5), 796–812. https://doi.org/10.1287/orsc.1070.0286

Kinateder, M., Gualtieri, J., Dunn, M. J., Jarosz, W., Yang, X.-D., & Cooper, E. A. (2018). Using an augmented reality device as a distance-based vision aid—promise and limitations. *Optometry and Vision Science*, *95*(9), 727.

Kluge, C., Dietzsch, A., & Rosemann, M. (2006, June 12). *How to realise corporate value from Enterprise Architecture*. Presented at the ECIS 2006 Proceedings.

Korhonen, J. J., Hiekkanen, K., & Lähteenmäki, J. (2009). EA and IT governance- A systemic approach. *European Conference on Leadership, Management and Governance*.

Kotusev, S., Singh, M., & Storey, I. (2015). Investigating the Usage of Enterprise Architecture Artifacts. *ECIS 2015 Research-in-Progress Papers*.

Lee, S. H., Kim, M., Kim, H., & Park, C. Y. (2020). Relationship between Ocular Fatigue and Use of a Virtual Reality Device. *Jkos*, *61*(2), 125–137. https://doi.org/10.3341/jkos.2020.61.2.125

Levy, Y., & Ellis, T. J. (2006). A Systems Approach to Conduct an Effective Literature Review in Support of Information Systems Research. *Informing Science*, *9*.

Livingston, M. A., Swan II, J. E., Gabbard, J. L., Höllerer, T. H., Hix, D., Julier, S. J., … Brown, D. (2003). Resolving multiple occluded layers in augmented reality. *Proceedings of the 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality*, 56. IEEE Computer Society.

Löhe, J., & Legner, C. (2014). Overcoming implementation challenges in enterprise architecture management: a design theory for architecture-driven IT Management (ADRIMA). *Information Systems and E-Business Management*, *12*(1), 101–137. https://doi.org/10.1007/s10257-012-0211-y

Lušić, M., Fischer, C., Bönig, J., Hornfeck, R., & Franke, J. (2016). Worker information systems: state of the art and guideline for selection under consideration of company specific boundary conditions. *Procedia CIRP*, *41*, 1113–1118.

Lux, J., Riempp, G., & Urbach, N. (2010). Understanding the performance impact of enterprise architecture management. *Proceedings of the 16th Americas Conference on Information Systems (AMCIS 2010)*. Presented at the Lima, Peru. Lima, Peru.

Markus, M. L., & Silver, M. S. (2008). A Foundation for the Study of IT Effects: A New Look at DeSanctis and Poole's Concepts of Structural Features and Spirit. *Journal of the Association for Information Systems*, *9*, 609–632.

Marques, A. F., Borges, J. G., Sousa, P., & Pinho, A. M. (2011). An enterprise architecture approach to forest management support systems design: an application to pulpwood supply management in Portugal. *European Journal of Forest Research*, *130*(6), 935–948. https://doi.org/10.1007/s10342-011-0482-8

Martin, A. (2012). Enterprise IT Architecture in Large Federated Organizations: The Art of the Possible. *Information Systems Management*, *29*(2), 137–147. https://doi.org/10.1080/10580530.2012.662103

Matthes, F., Buckl, S., Leitel, J., & Schweda, C. M. (2008). *Enterprise Architecture Management Tool Survey 2008*. München: TU München, Chair for Informatics 19, Prof. Matthes (sebis).

McGill, M., Boland, D., Murray-Smith, R., & Brewster, S. (2015). A dose of reality: Overcoming usability challenges in vr head-mounted displays. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2143–2152. ACM.

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies*, *2351*(11), 282–292.

Niemi, E., & Pekkola, S. (2013, January). *Enterprise Architecture Quality Attributes: A Case Study*. 3878–3887. IEEE. https://doi.org/10.1109/HICSS.2013.201

Ohta, Y., & Tamura, H. (1999). *Mixed Reality: Mergin Real and Virtual Worlds*. Springer Berlin Heidelberg.

Pozzi, G., Pigni, F., & Vitari, C. (2014). Affordance theory in the IS discipline: A review and synthesis of the literature. *AMCIS 2014 Proceedings*.

Prem, I., Monahov, I., Buckl, S., & Matthes, F. (2011). *APPLYING THE CONCEPT OF BUILDING BLOCKS FOR ENTERPRISE ARCHITECTURE MANAGEMENT SOLUTIONS IN PRACTICE*. Presented at the MCIS 2011 Proceedings.

Rahimi, F., Gøtze, J., & Møller, C. (2017). Enterprise Architecture Management: Toward a Taxonomy of Applications. *Communications of the Association for Information Systems*, *40*(1).

Rijo, R., Martinho, R., & Ermida, D. (2015). Developing an Enterprise Architecture Proof of Concept in a Portuguese Hospital. *Procedia Computer Science*, *64*, 1217–1225. https://doi.org/10.1016/j.procs.2015.08.511

Ross, J. W., Weill, P., & Robertson, D. C. (2006). *Enterprise architecture as strategy: Creating a foundation for business execution*. Boston, Massachusetts, USA: Harvard Business School Press.

Roth, S., Zec, M., & Matthes, F. (2014). *Enterprise Architecture Visualization Tool Survey 2014*. Germany: epubli GmbH.

Rouhani, B. D., Mahrin, M. N., Shirazi, H., Nikpay, F., & Rouhani, B. D. (2015). An Effectiveness Model for Enterprise Architecture Methodologies: *International Journal of*

Enterprise Information Systems, *11*(2), 50–64. https://doi.org/10.4018/IJEIS.2015040103

Seppanen, V., Heikkila, J., & Liimatainen, K. (2009). Key issues in EA-implementation: Case study of two Finnish government agencies. *Proceedings of the IEEE Conference on Commerce and Enterprise Computing (CEC 2009)*. Presented at the Vienna, Austria. Vienna, Austria.

Sherman, W. R., & Craig, A. B. (2002). *Understanding Virtual Reality: Interface, Application, and Design*. Elsevier Science.

Simon, D., Fischbach, K., & Schoder, D. (2014). Enterprise architecture management and its role in corporate strategic management. *Information Systems and E-Business Management*, *12*(1), 5–42. https://doi.org/10.1007/s10257-013-0213-4

Smith, H. A., Watson, R. T., & Sullivan, P. (2012). Delivering an Effective Enterprise Architecture at Chubb Insurance. *MIS Quarterly Executive*, *11*(2).

Smith, H., & Watson, R. (2015). The Jewel in the Crown–Enterprise Architecture at Chubb. *MIS Quarterly Executive*, *14*(4), 195–209.

Stahl, I. (2015, June 29). Augmented Virtuality an der THI. Retrieved October 27, 2019, from Augmented Virtuality an der THI website: https://uxd.thi.de/blog/2015/06/29/augmented-virtuality-an-der-thi/

Stendal, K., Thapa, D., & Lanamaki, A. (2016, January). *Analyzing the Concept of Affordances in Information Systems*. 5270–5277. IEEE. https://doi.org/10.1109/HICSS.2016.651

Tamm, T., Seddon, P. B., Shanks, G., & Reynolds, P. (2011). How does enterprise architecture add value to organisations. *Communications of the Association for Information Systems*, *28*(1), 141–168.

Tamm, T., Seddon, P. B., Shanks, G., Reynolds, P., & Frampton, K. M. (2015). How an Australian Retailer Enabled Business Transformation Through Enterprise Architecture. *MIS Quarterly Executive*, *14*(4), 181–193.

The Open Group. (2011). TOGAF® 9.1. Retrieved September 15, 2017, from http://pubs.opengroup.org/architecture/togaf9-doc/arch/

van der Raadt, B., Bonnet, M., Schouten, S., & van Vliet, H. (2010). The relation between EA effectiveness and stakeholder satisfaction. *Journal of Systems and Software*, *83*(10), 1954–1969. https://doi.org/10.1016/j.jss.2010.05.076

vom Brocke, J., Simons, A., Riemer, K., Niehaves, B., Plattfaut, R., & Cleven, A. (2015). Standing on the Shoulders of Giants: Challenges and Recommendations of Literature Search in Information Systems Research. *Communications of the Association for Information Systems*, *37*(1).

Walsh, K. R., & Pawlowski, S. D. (2002). Virtual Reality: A Technology in Need of IS Research. *Communications of the Association for Information Systems*, *8*(1).

Wang, X., & Zhao, Y. (2009). An enterprise architecture development method in chinese manufacturing industry. *Hybrid Intelligent Systems, 2009. HIS'09. Ninth International Conference On*, *3*, 226–230.

Wenger, E. (2011). *Communities of practice: A brief introduction*.

Widjaja, T., & Gregory, R. (2012). Design Principles for Heterogeneity Decisions in Enterprise Architecture Management. *ICIS 2012 Proceedings*.

Winter, K., Buckl, S., Matthes, F., & Schweda, C. M. (2010). *Investigating the state-of-the-art in enterprise architecture management methods in literature and practice*.

Winter, R., & Fischer, R. (2007). Essential layers, artifacts, and dependencies of enterprise architecture. *Journal of Enterprise Architecture*, *3*(2), 7–18.

Winter, R., Legner, C., & Fischbach, K. (2014). Introduction to the special issue on enterprise architecture management. *Information Systems and E-Business Management*, *12*(1), 1–4. https://doi.org/10.1007/s10257-013-0221-4

Winter, R., & Schelp, J. (2008). *Enterprise architecture governance: the need for a business-to-IT approach*. Presented at the 23rd Annual ACM Symposium on Applied Computing.

Zammuto, R. F., Griffith, T. L., Majchrzak, A., Dougherty, D. J., & Faraj, S. (2007). Information Technology and the Changing Fabric of Organization. *Organization Science*, *18*(5), 749–762.

Zhou, N.-N., & Deng, Y.-L. (2009). Virtual reality: A state-of-the-art survey. *International Journal of Automation and Computing*, *6*(4), 319–325. https://doi.org/10.1007/s11633-009-0319-9

Appendix

Appendix II-1. Detailed Results of Literature Review

State of the art about Enterprise Architecture and Enterprise Architecture Management in academic literature (2006 - 2016)

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
1	IEEE Xplore	A new operations model of logistics service providers: Evidence from EACompany	no	n/a	no	no	no
2	IEEE Xplore	A Modeling and Evaluation Method of COA Effectiveness Based on EA	no	n/a	no	no	no
3	IEEE Xplore	EA As a Tool in Change and Coherency Management - A Case of a Local Government	yes	yes	no	no	no
4	IEEE Xplore	EA-Analyzer: Automating Conflict Detection in Aspect-Oriented Requirements	no	n/a	no	no	no
5	IEEE Xplore	Key Issues in EA-Implementation: Case Study of Two Finnish Government Agencies	yes	yes	no	yes	yes
6	IEEE Xplore	Integration and Implementation of an EA strategy based operating model with BPM technology - Case Study: Housing credit process, Banco Estado Ecuador	yes	no	no	no	no
7	IEEE Xplore	Type-Safety in EA Model Analysis	no	n/a	no	no	no
8	IEEE Xplore	The study of activation energy(Ea) by aging and high temperature storage for quartz resonator's life evaluation	no	n/a	no	no	no
9	IEEE Xplore	Rule-Based Architectural Compliance Checks for Enterprise ArchitectureManagement	yes	no	no	no	no
10	IEEE Xplore	Enterprise Architecture Content Model Applied to ComplexityManagement While Delivering IT Services	yes	no	no	no	no
11	IEEE Xplore	An Access Control Model for Organisational Management in EnterpriseArchitecture	yes	no	no	no	no
12	IEEE Xplore	Systemic Management of Architectural Decisions in EnterpriseArchitecture Planning. Four Dimensions and Three Abstraction Levels	yes	no	no	no	no
13	IEEE Xplore	Enterprise Architecture Implementation and Management: A Case Studyon Interoperability	yes	yes	no	yes	yes
14	IEEE Xplore	Enterprise Architecture Descriptions for Enhancing Local Government Transformation and Coherency Management: Case Study	yes	yes	no	no	no
15	IEEE Xplore	An Enterprise Architecture Development Method in Chinese Manufacturing Industry	yes	yes	no	yes	yes
16	IEEE Xplore	How Does Enterprise Architecture Support Innovation?	no	n/a	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
17	IEEE Xplore	Enterprise information security architecture a review of frameworks, methodology, and case studies	no	n/a	no	no	no
18	IEEE Xplore	An Executable Model Driven Framework for Enterprise ArchitectureApplication to the Smart Grids Context	yes	no	no	no	no
19	IEEE Xplore	Design of information architecture with Enterprise Ontology approach: Acase study in West Java Educational Quality Assurance Institution	no	n/a	no	no	no
20	IEEE Xplore	Exploring Intentional Modeling and Analysis for Enterprise Architecture	yes	yes	no	no	no
21	IEEE Xplore	A Conceptual Model for Compliance Checking Support of EnterpriseArchitecture Decisions	yes	no	no	no	no
22	IEEE Xplore	Adding a Human Perspective to Enterprise Architectures	yes	no	no	no	no
23	IEEE Xplore	A Modular Ontology for the Enterprise Architecture Domain	no	n/a	no	no	no
24	IEEE Xplore	A model for enterprise architecture scenario analysis based on fuzzy cognitive maps and OWA operators	no	n/a	no	no	no
25	IEEE Xplore	Incorporating Directives into Enterprise TO-BE Architecture	no	n/a	no	no	no
26	IEEE Xplore	Notice of Retraction Design portal Enterprise services using Enterprise architecturemethodology (case study : Portal Kermanshah University of Medical Sciences)	no	n/a	no	no	no
27	IEEE Xplore	Employing Zachman Enterprise Architecture Framework to Systematically Perform Model-Based System Engineering Activities	yes	no	no	no	no
28	IEEE Xplore	The Integrated Enterprise: Enterprise Architecture, Investment Process and System Development	yes	yes	no	no	no
29	IEEE Xplore	Semantic derivation of Enterprise Information Architecture from Business Process Architecture	no	n/a	no	no	no
30	IEEE Xplore	Enterprise Architecture Intelligence: Combining Enterprise Architectureand Operational Data	yes	no	no	no	no
31	IEEE Xplore	Validating enterprise architecture using ontology-based approach: A case study of student internship programme	yes	no	no	no	no
32	IEEE Xplore	A Decision-Oriented Approach Supporting Enterprise ArchitectureEvolution	no	n/a	no	no	no
33	IEEE Xplore	Agent-based enterprise information architecture with a 3PLcase study	no	n/a	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
34	IEEE Xplore	Systemic Management of Architectural Decisions in EnterpriseArchitecture Planning. Four Dimensions and Three Abstraction Levels	n/a	n/a	yes	no	no
35	IEEE Xplore	Enterprise Information Architecture (EIA): Assessment of Current Practices in Malaysian Organizations	yes	yes	no	no	no
36	IEEE Xplore	Enterprise Architecture and Web Services	yes	no	no	no	no
37	IEEE Xplore	Enterprise Architecture Practice and Organizational Agility: An Exploratory Study	yes	yes	no	yes	yes
38	IEEE Xplore	A new AHP-based approach towards Enterprise Architecture quality attribute analysis	yes	no	no	no	no
39	IEEE Xplore	The application of enterprise architecture approach to military concept development-Case study	yes	yes	no	no	no
40	IEEE Xplore	Enterprise architecture modeling with SoaML using BMM and BPMN - MDA approach in practice	yes	no	no	no	no
41	IEEE Xplore	Formalizing Enterprise Architecture Decision Models Using Integrity Constraints	yes	no	no	no	no
42	IEEE Xplore	Strategic Business and IT Alignment Assessment: A Case Study Applying an Enterprise Architecture-Based Metamodel	yes	yes	no	no	no
43	IEEE Xplore	The Impact of managerial Enterprise Architecture decisions on software development employees	yes	yes	no	no	no
44	IEEE Xplore	Enterprise Architecture Content Model Applied to Complexity Management While Delivering IT Services	n/a	n/a	yes	no	no
45	IEEE Xplore	Healthcare Modelling through Enterprise Architecture: A Hospital Case	yes	no	no	no	no
46	IEEE Xplore	Enterprise Architecture in the Supply Chain	yes	yes	no	no	no
47	IEEE Xplore	Using Enterprise Architecture Models for System Quality Analysis	yes	no	no	no	no
48	IEEE Xplore	Enterprise Architecture Analysis for Data Accuracy Assessments	yes	no	no	no	no
49	IEEE Xplore	Rule-Based Architectural Compliance Checks for Enterprise ArchitectureManagement	n/a	n/a	yes	no	no
50	IEEE Xplore	Addressing Crosscutting Concerns in Enterprise Architecture	yes	no	no	no	no
51	IEEE Xplore	Enterprise architecture for e-government in Indonesia	no	n/a	no	no	no
52	IEEE Xplore	A Service-Oriented Virtual Enterprise Architecture and its Applications in Chinese Tobacco Industrial Sector	yes	no	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
53	IEEE Xplore	A Case Study on Textual Enterprise Architecture Modeling	no	n/a	no	no	no
54	IEEE Xplore	Assessing Risks and Opportunities in Enterprise Architecture Using an Extended ADT Approach	yes	no	no	no	no
55	IEEE Xplore	Government Enterprise Architecture Grid Adaptation in Finland	yes	yes	yes	no	no
56	IEEE Xplore	Information resources planning based on enterprise architecture	yes	no	no	no	no
57	IEEE Xplore	How the Liebert adaptive architecture enables the ICT evolution in the modern enterprise, offering the lowest cost of ownership and the highest energy efficiency. Case study in telecom Italia Data Centre, Milan, Italy.	no	n/a	no	no	no
58	IEEE Xplore	From Software Architecture Analysis to Service Engineering: An Empirical Study of Methodology Development for Enterprise SOA Implementation	no	n/a	no	no	no
59	IEEE Xplore	Case study on RM-ODP and Enterprise Architecture	no	n/a	no	no	no
60	IEEE Xplore	Enterprise Architecture for Addressing Business Transformation Challenges: The Case of Embedded Mobile Provisioning Process in the Telecommunications Industry	yes	yes	no	no	no
61	IEEE Xplore	Augmenting the Zachman Enterprise Architecture Framework with a Systemic Conceptualization	yes	no	no	no	no
62	IEEE Xplore	A Traceable Maturity Assessment Method Based on EnterpriseArchitecture Modelling	no	n/a	no	no	no
63	IEEE Xplore	Connecting Enterprise Architecture with Strategic Planning Processes:Case Study of a Large Nordic Finance Organization	yes	yes	no	yes	yes
64	IEEE Xplore	Organizational Subcultures and Enterprise Architecture Effectiveness: Findings from a Case Study at a European Airport Company	yes	yes	no	no	no
65	IEEE Xplore	A Service-Oriented Architecture in a Multi-Agency Environment: A Case Study in Enterprise Dynamics	yes	no	no	no	no
66	IEEE Xplore	Enterprise Architecture Quality Attributes: A Case Study	yes	yes	no	yes	yes
67	IEEE Xplore	Application of a lightweight enterprise architecture elicitation technique using a case study approach	yes	no	no	no	no
68	IEEE Xplore	Enterprise Architecture as Information Technology Strategy	yes	yes	no	yes	yes

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
69	IEEE Xplore	Enterprise Architecture Descriptions for Enhancing Local Government Transformation and Coherency Management: Case Study	n/a	n/a	yes	no	no
70	IEEE Xplore	Enterprise Architecture Implementation and Management: A Case Studyon Interoperability	n/a	n/a	yes	no	no
71	IEEE Xplore	Capturing Business Strategy and Value in Enterprise Architecture to Support Portfolio Valuation	no	n/a	no	no	no
72	IEEE Xplore	A Case Study in Defining Colored Petri Nets Based Model Driven Development of Enterprise Service Oriented Architectures	no	n/a	no	no	no
73	IEEE Xplore	An Access Control Model for Organisational Management in EnterpriseArchitecture	no	n/a	no	no	no
74	IEEE Xplore	Co-evolving industry and enterprise architecture: Exploring the platform architectural advantage of BT in the UK	yes	no	no	no	no
75	IEEE Xplore	Improving Testing in an Enterprise SOA with an Architecture-Based Approach	no	n/a	no	no	no
76	IEEE Xplore	Exploring Enterprise Architecture Evaluation Practices: The Case of a Large University	yes	yes	no	yes	yes
77	IEEE Xplore	A Domain-Specific Framework for Creating Early Trusted Underwater Systems Relying on Enterprise Architecture	yes	no	no	no	no
78	IEEE Xplore	Enterprise Architecture and Its Role in Solving Business Issues: Case Study of the NSW Department of Lands	yes	yes	no	yes	yes
79	IEEE Xplore	Toward the selection of an enterprise architecture model for a cloud environment	yes	no	no	no	no
80	AISel	Anforderungen an ein EAM-Konzept für die öffentliche Verwaltung in Deutschland – Eine Fallstudie	yes	no	no	no	no
81	AISel	EA CONFIGURATIONS: INTERPLAY OF EA DESIGN FACTORS, STRATEGY TYPES, AND ENVIRONMENTS	yes	no	no	no	no
82	AISel	Services for Business Processes in EA – Are They in Relation?	no	n/a	no	no	no
83	AISel	Context Based Knowledge Management in Healthcare: An EA Approached	yes	no	no	no	no
84	AISel	Business Information Driven Approach for EA Development in Practice	yes	no	no	no	no
85	AISel	BEYOND EA FRAMEWORKS: TOWARDS AN UNDERSTANDING OF THE ADOPTION OF ENTERPRISE ARCHITECTURE MANAGEMENT	n/a	n/a	yes	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
86	AISel	Goal-oriented requirements modeling as a means to address stakeholder-related issues in EA	no	n/a	no	no	no
87	AISel	AN EA-BASED APPROACH TO VALUATE ENTERPRISE TRANSFORMATION: THE CASE OF IS INVESTMENTS ENABLING ON DEMAND INTEGRATION OF SERVICE PROVIDERS	yes	no	no	no	no
88	AISel	Understanding the Performance Impact of Enterprise Architecture Management	yes	yes	no	yes	yes
89	AISel	Awaiting Explanation in the Field of Enterprise Architecture Management	yes	no	no	no	no
90	AISel	Enterprise architecture: critical factors affecting modelling and management	n/a	n/a	yes	no	no
91	AISel	Institutionalization and the Effectiveness of Enterprise Architecture Management	yes	no	no	no	no
92	AISel	Design Principles for Heterogeneity Decisions in Enterprise Architecture Management	yes	no	no	no	no
93	AISel	Foundations for the Integration of Enterprise Wikis and Specialized Tools for Enterprise Architecture Management	yes	no	no	no	no
94	AISel	APPLYING THE CONCEPT OF BUILDING BLOCKS FOR ENTERPRISE ARCHITECTURE MANAGEMENT SOLUTIONS IN PRACTICE	yes	yes	no	yes	yes
95	AISel	BEYOND EA FRAMEWORKS: TOWARDS AN UNDERSTANDING OF THE ADOPTION OF ENTERPRISE ARCHITECTURE MANAGEMENT	yes	yes	no	yes	yes
96	AISel	An Enterprise Architecture Framework for Information Management Improvement: Transforming Research into Practice	n/a	n/a	yes	no	no
97	AISel	Toward Understanding Enterprise Architecture Management's Role in Strategic Change: Antecedents, Processes, Outcomes	yes	no	no	no	no
98	AISel	FROM ENTERPRISE MODELLING TO ARCHITECTURE-DRIVEN IT MANAGEMENT ? A DESIGN THEORY	n/a	n/a	yes	no	no
99	AISel	Enterprise Architecture Comes of Age	yes	n/a	no	no	no
100	AISel	Investigating the Usage of Enterprise Architecture Artifacts	yes	no	no	no	no
101	AISel	Enterprise Architecture And The Integration Of Service-Oriented Architecture	no	n/a	no	no	no
102	AISel	Enterprise Architecture Service Provision: Pathways to Value	yes	no	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
103	AISel	ENTERPRISE ARCHITECTURE EVALUATION: A SYSTEMATIC LITERATURE REVIEW	no	n/a	no	no	no
104	AISel	Enterprise Architecture Stakeholders - a Holistic View	no	n/a	no	no	no
105	AISel	Analysis of Federated Enterprise Architecture Models	no	n/a	no	no	no
106	AISel	An Exploration of Enterprise Architecture Research	no	n/a	no	no	no
107	AISel	Domain Architectures as an Instrument to Refine Enterprise Architecture	yes	no	no	no	no
108	AISel	A Procedure Model for Enterprise-Wide Authorization Architecture	yes	yes	no	no	no
109	AISel	How to realise corporate value from enterprise architecture	yes	yes	no	yes	yes
110	AISel	Understanding the Performance Impact of Enterprise Architecture Management	n/a	n/a	yes	no	no
111	AISel	Reflections on Teaching Enterprise Architecture to Graduate Students	no	n/a	no	no	no
112	AISel	Teaching Enterprise Integration and Architecture – Tools, Patterns, and Model Problems	no	n/a	no	no	no
113	AISel	Emerging Issues Of Enterprise Architecture In UK Universities	yes	yes	no	no	no
114	AISel	Awaiting Explanation in the Field of Enterprise Architecture Management	n/a	n/a	yes	no	no
115	AISel	ENTERPRISE ARCHITECTURE AS A CONTRIBUTOR TO SUSTAINABILITY OBJECTIVES	yes	no	no	no	no
116	AISel	Decision Modeling for Healthcare Enterprise IT Architecture Utilizing Cloud Computing	no	n/a	no	no	no
117	AISel	Enterprise architecture: critical factors affecting modelling and management	yes	yes	no	yes	yes
118	AISel	Institutionalization and the Effectiveness of Enterprise Architecture Management	n/a	n/a	yes	no	no
119	AISel	Understanding The Role Of Subcultures In The Enterprise Architecture Process	yes	no	no	no	no
120	AISel	Towards Improving Enterprise Architecture Decision-Making through Service-Dominant Logic	no	n/a	no	no	no
121	AISel	Design Principles for Heterogeneity Decisions in Enterprise Architecture Management	n/a	n/a	yes	no	no
122	AISel	Service-Oriented Design of an Enterprise Architecture in Home Telecare	no	n/a	no	no	no
123	AISel	Formal Models of Virtual Enterprise Architecture: Motivations and Approaches	no	n/a	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
124	AISel	REALIZING BENEFITS FROM ENTER-PRISE ARCHITECTURE: A MEASURE-MENT MODEL	no	n/a	no	no	no
125	AISel	A wiki-based approach to enterprise architec-ture documentation and analysis	no	n/a	no	no	no
126	AISel	IT strategy Implementation Framework – Bridging Enterprise Architecture and IT Gov-ernance	no	n/a	no	no	no
127	AISel	A Pattern-based Approach to Quantitative En-terprise Architecture Analysis	yes	no	no	no	no
128	AISel	Service Elements Valuation Using an Enter-prise Architecture Language	yes	no	no	no	no
129	AISel	Towards A Conceptualization Of Architectural Support For Enterprise Transformation	yes	no	no	no	no
130	AISel	THE RELATIONSHIP BETWEEN IS STRA-TEGIC PLANNING AND ENTERPRISE AR-CHITECTURAL PRACTICE: CASE STUD-IES IN NEW ZEALAND ENTERPRISES	yes	no	no	no	no
131	AISel	Enterprise Architecture Software Tool Support for Small and Medium-Sized Enterprises: EASE	no	n/a	no	no	no
132	AISel	AGILE ENTERPRISE ARCHITECTURE: A CASE OF A CLOUD TECHNOLOGY-ENA-BLED GOVERNMENT ENTERPRISE TRANSFORMATION	yes	no	no	no	no
133	AISel	Foundations for the Integration of Enterprise Wikis and Specialized Tools for Enterprise Ar-chitecture Management	n/a	n/a	yes	no	no
134	AISel	The Role of Service Oriented Architecture as an enabler for Enterprise Architecture.	yes	no	no	no	no
135	AISel	The Enterprise Architecture Analysis Tool – Support for the Predictive, Probabilistic Archi-tecture Modeling Framework	yes	no	no	no	no
136	AISel	APPLYING THE CONCEPT OF BUILDING BLOCKS FOR ENTERPRISE ARCHITEC-TURE MANAGEMENT SOLUTIONS IN PRACTICE	n/a	n/a	yes	no	no
137	AISel	THE IMPACT OF CULTURAL DIFFER-ENCES ON ENTERPRISE ARCHITECTURE EFFECTIVENESS: A CASE STUDY	yes	no	no	no	no
138	AISel	Construction and Evaluation of a Meta-Model for Enterprise Architecture Design Principles	yes	yes	no	yes	yes
139	AISel	Enterprise Architecture – how does it work in the Australian Bureau of Statistics?	yes	yes	no	no	no
140	AISel	Enterprise Architecture as Enabler of Organiza-tional Agility - A Municipality Case Study	yes	yes	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
141	AISel	BEYOND EA FRAMEWORKS: TOWARDS AN UNDERSTANDING OF THE ADOPTION OF ENTERPRISE ARCHITECTURE MANAGEMENT	n/a	n/a	yes	no	no
142	AISel	'Shelfware' or Strategic Alignment? An Enquiry into the Design of Enterprise Architecture Programs	yes	yes	no	no	no
143	AISel	Orchestrating Service Innovation Using Design Moves: The Dynamics of Fit between Service and Enterprise IT Architectures	yes	no	no	no	no
144	AISel	Assessing the Complexity of Dynamics in Enterprise Architecture Planning – Lessons from Chaos Theory	yes	yes	no	no	no
145	AISel	An Enterprise Architecture Framework for Information Management Improvement: Transforming Research into Practice	yes	yes	no	no	no
146	AISel	Toward Understanding Enterprise Architecture Management's Role in Strategic Change: Antecedents, Processes, Outcomes	n/a	n/a	yes	no	no
147	AISel	An Agile Enterprise Architecture Driven Model for Geographically Distributed Agile Development	no	n/a	no	no	no
148	AISel	Enterprise Architecture Principles In Research And Practice: Insights From An Exploratory Analysis	yes	no	no	no	no
149	AISel	USING ENTERPRISE INFORMATION ARCHITECTURE METHODS TO MODEL WICKED PROBLEMS IN INFORMATION SYSTEMS DESIGN RESEARCH	yes	no	no	no	no
150	AISel	Making Connections: A Typological Theory on Enterprise Architecture Features and Organizational Outcomes	yes	no	no	no	no
151	AISel	Role of Testers in Selecting an Enterprise Architecture Solution: An Exploratory Study	yes	no	no	no	no
152	AISel	Integrate Enterprise Systems to our Hyperconnected World: Anything, Anywhere, Anytime through architectural design	no	n/a	no	no	no
153	AISel	Where Do We Find Services in Enterprise Architectures? A Comparative Approach	no	n/a	no	no	no
154	AISel	FROM ENTERPRISE MODELLING TO ARCHITECTURE-DRIVEN IT MANAGEMENT ? A DESIGN THEORY	yes	yes	no	no	no
155	AISel	Design of an Enterprise Architecture for Electronic Patient Care Record (ePCR) Information Exchange in EMS	no	n/a	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
156	AISel	Alternative Designs in Widespread Innovation Adoption: Empirical Evidence from Enterprise Architecture Implementation in US State Governments	yes	no	no	no	no
157	AISel	UNDERSTANDING THE RELATIONSHIP BETWEEN INTEGRATION ARCHITECTURE AND ENTERPRISE ARCHITECTURE: THE CANONICAL MODEL AS A GOVERNANCE RESOURCE - A CASE STUDY IN A TELECOMMUNICATIONS COMPANY	yes	no	no	no	no
158	AISel	Research, Design, and Validation of a Normative Enterprise Architecture for Guiding End-to-End, Emergency Response Services	yes	no	no	no	no
159	AISel	Genuinely Service-Oriented Enterprises: Using Work System Theory to See Beyond the Promise of Efficient Software Architecture	no	n/a	no	no	no
160	AISel	EXTENDING THE THEORY OF EFFECTIVE USE: THE IMPACT OF ENTERPRISE ARCHITECTURE MATURITY STAGES ON THE EFFECTIVE USE OF BUSINESS INTELLIGENCE SYSTEMS	no	n/a	no	no	no
161	Web of Science	EA follow-up in the Ghanaian mining sector: Challenges and opportunities	n/a	n/a	yes	no	no
162	Web of Science	EA-Analyzer: automating conflict detection in a large set of textual aspect-oriented requirements	no	n/a	no	no	no
163	Web of Science	The relation between EA effectiveness and stakeholder satisfaction	n/a	n/a	yes	no	no
164	Web of Science	A system architecture based on open source enterprise content management systems for supporting educational institutions	n/a	n/a	yes	no	no
165	Web of Science	An enterprise architecture approach to forest management support systems design: an application to pulpwood supply management in Portugal	yes	yes	no	yes	yes
166	Web of Science	Developing a scaleable information architecture for an enterprise-wide consolidated information management platform	n/a	n/a	yes	no	no
167	Web of Science	A situational method for semi-automated Enterprise Architecture Documentation	yes	no	no	no	no
168	Web of Science	A system architecture based on open source enterprise content management systems for supporting educational institutions	n/a	n/a	yes	no	no
169	Web of Science	What do we know about the role of enterprise architecture in enterprise integration? A systematic mapping study	no	n/a	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
170	Web of Science	Agile enterprise architecture modelling: Evaluating the applicability and integration of six modelling standards	n/a	n/a	yes	no	no
171	Web of Science	From enterprise architecture to business models and back	yes	no	no	no	no
172	Web of Science	Enterprise architecture availability analysis using fault trees and stakeholder interviews	yes	no	no	no	no
173	Web of Science	Ontology-based process model for business architecture of a virtual enterprise	no	n/a	no	no	no
174	Web of Science	Leveraging the Zachman framework implementation using action-research methodology - a case study: aligning the enterprise architecture and the business goals	yes	no	no	no	no
175	Web of Science	A role-oriented service system architecture for enterprise process collaboration	n/a	n/a	yes	no	no
176	Web of Science	Customer oriented enterprise IT architecture framework	n/a	n/a	yes	no	no
177	Web of Science	Enterprise IT Architecture in Large Federated Organizations: The Art of the Possible	yes	yes	no	yes	yes
178	Web of Science	SCOR-based enterprise architecture methodology	yes	no	no	no	no
179	Web of Science	A fuzzy group multi-criteria enterprise architecture framework selection model	n/a	n/a	yes	no	no
180	Web of Science	OASIS: An architecture for dynamic instrumentation of enterprise distributed real-time and embedded systems	no	n/a	no	no	no
181	Web of Science	An enterprise architecture approach to forest management support systems design: an application to pulpwood supply management in Portugal	n/a	n/a	yes	no	no
182	Web of Science	An AHP-based approach toward enterprise architecture analysis based on enterprise architecturequality attributes	yes	no	no	no	no
183	Web of Science	Data accuracy assessment using enterprise architecture	no	n/a	no	no	no
184	Web of Science	DESIGNING ENTERPRISE IT ARCHITECTURES TO OPTIMIZE FLEXIBILITY AND STANDARDIZATION IN GLOBAL BUSINESS	n/a	n/a	yes	no	no
185	Web of Science	From Software Architecture Analysis to Service Engineering: An Empirical Study of Methodology Development for Enterprise SOA Implementation	n/a	n/a	yes	no	no
186	Web of Science	Complex service design: A virtual enterprise architecture for logistics service	yes	no	no	no	no
187	Web of Science	A hybrid control architecture and coordination mechanism in virtual manufacturing enterprise	no	n/a	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
188	Web of Science	Managing information security in a business network of machinery maintenance services business -Enterprise architecture as a coordination tool	n/a	n/a	yes	no	no
189	Web of Science	Developing a scaleable information architecture for an enterprise-wide consolidated information management platform	yes	no	no	no	no
190	Web of Science	A distributed product development architecture for engineering collaborations across ubiquitous virtual enterprises	no	n/a	no	no	no
191	Sage Journals	xArchiMate: Enterprise Architecture simulation, experimentation and analysis	no	n/a	no	no	no
192	Sage Journals	Sociopolitical Aspects of Interoperability and Enterprise Architecture in E-Government	no	n/a	no	no	no
193	ACM	Enterprise Architecture Benefit Realization: Review of the Models and a Case Study of a Public Organization	yes	yes	yes	no	no
194	ACM	Enterprise architecture governance: the need for a business-to-IT approach	yes	yes	no	yes	yes
195	ACM	Towards an integrated service-oriented reference enterprise architecture	yes	no	no	no	no
196	ACM	Evaluating software architecture in a model-based approach for enterprise information system design	yes	no	no	no	no
197	ACM	Using architecture-level performance models as resource profiles for enterprise applications	no	n/a	no	no	no
198	ACM	A multi-level framework for measuring and benchmarking public service organizations: connecting stages-of-growth models and enterprise architecture	yes	no	no	no	no
199	ACM	Plug-in architecture and design guidelines for customizable enterprise applications	no	n/a	no	no	no
200	Science Direct	Chapter 8 - Inviting to Participation: EAM 2.0	no	n/a	no	no	no
201	Science Direct	Emotional availability (EA): Theoretical background, empirical research using the EA Scales, and clinical applications	no	n/a	no	no	no
202	Science Direct	EA follow-up in the Ghanaian mining sector: Challenges and opportunities	no	n/a	no	no	no
203	Science Direct	Parametric effects on embedded delamination buckling in composite structures using the EAS three-dimensional element	no	n/a	no	no	no
204	Science Direct	Chapter 7 - Toward Pragmatism: Lean and Agile EA	no	n/a	no	no	no
205	Science Direct	Chapter 6 - Foundations of Collaborative EA	no	n/a	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
206	Science Direct	Fracture simulation based on EA-cohesive model with natural fracture/decohesion mechanism	no	n/a	no	no	no
207	Science Direct	The relation between EA effectiveness and stakeholder satisfaction	yes	no	no	no	no
208	Science Direct	The influence of the topographic position within highlands of Western Rwanda on the interactions between banana (Musa spp. AAA-EA), parasitic nematodes and soil factors	no	n/a	no	no	no
209	Science Direct	EAS Summer School 2009 in Hamburg, Germany: "A great opportunity to learn a lot about atherosclerosis and to get to know other scientific approaches than one's own" (Lujia from Heidelberg, one of this year's participants)	no	n/a	no	no	no
210	Science Direct	A new paradigm for Environmental Assessment (EA) in Korea	no	n/a	no	no	no
211	Science Direct	Performance of EAs for four-bar linkage synthesis	no	n/a	no	no	no
212	Science Direct	Approximation of piecewise smooth functions and images by edge-adapted (ENO-EA) nonlinear multiresolution techniques	no	n/a	no	no	no
213	Science Direct	Time for a new approach to public participation in EA: Promoting cooperation and consensus for sustainability	no	n/a	no	no	no
214	Science Direct	A system architecture based on open source enterprise content management systems for supporting educational institutions	no	n/a	no	no	no
215	Science Direct	An architecture for access control management in collaborative enterprise systems based on organization models	no	n/a	no	no	no
216	Science Direct	4 - Integrating risk management through an enterprise architecture	no	n/a	no	no	no
217	Science Direct	A system architecture based on open source enterprise content management systems for supporting educational institutions	n/a	n/a	yes	no	no
218	Science Direct	Chapter 9 - Continuous Architecture in the Enterprise	no	n/a	no	no	no
219	Science Direct	A note on an architecture for integrating cloud computing and enterprise systems using REA	no	n/a	no	no	no
220	Science Direct	Modeling resources and capabilities in enterprise architecture: A well-founded ontology-based proposal for ArchiMate	yes	no	no	no	no
221	Science Direct	Agile enterprise architecture modelling: Evaluating the applicability and integration of six modelling standards	yes	no	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
222	Science Direct	Inter-enterprise architecture as a tool to em-power decision-making in hierarchical collabo-rative production planning	no	n/a	no	no	no
223	Science Direct	Empirical insights into the development of a service-oriented enterprise architecture	yes	yes	no	yes	yes
224	Science Direct	A novel credibility-based group decision mak-ing method for Enterprise Architecture scenario analysis using Data Envelopment Analysis	yes	no	no	no	no
225	Science Direct	A systematic literature review on Enterprise Architecture Implementation Methodologies	yes	no	no	no	no
226	Science Direct	9 - Enterprise Architecture Case Study: Elec-tronicsDeals Online	yes	n/a	no	no	no
227	Science Direct	Developing an Enterprise Architecture Proof of Concept in a Portuguese Hospital	yes	yes	no	yes	yes
228	Science Direct	Enterprise architecture: Twenty years of the GERAM framework	no	n/a	no	no	no
229	Science Direct	The new data-driven enterprise architecture for e-healthcare: Lessons from the Indian public sector	yes	no	no	no	no
230	Science Direct	Enterprise Architecture: Twenty Years of the GERAM Framework	n/a	n/a	yes	no	no
231	Science Direct	Use of Connections and Architecture Dynamics in Enterprises Employing Disabled Individuals	no	n/a	no	no	no
232	Science Direct	Hierarchy-oriented modeling of enterprise ar-chitecture using reference-model of open dis-tributed processing	no	n/a	no	no	no
233	Science Direct	Using enterprise architecture analysis and inter-view data to estimate service response time	no	n/a	no	no	no
234	Science Direct	Designing IT Personnel Hard Competencies Model in the Enterprise Architecture Case Study: Forestry Research and Development Agency of Indonesia	no	n/a	no	no	no
235	Science Direct	Examining e-government enterprise architec-ture research in China: A systematic approach and research agenda	no	n/a	no	no	no
236	Science Direct	A role-oriented service system architecture for enterprise process collaboration	no	n/a	no	no	no
237	Science Direct	Using enterprise architecture and technology adoption models to predict application usage	no	n/a	no	no	no
238	Science Direct	Customer oriented enterprise IT architecture framework	yes	no	no	no	no
239	Science Direct	A fuzzy group multi-criteria enterprise archi-tecture framework selection model	no	n/a	no	no	no
240	Science Direct	A Flexible Approach to Realize an Enterprise Architecture	yes	no	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
241	Science Direct	Chapter 1 - Why Collaborative Enterprise Architecture?	no	n/a	no	no	no
242	Science Direct	Enterprise information security, a review of architectures and frameworks from interoperability perspective	no	n/a	no	no	no
243	Science Direct	Architecture analysis of enterprise systems modifiability – Models, analysis, and validation	no	n/a	no	no	no
244	Science Direct	Managing information security in a business network of machinery maintenance services business – Enterprise architecture as a coordination tool	yes	no	no	no	no
245	Science Direct	Using FDAF to bridge the gap between enterprise and software architectures for security	no	n/a	no	no	no
246	Science Direct	An architecture for access control management in collaborative enterprise systems based on organization models	n/a	n/a	yes	no	no
247	Science Direct	Special section: Information engineering and enterprise architecture in distributed computing environments	no	n/a	no	no	no
248	Science Direct	Chapter six - Data access technologies/GSA: Executable enterprise architecture	yes	n/a	no	no	no
249	Science Direct	4 - Integrating risk management through an enterprise architecture	n/a	n/a	yes	no	no
250	Science Direct	Interface descriptions for enterprise architecture	yes	no	no	no	no
251	MisQ	How Cisco Systems Used Enterprise Architecture Capability to Sustain Acquisition-Based Growth	n/a	n/a	yes	no	no
252	MisQ	Designing Enterprise IT Architectures to Optimize Flexibility and Standardization in Global Business	n/a	n/a	yes	no	no
253	MisQ	Sustainable IT Outsourcing Success: Let Enterprise Architecture Be Your Guide	n/a	n/a	yes	no	no
254	MisQ	Enterprise Architecture Maturity: The Story of the Veterans Health Administration	n/a	n/a	yes	no	no
255	MisQ	The Role of Enterprise Architecture in the Quest for IT Value	n/a	n/a	yes	no	no
256	MisQ	Restructuring Information Systems Following the Divestiture of Carestream Health	n/a	n/a	yes	no	no
257	MisQ	How an Australian Retailer Enabled Business Transformation Through Enterprise Architecture	yes	yes	no	yes	yes
258	MisQ	How Cisco Systems Used Enterprise Architecture Capability to Sustain Acquisition-Based Growth	yes	no	no	no	no

ID	Data-base	Article	Title and abstract fit	Full text fit	Dublicate paper/case	Detailed case description	Final selection
259	MisQ	Increasing the Relevance of Enterprise Architecture through "Crisitunities" in U.S. State Governments	yes	yes	no	yes	yes
260	MisQ	Designing Enterprise IT Architectures to Optimize Flexibility and Standardization in Global Business	yes	no	no	no	no
261	MisQ	Sustainable IT Outsourcing Success: Let Enterprise Architecture Be Your Guide	yes	no	no	no	no
262	MisQ	Delivering an Effective Enterprise Architecture at Chubb Insurance	yes	yes	no	yes	yes
263	MisQ	How Schlumberger Achieved Networked Information Leadership by Transitioning to a Product-Platform Software Architecture	no	n/a	no	no	no
264	MisQ	Enterprise Architecture Maturity: The Story of the Veterans Health Administration	yes	no	no	no	no
265	MisQ	Managing IT Collaboration in Multi-Organizational Time-Critical Services	no	n/a	no	no	no
266	MisQ	Transitioning to a Modular Enterprise Architecture: EA drivers, Constraints, and Actions	yes	yes	no	no	no
267	MisQ	Service-Oriented Architecture: Myths, Realities, and a Maturity Model	no	n/a	no	no	no
268	MisQ	The Role of Enterprise Architecture in the Quest for IT Value	no	n/a	no	no	no
269	MisQ	APC Forum: Chubb's Enterprise Architecture	no	n/a	no	no	no
270	MisQ	How CIOs Can Enable Governance of Value Nets	no	n/a	no	no	no
271	MisQ	Creating a Process-Centric Organization at FCC: SOA from the Top Down	no	n/a	no	no	no
272	MisQ	Restructuring Information Systems Following the Divestiture of Carestream Health	yes	no	no	no	no
273	MisQ	The Jewel in the Crown – Enterprise Architecture at Chubb	yes	yes	yes	yes	yes

III

LET'S GET IN TOUCH - DECISION MAKING ABOUT ENTERPRISE ARCHITECTURE USING 3D VISUALIZATION IN AUGMENTED REALITY

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.

Keywords: *Enterprise Architecture, Enterprise Architecture Management, Augmented Reality, Prototyping*

This article was co-authored with Malte Greulich, Laurenz Bredenfeld, and Frederik Ahlemann. An earlier version of this article was published in Proceedings of the 52nd Hawaii International Conference on System Sciences (HICSS):

Rehring, K., Greulich, M., Bredenfeld, L., & Ahlemann, F. (2019). Let's Get in Touch-Decision Making about Enterprise Architecture Using 3D Visualization in Augmented Reality. In *Proceedings of the 52nd Hawaii International Conference on System Sciences* (HICSS). Maui, Hawaii, USA

Table of Contents

List of Figures

List of Tables

1 Introduction

Advances in Information Technology (IT) enable organizations to enhance enterprise effectiveness, increase flexibility, and develop new business models (Korhonen & Halén, 2017, p. 349). At the same time, the complexity of IT landscapes has grown considerably in recent years (Winter, Legner, & Fischbach, 2014, p. 1), 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 (Tamm, Seddon, Shanks, & Reynolds, 2011, p. 142; The Open Group, 2009, p. 411). Hence, EAs offer a consistent basis for decision-making about, for instance, business-IT alignment, complexity reduction, or future planning of organizations (Tamm et al., 2011, p. 142). This fact-based foundation provides rational arguments about EAs (van der Linden & Van Zee, 2015, p. 28) and therefore facilitates better and timely decision-making for a variety of EA stakeholders (Ahlemann, Stettiner, Messerschmidt, & Legner, 2012, pp. 39 & 44). EAs can be made visual as i.e. texts, matrix views, layer perspectives, bar charts, or pie charts (Roth, Zec, & Matthes, 2014, p. 46), which support decision-makers' understanding of EA descriptions (Olshannikova, Ometov, Koucheryavy, & Olsson, 2015, p. 19). The establishment, maintenance, and development of EAs and corresponding EA visualizations are the main outcomes of Enterprise Architecture Management (EAM) (Ahlemann et al., 2012, p. 20; Aier, 2013, p. 645). 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 (Ahlemann et al., 2012, p. 6).

However, research indicates low use of EAs for decision-making in organizations (Abraham, 2013, p. 2; Hiekkanen et al., 2013, p. 296; Löhe & Legner, 2014, p. 116), in particular for visualizing and, hence, understanding complex IT landscapes (Buckl, Ernst, Matthes, & Schweda, 2009, p. 4; Nowakowski et al., 2017, p. 4853; Vieira, Cardoso, & Becker, 2014, p. 245). Potential reasons for this include the limited perceived usefulness of EA visualizations, which are often characterized by their complexity (van der Raadt, Schouten, & Vliet, 2008, p. 20), lack of focus (Buckl et al., 2009, p. 4), an inappropriate level of abstraction (Nowakowski et al., 2017, p. 4854; Vieira et al., 2014, p. 245), or insufficient tool support (Nowakowski et al., 2017, p. 4854). In sum, this inhibits the effective use of EAs for decision-making (Banaeianjahromi & Smolander, 2017, p. 25), so that stakeholders often find the added value of EA visualizations to be rather low (Hiekkanen et al., 2013, p. 292; van der Raadt et al., 2008, p. 20).

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 (John & Kundisch, 2015, p. 4; Vessey & Galletta, 1991, p. 67; Weiss, Aier, & Winter, 2012, p. 6). 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 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 (Azuma, 1997, p. 356; Ohta & Tamura, 1999, p. 224). 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 (Dunleavy, Dede, & Mitchell, 2009, p. 17; Ibáñez, Di Serio, Villarán, & Delgado Kloos, 2014, p. 3; Sommerauer & Müller, 2014, p. 67; Wang, Love, Kim, & Wang, 2014, p. 13). Moreover, due to the natural integration of the virtual objects into the real world (Ohta & Tamura, 1999, p. 224) and the use of hand gestures (Azuma, 1997, p. 357), 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 (Steffen, Gaskin, Meservy, & Jenkins, 2017, p. 4). Decision-makers who use AR can still perceive the real world (Azuma, 1997, p. 356; Ohta & Tamura, 1999, p. 224), engage in face-to-face collaboration (Wu, Lee, Chang, & Liang, 2013, p. 44), and experience almost no motion sickness (Vovk, Wild, Guest, & Kuula, 2018, p. 6), 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 (Finextra, 2017). 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 (Gartner, 2017).

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 Theoretical Foundation

In what follows, we provide an overview of possible EA-related decision tasks (section 2.1) and 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 Uses Cases of EA-Based Decision-Making

EAM can support strategic decision-making by providing relevant information on the current and future state of EAs (Ahlemann et al., 2012, pp. 16 & 137; Kotusev, Singh, & Storey, 2015, p. 6; Weiss et al., 2012, p. 2). Decision-makers are business or IT representatives in an organization, who design or use EAs (Boh & Yellin, 2006, p. 170). Typical decision-makers would be enterprise architects, board members, business project managers, business project analysts, or application managers (Aleatrati Khosroshahi, Hauder, & Matthes, 2016, p. 5; van der Raadt et al., 2008, p. 1956). They consider EAs for communication, analysis, and decision-making (Kotusev et al., 2015, p. 3).

According to Aleatrati Khosroshahi et al. (2016, p. 8), most upper management EA stakeholders recognize EAM to be a relevant strategic tool that provides meaningful information about the organization (Aleatrati Khosroshahi et al., 2016, p. 8). High-level strategic decisions can draw on EAs, which therefore, have a strong impact on the future development of the organization (Lux, Riempp, & Urbach, 2010, p. 6; Nowakowski et al., 2017, p. 4850; Rahimi, Gøtze, & Møller, 2017, p. 134). Examples include feasibility analyses for implementing new products, identifying market offers depending on the existing IT landscape, or discovering redundant processes (Riege & Aier, 2009, p. 396). In a similar way, EA stakeholders make decisions on business structuring to plan and guide the implementation of strategic initiatives (Pulkkinen, 2006, p. 3; Rahimi et al., 2017, p. 134). This could affect not only IT-related aspects, but also the design of business processes and information assets (Rahimi et al., 2017, p. 134). The selection and prioritization of IT projects can be based on project-related EA information (Rahimi et al., 2017, p. 134). This includes, for instance, the consideration of standards (Aleatrati Khosroshahi et al., 2016, p. 5), the results of risk analyses, and EA project proposals (Lux et al., 2010, p. 6). IT standards can ensure IT projects' compliance (Riege & Aier, 2009, p. 396) and help to avoid implementing redundant technologies (Lux et al., 2010, p. 7). IT investment or IT portfolio decisions could consider EA requirements like capabilities, qualities, and cost of technologies (Pulkkinen, 2006, p. 2). Application replacement or retracting decisions could depend on the applications' lifecycle, or other organizationally relevant assessment dimensions like the number of users (Lux et al., 2010, p. 7; Nowakowski et al., 2017, p. 4850; Riege & Aier, 2009, p. 396).

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 (Tamm et al., 2011, p. 142; The Open Group, 2009, p. 411). 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 (Kotusev et al., 2015, p. 2). Researchers claim that visualizing EAs can improve decision-making, and finally enable better-informed decisions (Hiekkanen et al., 2013, p. 292; Tamm et al., 2011, p. 146f). 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 (Tamm et al., 2011, p. 147).

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. Roth et al. (2014) provide a sophisticated overview of those visualization types. More sophisticated visualizations combine a number of elements to form tables or various kinds of visualization: clusters, dependencies, portfolios, life-cycles, or roadmaps (Hanschke, 2009, pp. 238–239). Figure III-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 (Hanschke, 2009, pp. 238–239).

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 (Ahlemann et al., 2012, p. 60; Nowakowski et al., 2017, p. 4851f; Pulkkinen, 2006, p. 3). Surprisingly, only a few organizations employ 3D visualizations of EA (Roth et al., 2014, p. 71) although 3D is considered beneficial for understanding complex relationships (Ibáñez et al., 2014, p. 3; Sommerauer & Müller, 2014, p. 67; Wang et al., 2014, p. 13). An in-depth analysis of EA visualizations lies outside of this paper's scope. However, interested readers should consider Roth et al. (Roth et al., 2014).

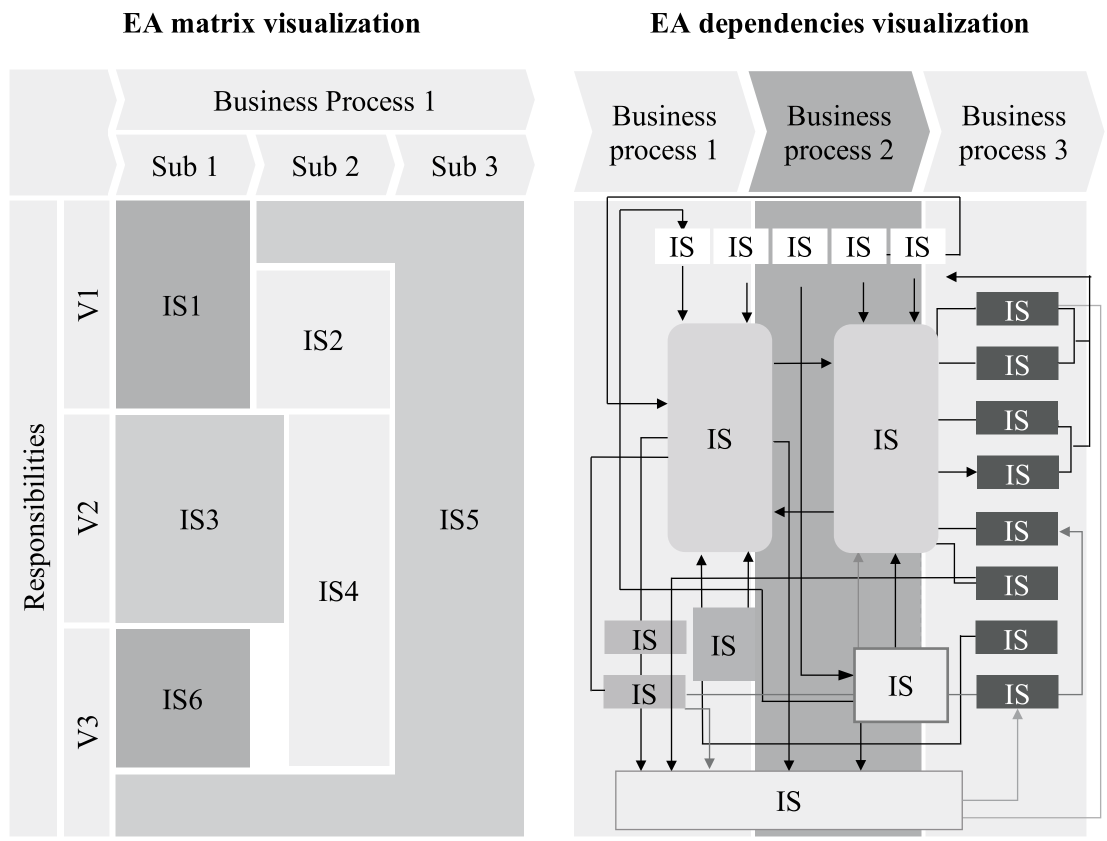


Figure III-1. Exemplary detailed EA visualizations (Hanschke, 2009, pp. 238–239)

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" (Vessey, 1991, p. 221). 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" (Vessey, 1991, p. 221). 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 (Vessey, 1991, p. 226). The corresponding problem representation addresses a structural layer, that describes *how* information is presented, and a content layer, that describes *what* information is presented (John & Kundisch, 2015, p. 4). 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 (Vessey, 1991, p. 221) because transforming the inadequate information to suit the task requirements requires more mental capacity (John & Kundisch, 2015, p. 4).

Even though some researchers acknowledge the appropriateness of cognitive fit to EAM research (e.g. Weiss et al., 2012, p. 6), this theory has been limitedly considered. Exceptions are Kurpjuweit (Kurpjuweit, 2009, p. 22), who concludes that not all EA visualizations fit to every problem, Franke et al. (Franke, Cohen, & Sigholm, 2018, p. 704) whose empirical results suggest that models have a greater influence on understanding EA than text documents, and Winter (Winter, 2011, p. 159) 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 III-2 shows the CFT model as applied to the EAM context.

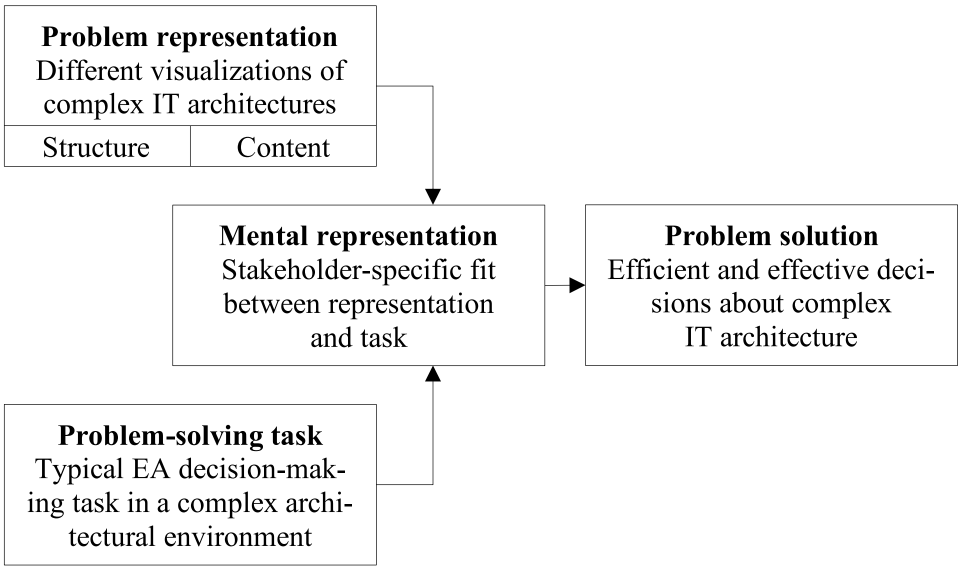


Figure III-2. CFT applied to the EAM context

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 (Azuma, 1997, p. 356; Ohta & Tamura, 1999, p. 224), 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, (Dunleavy et al., 2009, p. 17; Ibáñez et al., 2014, p. 3; Sommerauer & Müller, 2014, p. 67; Wang et al., 2014, p. 13), decrease individual learning effort, and allow face-to-face collaboration (Wu et al., 2013, p. 44).

2.4 Augmented Reality

According to Azuma's widely cited definition, AR is characterized by three properties (1997, p. 356). 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. An example of such an application is presented in Figure III-3. 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 (Ohta & Tamura, 1999, p. 23; Sherman & Craig, 2002, p. 155). Optical see-through HMDs project virtual objects into the real world with the support of mirrors (Milgram, Takemura, Utsumi, & Kishino, 1994, p. 284), whereas video see-through HMDs present and manipulate a user's view on the real world by using cameras (Azuma, 1997, p. 361). Handheld AR displays, like smartphones, are small devices that also use cameras to overlay real and virtual objects on a screen (Rehman & Cao, 2016, p. 140; Sherman & Craig, 2002, p. 160).

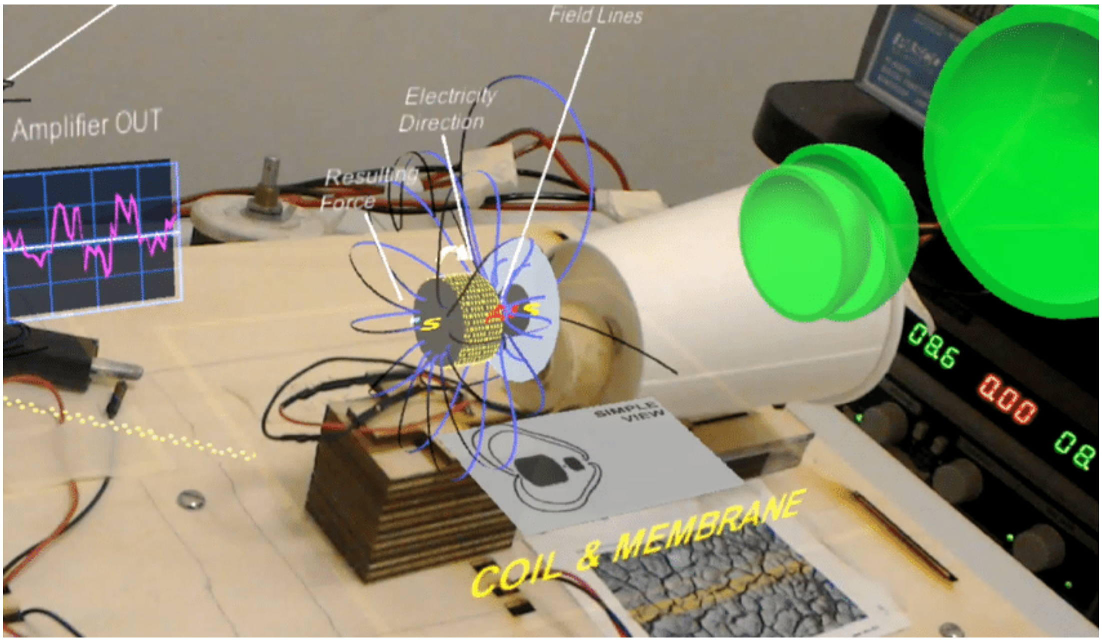


Figure III-3. Example of a AR prototype that visualizes a magnet field around a coil (Radu & Schneider, 2019, p. 3)

3 Research Design

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 (Hevner, March, Park, & Ram, 2004, p. 82). DSR provides principles and procedures to design, develop, and evaluate IT artefacts (Peffers et al., 2006). From a DSR perspective, IT Constructs and propositions artefacts should address specific organizational problems (Hevner et al., 2004, p. 83). 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. (2006), which is summarized in Figure III-4.

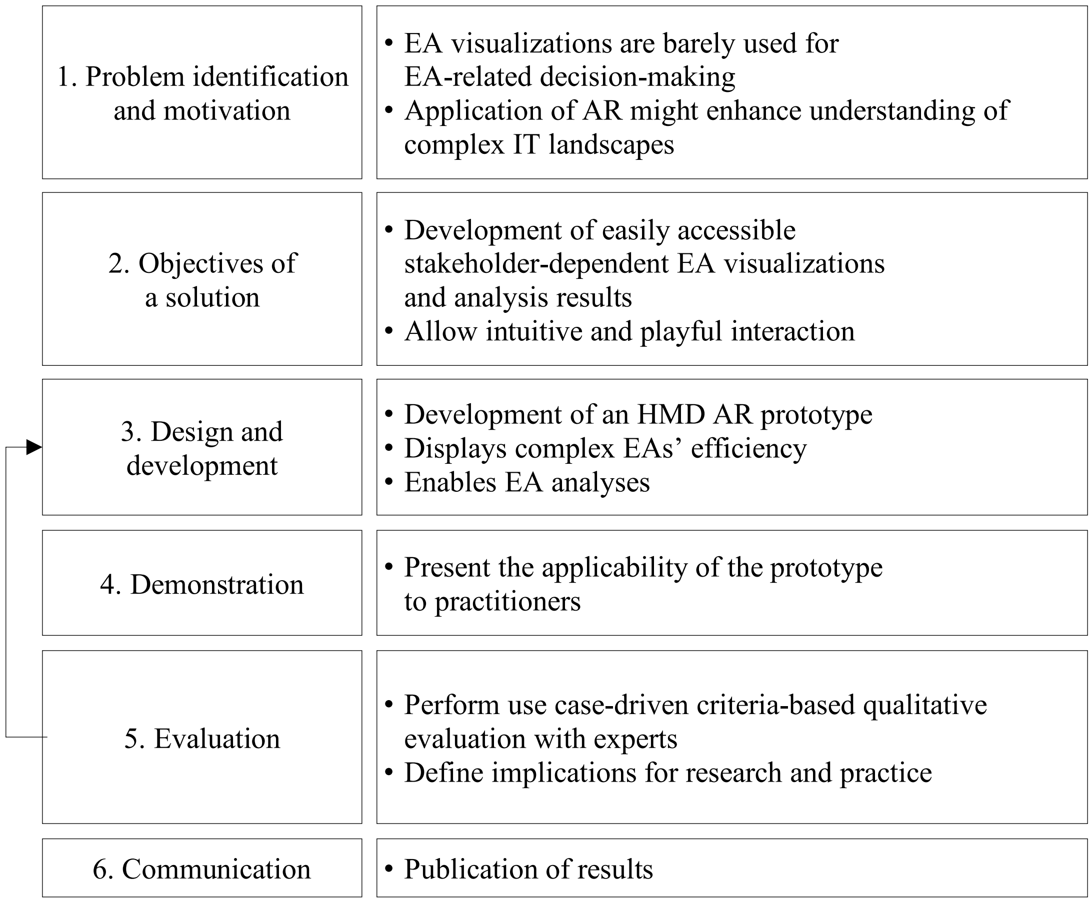


Figure III-4. DSR process by Peffers et al. (2006)

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 (Vovk et al., 2018, p. 3). 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 (Roth et al., 2014, p. 15). 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 (2008, p. 3). 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 (2008, p. 3). 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 (2008, p. 12). 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 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 1000 applications for a variety of purposes in different phases of the application life cycle. These applications are used by over 12000 users and run over more than 2600 servers at 4 locations. 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 III-1.

Table III-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 III-5 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.

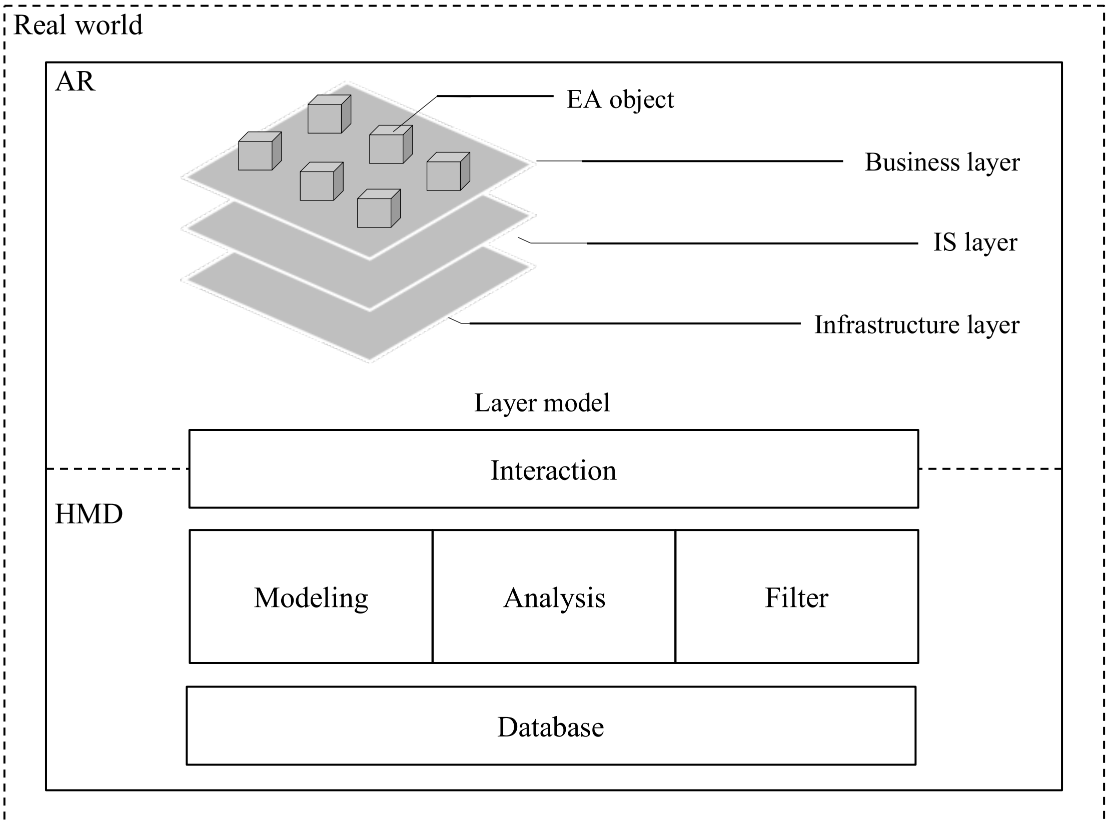


Figure III-5. AR EAM software architecture

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 III-6). Each layer groups similar EA objects to help reduce the cognitive load of working with complex data (Olshannikova et al., 2015, p. 17). 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 (Hanschke, 2009, p. 238) needed in most EA decision tasks (section 2.1). Third, the layer representation is well-known in the EAM domain and is widely accepted (Roth et al., 2014, p. 15). To achieve a high acceptance, we based the model on the TOGAF meta model (The Open Group, 2009) and ArchiMate notation (The Open Group ArchiMate Forum, 2016) which are also broadly accepted in the community.

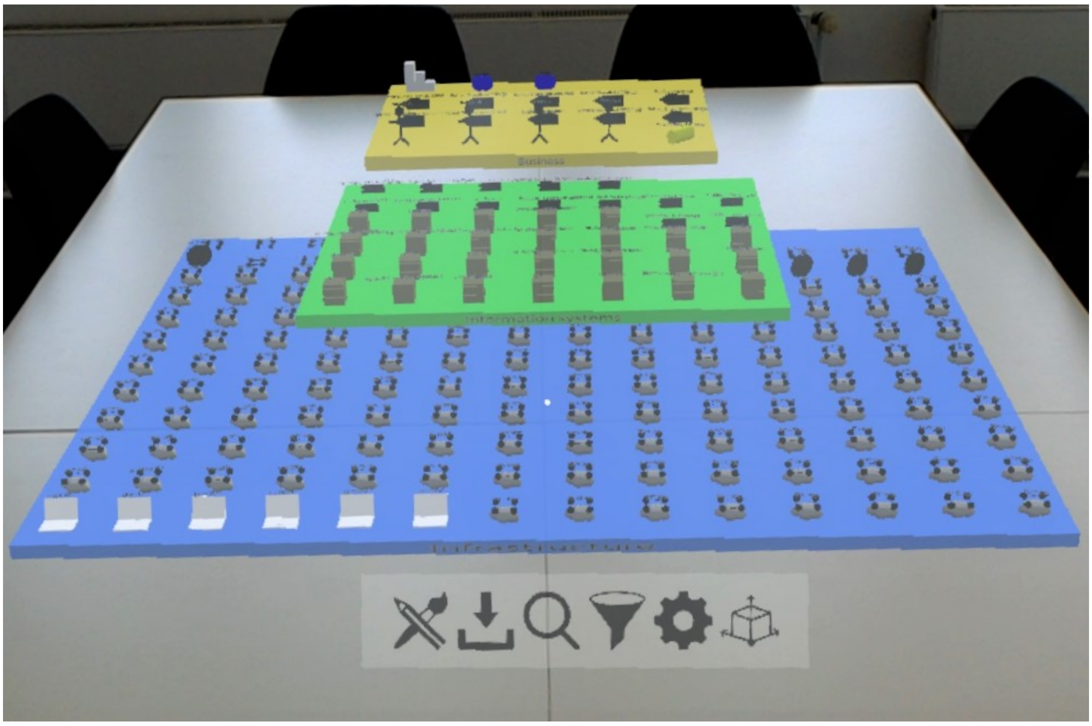


Figure III-6. Layer model of the AR prototype in the real world

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 (Olshannikova et al., 2015, p. 17), 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 (Moller, Elliot, & Maier, 2009, p. 898). In addition, different EA object sizes support the visualizations of e.g. the importance or uses of EA objects. Figure III-7 shows an example of a combined analysis visualization.

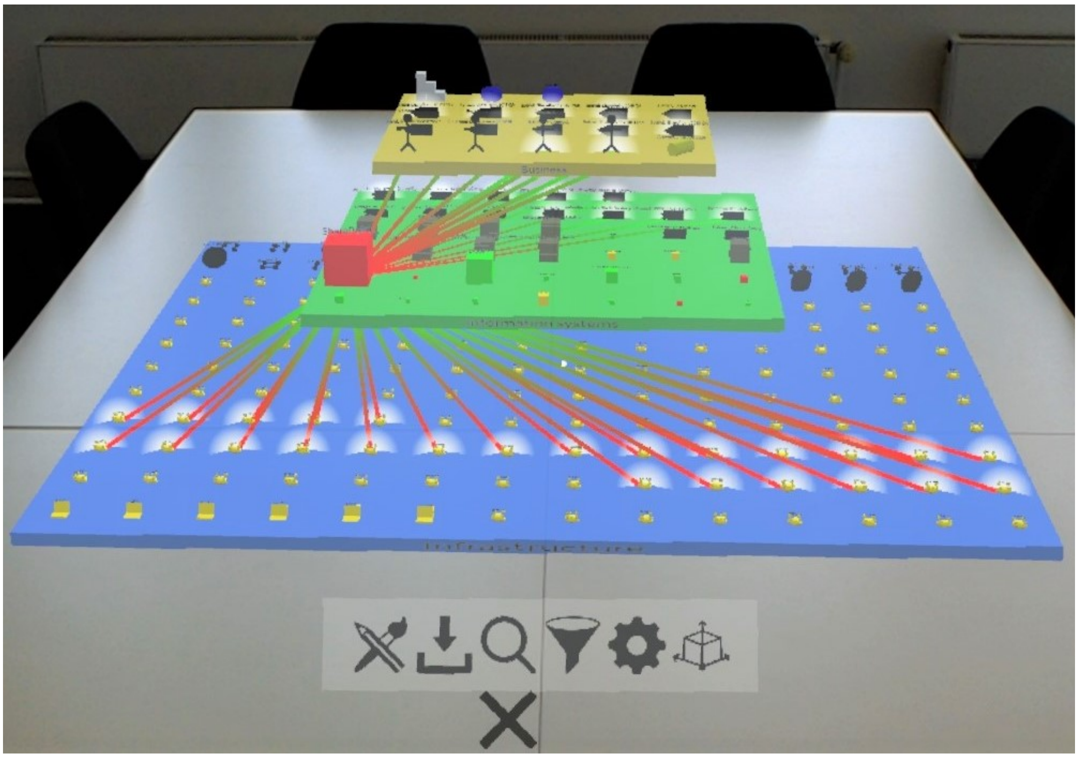


Figure III-7. Layer model of the AR prototype with analysis functions

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) (Microsoft, 2018), 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 (2008, p. 3). Table III-2 provides an overview of the participants' roles and EA information needs.

Table III-2. Overview of interview partner

ID	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 • Especially. 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 natural 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 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. (2018, p. 6).

7 Conclusion

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.

References

Abraham, R. (2013). Enterprise Architecture Artifacts as Boundary Objects-A Framework of Properties. *ECIS 2013 Proceedings*.

Ahlemann, F., Stettiner, E., Messerschmidt, M., & Legner, C. (2012). *Strategic Enterprise Architecture Management: Challenges, Best Practices, and Future Developments*. Berlin ; New York: Springer.

Aier, S. (2013). Understanding the Role of Organizational Culture for Design and Success of Enterprise Architecture Management. In R. Alt & B. Franczyk (Eds.), *Proceedings of the 11th International Conference on Wirtschaftsinformatik (WI 2013)* (Vol. 1, pp. 879–894). Leipzig.

Aleatrati Khosroshahi, P., Hauder, M., & Matthes, F. (2016). Analyzing the Evolution and Usage of Enterprise Architecture Management Patterns. *AMCIS 2016 Proceedings*.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355–385.

Banaeianjahromi, N., & Smolander, K. (2017). Lack of Communication and Collaboration in Enterprise Architecture Development. *Information Systems Frontiers*. https://doi.org/10.1007/s10796-017-9779-6

Boh, W. F., & Yellin, D. (2006). Using Enterprise Architecture Standards in Managing Information Technology. *Journal of Management Information Systems*, *23*(3), 163–207. https://doi.org/10.2753/MIS0742-1222230307

Buckl, S., Ernst, A. M., Matthes, F., & Schweda, C. M. (2009). How to make your enterprise architecture management endeavor fail! *Proceedings of the 16th Conference on Pattern Languages of Programs*. Presented at the Proceedings of the 16th Conference on Pattern Languages of Programs, Chicago, Illinois, USA.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, *18*(1), 7–22. https://doi.org/10.1007/s10956-008-9119-1

Finextra. (2017). Rabobank constructs physical model to understand IT architecture. Retrieved April 13, 2018, from https://www.finextra.com/newsarticle/30988/rabobank-constructs-physical-model-to-understand-it-architecture

Franke, U., Cohen, M., & Sigholm, J. (2018). What can we learn from enterprise architecture models? An experiment comparing models and documents for capability development. *Software & Systems Modeling*, *17*(2), 695–711. https://doi.org/10.1007/s10270-016-0535-z

Gartner. (2017). Transform Business Outcomes With Immersive Technology. Retrieved February 3, 2018, from Transform Business Outcomes With Immersive Technology website: https://www.gartner.com/smarterwithgartner/transform-business-outcomes-with-immersive-technology/

Hanschke, I. (2009). *Strategisches Management der IT-Landschaft: Ein praktischer Leitfaden für das Enterprise Architecture Management*. Hanser Verlag.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, *28*(1), 75–105.

Hiekkanen, K., Korhonen, J. J., Collin, J., Patricio, E., Helenius, M., & Mykkänen, J. (2013). Architects' Perceptions on EA Use – An Empirical Study. *2013 IEEE 15th Conference on Business Informatics*, 292–297. https://doi.org/10.1109/CBI.2013.48

Ibáñez, M. B., Di Serio, Á., Villarán, D., & Delgado Kloos, C. (2014). Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness. *Computers & Education*, *71*(Supplement C), 1–13. https://doi.org/10.1016/j.compedu.2013.09.004

John, T., & Kundisch, D. (2015). Why fit leads to surprise: An extension of cognitive fit theory to creative problems. *ICIS*. Presented at the Fort Worth. Fort Worth.

Korhonen, J. J., & Halén, M. (2017). Enterprise Architecture for Digital Transformation. *Business Informatics (CBI), 2017 IEEE 19th Conference On*, *1*, 349–358. IEEE.

Kotusev, S., Singh, M., & Storey, I. (2015). Investigating the Usage of Enterprise Architecture Artifacts. *ECIS 2015 Research-in-Progress Papers*.

Kurpjuweit, S. (2009). *Stakeholder-orientierte Modellierung und Analyse der Unternehmensarchitektur: unter besonderer Berücksichtigung der Geschäfts- und IT-Architektur*. Logos Verlag Berlin GmbH.

Löhe, J., & Legner, C. (2014). Overcoming implementation challenges in enterprise architecture management: a design theory for architecture-driven IT Management (ADRIMA). *Information Systems and E-Business Management*, *12*(1), 101–137. https://doi.org/10.1007/s10257-012-0211-y

Lux, J., Riempp, G., & Urbach, N. (2010). Understanding the performance impact of enterprise architecture management. *Proceedings of the 16th Americas Conference on Information Systems (AMCIS 2010)*. Presented at the Lima, Peru. Lima, Peru.

Microsoft. (2018, March 21). Gestures - Mixed Reality. Retrieved May 30, 2018, from https://docs.microsoft.com/en-us/windows/mixed-reality/gestures

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies*, *2351*(11), 282–292.

Moller, A. C., Elliot, A. J., & Maier, M. A. (2009). Basic hue-meaning associations. *Emotion*, *9*(6), 898–902. https://doi.org/10.1037/a0017811

Nowakowski, E., Farwick, M., Trojer, T., Häusler, M., Kessler, J., & Breu, R. (2017). Enterprise Architecture Planning: Analyses of Requirements from Practice and Research. *Proceedings of the 50th Hawaii International Conference on System Sciences*.

Ohta, Y., & Tamura, H. (1999). *Mixed Reality: Mergin Real and Virtual Worlds*. Springer Berlin Heidelberg.

Olshannikova, E., Ometov, A., Koucheryavy, Y., & Olsson, T. (2015). Visualizing Big Data with augmented and virtual reality: challenges and research agenda. *Journal of Big Data*, *2*(1), 22. https://doi.org/10.1186/s40537-015-0031-2

Peffers, K., Tuunanen, T., Gengler, C. E., Rossi, M., Hui, W., Virtanen, V., & Bragge, J. (2006). The Design Science research process: a model for producing and presenting information systems research. *Proceedings of the First International Conference on Design Science Research in Information Systems and Technology*, 83–106.

Pulkkinen, M. (2006). Systemic Management of Architectural Decisions in Enterprise Architecture Planning. Four Dimensions and Three Abstraction Levels. *Proceedings of the 39th Annual Hawaii International Conference on System Sciences*, *8*, 1–9. https://doi.org/10.1109/HICSS.2006.447

Radu, I., & Schneider, B. (2019). What can we learn from augmented reality (ar)? *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, 1–12.

Rahimi, F., Gøtze, J., & Møller, C. (2017). Enterprise Architecture Management: Toward a Taxonomy of Applications. *Communications of the Association for Information Systems*, *40*(1).

Rehman, U., & Cao, S. (2016). Augmented-Reality-Based Indoor Navigation: A Comparative Analysis of Handheld Devices Versus Google Glass. *IEEE Transactions on Human-Machine Systems*, 140–151. https://doi.org/10.1109/THMS.2016.2620106

Riege, C., & Aier, S. (2009). A contingency approach to enterprise architecture method engineering. *Journal of EA*, *5*(1), 36–48.

Rosemann, M., & Vessey, I. (2008). Toward improving the relevance of information systems research to practice: the role of applicability checks. *MIS Quarterly*, *32*(1), 1–22.

Roth, S., Zec, M., & Matthes, F. (2014). *Enterprise Architecture Visualization Tool Survey 2014*. Germany: epubli GmbH.

Sherman, W. R., & Craig, A. B. (2002). *Understanding Virtual Reality: Interface, Application, and Design*. Elsevier Science.

Sommerauer, P., & Müller, O. (2014). Augmented reality in informal learning environments: A field experiment in a mathematics exhibition. *Computers & Education*, *79*, 59–68. https://doi.org/10.1016/j.compedu.2014.07.013

Steffen, J., Gaskin, J., Meservy, T., & Jenkins, J. (2017). The Missing Framework for Virtually Assisted Activities. *Thirty Eighth International Conference on Information Systems*. Presented at the Seoul. Seoul.

Tamm, T., Seddon, P. B., Shanks, G., & Reynolds, P. (2011). How does enterprise architecture add value to organisations. *Communications of the Association for Information Systems*, *28*(1), 141–168.

The Open Group. (2009). *TOGAF® Version 9*. Van Haren Publishing.

The Open Group ArchiMate Forum. (2016, June). The Open Group ArchiMate® Forum Landing Page | The Open Group. Retrieved May 30, 2018, from http://www.opengroup.org/subjectareas/enterprise/archimate

van der Linden, D., & Van Zee, M. (2015). Insights from a Study on Decision Making in Enterprise Architecture. *In Short Paper Proceedings of the 8th IFIP WG 8.1 Working Conference on the Practice of Enterprise Modeling (PoEM)*, 21–30.

van der Raadt, B., Schouten, S., & Vliet, H. van. (2008). Stakeholder Perception of Enterprise Architecture. In R. Morrison, D. Balasubramaniam, & K. Falkner (Eds.), *Software Architecture* (pp. 19–34). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-88030-1_4

Vessey, I. (1991). *Cognitive fit: A theory-based analysis of the graphs versus tables literature*. *22*(2), 219–240.

Vessey, I., & Galletta, D. (1991). Cognitive Fit: An Empirical Study of Information Acquisition. *Information Systems Research*, *2*(1), 63–84. https://doi.org/10.1287/isre.2.1.63

Vieira, R., Cardoso, E., & Becker, C. (2014, September). *A Traceable Maturity Assessment Method Based on Enterprise Architecture Modelling*. 245–253. IEEE. https://doi.org/10.1109/EDOCW.2014.44

Vovk, A., Wild, F., Guest, W., & Kuula, T. (2018). Simulator Sickness in Augmented Reality Training Using the Microsoft HoloLens. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 209. ACM.

Wang, X., Love, P. E. D., Kim, M. J., & Wang, W. (2014). Mutual awareness in collaborative design: An Augmented Reality integrated telepresence system. *Computers in Industry*, *65*(2), 314–324. https://doi.org/10.1016/j.compind.2013.11.012

Weiss, S., Aier, S., & Winter, R. (2012). Towards a reconstruction of theoretical foundations of enterprise architecture management. In *Information systems: crossroads for organization, management, accounting and engineering* (pp. 461–468). Springer.

Winter, R. (2011). *Business Engineering Navigator: Gestaltung und Analyse von Geschäftslösungen "Business-to-IT."* Berlin Heidelberg: Springer-Verlag.

Winter, R., Legner, C., & Fischbach, K. (2014). Introduction to the special issue on enterprise architecture management. *Information Systems and E-Business Management*, *12*(1), 1–4. https://doi.org/10.1007/s10257-013-0221-4

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*(Supplement C), 41–49. https://doi.org/10.1016/j.compedu.2012.10.024

IV

CONCEPTUALIZING EA CITIES: TOWARDS VISUALIZING COMPLEX ENTERPRISE ARCHITECTURES AS CITIES

Abstract

Enterprise Architectures (EAs) are commonly visualized in form of text, numbers, tables, graphs, models, and diagrams. These information visualization types are used to describe complex EAs in today's organizations but oftentimes lack an intuitive representation. In this paper, we provide another form of EA visualization utilizing the city metaphor. This spatial metaphor is suitable for visualizing complex information structures and potentially allows easy understanding of EAs, especially for non-IT staff. Based on a literature review and three rounds of open card sorting, we mapped eleven classes of EA objects to city elements. Our results enabled us to develop a formal language that allows an implementable and human-readable specification of various views, which we call EA City. We created an early stage 3D EA City prototype to demonstrate its applicability. Our model provides a solid foundation for further work on the city metaphor in the context of EA visualization.

Keywords: *Enterprise Architecture Management, Enterprise Architecture Visualization, City Metaphor*

This article was co-authored with Tim Brée, Jens Gulden, and Laurenz Bredenfeld. An earlier version of this article was published in Proceedings of the 27th European Conference on Information Systems (ECIS):

Rehring, K., Brée, T., Gulden, J., & Bredenfeld, L. (2019). CONCEPTUALIZING EA CITIES: TOWARDS VISUALIZING ENTERPRISE ARCHITECTURES AS CITIES. In *Proceedings of the 27th European Conference on Information Systems* (ECIS). Stockholm, Sweden.

Table of Contents

List of Figures

List of Tables

1 Introduction

In the digital world it is increasingly important to react quickly to environmental changes and new business needs in order to stay competitive. Hence, understanding, developing, and managing organizational complexity is critical to a company's success (Nightingale & Rhodes, 2004, p. 1). A suitable approach to understand the entire organizational landscape and its interrelations, manage its complexity, drive transformation projects, and support innovation is the application of Enterprise Architecture Management (EAM) (Lange & Mendling, 2011, pp. 5–6). EAM provides methods and tools to establish, maintain, and develop Enterprise Architectures (EA), which are representations of time-dependent fundamental structures and relationships between business and IT components of organizations (Tamm, Seddon, Shanks, & Reynolds, 2011, p. 142; Aier, Gleichauf, & Winter, 2011, p. 645). In previous years, many researchers as well as practitioners described EAs e.g. in form of text documents, matrices, layers, bar charts, or pie charts (Roth, Zec, & Matthes, 2014, p. 46) and consisting of EA objects like processes, applications, and computer hardware (The Open Group, 2018). Understanding complex information by employing specific visualizations is important for effective EA analysis.

Following Baker et al. (2009, p. 540), individual sensemaking of complex information using information visualization is based on four aspects: the support of basic visual perceptual approaches, the support for Gestalt qualities, consistency with existing knowledge, and support for analogical reasoning. Although current EA visualization types take the first three aspects into account (e.g. Roth et al., 2014), metaphors, which are facilitators of analogical reasoning (Johnson & Lakoff, 1980), are used to a limited extent. This comes as a surprise, as the use of metaphors "can make the structure of information systems easier to understand and therefore easier to use" (Dieberger & Frank, 1998, p. 597) - a desired objective of each EA visualization.

One specific type of metaphors makes use of spatial patterns, locations and movements to transport meaning (Gärdenfors, 2000). These spatial metaphors are able to activate cognitive capabilities of the human mind that enable spatial orientation and a sense for bodily movement, as well as the perception and understanding of conceptual meaning (Johnson & Lakoff, 1999; Lakoff, 1987). This way of conveying knowledge is highly efficient, as it allows for much faster and parallel cognitive processing of sensual impressions than the use of language (Humphreys & Bruce, 1989). The reason for this advantage lies in the human's cognitive capabilities for handling movements, distances, locations, etc., which are far more underlying to the cognitive apparatus than conceptual thinking.

Using the metaphor of a city, its elements, and well-known spatial arrangements in a city to describe complex facts thus is a promising way to facilitate spatial metaphors. The city metaphor has been applied to visualize complex information e.g. for software code visualization

(Wettel & Lanza, 2007; Merino, Bergel, & Nierstrasz, 2018), representation of the Internet (Dieberger & Frank, 1998; Sparacino, Wren, Azarbayejani, & Pentland, 2002), multimedia files (Derthick et al., 2003; Chiu, Girgensohn, Lertsithichai, Polak, & Shipman, 2005), application architectures (Soares, 2008), or IS governance rules (Guetat & Dakhli, 2015). As a result, the use of spatial metaphors seems to be suitable for visualizing complex information structures, which lets us assume it is also suitable for visualizing EAs. This use case nonetheless has not been implemented yet, even though some mention its applicability (e.g. Panas, Berrigan, & Grundy, 2003, p. 5). Furthermore, most authors do not provide reasons for the assignment of city elements to the objects under investigation (e.g. software). Therefore, our research goal is to develop a holistic description of EAs applying the city metaphor based on empirical data. We state the following research question: *How can Enterprise Architectures be modeled using the city metaphor?*

Based on the existing body of knowledge about implemented EA objects in organizations as well as discernible city elements, we applied card sorting to explore people's mental models of how they would perceive a city describing complex EAs. Through three rounds of card sorting with 14 participants experienced in the area of EA, we developed a comprehensive model that mapped EA objects to city elements. Our final model contains eleven classes of EA objects and equivalent city elements. Thus, our paper contributes to research in that it provides a terminology for describing EAs using commonly known concepts from the city metaphor. Further, we propose a method for collecting data through card sorting and develop a formal language that describes our results.

This paper proceeds as follows: section 2 presents previous research about the use of metaphors in IS research and the city metaphor in particular. In section 3, we describe our research approach in detail. Section 4 summarizes the mapping between EA objects and city elements as well as the development of a formal language. Section 5 then outlines the applicability of this approach and the development of an exemplary prototype. We conclude our paper in section 6, discussing the results and providing avenues for future research.

2 Theoretical Foundation

2.1 Uses of Spatial Metaphors for Enterprise Architecture

In general, the application of metaphors is not a new concept in IS and management research. The well-cited book *Images of Organization* by Morgan (1986) suggests various metaphors to describe organizations in terms of organism, brain, culture, political system, psychic prison, flux and transformation, as well as instrument of domination. Other authors propose additional metaphors e.g. for Information System (IS) development projects (Oates & Fitzgerald, 2007), organizational (IT) projects (Winter & Szczepanek, 2009), or IS development in general (Kendall & Kendall, 1993).

Most approaches share more or less similar motives in that they aim to represent a certain system in a meaningful and easily understandable way that provides direction, insights, and methods for analysis and design (Alter, 2013, p. 1). The growing data volumes and consequently available information raise the need for effective visualizations and data analysis techniques of complex structures that can be addressed by metaphors (Andrews, 1995, p. 97). Specifically spatial metaphors, which organize objects in space, seem to address this demand well, as they allow users to understand and effectively navigate through visualized dynamic information structures by using the distinct space-related cognitive abilities of humans (Dieberger, 1997, p. 2; Chiu et al., 2005, p. 1). Moreover, it is easy for humans to remember spatial environments (Sparacino et al., 2002).

Similar to use cases including spatial metaphors, EAs can benefit from applying them as well. EAs commonly represent time-dependent structures and relationships containing numerous business and IT components (Tamm et al., 2011, p. 142; Aier et al., 2011, p. 645). These requirements fit well with the city metaphor. It provides a rich set of familiar concepts like city districts (Wettel & Lanza, 2007, p. 2), various kinds of buildings (Chiu et al., 2005, p. 1), and roads (Guetat & Dakhli, 2009, p. 1381f) that can be mapped with EA objects (Chiu et al., 2005, p. 1). In addition, most viewers know immediately how to navigate through a city (Andrews, 1995, p. 98; Sparacino et al., 2002, p. 4), which enables them to engage with complex structures like EA. The city metaphor also eases communication and collaboration due to the known concepts (Dieberger, 1997, p. 4). In the following subchapter, we want to take a deeper look at the application of the city metaphors in information system research.

2.2 Uses of City Metaphors in Information Visualization

Multiple authors have already proposed the application and suitability of the *city planning* or *city landscape metaphor* to visualize complex information. In the following, we provide a brief overview.

Early attempts focus on the gaining complexity of the Internet. Andrew (1995) is one of the first authors who applied the city metaphor to visualize content from the Internet. As represented in Figure IV-1, he developed a static 3D map of the City of Graz including existing landmarks with embedded hyperlinks that direct a user to further information. In the same vein, Dieberger (1997) and Dieberger and Frank (1998) developed a text-based virtual city, which consists of districts that encompass buildings including floors, rooms, and doors. Their implementation is meant to support users in retrieving and re-finding information in a natural way. The ability of humans to remember spatial environments motivated Sparacino and Wren (2002) to develop a body gestures-controlled web browser that dynamically displays content from the Internet in form of a city. As shown in Figure IV-2, the city's districts represent topics, whereas the facades of buildings represent individual content.

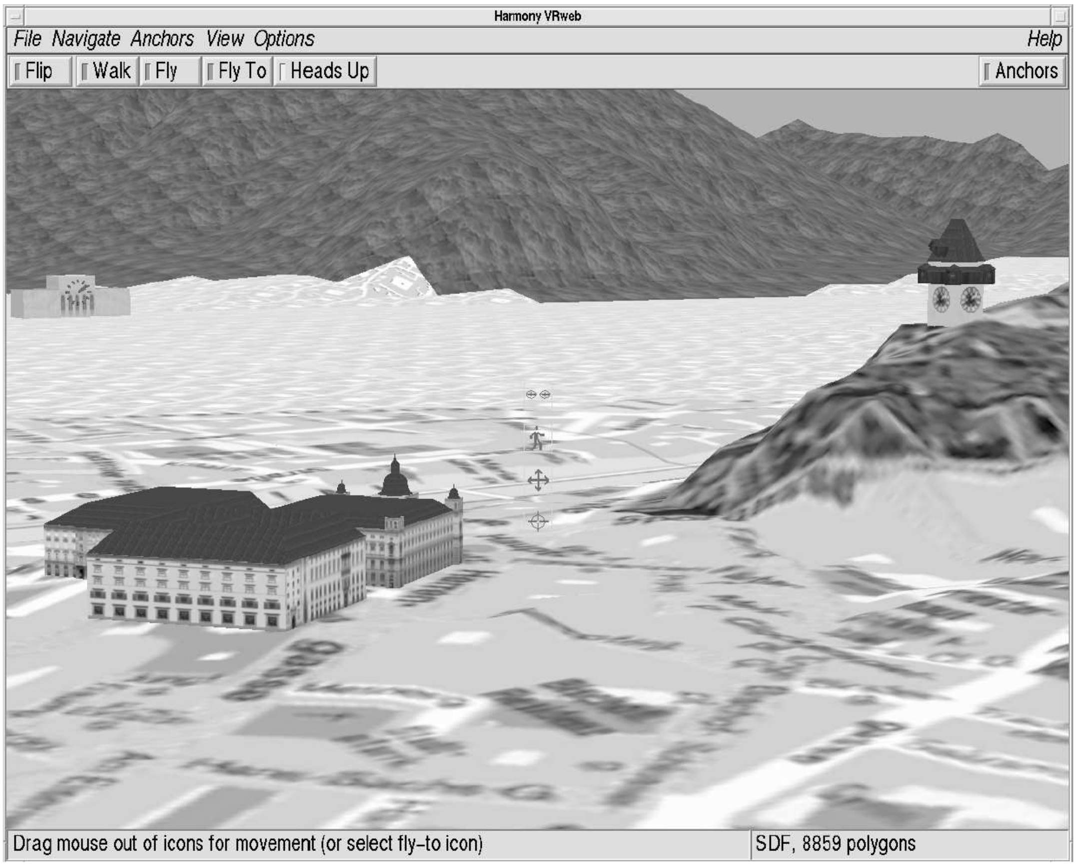


Figure IV-1. 3D map of the City of Graz with links to further information in the Internet by Andrew (1995)

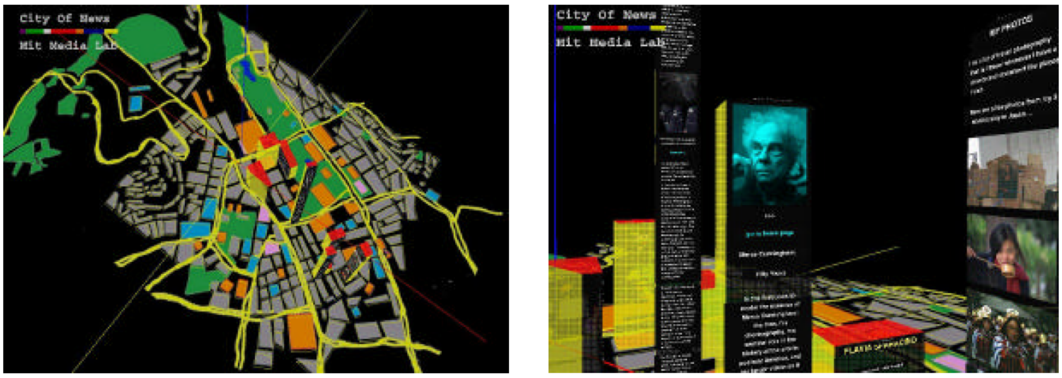


Figure IV-2. "City of News" by Sparacino and Wren (2002) - Left: Arial view / Right: Detail view

Technology advantages enhance the consumption of multimedia documents from the Internet. A work by Derthick et al. (2003), as seen in Figure IV-3, describes the application of the cityscape metaphor to show contextual similar videos. Commonly used thumbnails of videos as well as text results of similar documents seem to be improper to provide useful overviews of video libraries. Therefore, they define buildings as perspectives on topics that dynamically change depending on the interest of a user. Flying and zooming enables a user to change the view on the city. The use of spotlights and different colours highlights objects of interest. Chiu et al. (2005) implemented a treemap-based 3D city called MediaMetro as shown in Figure IV-4. The buildings are placed on a grid layout and display relevant frames from single multimedia documents on its facade, whereby the most important frame is located on top of the building.

Figure IV-3. “Cityscapes” visualization by Derthick et al. (2003) - Left: Conceptual model / Right: Realistic representation

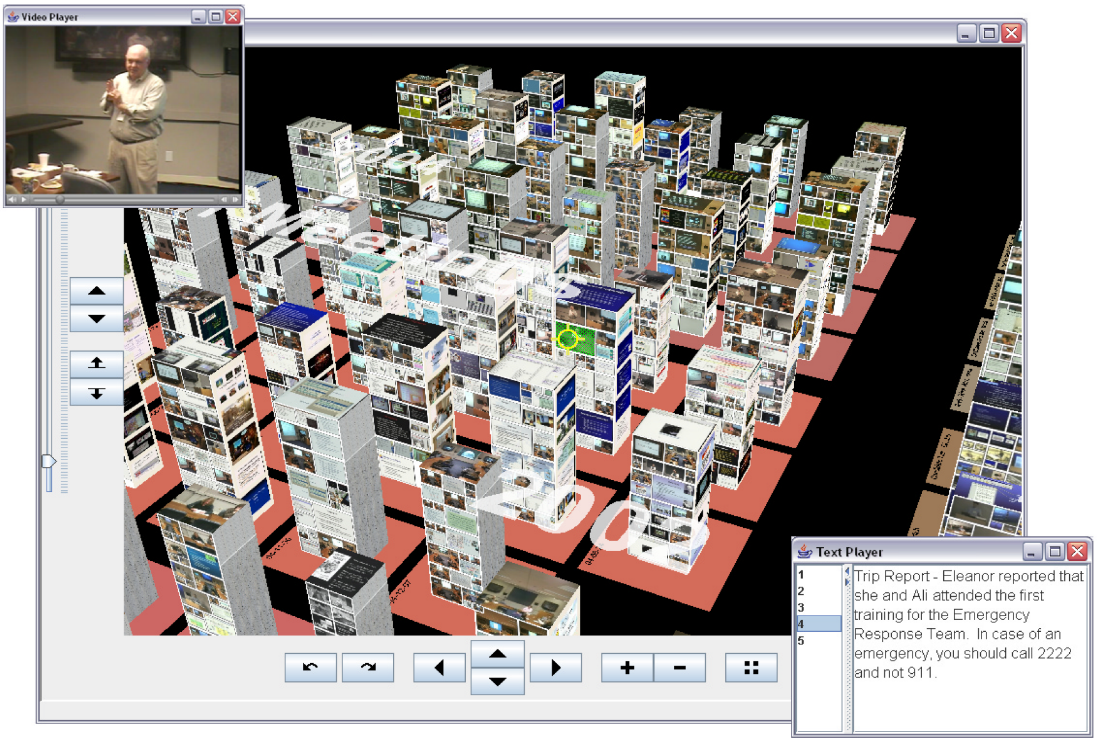


Figure IV-4. Visualization of "MediaMetro" by Chiu et al. (2005)

A popular area of the application of the city metaphor comes from software code visualizations. Previous work mainly focuses on representing software packages and classes in form of a city. Panas et al. (2003) created realistic-looking 3D cities that represent a java code package using various city elements like streets, water, clouds, trees, and street lamps, as presented in Figure IV-5. Moreover, the appearance of buildings depends on quality criteria e.g. old or muddy buildings represent improvable code, high costs, and high risks. Moving cars show paths between origin and destination objects and their speed and type indicate performance and priorities of method calls. The authors also mention the possibilities of adding business processes, control flows, and data-flow or changing the appearance of the entire city depending on analysis results.

Figure IV-5. 3D city representing software code including additional information by Panas et al. (2003)

Langelier et al. (2005) propose a city visualization that supports the analysis of large-scaled software code. Boxes represent software classes and can differ in terms of colour, size, and twist. Pre-defined software metrics can be selected to change the appearance of the visualization. Another well-cited visualization of software code illustrated in Figure IV-6 following the city metaphor is developed by Wettel and Lanza (2007, 2008). Their goal is to identify software design problems. For this, they map software classes to buildings and cluster buildings to districts that represent software packages (Wettel & Lanza, 2007, p. 1). The height of the buildings depends on the number of functions and the width on the number of attributes within the classes. An evaluation of the visualization revealed a statistical improvement of task correctness and a decrease in task completion time (Wettel, Lanza, & Robbes, 2011, p. 558). Fittkau et al. (2015) use a Virtual Reality (VR) head-mounted display (HMD) to visualize software code with the goal of promoting easy navigation and improved understanding. Their implementation represents software packages as boxes that can be closed and opened. In a similar manner, Capece et al. (2017) also developed a VR-based city that represents software packages in which different sizes and colours of buildings represent software classes and districts represent software

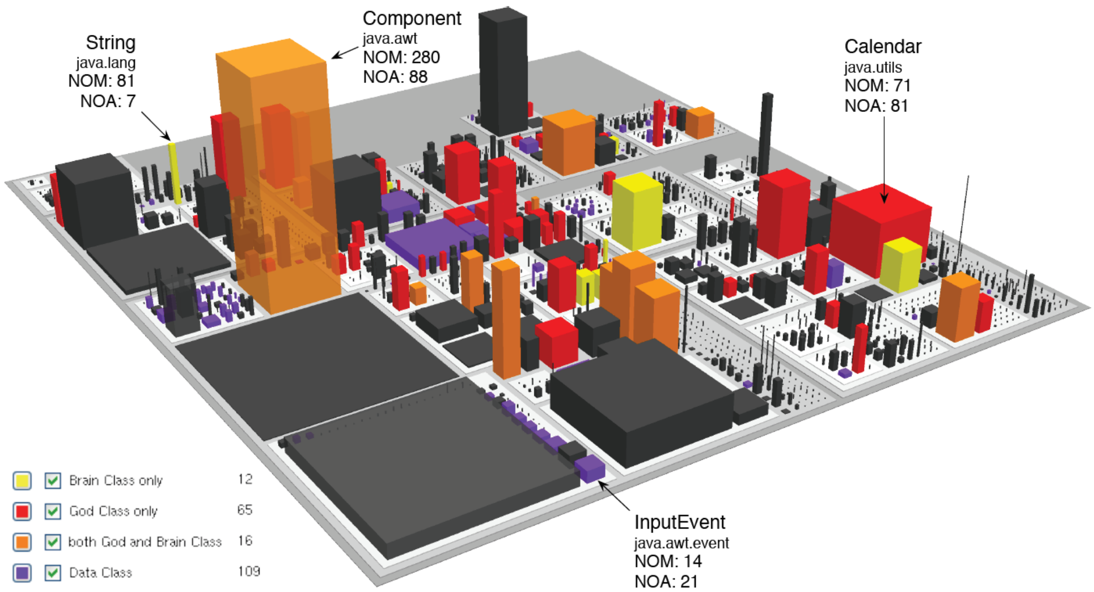


Figure IV-6. Software code visualization by Wettel et al. (2011, p. 558)

packages. In the same year, Merino et al. (2017) also developed an interactive software visualization tool using VR, where buildings symbolize software classes and districts represent software packages. A subsequent evaluation with six participants revealed increased navigation by allowing users to physically walk and inspect the source code (Merino et al., 2017, p. 4). In a recent work, Merino et al. (2018) implemented the same city model in an Augmented Reality (AR) environment using an HMD and evaluated its effectiveness and emotions as shown in Figure IV-7. In a controlled experiment with nine participants, they found out that

AR eases navigation and reduces occlusion. Souza et al. (2012) implement an AR-based software evolution visualization. They used a webcam on a laptop and a piece of paper, a so-called marker, to display a city model on a monitor. Users can rotate that paper to change the perspective of the city on the monitor. Like existing approaches, buildings show software classes and district packages, whereas the size and colour of buildings display the evolution of classes in terms of their number of changes.

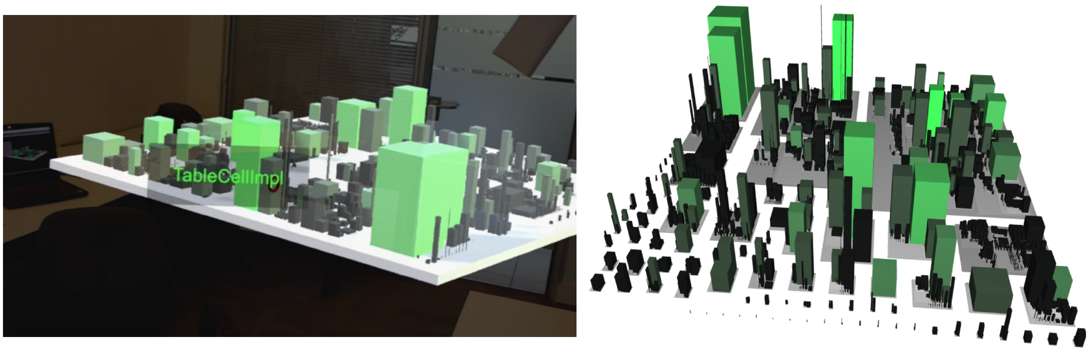


Figure IV-7. Software code visualization by Merino et al. (2018) – Left: in AR / Right: 3D model

The application of the city metaphor can also be recognized in other EA-relevant areas. As represented in Figure IV-8, Soares (2008) applied the city metaphor to visualize application architecture. The proposed conceptual model defines blocks as systems of applications and buildings as single applications that contain several modules. Different positions, colours and sizes of buildings are used to present further information. Another example is provided by Guetat and Dakhli (2009) who linked EA and information systems governance using the city landscape metaphor. For this, they defined a variety of districts, areas and blocks within the city, in which applications are classified. Architecture principles and rules define the exchange between these applications and related objects as well as “prioritize, manage, and measure the information systems” (Guetat & Dakhli, 2009, p. 1382). Figure IV-9 shows their concept of visualizing EA information in districts.

Figure IV-8. EA representation as “the cITy” by Soares (2008) - Left: Arial view / Right: Detail view

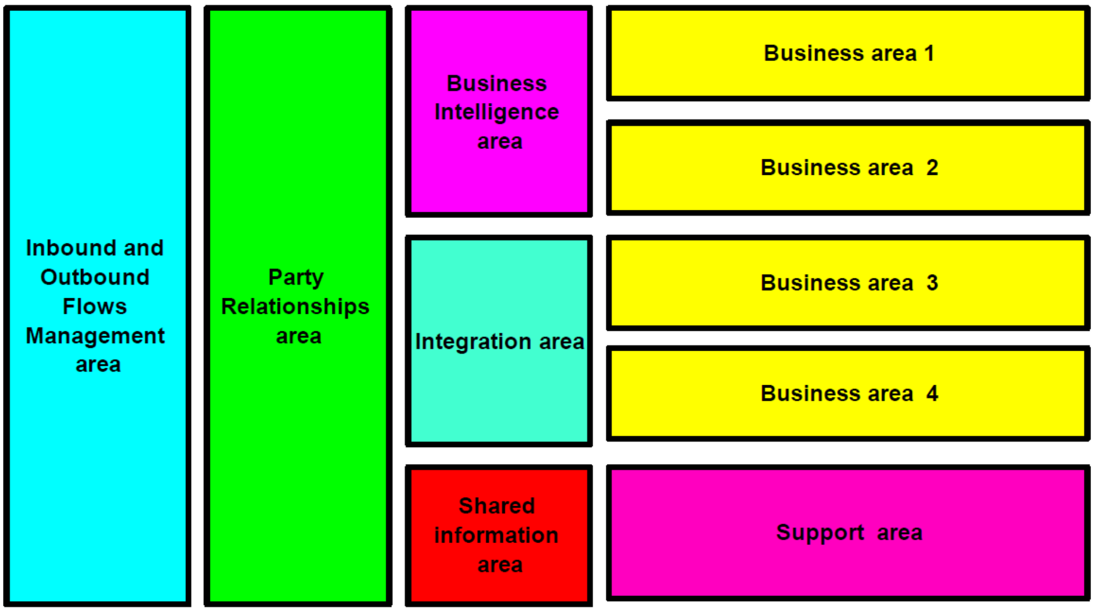


Figure IV-9. Districts, areas and blocks representing an EA by Guetat and Dakhli (2009)

3 Research Design

Our goal is to create a representation of EAs in form of a city. We acknowledge that every person perceives cities differently, hence, we propose card sorting as a suitable research method for (a) exploring people's mental models (Schaffer & Fang, 2018, p. 1) of how they perceive a city describing EAs and (b) developing a generally acceptable representation of EA in form of a city. For this, we followed the card sorting approach described by Moore and Benbasat (1991) and utilized the description structure by Schaffer and Fang (2018). The following Figure IV-10 provides an overview of our research approach.

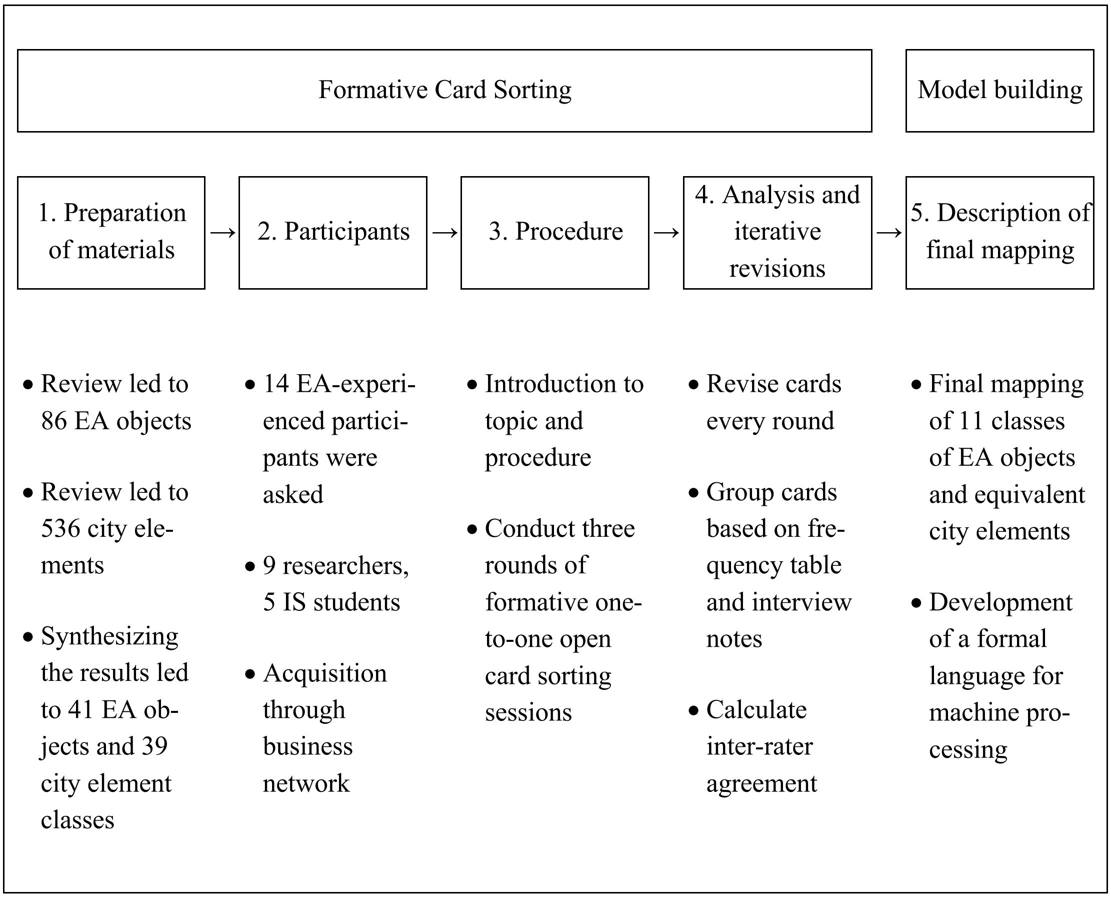


Figure IV-10. Research approach influenced by from Schaffer and Fang (2018)

3.1 Development of a EA Visualization Using Card Sorting

Preparation of materials

We conducted two broad literature reviews to identify relevant EA objects and city elements. For the former, we first derived EA objects from the commonly accepted and industry-independent EAM implementation framework TOGAF 9.2 (The Open Group, 2018). The meta model in TOGAF provides an overview of relevant abstract entities and relationships of EAs. To ensure the development of a useful and applicable EA representation for EA stakeholders, we utilized the four layers of the meta model as an analysis framework in a subsequent literature review and mapped the entities from the meta model to identified EA objects implemented in organizations. The layers are business architecture, application architecture, data architecture, and technology architecture. This is a necessary step as the meta model consists of abstract entities (e.g. logical technology component) that might contain concrete objects from real world (e.g. servers, databases). In addition, we considered all sources that named and described implemented EA objects either from case studies or from conceptual discussions informed by real-world organizational settings. This approach, as presented in Figure IV-11, allowed us to identify relevant EA objects for a wide range of stakeholders. The results of the final analysis are presented in the appendix. Analysing 34 relevant articles from the senior basket of journals, AISEL database as well as IEEE published between 2009 and 2018 revealed 86 potentially relevant EA objects. We further synthesized the results to 41 unique EA objects that were named and briefly described on single cards.

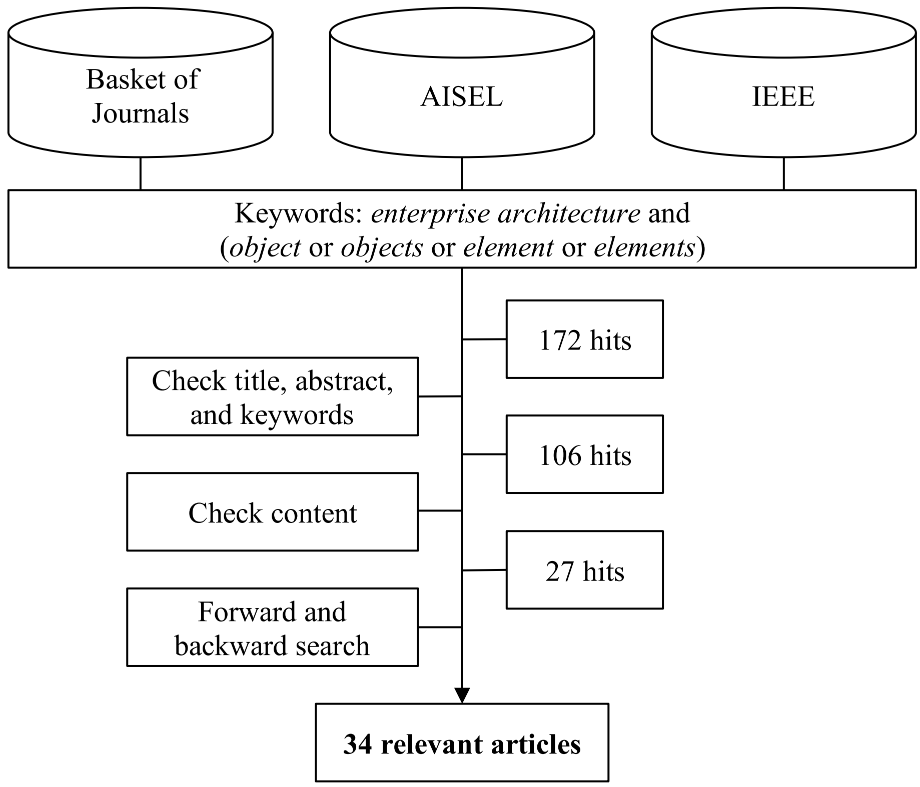


Figure IV-11. Literature search results for EA visualization objects

We conducted another literature review to identify potentially relevant city elements. We based our analysis on the five well-cited generic elements of cities defined by Lynch (1960), which are paths, edges, districts, nodes, and landmarks. This helped us to structure our review and keep track of the important aspects of a city. We considered all articles where aspects of cities were the subject of discussion. After analysing 41 papers from ScienceDirect and IEEE as well as seminal books, we identified 536 (partly redundant) city elements that we grouped into 39 distinctive city element classes like educational buildings, roads, and pipes. This step is needed as it reduces the number of possible elements for easier mapping. The results of this step are present in the appendix. We printed cards where all classes of city element (e.g. industrial plants) were named as well as all identified specific city elements (e.g. factory, electric power plant, and refinery). This approach, as presented in Figure IV-12, ensured a more abstract discussion on city elements instead of focusing too much on trivial details. The cards describing the city elements were coloured differently compared to the cards about EA objects.

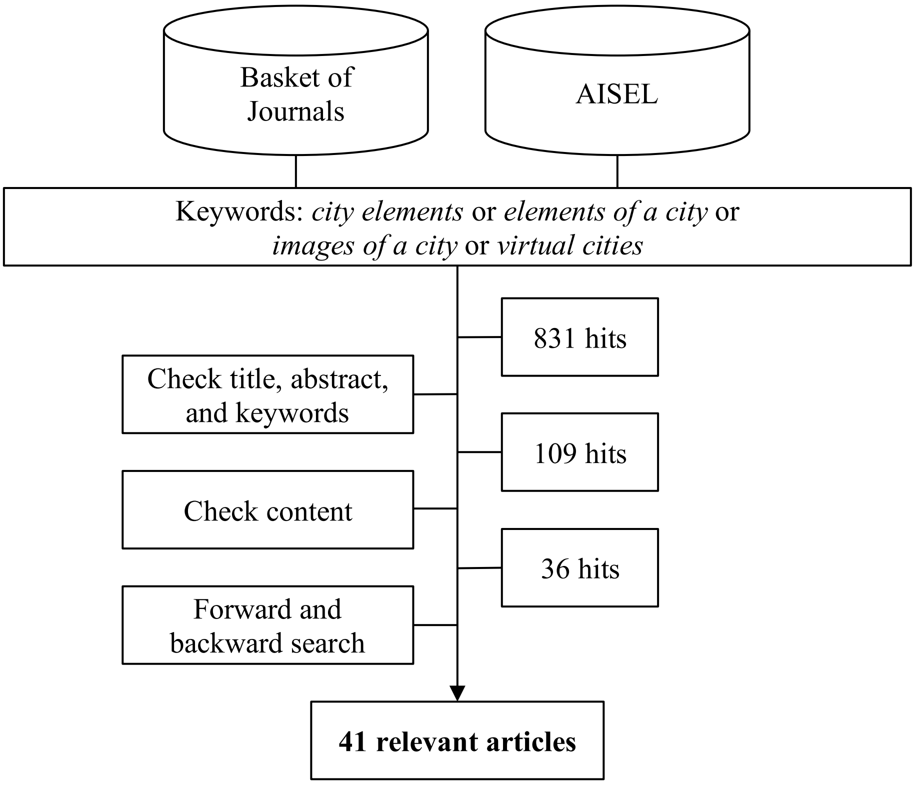


Figure IV-12. Literature review results for city objects

Participants

Developing new forms of visualizations requires creativity but also an understanding about the topic of interest to ensure applicability. By questioning potentially appropriate candidates, we ensured that only participants with prior knowledge about EA participated. We recruited researchers, practitioners, as well as students to consider a wide range of possible perceptions about EA City visualizations. In total, 14 people participated, whereby nine were researchers and five students. We acquired each participant through the author's professional network.

Procedure

We conducted individual observed open card sorting sessions for two reasons. First, we could ask further questions that helped us to understand the rationale behind the mapping. Second, we did not alternate between unobserved and observed sessions to avoid potentially incomparable results (Denford & Schobel, 2018). Before each card sorting session started, one author introduced the topic, described the rules and explained all EA objects and city elements briefly.

Further, we asked the participants to imagine a possible and general visualization of any complex EA in form of city. We then asked the participants individually to associate the prepared cards describing explicit real-world EA objects (e.g. business unit, computer, customer record, application component) with cards describing classes of city elements (e.g. industry plants, streets, pipes) where they found it fit the most. Participants could create one-to-one but also many-to-many relationships. We provided sticky notes if they wanted to add or modify EA objects or city elements. Cards could be assigned to a category called “I don’t know” if a mapping was not possible for them. All card sorting sessions were conducted individually and supervised by one author to reduce external influences. Questions by participants were answered during the card sorting; however, no hints or advice were given. Afterwards, the supervisor asked why a participant mapped certain cards together and took notes. This helped us to get a further understanding of the perceived image of an EA City by each participant.

We applied three rounds of open card sorting sessions with different participants in each round. Two authors performed the first round. This round helped us to go through the process of mapping by ourselves and to refine definitions and examples where necessary. Seven researchers and one student participated in the second round and two researchers and four students in the third and last round. The first two rounds were performed using printed cards, whereas the last round was performed using a computer-based spreadsheet for efficiency reasons. Following Denford and Schobel (2018, p. 6), the different mapping methods (manual vs. computer-aided) seemed without effect on the results as long as it was an observed approach.

Analysis and Iterative Revisions

In order to improve the descriptions on our cards, reduce the number of EA objects, and to provide a parsimonious mapping table, we analysed the results and revised all cards after each round of card sorting. Based on our notes, we rephrased names and descriptions, and used examples to improve each card and reduce ambiguous meanings. Newly proposed EA objects and city elements were added to the stack of cards or linked to existing cards to avoid redundancies. Afterwards, we analysed the results. For this, we created a matrix showing the frequency of used relationships between EA objects and city elements. Pair-by-pair comparisons supported us, first, in identifying often-considered mapping relationships and, second, grouping of EA objects with similar visualization mappings. We considered grouping EA objects whenever these objects shared at least 50% of the same mapping. This is consistent with previous works, which claim that an acceptable validity level is reached when half of the judges sorted the cards in the same category, especially for early stage research projects (Nunnally, 1967, p. 226; Urbach, Smolnik, & Riempp, 2009, p. 8; Corbett & Idrissi, 2017). We initially planned another closed card sorting session; however, we achieved a sufficient degree of consistency except for the two TOGAF objects Value Stream and Course of Action. We dropped both elements as the mapping of them was generally inconsistent and we did not expect to identify a commonly acceptable visualization. Furthermore, three classes of EA objects show similar mappings to city elements, but no specific and unique city element could be identified. To build a consistent representation, we then chose the most appropriate city element visualization that fits to the remaining city elements. Finally, we identified eleven groups of EA objects with similar mapping results. We described them briefly as shown in Table IV-1.

3.2 Formalizing the Description of EA City Visualizations

The domain analysis resulted in a set of suggested concepts from the TOGAF framework and a range of suitable visualizations to represent the domain concepts. As a contribution to the design of an end-user application in which EA analysis scenarios are rendered and made accessible to human users, the definition of a formalism is required. It allows to express the information needs of a given analysis scenario, in a way that it can automatically be processed to render a city metaphor visualization as desired. Without such an automation, EA City visualizations could not be created efficiently with reasonable effort. EA analysis tasks in focus are, e.g., to "identify all the EA objects that belong to the sales unit as well as the dependencies to other units". This natural-language statement is to be formulated in such a format that all information which is required to render EA City visualizations is given in a software processable way. This incorporates stating the objects of interest and their selected characteristics which are to occur in the visualization, as well as decisions on which city element to choose when populating the EA City landscape. Formally speaking, there must be a mechanism to specify the objects of interest in an EA analysis scenario together with the visual representation by which they are to be shown as part of the EA City visualization.

At this point in the design process we care about identifying required information objects and formal structures needed to describe EA City visualization. It is not yet the aim to reason about a user interface which allows for easy and efficient formation of EA Cities with an ecologic interface and little cognitive load. Therefore, the following considerations can remain abstract, without taking usability aspects into account.

We define a formal language that allows for the formal, yet human-readable, specification of views. Sentences in this language describe analysis scenarios and EA City visualizations in terms of a declarative language that allows to specify all required content and projection parameters of an EA City visualization. The language aims at expressing domain objects of interest and relationships among them on the one hand, and on the other hand corresponding visual metaphors for representing the domain objects in the topology of a city with the available visual representation means elaborated in the following section.

4 The Development of an EA City

4.1 Elements of EA City

The final eleven classes of EA objects from the card sorting and revision are presented in Table IV-1. Each class of EA objects is described and includes the sorted city elements.

Table IV-1. Description of the EA objects and the mapping to city elements

EA Objects	Description	City Elements
BUSINESS ARCHITECTURE		
Business actor, actor, role, person	Someone that communicates and interacts with others. This can be a real person (Bakar, Harihodin, & Kama, 2016a, p. 1) or an organizational role of a person (Cardoso, Almeida, & Guizzardi, 2010a, pp. 340–341; The Open Group, 2012).	Human (e.g. pedestrian)
Laws, regulations, business rules, contracts, SLAs, control	All laws, regulations, and business rules (The Open Group, 2018), as well as arrangements like contracts and SLAs (Alwadain, Fielt, Korthaus, & Rosemann, 2011b, p. 8), which must be obeyed.	Government building (e.g. administration, city hall, parliament)
Business function, function, business capability, business service	The provision and delivery of specific skills and know-hows (El Sawy & Pavlou, 2008a, p. 140) that describe the offering (Ramljak, 2017a, p. 3) and support the achievement of a goal (The Open Group, 2018).	Industrial building (e.g. factory, electric power plant, refinery)
Event	Internal or external occasion that causes any form of change in the organization (The Open Group, 2018). This could trigger, e.g., business processes.	Conference center (e.g. convention center)
Business goal, strategic goal, objectives, driver	The description of strategic and business goals, their milestones, driving forces as well as their intended direction and focus of the organization (Ramljak, 2017a, p. 2; Santana, Souza, Simon, Fischbach, & Moura, 2017a, p. 10; The Open Group, 2018).	Monument (e.g. Eiffel Tower, Brandenburg Gate, Arc de Triomphe)

Organizational unit, business unit	A self-contained unit including internal and external stakeholders, partners, and organizations as well as further resources with individual goals, objectives and measures (The Open Group, 2018; Rohloff, 2011a, p. 779).	Office building (e.g. bank, office tower, headquarters)
Business process, process	A predefined sequence of activities that creates any value to an external or internal customer (Dick Quartel, Engelsman, Jonkers, & Van Sinderen, 2009, p. 4; The Open Group, 2018; Whittle & Myrick, 2004, p. 58).	Street (e.g. road, highway, path)
Product	An output of a business that is likely created through the execution of business processes (The Open Group, 2012, 2018).	Shopping mall (e.g. mall, department store, shop)
Measurable indicator, KPI, service quality	Functional and non-functional measurable indication of service delivery, which allows the assessment of quality and success and eventually the performance of EAs through KPIs (Ganesan & Paturi, 2009a, p. 3; Papazoglou, 2003a, p. 4; The Open Group, 2018).	Billboard*
APPLICATION ARCHITECTURE		
Software application service, application service, software, application, business application, software application component, application component	Computer-based information system that provides functionality to end users (Riempp & Gieffers-Ankel, 2007, p. 361). This can be (software) application services (Cardoso et al., 2010a, p. 340; The Open Group, 2012), applications (Alonso, Verdún, & Caro, 2010a, pp. 4–5), software (Farwick et al., 2010, p. 35), or components and functions of applications (Veneberg, Iacob, Sinderen, & Bodenstaff, 2014a, p. 26).	Residential building (e.g. apartment building, house, bungalow)
DATA ARCHITECTURE		
Business object, data object, customer record, file, document, script, records	A general meaningful piece of information. Any business-related data objects like customer records (The Open Group, 2012, pp. 54–55) as well as all of their individual data units and values (The Open Group, 2018).	Transport vehicle (e.g. car, truck)

Database, database table	A structured or unstructured collection of data elements (The Open Group, 2012, pp. 54–55).	Parking (e.g. parking space, parking meter, off-street parking)
TECHNOLOGY ARCHITECTURE		
Platform service, infrastructural service	The composition of technical capabilities like computers, communication devices, and related software systems forming an infrastructure service (Cardoso et al., 2010a, p. 340), also known as platform service (Hess, Lautenbacher, & Fehlner, 2013a, p. 196; Santana et al., 2017a, p. 11), that enables the delivery of applications (The Open Group, 2018).	Gas station*
Computer, server, client workstation, communication device	Necessary classes of implemented physical hardware to provide and operate infrastructural services (Cardoso et al., 2010a, p. 340; The Open Group, 2018).	Single fuel pump*
Network	A physical communication path between two and more devices or other networks (The Open Group, 2012, p. 64).	Pipes (e.g. water supply, electricity supply)
* Self-assigned objects, as no consistent mapping could be identified		

4.2 Elements of EA City Visualization Language

A formal language that serves the above described purpose must allow to express three main elements of knowledge that are required to render a complete EA city visualization. At first, the language demands for the flexibility of defining objects of interest from a source domain of discourse, which in this case are the identified EA objects presented in previous subsection. Secondly, the visual metaphors that can be used to populate an EA city scenario need to be specified, together with optional parameters that can configure their visual appearance. Finally, for each city metaphor visualization the decisions, which EA objects are to be represented by which visual metaphor has to be expressed with the language. The first set of knowledge elements that describe the source domain can be provided by method designers, who configure the EA city visualization approach to be used with the EA analysis domain described by TOGAF concepts. The second set of knowledge elements, which specify available visual metaphors is depending on the underlying rendering engine, which is configured with the language. Thus, the developers of the rendering procedure provide the metaphor description. The third part, the mapping of domain elements to visual metaphors, is the most important one, because each of these mappings makes up the description of a different EA city visualization. These mappings will be created by EA analysts when applying the approach, which means the language constructs to express these mapping should be easy to understand and apply.

We designed a formal textual language, which adheres to the identified requirements. In the current version of the language there are three kinds of metaphors which can be used in combination to form an EA City visualization. These are metaphors for spatial *areas*, spatial *relations*, and *elements* that are located in areas and optionally placed along relations. When specifying mapping for EA Cities, domain elements can be associated with metaphors of each of these kinds, and the resulting mapping definitions will be interpreted by a rendering engine to organize visual elements in a 3D projection accordingly. Without further going into details here about the use of each language feature and the intended interpreter behavior, the EBNF-like grammar of the language is shown in the following Figure IV-13.

```
Model: name="ArchQLv0.2" "Domain:" domain+=DomainElement ("," domain+=DomainElement)* "Metaphor:" metaphor=Metaphor ("City" view+=View)*;

DomainElement: name=ID;

Metaphor: ("element" elements+=MetaphorElement ("," elements+=MetaphorElement)* | "area" areas+=MetaphorArea ("," areas+=MetaphorArea)* | "relation" relations+=MetaphorRelation ("," relations+=MetaphorRelation)* )+;

MetaphorArea: MetaphorDef;

MetaphorElement: MetaphorDef;

MetaphorRelation: MetaphorDef;

MetaphorDef: name=ID ("(" parameters+=ID ("," parameters+=ID)* ")")?;

View: name=ID ":" mappings+=Mapping*;

Mapping: MappingArea | MappingElement | MappingRelation;

MappingArea: "area" (domain=[DomainElement]("(" alias=ID ")")? "as")? metaphor=[MetaphorArea]("(" parameters+=STRING ("," parameters+=STRING)* ")")? ("contains" mappings+=Mapping* "complete")? ("if" condition=STRING)?;

MappingElement: (domain=[DomainElement]("(" alias=ID ")")? "as")? metaphor=[MetaphorElement]("(" parameters+=STRING ("," parameters+=STRING)* ")")? ("if" condition=STRING)?;

MappingRelation: "relation" domainA=[DomainElement]("(" aliasA=ID ")")? "-" domainB=[DomainElement]("(" aliasB=ID ")")? predicate=STRING "as" metaphor=[MetaphorRelation]("(" parameters+=STRING ("," parameters+=STRING)* ")")? ("if" condition=STRING)?;
```

Figure IV-13. Grammar for the EA City visualization language

The first two kinds of knowledge elements required to express EA City visualizations with this language are easily stated by, at first, listing the available concepts from the source domain, and secondly the visual metaphors provided by a rendering engine together with their parameters. This basic configuration only needs to be performed once before specifying EA City visualizations. The meta-model in Figure IV-14 gives an overview on the EA City visualization language elements and the relationships among them.

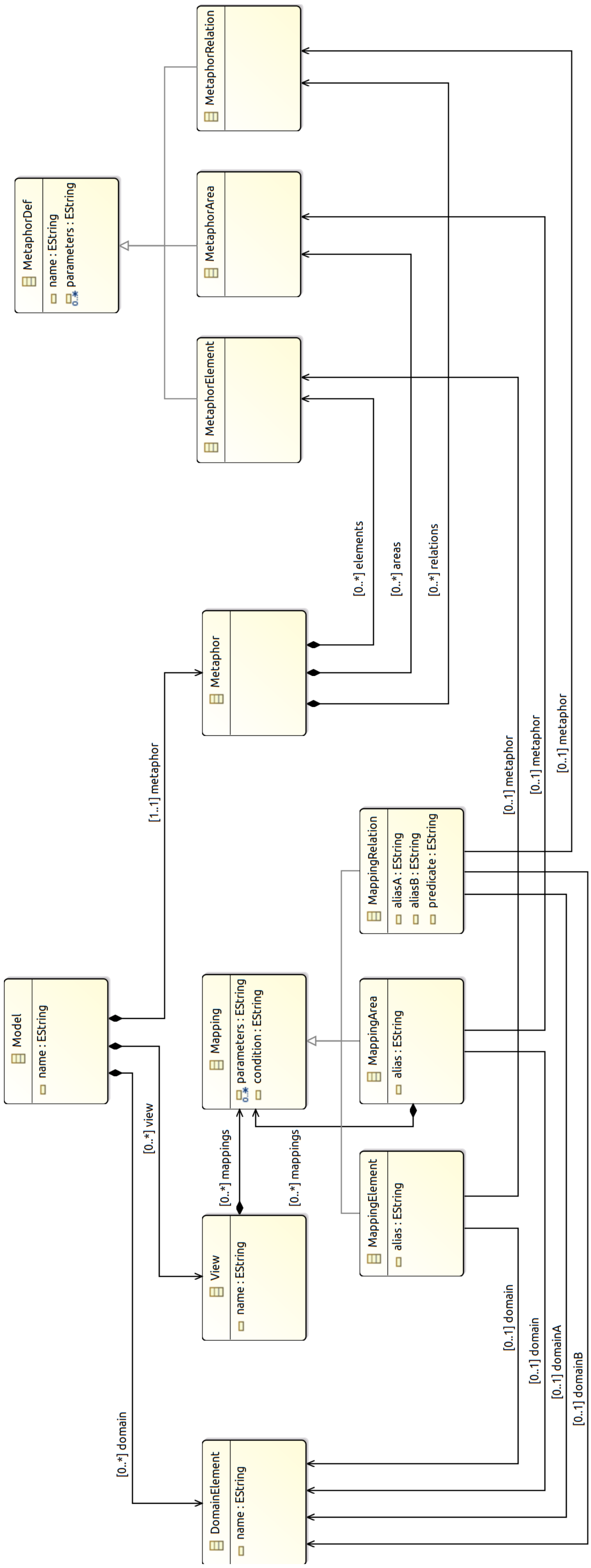


Figure IV-14. Meta-model of a formal description language for CMV

5 Exemplary Application of an EA City

In this chapter, we briefly propose a spatial ability-facing information visualization based on the city metaphor that we call EA City. This example provides an overview of selected EA objects, grouped by another EA object. Figure IV-17 is an exemplary three-dimensional EA City, which is generated by an early stage prototype of a manual implementation based on the formal language presented in Section 4.2. This prototype is developed in the game engine Unity (version 2017.2.1f1) and written in C#. As city elements, we used slightly adapted 3D models taken free of charge from the Internet. The pictured EA city was rendered in the Unity Editor running on a desktop client. In the first step of city creation, related city elements were arranged to form rectangular districts. All districts received a border-strip which enables the possibility to display streets when the compiled use case needs it. The city elements are located along this border to allow a connection through these streets. In the last step, the districts were arranged next to each other and if they share processes, they were linked by streets.

For the exemplary case, we assumed a likely EA use case, where a sales unit manager wants to identify all the EA objects that belong to the sales unit as well as the dependencies to other units. For testing purposes, we based our visualization on self-generated exemplary data and set a suitable configuration that is presented in Figure IV-15.

```
Domain: Unit, Database, Application, Server, Platform, Event, BusinessCapability, Indicator, OrganizationalRole, QualityRule, Goal

Metaphor:
element TransportVehicle(name), ResidentialBuilding(name, numberOfLevels), GovernmentBuilding, GasStation(name,
numberOfDispenders), FuelPump, PowerPlant(name, numberOfChimneys), Truck, ConferenceCenter, Factory, Billboard, Person,
Monument
area District(name), Parking(name, numberOfCars), Lake(name, roughness), Park(name)

relation Street(name), Powerlines(name, thickness), Pipes(name, depthInGround)
```

Figure IV-15. Domain elements and visual metaphor specifications

Based on this configuration, we defined an appropriate formal statement that can be seen in Figure IV-16. The statement provides all information that is required for an automatic rendering mechanism to populate the EA City landscape.

```
// area mapping
area Unit(u) as District("u.name") contains
// nested area mapping
area Database as Parking contains
Database as TransportVehicle
complete
// element mappings (default mapping can be provided by method designers)
Application as ResidentialBuilding
Server as FuelPump
Platform as GasStation
Event as ConferenceCenter
BusinessCapability as Factory
Indicator as Billboard
OrganizationalRole as Person
QualityRule as GovernmentBuilding
Goal as Monument
complete
// relation mapping between two units that are involved in the same process

relation Unit(u) - Unit(x) "exists(u.process == x.process)" as Street
```

Figure IV-16. Formal language statement for EA City example

The compiled and rendered model, which has been developed as a prototype based on this statement is shown in Figure IV-17 and consists of two districts that represent two organizational units.

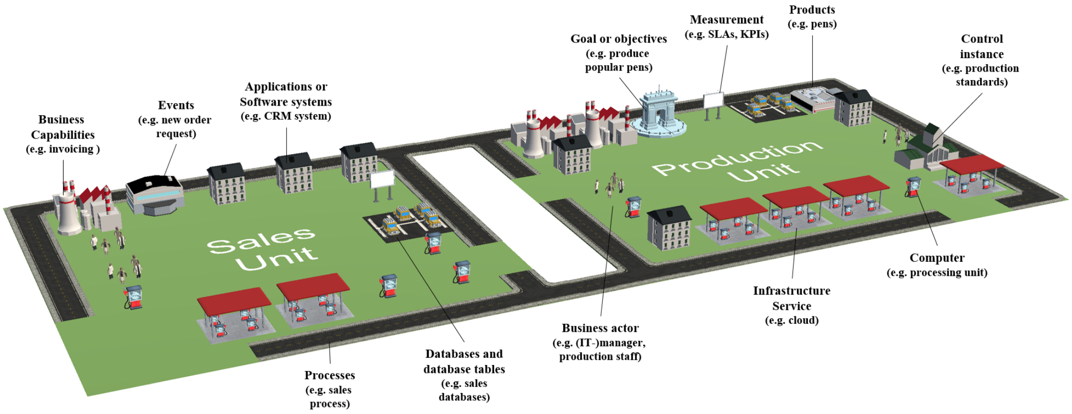


Figure IV-17. Compiled three-dimensional EA City

The district on the left-hand side describes EA objects associated with a sales unit. Two business processes are linked to this unit and are presented as two separate streets. These processes are connected to EA objects in the production unit on the right-hand side. Three residential buildings in the sales unit indicate three used applications. Four fuel pumps symbolise individual servers, and application platforms, e.g. a cloud service, are visualized as two large gas stations. The parking area implies several databases. A conference centre means that this unit handles events, such as order requests. The capability to process those events is represented as an industrial building in form of a factory. A billboard shows the presence of unit-related measurable indicators. Organizational roles belonging to the sales unit are depicted as eight persons. The other district additionally consists of a government building that indicates quality rules that must be obeyed. Furthermore, a monument, here exemplary in form of the Arc de Triomphe, represents goals and objectives of the respective organizational unit. According to this use case, the sales unit manager can see all sales-relevant EA objects and their procedural connection to objects in another business unit. Due to the three-dimensionality of the model, the manager can see the EA City from different perspectives, as presented in Figure IV-18. Figure IV-19 shows the compiled EA city in AR. The application of the city metaphor enables complexity reduction and allows to create lucid models.

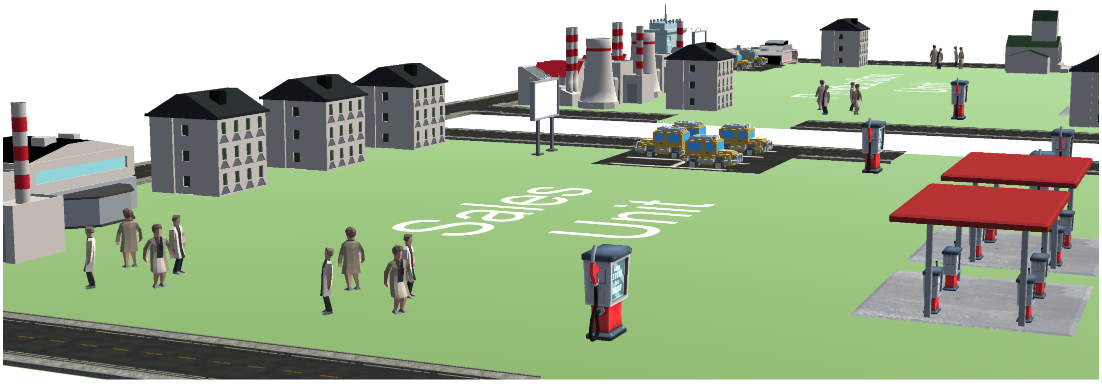


Figure IV-18. EA City from another perspective

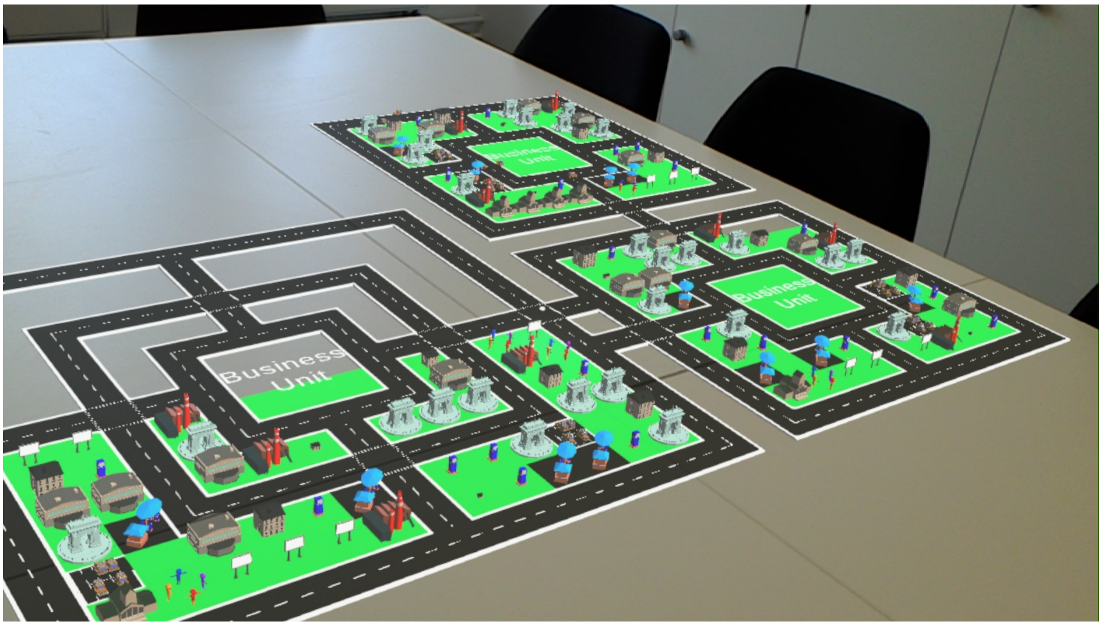


Figure IV-19. EA city in AR

6 Discussion and Conclusion

This paper presents a possible visualization of EAs using the city metaphor. The goal was to propose a visualization that (a) provides a familiar environment for various viewers, (b) is based on shared language, and (c) is able to visualize complex structures. For this, we performed a broad literature review to derive suitable EA objects and city elements. Three rounds of manual card sorting sessions with 14 participants revealed eleven classes of EA objects with similar mappings to city elements. Furthermore, we created a formal language, which we applied to test our results with an exemplary prototype.

The current body of knowledge about EA visualization benefits from our model in several ways. It provides a consistent and familiar language, which makes it easy for viewers to identify, interpret, and talk about the same object of interest. Considering previous knowledge enhances object recognition (Sparacino et al., 2002, p. 3; Baker et al., 2009, p. 540). This is especially helpful whenever viewers with different experiences in EA or business and IT backgrounds interact with each other. Our model as well as the formal language can foster the design of more appropriate EA Cities or excerpts of possible EA Cities. The formal language can be used by researchers and practitioners to develop only parts of a city and to focus on relevant aspects e.g. processes, applications, and networks. It can also facilitate different implementations as it follows the commonly accepted meta model of TOGAF and, hence, provides comprehensive and familiar EA objects for EA experts and it can be implemented using various technologies like desktop applications, Virtual Reality (VR), or Augmented Reality (AR). The dynamic character of districts, which are based on EA objects or other analysis criteria, enables flexible visualizations that allow multiple perspectives on the same EA.

However, this visualization might not be suitable for every purpose. Following the results of the card sorting sessions, we aggregated EA objects with similar mappings. As a result, EA objects in the same class, such as application components and applications, cannot be distinguished on a detailed level. On the one hand, this aggregation limits the applicability of the EA City visualization for detailed EA analyses, whereas on the other hand, it streamlines EAs to an abstract representation and, therefore, enables an easily understandable visualization. In addition, process steps cannot be visualized as our model does not consider the order of EA objects but associates EA objects with districts and processes. Streets, which represent processes, also heavily influence the design of EA Cities, because all process-linked city elements must be closely arranged to each individual street. This can be challenging if single EA objects are linked with multiple processes and might lead to big streets, complex crossings, or a general confusing routing. Future research should derive design principles and algorithms that cope with these routing and alignment challenges in order to design appealing visualizations.

Our work is not free from limitations. We focus on the four commonly used layers business, application, data, and technology architecture. The TOGAF meta model further proposes general entities like principles, constraints, assumptions, requirements, locations, gaps and work packages (The Open Group, 2018), which we did not consider in our paper. Even though the number and the experience of the participants seem to be sufficient, including practitioners might uncover further organizational-relevant aspects. A future evaluation of the prototype in an organizational setting can address this issue by explicitly customizing the prototype towards organizational requirements. Moreover, we tested our model using self-created data. Our prototype will benefit from the inclusion of real-world data, e.g. from a case study. Also, the EA City visualizations language will be used as a basis for automating the renderer configuration. This will further show the applicability of the city metaphor for large-scale EA data.

As the main purpose of this paper is to develop a mapping between EA objects and city elements, we did not develop a comprehensive prototype but showed the general possibility to implement our EA City mapping. Especially, we did not discuss how to display additional information or enable drill down in our city representation. Hence, our prototype does not provide further information, e.g. when looking at or selecting a city element. Previous work frequently implements a text box that presents more information when clicking on, or looking at an object (e.g. Wettel & Lanza, 2008; Merino et al., 2018). Another approach might be to display the name of an EA object on the respective city element, e.g. process names on streets or application names on facades of buildings. In addition, we did not discuss size, colour, or rotation of city elements, which have been shown to impact the perception of the visualization (Langelier et al., 2005). These characteristics provide another dimension for assessing the condition of EAs or enable dynamic representation of analysis results, but were not part of the scope of this paper.

Our results provide avenues for future research. Another implementation and evaluation of our model using organizational data will reveal the applicability and acceptance of EA City visualization. A comparison between different types of visualization techniques might focus on the degree of understanding, decision-making completion time, and correctness. As our proposed model is based on participants' mental models, it potentially provides a more valid explanation of the mapping between EA objects and city elements compared to previous work. We hope that our model is used to develop more sophisticated EA representations using metaphors.

References

Achibet, M., Balev, S., Dutot, A., & Olivier, D. (2014). A Model of Road Network and Buildings Extension Co-evolution. *Procedia Computer Science*, *32*, 828–833. https://doi.org/10.1016/j.procs.2014.05.498

Ahsan, K., Kingston, P., & Shah, H. (2009). *Context Based Knowledge Management in Healthcare: An EA Approached*. 7.

Aier, S., Gleichauf, B., & Winter, R. (2011). Understanding Enterprise Architecture Management Design - An Empirical Analysis. *Proceedings of the 10th International Conference on Wirtschaftsinformatik*, 645–654. Zurich, Switzerland.

Alessi, M., Castelli, S., Chetta, V., Giangreco, E., Pino, S., Storelli, D., … Gentile, A. (2015). A Study on the Collective Perceived Representation of a Real Urban Area through the Usage of an Engaging Framework, Based on a 3D Virtual Environment and Openstreetmap Data. *2015 7th International Conference on Games and Virtual Worlds for Serious Applications (VS-Games)*, 1–8. https://doi.org/10.1109/VS-GAMES.2015.7295762

Alonso, I. A., Verdún, J. C., & Caro, E. T. (2010a). The IT implicated within the enterprise architecture model: Analysis of architecture models and focus IT architecture domain. *2010 IEEE International Conference on Service-Oriented Computing and Applications (SOCA)*, 1–5. Perth, Australia.

Alonso, I. A., Verdún, J. C., & Caro, E. T. (2010b). The IT implicated within the enterprise architecture model: Analysis of architecture models and focus IT architecture domain. *2010 IEEE International Conference on Service-Oriented Computing and Applications (SOCA)*, 1–5. https://doi.org/10.1109/SOCA.2010.5707174

Alter, S. (2013). Incorporating more system-related knowledge into systems analysis and design. *Proceedings of the Nineteenth Americas Conference on Information Systems*. Presented at the Chicago, IL. Chicago, IL.

Alwadain, A., Fielt, E., Korthaus, A., & Rosemann, M. (2011a). Where Do We Find Services in Enterprise Architectures? A Comparative Approach. *ACIS 2011 Proceedings*.

Alwadain, A., Fielt, E., Korthaus, A., & Rosemann, M. (2011b). Where Do We Find Services in Enterprise Architectures? A Comparative Approach. *Proceedings of the 22nd Australasian Conference on Information Systems*, 1–11. Sydney, Australia.

Andrews, K. (1995). Visualising cyberspace: information visualisation in the harmony internet browser. *Proceedings of 1st IEEE Symposium on Information Visualization*, 97–104. Atlanta, GA.

Aschwanden, G. D. P. A., Haegler, S., Bosché, F., Van Gool, L., & Schmitt, G. (2011). Empiric design evaluation in urban planning. *Automation in Construction*, *20*(3), 299–310. https://doi.org/10.1016/j.autcon.2010.10.007

Bagchi, A., Sprintson, A., & Singh, C. (2013). Modeling the impact of fire spread on an electrical distribution network. *Electric Power Systems Research*, *100*, 15–24. https://doi.org/10.1016/j.epsr.2013.01.009

Bakar, N. A. A., Harihodin, S., & Kama, N. (2016a). Enterprise architecture implementation model: Measurement from experts and practitioner perspectives. *2016 4th IEEE International Colloquium on Information Science and Technology (CiSt)*, 1–6. Tangier, Morocco.

Bakar, N. A. A., Harihodin, S., & Kama, N. (2016b). Enterprise architecture implementation model: Measurement from experts and practitioner perspectives. *2016 4th IEEE International Colloquium on Information Science and Technology (CiSt)*, 1–6. https://doi.org/10.1109/CIST.2016.7804849

Baker, J., Jones, D., & Burkman, J. (2009). Using visual representations of data to enhance sensemaking in data exploration tasks. *Journal of the Association for Information Systems*, *10*(7), 533–559.

Bannwart, E. (1997). <<Cyber City>> - die Stadt im Kopf. In C. Maar & F. Rötzer (Eds.), *Virtual Cities - Die Neuerfindung der Stadt im Zeitalter der globalen Vernetzung* (pp. 87–94). Birkhäuser Verlag.

Branch, M. C. (1971). *City planning and aerial information*. Harvard University Press.

Braunnagel, D., Johannsen, F., & Leist, S. (2015). Analysing the Contribution of Coupling Metrics for the Development and Management of Process Architectures. *ECIS 2015 Completed Research Papers*. https://doi.org/10.18151/7217278

Brunn, S. D., Hays-Mitchell, M., Zeigler, D. J., & Graybill, J. K. (2016). *Cities of the World: Regional Patterns and Urban Environments*. Rowman & Littlefield.

Capece, N., Erra, U., Romano, S., & Scanniello, G. (2017). Visualising a software system as a city through virtual reality. *4th International Conference on Augmented Reality, Virtual Reality and Computer Graphics*, 319–327. Ugento, Italy.

Cardoso, E. C. S., Almeida, J. P. A., & Guizzardi, R. S. S. (2010a). On the Support for the Goal Domain in Enterprise Modelling Approaches. *2010 14th IEEE International Enterprise Distributed Object Computing Conference Workshops*, 335–344. Vitoria, Brazil.

Cardoso, E. C. S., Almeida, J. P. A., & Guizzardi, R. S. S. (2010b). On the Support for the Goal Domain in Enterprise Modelling Approaches. *2010 14th IEEE International Enterprise Distributed Object Computing Conference Workshops*, 335–344. https://doi.org/10.1109/EDOCW.2010.45

Castellanos, C., Correal, D., & Murcia, F. (2011). An Ontology-Matching Based Proposal to Detect Potential Redundancies on Enterprise Architectures. *2011 30th International Conference of the Chilean Computer Science Society*, 118–126. https://doi.org/10.1109/SCCC.2011.16

Castells, M. (1997). Die Städte Europas, die Informationsgesellschaft und die globale Wirtschaft. In C. Maar & F. Rötzer (Eds.), *Virtual Cities - Die Neuerfindung der Stadt im Zeitalter der globalen Vernetzung* (pp. 101–116).

Chang, W., & Wang, Y. F. (2016). Style-centric image summarization from photographic views of a city. *2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2787–2791. https://doi.org/10.1109/ICASSP.2016.7472185

Chang, W., Yeh, Y., & Wang, Y. F. (2016). Style-oriented landmark retrieval and summarization. *2016 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA)*, 1–4. https://doi.org/10.1109/APSIPA.2016.7820857

Chen, B., Huang, F., & Fang, Y. (2011). Integrating virtual environment and GIS for 3D virtual city development and urban planning. *2011 IEEE International Geoscience and Remote Sensing Symposium*, 4200–4203. https://doi.org/10.1109/IGARSS.2011.6050156

Chiu, P., Girgensohn, A., Lertsithichai, S., Polak, W., & Shipman, F. (2005). MediaMetro: browsing multimedia document collections with a 3D city metaphor. *Proceedings of the 13th Annual ACM International Conference on Multimedia*, 213–214. Singapore.

Corbett, J., & Idrissi, S. C. E. (2017). ASSESSING THE INFLUENCE OF PERSUASIVE SYSTEMS FOR SUSTAINABILITY ACROSS WORK-HOME-COMMUNITY BOUNDARIES. *Proceedings of the 25th European Conference on Information Systems (ECIS)*, 2874–2884. Guimarães, Portugal.

D'Acci, L. (2013). Simulating future societies in Isobenefit Cities: Social isobenefit scenarios. *Futures*, *54*, 3–18. https://doi.org/10.1016/j.futures.2013.09.004

Dávalos, D., Maldonado, D., & Polit, D. J. (2016). The Hidden Potential behind the City Planned for Cars. *Procedia Engineering*, *145*, 924–931. https://doi.org/10.1016/j.proeng.2016.04.120

Denford, J., & Schobel, K. (2018). Manual Versus Online Card Sorts: A Cautionary Tale for IS Researchers. *24th Americas Conference on Information Systems*, 1–10.

Derthick, M., Christel, M., Hauptmann, A., Ng, D., Stevens, S., & Wactlar, H. (2003). A Cityscape Visualization of Video Perspectives. *Proceedings of the National Academy of Sciences Arthur M. Sackler Colloquium on Mapping Knowledge Domains (Unpublished)*, 1–2. Irvine, CA.

Dieberger, A. (1997). A city metaphor to support navigation in complex information spaces. *Spatial Information Theory A Theoretical Basis for GIS*, 53–67. Semmering, Austria.

Dieberger, A., & Frank, A. U. (1998). A city metaphor for supporting navigation in complex information spaces. *Journal of Visual Languages and Computing*, *9*(6), 597–622.

Dong, W., Jiangli, Y., & Huiqi, P. (2010). The impact of global cities' cultural facilities—Inspiration for Shenzhen. *Next Generation Infrastructure Systems for Eco-Cities*, 1–5. https://doi.org/10.1109/INFRA.2010.5679213

El Sawy, O. A., & Pavlou, P. A. (2008a). IT-enabled business capabilities for turbulent environments. *MIS Quarterly Executive*, *7*(3), 139–150.

El Sawy, O. A., & Pavlou, P. A. (2008b). It-Enabled Business Capabilities for Turbulent Environments. *MIS Quarterly Executive*, *7*(3), 139–150.

Farwick, M., Agreiter, B., Breu, R., Häring, M., Voges, K., & Hanschke, I. (2010). Towards living landscape models: Automated integration of infrastructure cloud in enterprise architecture management. *Cloud Computing (CLOUD), 2010 IEEE 3rd International Conference On*, 35–42. IEEE.

Ferbrache, F., & Knowles, R. D. (2017). City boosterism and place-making with light rail transit: A critical review of light rail impacts on city image and quality. *Geoforum*, *80*, 103–113. https://doi.org/10.1016/j.geoforum.2017.01.013

Fittkau, F., Krause, A., & Hasselbring, W. (2015). Exploring software cities in virtual reality. *2015 IEEE 3rd Working Conference on Software Visualization (VISSOFT)*, 130–134. Bremen, Germany.

Flint, J. (1997). Das Amsterdam-Freenet <<De Digitale Stad>> (DDS). In C. Maar & F. Rötzer (Eds.), *Virtual Cities - Die Neuerfindung der Stadt im Zeitalter der globalen Vernetzung* (pp. 57–69). Birkhäuser Verlag.

Florez, H., Sánchez, M., & Villalobos, J. (2014a). Extensible Model-Based Approach for Supporting Automatic Enterprise Analysis. *2014 IEEE 18th International Enterprise Distributed Object Computing Conference*, 32–41. https://doi.org/10.1109/EDOC.2014.15

Florez, H., Sánchez, M., & Villalobos, J. (2014b). Supporting drafts for enterprise modeling. *2014 9th Computing Colombian Conference (9CCC)*, 200–206. https://doi.org/10.1109/ColumbianCC.2014.6955334

Fominykh, M., Prasolova-Førland, E., Morozov, M., Gerasimov, A., Bellotti, F., Berta, R., … Gloria, A. D. (2010). Universcity: Towards a holistic approach to educational virtual city design. *2010 16th International Conference on Virtual Systems and Multimedia*, 371–374. https://doi.org/10.1109/VSMM.2010.5665929

Ganesan, E., & Paturi, R. (2009a). Key Performance Indicators Framework - A Method to Track Business Objectives, Link Business Strategy to Processes and Detail Importance of Key Performance Indicators in Enterprise Business Architecture. *AMCIS 2009 Proceedings*, 1–10.

Ganesan, E., & Paturi, R. (2009b). Key Performance Indicators Framework - A Method to Track Business Objectives, Link Business Strategy to Processes and Detail Importance of Key Performance Indicators in Enterprise Business Architecture. *AMCIS 2009 Proceedings*.

Gärdenfors, P. (2000). *Conceptual spaces: the geometry of thought*. Cambridge, MA: MIT Press.

Gilboa, S., Jaffe, E. D., Vianelli, D., Pastore, A., & Herstein, R. (2015). A summated rating scale for measuring city image. *Cities*, *44*, 50–59. https://doi.org/10.1016/j.cities.2015.01.002

Glander, T., & Döllner, J. (2009). Abstract representations for interactive visualization of virtual 3D city models. *Computers, Environment and Urban Systems*, *33*(5), 375–387. https://doi.org/10.1016/j.compenvurbsys.2009.07.003

Grant, G. (2012). *Ecosystem Services Come To Town: Greening Cities by Working with Nature*. John Wiley & Sons.

Grassmuck, V. (1997). Tokia - Stadt als Terminal und Terminal as Stadt. In C. Maar & F. Rötzer (Eds.), *Virtual Cities - Die Neuerfindung der Stadt im Zeitalter der globalen Vernetzung* (pp. 38–48). Birkhäuser Verlag.

Guetat, S. B. A., & Dakhli, S. B. D. (2015). The Architecture Facet of Information Governance: The Case of Urbanized Information Systems. *Procedia Computer Science*, *64*, 1088–1098.

Guetat, S., & Dakhli, S. B. D. (2009). The Information City: A Framework For Information Systems Governance. *MCIS 2009 Proceedings*, 1377–1388.

Haken, H., & Portugali, J. (2003). The face of the city is its information. *Journal of Environmental Psychology*, *23*(4), 385–408. https://doi.org/10.1016/S0272-4944(03)00003-3

Hanschke, I. (2013). *Strategisches Management der IT-Landschaft: Ein praktischer Leitfaden für das Enterprise Architecture Management*. Carl Hanser Verlag GmbH Co KG.

Hess, C., Lautenbacher, F., & Fehlner, K. (2013a). Business Building Blocks as Coordination Mechanism for Enterprise Transformations. *2013 17th IEEE International Enterprise Distributed Object Computing Conference Workshops*, 194–203. Vancouver, BC, Canada.

Hess, C., Lautenbacher, F., & Fehlner, K. (2013b). Business Building Blocks as Coordination Mechanism for Enterprise Transformations. *2013 17th IEEE International Enterprise Distributed Object Computing Conference Workshops*, 194–203. https://doi.org/10.1109/EDOCW.2013.29

Honda, M., Mizuno, K., Fukui, Y., & Nishihara, S. (2004a). Generating autonomous time-varying virtual cities. *2004 International Conference on Cyberworlds*, 1–8. https://doi.org/10.1109/CW.2004.34

Honda, M., Mizuno, K., Fukui, Y., & Nishihara, S. (2004b). Updating building layouts of time-varying virtual cities. *Proceedings Computer Graphics International, 2004.*, 365–368. https://doi.org/10.1109/CGI.2004.1309234

Humphreys, G. W., & Bruce, V. (1989). *Visual Cognition: Computational, Experimental and Neuropsychological Perspectives*. Hove, UK: Lawrence Erlbaum Associates Ltd.

Johnson, M., & Lakoff, G. (1980). *Metaphors We Live By*. Chicago, IL: The University of Chicago Press.

Johnson, M., & Lakoff, G. (1999). *Philosophy in the Flesh : The Embodied Mind and Its Challenge to Western Thought*. New York, NY: Basic Books.

Judd, D. R. (1995). Promoting tourism in US cities. *Tourism Management*, *16*(3), 175–187. https://doi.org/10.1016/0261-5177(94)00018-6

Jugel, D., & Schweda, C. M. (2014). Interactive Functions of a Cockpit for Enterprise Architecture Planning. *2014 IEEE 18th International Enterprise Distributed Object Computing Conference Workshops and Demonstrations*, 33–40. https://doi.org/10.1109/EDOCW.2014.14

Kato, N., Okuno, T., Okano, A., Kanoh, H., & Nishihara, S. (1998). An ALife approach to modeling virtual cities. *SMC'98 Conference Proceedings. 1998 IEEE International Conference on Systems, Man, and Cybernetics (Cat. No.98CH36218)*, *2*, 1168–1173 vol.2. https://doi.org/10.1109/ICSMC.1998.727864

Kendall, J. E., & Kendall, K. E. (1993). Metaphors and methodologies: Living beyond the systems machine. *MIS Quarterly*, *17*(2), 149–171.

Krier, L. (1997). Eine Stadt ist mehr als eine Anhäufung von Gebäuden. In C. Maar & F. Rötzer (Eds.), *Virtual Cities - Die Neuerfindung der Stadt im Zeitalter der globalen Vernetzung* (pp. 180–187). Birkhäuser Verlag.

Krim, A. (1992). Los Angeles and the anti-tradition of the suburban city. *Journal of Historical Geography*, *18*(1), 121–138. https://doi.org/10.1016/0305-7488(92)90280-M

Krolczyk, A., Senf, C., & Cordes, N. (2010). Construction of a Complex Adaptive Systems Pattern as an Epistemological Lens for E-Government Systems. *2010 43rd Hawaii International Conference on System Sciences*, 1–10. https://doi.org/10.1109/HICSS.2010.118

Lakoff, G. (1987). *Women, Fire, and Dangerous Things*. Chicago, IL: University of Chicago Press.

Lange, M., & Mendling, J. (2011). An Experts' Perspective on Enterprise Architecture Goals, Framework Adoption and Benefit Assessment. *2011 IEEE 15th International Enterprise Distributed Object Computing Conference Workshops*, 304–313. Helsinki, Finland. https://doi.org/10.1109/EDOCW.2011.41

Langelier, G., Sahraoui, H., & Poulin, P. (2005). Visualization-based analysis of quality for large-scale software systems. *Proceedings of the 20th IEEE/ACM International Conference on Automated Software Engineering*, 214–223. Long Beach, CA.

LEE, G., Lee, Z., & Park, Y. (2015). CONFIGURATIONAL APPROACH TO UNCOVERING THE EFFECT OF ENTERPRISE ARCHITECTURE DESIGN ON ORGANIZATIONAL PERFORMANCE. *AMCIS 2015 Proceedings*.

Luo, A., Fu, J., & Liu, J. (2016). An impact analysis method of business processes evolution in enterprise architecture. *2016 International Conference on Progress in Informatics and Computing (PIC)*, 733–737. https://doi.org/10.1109/PIC.2016.7949595

Luque-Martínez, T., Del Barrio-García, S., Ibáñez-Zapata, J. Á., & Rodríguez Molina, M. Á. (2007). Modeling a city's image: The case of Granada. *Cities*, *24*(5), 335–352. https://doi.org/10.1016/j.cities.2007.01.010

Lynch, K. (1960). *The image of the city* (Nachdr.). Cambridge, MA: MIT Press.

Meixner, P., Leberl, F., & Brédif, M. (2011). 3D roof details by 3D aerial vision. *2011 IEEE International Conference on Computer Vision Workshops (ICCV Workshops)*, 212–218. https://doi.org/10.1109/ICCVW.2011.6130245

Merino, L., Bergel, A., & Nierstrasz, O. (2018). Overcoming issues of 3D software visualization through immersive augmented reality. *2018 IEEE Working Conference on Software Visualization (VISSOFT)*, 54–64. Madrid, Spain.

Merino, L., Ghafari, M., Anslow, C., & Nierstrasz, O. (2017). CityVR: Gameful software visualization. *2017 IEEE International Conference on Software Maintenance and Evolution (ICSME)*, 633–637. Shanghai, China.

Moore, G. C., & Benbasat, I. (1991). Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information Systems Research*, *2*(3), 192–222.

Morgan, G. (1986). *Images of organization*. Beverly Hills, CA: SAGE Publications.

Morris, B., & Marshall, P. (2011). Business Architecture: The Basis for a Design-Oriented Approach to Business Process Outsourcing. *ACIS 2011 Proceedings*.

Nardi, J. C., Almeida, J. P. A., Pereira, M. C., Falbo, R. d A., Iacob, M. E., Sinderen, M. van, & Pires, L. F. (2016). Service Commitments and Capabilities across the ArchiMate Architectural Layers. *2016 IEEE 20th International Enterprise Distributed Object Computing Workshop (EDOCW)*, 1–10. https://doi.org/10.1109/EDOCW.2016.7584386

Nardi, J. C., Falbo, R. d A., & Almeida, J. P. A. (2014). An Ontological Analysis of Service Modeling at ArchiMate's Business Layer. *2014 IEEE 18th International Enterprise Distributed Object Computing Conference*, 92–100. https://doi.org/10.1109/EDOC.2014.22

Narman, P., Johnson, P., Ekstedt, M., Chenine, M., & Konig, J. (2009). Enterprise Architecture Analysis for Data Accuracy Assessments. *2009 IEEE International Enterprise Distributed Object Computing Conference*, 24–33. https://doi.org/10.1109/EDOC.2009.26

Nightingale, D. J., & Rhodes, D. H. (2004). Enterprise systems architecting: Emerging art and science within engineering systems. *Proceedings of the ESD External Symposium Session VI*, 1–13. Cambridge, MA.

Nunnally, J. C. (1967). *Psychometric theory*. New York, NY: McGraw-Hill.

Oates, B. J., & Fitzgerald, B. (2007). Multi-metaphor method: organizational metaphors in information systems development. *Information Systems Journal*, *17*(4), 421–449.

Ortegon-Sanchez, A., & Tyler, N. (2016). Constructing a Vision for an 'Ideal' Future City: A Conceptual Model for Transformative Urban Planning. *Transportation Research Procedia*, *13*, 6–17. https://doi.org/10.1016/j.trpro.2016.05.002

Panas, T., Berrigan, R., & Grundy, J. (2003). A 3D metaphor for software production visualization. *Proceedings on Seventh International Conference on Information Visualization, 2003. IV 2003.*, 314–319. London, UK: IEEE.

Papazoglou, M. P. (2003a). Service-oriented computing: concepts, characteristics and directions. *Proceedings of the Fourth International Conference on Web Information Systems Engineering, 2003. WISE 2003.*, 3–12. Rome, Italy: IEEE.

Papazoglou, M. P. (2003b). Service-oriented computing: concepts, characteristics and directions. *Proceedings of the Fourth International Conference on Web Information Systems Engineering, 2003. WISE 2003.*, 3–12. https://doi.org/10.1109/WISE.2003.1254461

Park, Y., LEE, G., & Lee, Z. (2013). EA CONFIGURATIONS: INTERPLAY OF EA DESIGN FACTORS, STRATEGY TYPES, AND ENVIRONMENTS. *ICIS 2013 Proceedings*.

Pawley, M. (1997). Auf dem Weg zur digitalen Desurbanisierung. In C. Maar & F. Rötzer (Eds.), *Virtual Cities - Die Neuerfindung der Stadt im Zeitalter der globalen Vernetzung* (pp. 17–29). Birkhäuser Verlag.

Pena, C., & Villalobos, J. (2010). An MDE Approach to Design Enterprise Architecture Viewpoints. *2010 IEEE 12th Conference on Commerce and Enterprise Computing*, 80–87. https://doi.org/10.1109/CEC.2010.25

Quartel, D., Steen, M. W. A., & Lankhorst, M. (2010). IT Portfolio Valuation - Using Enterprise Architecture and Business Requirements Modeling. *2010 14th IEEE International Enterprise Distributed Object Computing Conference*, 3–13. https://doi.org/10.1109/EDOC.2010.24

Quartel, Dick, Engelsman, W., Jonkers, H., & Van Sinderen, M. (2009). A goal-oriented requirements modelling language for enterprise architecture. *2009 IEEE International Enterprise Distributed Object Computing Conference*, 3–13. Auckland, New Zealand: IEEE.

Ramljak, D. (2017a). Business models and value oriented service design elements in ecosystem architecture. *2017 25th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, 1–6. Split, Croatia: IEEE.

Ramljak, D. (2017b). Business models and value oriented service design elements in ecosystem architecture. *2017 25th International Conference on Software, Telecommunications and Computer Networks (SoftCOM)*, 1–6. https://doi.org/10.23919/SOFTCOM.2017.8115513

Rasekh, A., & Brumbelow, K. (2015). A dynamic simulation–optimization model for adaptive management of urban water distribution system contamination threats. *Applied Soft Computing*, *32*, 59–71. https://doi.org/10.1016/j.asoc.2015.03.021

Rašković, S., & Decker, R. (2015). The influence of trees on the perception of urban squares. *Urban Forestry & Urban Greening*, *14*(2), 237–245. https://doi.org/10.1016/j.ufug.2015.02.003

Rehan, R. M. (2014). Urban branding as an effective sustainability tool in urban development. *HBRC Journal*, *10*(2), 222–230. https://doi.org/10.1016/j.hbrcj.2013.11.007

Reichold, O. (Ed.). (1998). *... erleben, wie eine Stadt entsteht. Städtebau, Architktur und Wohnen in Wolfsburg 1938-1998*. Joh. Heinr. Meyer Verlag.

Riempp, G., & Gieffers-Ankel, S. (2007). Application portfolio management: a decision-oriented view of enterprise architecture. *Information Systems and E-Business Management*, *5*(4), 359–378.

Rohloff, M. (2009). An agent-based approach to improving resource allocation in the Dutch youth health care sector. *ECIS 2009 Proceedings*.

Rohloff, M. (2011a). Integrating Innovation into Enterprise Architecture Management. *Proceedings of the 9th International Conference on Wirtschaftsinformatik*, 776–786.

Rohloff, M. (2011b). Integrating Innovation into Enterprise Architecture Management. *Wirtschaftsinformatik Proceedings 2011*.

Roth, S., Zec, M., & Matthes, F. (2014). *Enterprise Architecture Visualization Tool Survey 2014*. Germany: epubli GmbH.

Rötzer, F. (1997). Auszug aus der Stadt. In C. Maar & F. Rötzer (Eds.), *Virtual Cities - Die Neuerfindung der Stadt im Zeitalter der globalen Vernetzung* (pp. 11–16). Birkhäuser Verlag.

Salman, A. M., Li, Y., & Bastidas-Arteaga, E. (2017). Maintenance optimization for power distribution systems subjected to hurricane hazard, timber decay and climate change. *Reliability Engineering & System Safety*, *168*, 136–149. https://doi.org/10.1016/j.ress.2017.03.002

Santana, A., Souza, A., Simon, D., Fischbach, K., & Moura, H. D. (2017a). Network Science Applied to Enterprise Architecture Analysis: Towards the Foundational Concepts. *2017 IEEE 21st International Enterprise Distributed Object Computing Conference (EDOC)*, 10–19. Quebec City, Canada: IEEE.

Santana, A., Souza, A., Simon, D., Fischbach, K., & Moura, H. D. (2017b). Network Science Applied to Enterprise Architecture Analysis: Towards the Foundational Concepts. *2017 IEEE 21st International Enterprise Distributed Object Computing Conference (EDOC)*, 10–19. https://doi.org/10.1109/EDOC.2017.12

Savitch, H. V. (2010). What makes a great city great? An American perspective. *Cities*, *27*(1), 42–49. https://doi.org/10.1016/j.cities.2009.11.012

Schaffer, O., & Fang, X. (2018). What Makes Games Fun? Card Sort Reveals 34 Sources of Computer Game Enjoyment. *AMCIS 2018 Proceedings*, 1–10. Association for Information Systems.

Schröter, K., Lüdtke, S., Redweik, R., Meier, J., Bochow, M., Ross, L., … Kreibich, H. (2018). Flood loss estimation using 3D city models and remote sensing data. *Environmental Modelling & Software*, *105*, 118–131. https://doi.org/10.1016/j.envsoft.2018.03.032

Shafiee, M. E., & Berglund, E. Z. (2016). Agent-based modeling and evolutionary computation for disseminating public advisories about hazardous material emergencies. *Computers, Environment and Urban Systems*, *57*, 12–25. https://doi.org/10.1016/j.compenvurbsys.2016.01.001

Soares, L. (2008). Using Metaphors for Visualizing Enterprise Architectures. *SAC'08*, 1–5. Fortaleza, Ceará, Brazil: ACM.

Souza, R., Silva, B., Mendes, T., & Mendonça, M. (2012). SkyscrapAR: An augmented reality visualization for software evolution. *Proceedings of 2nd Brazilian Workshop on Software Visualization (WBVS 2012)*, 17–24.

Sparacino, F., Wren, C., Azarbayejani, A., & Pentland, A. (2002). Browsing 3-D spaces with 3-D vision: body-driven navigation through the internet city. *Proceedings. First International Symposium on 3D Data Processing Visualization and Transmission*, 224–231. Padova, Italy: IEEE.

Tamm, T., Seddon, P. B., Shanks, G., & Reynolds, P. (2011). How does enterprise architecture add value to organisations. *Communications of the Association for Information Systems*, *28*(1), 141–168.

The Open Group. (2012). *ArchiMate® 2.0 Specification*. Van Haren.

The Open Group. (2018). *The TOGAF® Standard, Version 9.2* (11th ed.). van Haren Publishing.

TOGAF. (2018a). The TOGAF Standard, Version 9.2 - Content Metamodel. Retrieved September 17, 2018, from http://pubs.opengroup.org/architecture/togaf9-doc/arch/chap30.html

TOGAF. (2018b). The TOGAF Standard, Version 9.2 - Definitions. Retrieved September 19, 2018, from http://pubs.opengroup.org/architecture/togaf9-doc/arch/chap03.html

Torres, J. M., Brumbelow, K., & Guikema, S. D. (2009). Risk classification and uncertainty propagation for virtual water distribution systems. *Reliability Engineering & System Safety*, *94*(8), 1259–1273. https://doi.org/10.1016/j.ress.2009.01.008

Urbach, N., Smolnik, S., & Riempp, G. (2009). Development and validation of a model for assessing the success of employee portals. *ECIS 2008 Proceedings*, 1699–1710.

Valdez, A., Cortes, G., Arzola, O., Castaneda, S., & Luna, A. (2015). Design of a business architecture in a medium metal mechanic firm. *2015 Science and Information Conference (SAI)*, 321–325. https://doi.org/10.1109/SAI.2015.7237163

Veneberg, R. K. M., Iacob, M. E., Sinderen, M. J. v, & Bodenstaff, L. (2014a). Enterprise Architecture Intelligence: Combining Enterprise Architecture and Operational Data. *2014 IEEE 18th International Enterprise Distributed Object Computing Conference*, 22–31. Ulm, Germany: IEEE.

Veneberg, R. K. M., Iacob, M. E., Sinderen, M. J. v, & Bodenstaff, L. (2014b). Enterprise Architecture Intelligence: Combining Enterprise Architecture and Operational Data. *2014 IEEE 18th International Enterprise Distributed Object Computing Conference*, 22–31. https://doi.org/10.1109/EDOC.2014.14

Wettel, R., & Lanza, M. (2007). Visualizing software systems as cities. *2007 4th IEEE International Workshop on Visualizing Software for Understanding and Analysis*, 92–99. Banff, Ont., Canada: IEEE.

Wettel, R., & Lanza, M. (2008). Codecity: 3d visualization of large-scale software. *Companion of the 30th International Conference on Software Engineering*, 921–922. Leipzig, Germany: ACM.

Wettel, R., Lanza, M., & Robbes, R. (2011). Software systems as cities: A controlled experiment. *2011 33rd International Conference on Software Engineering (ICSE)*, 551–560. Honolulu, HI: IEEE.

Whittle, R., & Myrick, C. B. (2004). *Enterprise business architecture: The formal link between strategy and results*. Boca Raton, FL: CRC Press.

Wilfling, S., & Baumoel, U. (2011). *A comprehensive information model for business change projects*. 10.

Winter, M., & Szczepanek, T. (2009). *Images of projects*. London, UK: Routledge.

Yasumoto, S., Jones, A. P., Nakaya, T., & Yano, K. (2011). The use of a virtual city model for assessing equity in access to views. *Computers, Environment and Urban Systems*, *35*(6), 464–473. https://doi.org/10.1016/j.compenvurbsys.2011.07.002

Yusoff, N. A. H., Noor, A. M., & Ghazali, R. (2014). City Skyline Conservation: Sustaining the Premier Image of Kuala Lumpur. *Procedia Environmental Sciences*, *20*, 583–592. https://doi.org/10.1016/j.proenv.2014.03.071

Zimmermann, A., Schmidt, R., Sandkuhl, K., Wißotzki, M., Jugel, D., & Möhring, M. (2015). Digital Enterprise Architecture - Transformation for the Internet of Things. *2015 IEEE 19th International Enterprise Distributed Object Computing Workshop*, 130–138. https://doi.org/10.1109/EDOCW.2015.16

Appendix

Appendix IV-1: Detailed Results of Identified City Elements

Group of city elements	City element	Source
Paths		
Railway lines		
Rails	Trunk rail line	(Brunn, Hays-Mitchell, Zeigler, & Graybill, 2016, p. 227)
	City's rail	(Savitch, 2010, p. 45)
	Rail systems	(Ortegon-Sanchez & Tyler, 2016, p. 9)
	Rail traffic	(Brunn et al., 2016, p. 192)
	Rail	(Branch, 1971, p. 26)
Metros	U-Bahn-Netz	(Rötzer, 1997, p. 13)
	Subway system	(Brunn et al., 2016; Savitch, 2010, p. 45)
Light rail	Light rails system	(Brunn et al., 2016, p. 230; Ferbrache & Knowles, 2017, p. 110)
	Light rail transit	(Ferbrache & Knowles, 2017, p. 103)
Railroads	Railroad connection	(Branch, 1971, p. 127)
Streets		
Highways	Access to highway	(Gilboa, Jaffe, Vianelli, Pastore, & Herstein, 2015, p. 52)
	Highway	(Brunn et al., 2016, pp. 17, 59; Honda, Mizuno, Fukui, & Nishihara, 2004a, p. 2, 2004b, pp. 1–2; Luque-Martínez, Del Barrio-García, Ibáñez-Zapata, & Rodríguez Molina, 2007, p. 340)
	Major and secondary highway	(Branch, 1971, pp. 26, 90, 127)
	Major highway	(Branch, 1971, pp. 93–94, 97; Gilboa et al., 2015, p. 53)
	Multi-lane highway	(Grant, 2012, pp. 33–34)
Freeways	Freeway	(Krim, 1992, p. 125; Castells, 1997, p. 113)
	Freeway system	(Branch, 1971, pp. 26, 90, 93–94, 97; Brunn et al., 2016, pp. 51–52, 230; Krim, 1992, p. 125)
Boulevards	Boulevard	(D'Acci, 2013, p. 4)
	Wilshire Boulevard	(Krim, 1992, p. 127)
	Wide Boulevard	(Brunn et al., 2016, pp. 209–210)
Roads	Road	(Achibet, Balev, Dutot, & Olivier, 2014, p. 830; Alessi et al., 2015, p. 3; Brunn et al., 2016, p. 59; Chen, Huang, & Fang, 2011, p. 4202; Dávalos, Maldonado, & Polit, 2016, p. 924; Gilboa et al., 2015, p. 52; Glander & Döllner, 2009, p. 379; Luque-Martínez et al., 2007, p. 340; Yasumoto, Jones, Nakaya, & Yano, 2011, pp. 464–465)
	Road access	(Achibet et al., 2014, p. 830)
	Road infrastructure	(Gilboa et al., 2015, p. 57)

Group of city elements	City element	Source
Roads	Road network	(Achibet et al., 2014, pp. 828–829; Glander & Döllner, 2009, pp. 375–376, 379; Honda et al., 2004a, pp. 1–2, 2004b, p. 1; Kato, Okuno, Okano, Kanoh, & Nishihara, 1998, p. 1168; Torres, Brumbelow, & Guikema, 2009, p. 1262)
Streets	Street	(Aschwanden, Haegler, Bosché, Van Gool, & Schmitt, 2011, pp. 306, 308; Dávalos et al., 2016, pp. 924–925; Gilboa et al., 2015, pp. 53, 56; Haken & Portugali, 2003, pp. 395, 404; Honda et al., 2004a, p. 2, 2004b, pp. 1–2; Ortegon-Sanchez & Tyler, 2016, p. 8; Rašković & Decker, 2015, p. 237)
	Local street	(Branch, 1971, pp. 90, 97)
	Narrow, widing street	(Brunn et al., 2016, p. 213)
	Street network	(Aschwanden et al., 2011, p. 308; Glander & Döllner, 2009, pp. 375–376)
Cycle track	Cycle path	(D'Acci, 2013, p. 4)
	Bicycle Lane	(Gilboa et al., 2015, p. 57)
Motorways	Motorways	(D'Acci, 2013, p. 4)
Paths	Path	(Haken & Portugali, 2003, p. 386)
Tunnels		
Tunnels	Tunnel	(Gilboa et al., 2015, p. 57)
Bridges		
Bridges	Bridge	(Chen et al., 2011, p. 4202; Gilboa et al., 2015; Meixner, Leberl, & Brédif, 2011, p. 1)
	Golden Gate Bridge	(Savitch, 2010, p. 44)
	Brooklyn Bridges	(Krim, 1992, p. 134)
Pedestrians		
Pedestrians	Pedestrian movement	(Aschwanden et al., 2011, p. 300)
	Sidewalk/ pavement	(Gilboa et al., 2015, p. 53; Haken & Portugali, 2003; Luque-Martínez et al., 2007, p. 340; Meixner et al., 2011, p. 1; Reichold, 1998, p. 47)
	Pedestrian areas	(Brunn et al., 2016, p. 213; D'Acci, 2013, p. 4; Ferbrache & Knowles, 2017, p. 108; Ortegon-Sanchez & Tyler, 2016, p. 9; Krier, 1997, p. 18)
Transport vehicles		
Cars	Automobile	(Krim, 1992, p. 125)
	Car	(Aschwanden et al., 2011, p. 299)
Bus	Bus	(Haken & Portugali, 2003, p. 404)
High-speed train	High-speed train	(Brunn et al., 2016, p. 203; Castells, 1997, p. 113)
Trolley	Trolley	(Brunn et al., 2016, p. 192)
Trams	Tram	(Ferbrache & Knowles, 2017, p. 103; Haken & Portugali, 2003, p. 404)
	Street railroad	(Krim, 1992, p. 135)

Group of city elements	City element	Source
Trams	Streetcar	(Ferbrache & Knowles, 2017, p. 103)
Subway	Subway	(Brunn et al., 2016, p. 230)
	Metro	(Ferbrache & Knowles, 2017, p. 103; Haken & Portugali, 2003, p. 404)
	Underground	(Haken & Portugali, 2003, p. 404)
Trains	Train	(Gilboa et al., 2015, p. 56; Haken & Portugali, 2003, p. 404)
Water supply		
Water Supply	Water supply	(Krim, 1992, p. 135)
	Water treatment plant	(Brunn et al., 2016, p. 89; Rasekh & Brumbelow, 2015, p. 64; Torres et al., 2009, p. 1262)
	Water distribution infrastructure	(Shafiee & Berglund, 2016, p. 13)
	Pumping station	(Branch, 1971, pp. 26)
	Tanks	(Rasekh & Brumbelow, 2015, p. 64)
	Pipeline	(Branch, 1971, pp. 9)
	Hydrant	(Rasekh & Brumbelow, 2015, p. 64)
	Pump	(Rasekh & Brumbelow, 2015, p. 64)
Energy supply		
Transmission lines	Transmission line	(Salman, Li, & Bastidas-Arteaga, 2017, p. 137)
Distribution lines	Distribution line	(Salman et al., 2017, p. 137)
Edges		
Government buildings		
Administrations	Administrative enter	(Branch, 1971, p. 26)
	Administration	(Rötzer, 1997, p. 13)
Achieves	Archives	(Gilboa et al., 2015, p. 56)
Community centers	Community center	(Bagchi, Sprintson, & Singh, 2013, p. 17)
Government buildings	Government buildings	(Bagchi et al., 2013, p. 17; Brunn et al., 2016, pp. 59, 213)
	Parliament	(Brunn et al., 2016, p. 226)
City hall	City hall	(Bagchi et al., 2013, p. 17; Krim, 1992, pp. 131–132)
	Town hall	(Brunn et al., 2016, p. 206)
Security buildings		
Fire	Fire	(Branch, 1971, p. 26)
Barracks	Barrack	(Pawley, 1997, p. 19)
Police	Police	(Branch, 1971, p. 26)
Religious buildings		
Abbeys	Abbey	(Gilboa et al., 2015, p. 56)
Churches	Church	(Bagchi et al., 2013, p. 17; Brunn et al., 2016, p. 206; Gilboa et al., 2015, p. 57; Reichold, 1998, p. 47)
	Cathedral	(Brunn et al., 2016, pp. 41, 213)

Group of city elements	City element	Source
Churches	Basilica di San Pietro	(Chang & Wang, 2016, p. 2789; Chang, Yeh, & Wang, 2016, p. 3)
	Notre Dame	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Mosque	(Savitch, 2010, p. 44)
Religious centers	Religious center	(Branch, 1971, p. 99)
Temples	Temple	(Yasumoto et al., 2011, p. 465)
Industrial buildings		
Industrial plants	Commercial building	(Honda et al., 2004a, p. 1, 2004b, p. 1)
	Electric power plant	(Branch, 1971, p. 127)
	Factory	(Branch, 1971, pp. 90, 97; Grant, 2012, p. 27; Yasumoto et al., 2011, pp. 464–465, 470)
	Farm	(Branch, 1971, pp. 123-126)
	Farm-aggricultural community	(Branch, 1971, p. 99)
	Refinery	(Branch, 1971, p. 91)
	Volkswagen factory	(Reichold, 1998, p. 20)
Office buildings		
Office buildings	Office park	(Brunn et al., 2016, pp. 51-52)
	Office tower	(Judd, 1995, p. 178)
	Office building	(Aschwanden et al., 2011, p. 302; Grassmuck, 1997, p. 39; Honda et al., 2004a, p. 1, 2004b, p. 1)
	Headquarter	(Grant, 2012, p. 27; Rötzer, 1997, p. 14)
	Bank	(Bannwart, 1997, p. 91; Flint, 1997, p. 64; Gilboa et al., 2015, p. 53; Pawley, 1997, pp. 53, 55, 58)
	Post-office	(Bagchi et al., 2013, p. 17; Gilboa et al., 2015, pp. 53, 55, 58)
	Service building	(Fominykh et al., 2010, p. 373)
	Tourist office	(Branch, 1971, p. 127)
	Travel agency	(Flint, 1997, p. 64)
Residential buildings		
Apartment	Apartment building	(Branch, 1971, pp. 123–126; Brunn et al., 2016, p. 227; Pawley, 1997, p. 19; Savitch, 2010, p. 45)
	Apartments	(Brunn et al., 2016, pp. 22, 208–210, 213; Honda et al., 2004a, p. 1, 2004b, p. 1)
Houses	Single/semi detaches houses	(Branch, 1971, pp. 123–126; Brunn et al., 2016, p. 22; Schröter et al., 2018, pp. 119, 122, 124)
	Row house	(Branch, 1971, p. 127)
	Dwellings	(Branch, 1971, pp. 123–126; Grant, 2012, p. 29; Schröter et al., 2018, p. 122)
	Tower house	(Haken & Portugali, 2003, p. 395)
	Bungalow	(Savitch, 2010, p. 45)

Group of city elements	**City element**	**Source**
Residential areas	Residential area	(Brunn et al., 2016, p. 20; Reichold, 1998, pp. 20, 47)
	Hotel buildings	
Hotels	Hotel	(Bannwart, 1997, p. 91; Brunn et al., 2016, p. 213; Chang & Wang, 2016, p. 2787; Gilboa et al., 2015, pp. 56–57; Judd, 1995, p. 183; Pawley, 1997, p. 19)
Resort	Resort	(Branch, 1971, pp. 91, 99)
	Castles and palaces	
Castles	Castle	(Rehan, 2014, p. 225; Yasumoto et al., 2011, p. 465)
Palaces	Palace	(Alessi et al., 2015, p. 3; Brunn et al., 2016, pp. 41, 206, 226; Gilboa et al., 2015, p. 56; Pawley, 1997, p. 19; Rehan, 2014, p. 225)
	Sport buildings	
Golf	Golf course	(Dong et al., 2010, pp. 4-5)
Clubs	Sport and country club	(Gilboa et al., 2015, pp. 53, 58)
Sport facilities	Sport facility	(Dong, Jiangli, & Huiqi, 2010, p. 2; Gilboa et al., 2015, pp. 52, 57; Schröter et al., 2018, p. 122)
Projects	Sports mega projects	(Gilboa et al., 2015, p. 57)
Stadiums	Stadium	(Brunn et al., 2016, p. 206; Judd, 1995, pp. 178, 181)
	Olympic Stadium	(Gilboa et al., 2015, p. 56)
	Educational buildings	
Colleges	Colleges	(Branch, 1971, p. 26)
	Clermont College	(Dong et al., 2010, p. 2)
	Western College	(Dong et al., 2010, p. 2)
Educational institutions	Educational Institution	(Dong et al., 2010, p. 2)
Kindergarten	Kindergarten	(Reichold, 1998, p. 47)
Schools	School	(Alessi et al., 2015, pp. 3, 5; Bagchi et al., 2013, p. 17; Branch, 1971, pp. 26, 127; Reichold, 1998, p. 47)
	High school	(Dong et al., 2010, p. 4)
Universities	University	(Branch, 1971, pp. 26, 93–94; Brunn et al., 2016, p. 226; Dong et al., 2010, pp. 2, 4; Fominykh et al., 2010, p. 373; Rötzer, 1997, p. 14)
	University of California at Los Angeles	(Dong et al., 2010, p. 2; Krim, 1992, p. 121)
	University of Southern California	(Dong et al., 2010, p. 2)
	California Institute of Technology	(Dong et al., 2010, p. 2)
	Norwegian University of Science and Technology	(Fominykh et al., 2010, p. 373)
Research facilities	Research facility	(Dong et al., 2010, p. 2)

Group of city elements	City element	Source
Cultural buildings		
Galleries	Art galleries	(Brunn et al., 2016, p. 206; Dong et al., 2010, pp. 2, 4; Gilboa et al., 2015, pp. 56–57; Pawley et al., 1997, p. 19)
	Artits' kiosk	(Gilboa et al., 2015, p. 57)
Museums	Exhibition hall	(Gilboa et al., 2015, p. 57)
	Museum	(Bagchi et al., 2013, p. 17; Brunn et al., 2016, p. 206; Dong et al., 2010, pp. 2, 4–5; Gilboa et al., 2015, pp. 56–58; Luque-Martínez et al., 2007, p. 340; Pawley, 1997, p. 19; Rötzer, 1997, p. 14)
	Louvre Museum	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Mercedes-Benz-Museum	(Rehan, 2014, p. 225)
	Porsche Museum	(Rehan, 2014, p. 225)
Cultural facilities	Cultural center	(Gilboa et al., 2015, p. 56)
	Cultural facility	(Bannwart, 1997, p. 91; Gilboa et al., 2015, p. 57)
Libraries	Library	(Brunn et al., 2016, p. 206; Dong et al., 2010, p. 4; Gilboa et al., 2015, p. 56)
Music halls	Music hall	(Dong et al., 2010, pp. 2, 4)
Theatres	National theatre	(Brunn et al., 2016, p. 226)
	Theatre	(Dong et al., 2010, pp. 2, 4; Gilboa et al., 2015, p. 58; Luque-Martínez et al., 2007, p. 340; Pawley, 1997, p. 19)
Operas	Opera	(Dong et al., 2010, p. 2; Pawley, 1997, p. 19; Rehan, 2014, p. 225)
Cosmos	Griffith Park Observatory	(Krim, 1992, pp. 131-132)
	Planetarium Stuttgart	(Rehan, 2014, p. 225)
Medical buildings		
Hospitals	Clinic	(Branch, 1971, p. 26)
	Hospital	(Aschwanden et al., 2011, p. 302; Branch, 1971, p. 26)
Sanatorium	Sanitarium	(Branch, 1971, p. 26)
Shopping buildings		
Shopping malls	Mall	(Alessi et al., 2015, p. 2; Brunn et al., 2016, pp. 51–52, 208–209, 213; Judd, 1995, pp. 178, 183)
	Shopping Center	(Branch, 1971, pp. 123–127; Gilboa et al., 2015, pp. 52, 56; Haken & Portugali, 2003, p. 402; Pawley, 1997, p. 19)
Department stores	Department store	(Brunn et al., 2016, pp. 208–209, 213; Rötzer, 1997, p. 12)
Shops	Bookstore	(Flint, 1997, p. 64)
	Clothing store	(Judd, 1995, p. 183)
	Gas station	(Branch, 1971, p. 127)
	Shops	(Brunn et al., 2016, pp. 208–209, 213; Haken & Portugali, 2003, p. 402; Judd, 1995, p. 183)
	Store	(Branch, 1971, p. 91; Chang & Wang, 2016, p. 2787)

Group of city elements	City element	Source
	Gastronomy buildings	
Restaurants	Restraurant	(Brunn et al., 2016, pp. 208–209, 213; Ferbrache & Knowles, 2017, p. 108; Gilboa et al., 2015, pp. 52–53, 58; Haken & Portugali, 2003, p. 402; Judd, 1995, p. 183; Pawley, 1997, p. 19)
	Foodstands	(Judd, 1995, p. 183)
	Foodcourts	(Judd, 1995, p. 183)
Bars	Pubs	(Gilboa et al., 2015, p. 58)
	Bars	(Pawley, 1997, p. 19)
Cafes	Cafes	(Ferbrache & Knowles, 2017, p. 108)
	Historical buildings	
Walls	Wall	(Brunn et al., 2016, pp. 41, 206; Reichold, 1998, p. 20)
	Jerusalem's Western Wall	(Savitch, 2010, p. 44)
Gates	Gate	(Brunn et al., 2016, pp. 206, 213; Fominykh et al., 2010, p. 373; Yasumoto et al., 2011, p. 464)
	Historic city gate	(Gilboa et al., 2015, p. 58)
Buildings	Colosseum	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Castel Saint Angelo	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Artisan guildhalls	(Brunn et al., 2016, p. 206)
	Historic building	(Brunn et al., 2016, p. 41; Gilboa et al., 2015, p. 57; Rehan, 2014, p. 225; Yasumoto et al., 2011, pp. 465, 470)
	Obsolete historic structure	(Brunn et al., 2016, pp. 208-209)
	Restored history neighborhood	(Judd, 1995, p. 178)
	Recreational facilities	
Aquarium	Aquarium	(Judd, 1995, p. 178)
Cinema	Cinema	(Aschwanden et al., 2011, p. 302; Dong et al., 2010, pp. 2, 4; Pawley, 1997, p. 58)
	Movie theater	(Gilboa et al., 2015, p. 58)
Disco	Club	(Gilboa et al., 2015, pp. 53, 58; Pawley, 1997, p. 19)
	Disco techs	(Gilboa et al., 2015, pp. 53, 58)
Entertainment park	Disneyland	(Dong et al., 2010, p. 3)
	Conference centers	
Conference center	Conference center	(Gilboa et al., 2015, p. 57; Luque-Martínez et al., 2007, p. 340)
	Convention center	(Judd, 1995, p. 178)
	Rivers	
River	Han River	(Gilboa et al., 2015, pp. 57)
	Waterfronts	
Waterfront	Waterfront	(Branch, 1971, pp. 93–94, 127; Judd, 1995, p. 178)

Group of city elements	City element	Source
Channels		
Channel	Channel	(Gilboa et al., 2015, pp. 58)
	Mittellandkanal	(Reichold, 1998, p. 20)
Reservoirs		
Reservoir	Resevoir	(Branch, 1971, pp. 26, 97; Rasekh & Brumbelow, 2015, p. 64; Torres et al., 2009, p. 1262)
Nodes		
Airports		
Airports	Airport extension	(Branch, 1971, p. 97)
	Airport	(Alessi et al., 2015, p. 2; Branch, 1971, p. 26; Brunn et al., 2016, p. 203; Castells, 1997; Gilboa et al., 2015, p. 113)
Ports		
Port	Harbor	(Branch, 1971, pp. 97, 99)
	Port	(Brunn et al., 2016, pp. 203, 208-209)
	South Street Seaport	(Judd, 1995, p. 183)
Train stations		
Train stations	Main station	(Brunn et al., 2016, p. 227; Pawley, 1997, p. 19)
	Train station	(Brunn et al., 2016, p. 227)
	Suburban stations	(Grassmuck, 1997, p. 38)
	Bus station	(Alessi et al., 2015, pp. 2, 5; Haken & Portugali, 2003, p. 404; Pawley, 1997, p. 19)
	Underground station	(Haken & Portugali, 2003, p. 404; Pawley, 1997, p. 19)
	Union Station	(Judd, 1995, p. 183)
Parking		
Parking	Central parking	(Brunn et al., 2016, p. 230)
	Off-street parking	(Grant, 2012, pp. 33-34)
	Parking lot for delivery trucks	(Branch, 1971, pp. 127)
	Parking spaces	(D'Acci, 2013, p. 4; Dávalos et al., 2016, p. 924; Luque-Martínez et al., 2007, p. 340; Pawley, 1997, p. 19)
	Parking meters	(Meixner et al., 2011, p. 1)
Squares		
Squares	Squares	(Brunn et al., 2016, p. 213; Dávalos et al., 2016, pp. 924–925; Gilboa et al., 2015, p. 56; Krier, 1997, p. 181; Rašković & Decker, 2015, pp. 237–238)
	Parade ground	(Pawley, 1997, p. 19)
	Alexanderplatz	(Brunn et al., 2016, p. 227)
	Palace Square	(Rehan, 2014, pp. 225-226)
Markets		
Market places	Regional trade center	(Branch, 1971, pp. 99)
	Faneuil Hall	(Judd, 1995, p. 183)

Group of city elements	City element	Source
Market places	Stock exchange	(Brunn et al., 2016, p. 226)
	Market	(Brunn et al., 2016, p. 41; Gilboa et al., 2015, p. 57)
	Festival market-place	(Brunn et al., 2016, pp. 208-209, 213)
Nature		
Coast	Beach	(Gilboa et al., 2015, p. 57)
	Coast line	(Glander & Döllner, 2009, pp. 375–376)
Garden	Garden	(Alessi et al., 2015, p. 3; Gilboa et al., 2015, p. 57; Luque-Martínez et al., 2007, p. 340; Rašković & Decker, 2015, p. 237; Schröter et al., 2018, p. 122)
Green spaces	Green space	(Alessi et al., 2015, p. 5; Gilboa et al., 2015, pp. 52–53, 57–58; Grant, 2012, pp. 29, 33–34; Meixner et al., 2011, p. 1; Rašković & Decker, 2015, p. 237; Reichold, 1998, p. 47; Schröter et al., 2018, p. 122; Yasumoto et al., 2011, pp. 464–465)
Parks	Park	(Branch, 1971, p. 26; Brunn et al., 2016, pp. 20, 59; D'Acci, 2013, p. 4; Gilboa et al., 2015, pp. 52–53, 56–58; Luque-Martínez et al., 2007, p. 340; Pawley, 1997, p. 19; Rašković & Decker, 2015, p. 237; Yasumoto et al., 2011, p. 465)
Plants	Plant	(Chen et al., 2011, p. 4202)
	Tree	(Alessi et al., 2015, p. 5; Haken & Portugali, 2003, p. 404; Meixner et al., 2011, p. 1; Rašković & Decker, 2015, pp. 237–238; Schröter et al., 2018, p. 122; Yasumoto et al., 2011, p. 465)
Forests	Urban forest	(Rašković & Decker, 2015, p. 237)
	Wood	(Gilboa et al., 2015, p. 57)
Landmarks		
Buildings		
Buildings	Stock exchange	(Brunn et al., 2016, p. 226)
	Parliament	(Brunn et al., 2016, p. 226)
	City hall	(Bagchi et al., 2013, p. 17; Krim, 1992, pp. 131–132)
	Town hall	(Brunn et al., 2016, p. 206)
	Church	(Bagchi et al., 2013, p. 17; Brunn et al., 2016, p. 206; Gilboa et al., 2015, p. 57; Reichold, 1998, p. 47)
	Cathedral	(Brunn et al., 2016, pp. 41, 213)
	Basilica di San Pietro	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Notre Dame	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Louvre Museum	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Mercedes-Benz-Museum	(Rehan, 2014, p. 225)
	Porsche Museum	(Rehan, 2014, p. 225)
	national theatre	(Brunn et al., 2016, p. 226)
	Wall	(Brunn et al., 2016, pp. 41, 206; Reichold, 1998, p. 20)

Group of city elements	City element	Source
Buildings	Jerusalem's Western Wall	(Savitch, 2010, p. 44)
	Gate	(Brunn et al., 2016, pp. 206, 213; Fominykh et al., 2010, p. 373; Yasumoto et al., 2011, p. 464)
	Historic city gate	(Gilboa et al., 2015, p. 58)
	Colosseum	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Castel Saint Angelo	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Artisan guildhalls	(Brunn et al., 2016, p. 206)
	Historic building	(Brunn et al., 2016, p. 41; Gilboa et al., 2015, p. 57; Rehan, 2014, p. 225; Yasumoto et al., 2011, pp. 465, 470)
	Obsolete historic structure	(Brunn et al., 2016, pp. 208-209)
	Palace	(Alessi et al., 2015, p. 3; Brunn et al., 2016, pp. 41, 206, 226; Gilboa et al., 2015, p. 56; Pawley, 1997, p. 19; Rehan, 2014, p. 225)
	Stadium	(Brunn et al., 2016, p. 206; Judd, 1995, pp. 178, 181)
	Olympic Stadium	(Gilboa et al., 2015, p. 56)
Monuments		
Monuments	Altare della Patria	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Arc de Triomphe	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3)
	Brandenburg Gate	(Brunn et al., 2016, p. 227)
	Eiffel Tower	(Chang & Wang, 2016, p. 2789; Chang et al., 2016, p. 3; Savitch, 2010, p. 44)
	St. Louis Arch	(Yusoff, Noor, & Ghazali, 2014, p. 584)
	Monument	(Gilboa et al., 2015, p. 57)
Statues		
Statues	Statue	(Brunn et al., 2016, p. 206)
	Statue of Liberty	(Krim, 1992, p. 134)

Appendix IV-2: Detailed Results of Identified EA Elements

TOGAF element	EA element	Source
Business architecture		
Actor	Actor	(Cardoso, Almeida, & Guizzardi, 2010b, p. 82; Hess, Lautenbacher, & Fehlner, 2013b, p. 195; Pena & Villalobos, 2010, p. 340)
	Business actor	(Florez, Sánchez, & Villalobos, 2014a, p. 33; Luo, Fu, & Liu, 2016, p. 734; Nardi et al., 2016, p. 141; Nardi, Falbo, & Almeida, 2014, p. 93)
	Business unit	(Alonso, Verdún, & Caro, 2010b, p. 4; Park, LEE, & Lee, 2013, p. 4; The Open Group, 2012, p. 19; Veneberg, Iacob, Sinderen, & Bodenstaff, 2014b, p. 26)

TOGAF element	**EA element**	**Source**
Actor	Persons	(Narman, Johnson, Ekstedt, Chenine, & Konig, 2009, p. 24)
	People	(Bakar, Harihodin, & Kama, 2016b, p. 1)
	Humans	(The Open Group, 2012, p. 19)
	Departments	(The Open Group, 2012, p. 19)
Organization Unit	Business actor	(Florez et al., 2014a, p. 33; Luo et al., 2016, p. 734; Nardi et al., 2016, p. 141, 2014, p. 93)
	Organization unit	(Bakar et al., 2016b, p. 1; Braunnagel, Johannsen, & Leist, 2015, p. 3; Hess et al., 2013b, p. 196; Rohloff, 2009, p. 779; Santana, Souza, Simon, Fischbach, & Moura, 2017b, p. 11; Wilfling & Baumoel, 2011, p. 2)
	Business unit	(Alonso et al., 2010b, p. 4; Park et al., 2013, p. 4; The Open Group, 2012, p. 19; Veneberg et al., 2014b, p. 26)
Role	Business role	(Nardi et al., 2016, p. 141, 2014, p. 93; Valdez, Cortes, Arzola, Castaneda, & Luna, 2015, p. 324)
	Role	(Cardoso et al., 2010b, pp. 340–341; Hess et al., 2013b, p. 196; Pena & Villalobos, 2010, p. 82; Valdez et al., 2015, p. 323)
Function	Business function	(Ramljak, 2017b, p. 2; Santana et al., 2017b, p. 11; Veneberg et al., 2014b, p. 26)
	Business interaction	(Cardoso et al., 2010b, p. 341)
	Function	(Braunnagel et al., 2015, p. 3; Hess et al., 2013b, p. 196)
Process	Business process	(Alonso et al., 2010, p. 4; Cardoso et al., 2010, p. 340; Castellanos et al., 2011, pp. 118–119; Farwick et al., 2010, p. 35; H. Florez et al., 2014b, p. 2, 2014a, pp. 33–34; Hess et al., 2013, p. 196; Jugel & Schweda, 2014, p. 33; LEE, Lee, & Park, 2015, p. 2; Luo et al., 2016, p. 734; Nardi et al., 2016, p. 141; Park et al., 2013, pp. 4–5; Pena & Villalobos, 2010, p. 82; Ramljak, 2017, p. 2; Rohloff, 2011, p. 779; Santana et al., 2017, p. 10; Valdez et al., 2015, p. 324)
	Business interaction	(Cardoso et al., 2010b, p. 341)
	Process	(Ahsan, Kingston, & Shah, 2009, p. 1; Bakar et al., 2016b, p. 1; Braunnagel et al., 2015, p. 3; Hess et al., 2013b, p. 196; Krolczyk, Senf, & Cordes, 2010, p. 4; Narman et al., 2009, p. 24; D. Quartel, Steen, & Lankhorst, 2010, p. 3; Santana et al., 2017b, p. 11; Veneberg et al., 2014b, p. 26; Zimmermann et al., 2015, p. 130)
	Activity	(Ahsan et al., 2009, p. 1)
Business Capability	Operational capability	(El Sawy & Pavlou, 2008b, p. 140)
	Dynamic capability	(El Sawy & Pavlou, 2008b, p. 140)
	Improvisational capability	(El Sawy & Pavlou, 2008b, p. 140)

TOGAF element	EA element	Source
Value Stream	Sequence of activities	(Morris & Marshall, 2011, p. 6)
	Building blocks	(Morris & Marshall, 2011, p. 6)
Course of Action	NN	NN
Business service	Business service	(Cardoso et al., 2010b, p. 341; Hess et al., 2013b, p. 196; Ramljak, 2017b, p. 2)
	IT services	(D. Quartel et al., 2010, p. 3)
Product	Product	(Pena & Villalobos, 2010, p. 82; D. Quartel et al., 2010, p. 3; Valdez et al., 2015, p. 323)
Control	Sign-off control	(TOGAF, 2018b)
Contract	Service Level Agreement (SLA)	(Alwadain, Fielt, Korthaus, & Rosemann, 2011a, pp. 5, 7; The Open Group, 2012, pp. 44–45)
	Service Conditions	(Alwadain et al., 2011a, pp. 5, 7; The Open Group, 2012, pp. 44–45)
	Quality of Software	(Alwadain et al., 2011a, pp. 5, 7)
Service Quality	Measurable indicator	(Papazoglou, 2003b, pp. 1–2, 4)
Event	Request event	(The Open Group, 2012, pp. 33–34)
	Sending event	(The Open Group, 2012, pp. 33–34)
Measure	KPI	(Ganesan & Paturi, 2009b, p. 4; Hanschke, 2013, p. 602)
Objective	Objective	(Valdez et al., 2015, p. 323)
Goal	Business goal	(Ramljak, 2017b, p. 2)
	Strategic goal	(Santana et al., 2017b, p. 10)
Driver	Regulations	(TOGAF, 2018a)
	Compliance rules	(The Open Group, 2012, p. 143; TOGAF, 2018a)
	Customer satisfaction	(The Open Group, 2012, p. 143)
	profitability	(The Open Group, 2012, p. 143)
Data architecture		
Data Entity	Organization's data entity	(Hess et al., 2013b, p. 195)
	Business object	(Florez et al., 2014a, p. 33; Pena & Villalobos, 2010, p. 82)
	Customer record	(The Open Group, 2012, pp. 54–55)
	Client database	(The Open Group, 2012, pp. 54–55)
	Insurance claim	(The Open Group, 2012, pp. 54–55)
Logical Data Component	Customer record	(The Open Group, 2012, pp. 54–55)
	Client database	(The Open Group, 2012, pp. 54–55)
	Insurance claim	(The Open Group, 2012, pp. 54–55)
	Protocol	(Alonso et al., 2010b, p. 5)
Physical Data Component	File	(The Open Group, 2012, pp. 73–74)
	Executable	(The Open Group, 2012, pp. 73–74)
	Script	(The Open Group, 2012, pp. 73–74)
	Document	(The Open Group, 2012, pp. 73–74)
	Database table	(The Open Group, 2012, pp. 73–74)
	Massage	(The Open Group, 2012, pp. 73–74)

TOGAF element	EA element	Source
Physical Data Component	Model file	(The Open Group, 2012, pp. 73–74)
	Specification	(The Open Group, 2012, pp. 73–74)
Application architecture		
Information System Service	Software application service	(Cardoso et al., 2010b, p. 340)
	Application service	(Luo et al., 2016, p. 734; Pena & Villalobos, 2010, p. 82)
Logical Application Component	(Software) application	(Luo et al., 2016, p. 734)
	(Software) application component	(Pena & Villalobos, 2010, p. 82)
	Application	(Ahsan et al., 2009, p. 1; Alonso et al., 2010b, pp. 4–5; Castellanos et al., 2011, p. 118; Hess et al., 2013b, p. 196; LEE et al., 2015; Narman et al., 2009, p. 24; Pena & Villalobos, 2010, p. 82; D. Quartel et al., 2010, p. 3; Rohloff, 2011b, p. 779; Santana et al., 2017b, p. 10; Zimmermann et al., 2015, p. 1307)
	Business application	(LEE et al., 2015, p. 2; Park et al., 2013, pp. 4–5)
	Application component	(Florez et al., 2014a, pp. 33–34, 2014b, p. 2; Hess et al., 2013b, p. 196; Nardi et al., 2016, p. 141; Veneberg et al., 2014b, p. 26)
Physical Application Component	Software	(Alonso et al., 2010, p. 5; Farwick et al., 2010, p. 35; Krolczyk et al., 2010, p. 4)
	Software application	(Cardoso et al., 2010b, p. 340; Nardi et al., 2016; Santana et al., 2017b, p. 11)
	Application component	(Florez et al., 2014a, pp. 33–34, 2014b, p. 2; Hess et al., 2013b, p. 196; Nardi et al., 2016, p. 141; Veneberg et al., 2014b, p. 26)
Technology architecture		
Technology Service	Platform service	(Hess et al., 2013b, p. 196; Santana et al., 2017b, p. 11)
	Infrastructural service	(Cardoso et al., 2010b, p. 340)
Logical Technology Component	Client workstation	(The Open Group, 2012, p. 64)
	Server	(The Open Group, 2012, p. 64)
	Node	(Alonso et al., 2010b, p. 5; The Open Group, 2012, p. 70)
	Infrastructure function	(The Open Group, 2012, p. 64)
	Database	(Park et al., 2013, p. 4; Pena & Villalobos, 2010, p. 82; Rohloff, 2011b, p. 779)
	Communication infrastructure	(Pena & Villalobos, 2010, p. 82)
	Cloud infrastructure	(Farwick et al., 2010, p. 36)

TOGAF element	**EA element**	**Source**
Physical Technology Component	Hardware system	(Nardi et al., 2016, p. 141; The Open Group, 2012, p. 65)
	Device	(Florez et al., 2014a, pp. 33–34; The Open Group, 2012, p. 65)
	Router	(The Open Group, 2012, p. 65)
	Computer	(Cardoso et al., 2010b, p. 340; Luo et al., 2016, p. 734; The Open Group, 2012, p. 65)
	Communication Device	(Luo et al., 2016, p. 734)
	DBMS	(Nardi et al., 2016, p. 141)
	Network	(The Open Group, 2012, p. 69)

V

EVALUATION OF AN AUGMENTED REALITY PROTOTYPE FOR ENTERPRISE ARCHITECTURE

Abstract

Enterprise Architecture (EA) visualizations like text, diagrams, and models ae 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. In this paper, we empirically evaluate a prototype deployed on an optical see-through head-mounded display (HMD) with 13 business professionals. The examined prototype displays a real-world databased 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. The results indicate an agreement using AR for EA analysis, but this is limited to high level tasks of which the purpose is to communicate with specific stakeholders. We further derive design requirements for similar AR prototype developments

Keywords: *Enterprise Architecture Management, Augmented Reality Evaluation, Evaluating User Experience, Design Requirements*

This article was co-authored with Frederik Ahlemann. An earlier version of this article was published in 15th International Conference on Wirtschaftsinformatik (WI):

Rehring, K., & Ahlemann, F. (2020). Evaluating the User Experience of an Augmented Reality Prototype for Enterprise Architecture. In *15th International Conference on Wirtschaftsinformatik* (WI), Potsdam, Germany

Table of Contents

List of Figures

List of Tables

1 Introduction

Recent technological improvements have led to the development of high-performing optical see-through head-mounted displays (HMDs) (Kortekamp, Werning, Thomas, & Ickerott, 2019, p. 1). These special forms of HMDs superimpose three-dimensional virtual objects over the real-world view of its operator (Milgram, Takemura, Utsumi, & Kishino, 1994) enabling interaction in a so-called augmented reality (AR) (Azuma, 1997, p. 357). Recent publications indicate that AR systems are capable of presenting large amounts of information (Olshannikova, Ometov, Koucheryavy, & Olsson, 2015) that can be accessed and manipulated by using gestures (Azuma, 1997, p. 357). This can reduce a user's cognitive load (Dunleavy, Dede, & Mitchell, 2009, p. 17; Wang, Love, Kim, & Wang, 2014, p. 13), also due to exploiting humans' spatial imagination capabilities, which subsequently can enable a better overall understanding of complex causal relationships (Dunleavy et al., 2009, p. 17; Sommerauer & Müller, 2014, p. 67; Wang et al., 2014, p. 13) and, hence, can lead to quicker decision-making processes (Deck & Jahedi, 2015). In addition and despite virtual reality (VR) applications which immerse users in a fully virtual environment and disconnect them from the real world (Steffen, Gaskin, Meservy, & Jenkins, 2017, p. 4), AR still enables face-to-face communication in a real-world setting with less reported motion sickness (Vovk, Wild, Guest, & Kuula, 2018, p. 6; Wu, Lee, Chang, & Liang, 2013, p. 44) – which is favorable for practitioners. These characteristics have resulted in various AR HMD implementations, e.g. in the area of medicine (Meola et al., 2017), teaching (Lee, 2012), and software development (Merino, Bergel, & Nierstrasz, 2018).

Motivated by these benefits and facing the relatively low use of enterprise architecture (EA) visualizations for decision-making in organizations (Hiekkanen et al., 2013, p. 296; Löhe & Legner, 2014, p. 116), 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 (Tamm, Seddon, Shanks, & Reynolds, 2011, p. 142; The Open Group, 2009, p. 411) in the form of text, graphs, charts, and 2D and 3D models (Roth, Zec, & Matthes, 2014), were represented in AR in the shape of a three-layer model. Our goal in this previous study (Rehring, Greulich, Bredenfeld, & Ahlemann, 2019, p. 1 & 8) 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 (Rehring, Greulich, et al., 2019, p. 1 & 8). As a result, we assume that this approach may address confront the low usage of EA visualization for EA-related decision-making in organizations (Rehring, Greulich, et al., 2019).

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. (Lam, Bertini, Isenberg, Plaisant, & Carpendale, 2012, p. 10–11) 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" (Greenberg & Buxton, 2008, p. 111). 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.

2 Theoretical Foundation

2.1 Augmented Reality

Following Azuma's (Azuma, 1997) 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 (Milgram et al., 1994). 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 (Milgram et al., 1994). 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 (Azuma, 1997, p. 31; Kortekamp et al., 2019, p. 1). In comparison, smartphones or tablets are handheld AR displays, which use cameras to overlay real and virtual objects on a screen (Dunleavy et al., 2009, p. 8; Lee, 2012, p. 14). 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 Architectures

Today's EAs are commonly visualized using e.g. text (tag clouds, textual descriptions), charts (pie chart, line chart, bar chart), models (ArchiMate, BPMN, UML), maps (geographic maps, tree maps), and many more such instruments (Roth et al., 2014). The great variety of EA visualization types enables stakeholders to "communicate and analyze complex information, promote stakeholder involvement, or increase transparency" (Roth et al., 2014, p. 4) with the aim of achieving "coherent and goal-oriented organizational processes, structures, information provision and technology" (Foorthuis, Steenbergen, Brinkkemper, & Bruls, 2016, p. 541). 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 integrates various sources in a commonly known layer representation.

3 Research Design

This paper aims to develop an understanding of the degree to which, from an expert's point of view, an AR HMD-based prototype visualizing an exemplary EA supports specific EA-related tasks. Following Lam et al. (Lam et al., 2012, p. 1529f), we evaluated user experiences to achieve this aim, as this allow us to evaluate our EA 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, questionnaires, and 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 (Rehring, Greulich, et al., 2019) 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 TOGAF meta model (The Open Group, 2009); it applies the ArchiMate notation (The Open Group, 2012) to ensure high acceptance by experts. 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 change the objects' appearance in terms of sizes and color, depending on the selected analytic function. If necessary, filter functions enable users to remove all non-relevant layers and objects through keywords or specific selections.

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 (The Open Group, 2009). 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° horizontal and 17.5° vertical field of view. Even though the prototype supports voice control, we limit the evaluation of user experience to 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 V-1 and Figure V-2 for an example of such visualizations.

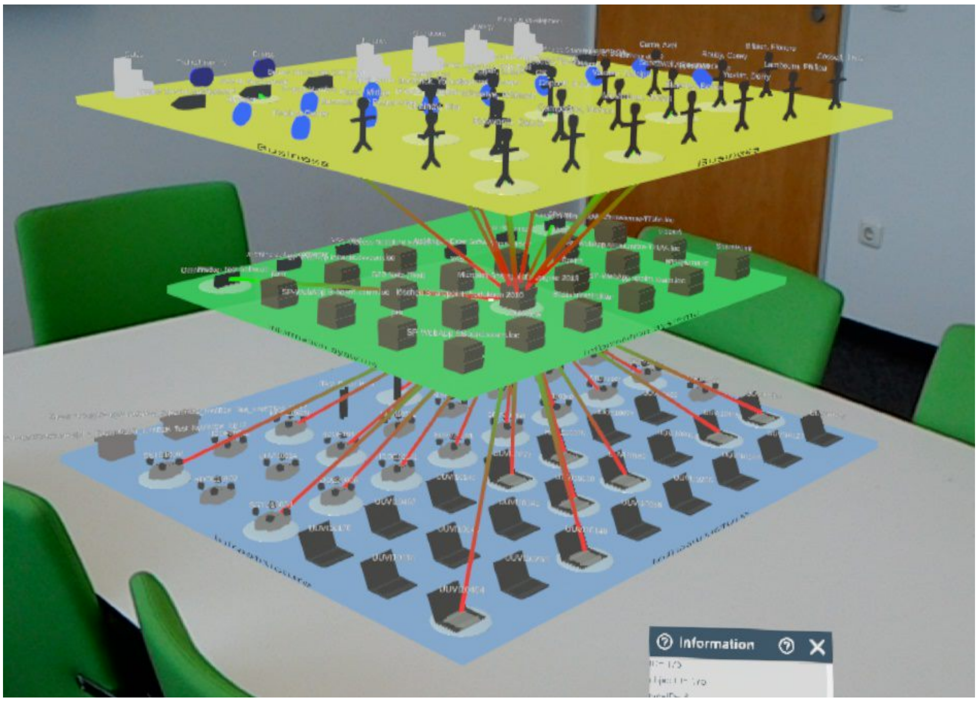


Figure V-1. Three-layer EA visualization showing connections

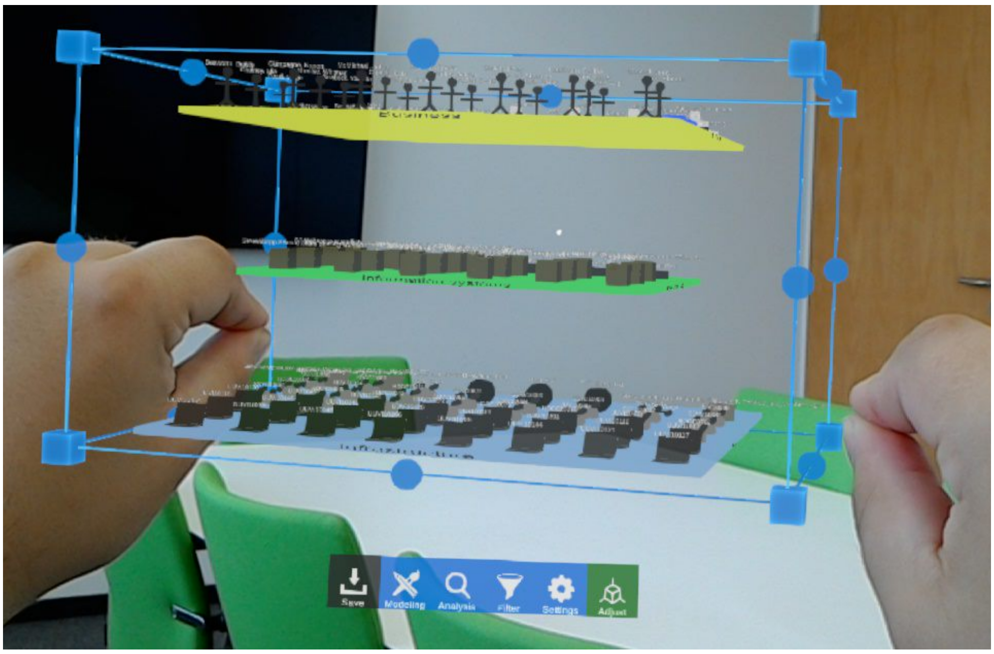


Figure V-2. Rotating the AR model using two hands

3.2 Participants

To achieve our research objectives, we required the participation of experts. Hence, based on our personal networks as well as via social media, we invited experts with a background in architecture modelling and analysis. Overall, we evaluated user experiences with 13 participants, of which 2 were woman and 11 men. Their average age was 37,3 years. 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 pre-questions helped us to assess broadly whether the participants' EA maturity was appropriate for our evaluation. After recognizing answers being repeated by our participants, we assumed a point of saturation and stopped inviting more potential candidates. On average, the participants had 9 years of experience with EAM, which was widely distributed across a range of between one year and 40 years of experience. Also, some of the experts 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) 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 V-1 provides an overview of the participating experts.

3.3 Evaluation

We conducted all evaluations in a similar environment, taking six of the appraisals at our university and eight on a company's premises. We put two tables together, at which the participants sat on one side and the moderator on the other side. The presenter was always the same person. We ensured that the experts 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 experts 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 spe-

Table V-1. Overview of participating experts

ID	Industry	Role	Years of EA experience	AR HMD experience [1-5]
1	Energy production	Software Architect	9	4
2	Industrial 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 / Data Analytics	Strategic Business Development and Research Innovation	5	4
13	Consulting / Data Analytics	Software Engineer	15	3

cific questions to assess the maturity of their EAM 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. Hence, we requested the participants to complete a tutorial with the official training app on the HMD. This app supports the experts in setting up the device to fit their individual needs, and trains them in using the gestures. After the tutorial had been finished successfully, we started with the evaluation of our EA visualization. For this, we prepared three classes of EA-related tasks that, in all, can be completed in approximately 30 minutes: participants had to use the EA visualization (in creating, moving, rotating, zooming), analyze the EA (by finding dependencies and comparing objects), and manipulate the appearance (by disabling layers and objects, searching for keywords). Table V-2 gives an overview of all tasks. We went through the tasks one-by-one, first reading out the question 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. Finally, all participants completed a post-evaluation questionnaire. We followed Lam et al. (Lam et al., 2012, p. 1529f) 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

Table V-2. Conducted EA tasks during evaluation

Task ID	Task description
Visualization tasks	
1	Create a new EA model
2	Rotate the EA model
3	Zoom into the EA model
4	Move the EA model to another location
Analysis - Find dependencies tasks	
5	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
Analysis - Compare objects tasks	
7	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
Filter tasks	
11	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"

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. The pre-questions (GQ) and post-questions (PQ) are summarized in Table V-3.

3.4 Data Analysis

During the evaluation, we audio recorded everything that was said, to ensure we would not miss any important statements. We transcribed the audio files and noted remarkable reactions or usage of the prototype, so that we could ask individual questions during the evaluation to understand how the participants worked with the visualization. In combination with the pre- and post-evaluation questionnaires, we coded all data using the tool Atlas.Ti in order to qualitatively describe the user experience. Moreover, we recorded the video file of the HMD for each participant. This enabled us to analyze the specific use of the EA visualization from a user point of view. Figure V-3 shows a sample of an exemplary video recording from an users 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. Our qualitative analysis is based on a common used and suitable coding approach featured by Corbin and Strauss (1990). In a first step, we read all papers, tagged all words and sets of words that

Table V-3. Pre- and post-questions of the evaluation

Pre-Questions	GQ1: What is your age?
	GQ2: What is your gender?
	GQ3: In which industry do you work?
	GQ4: What is your role in the company?
	GQ5: What do you understand by Enterprise Architecture Management?
	GQ6: How many years have you had experience with EAM?
	GQ7: What types of EA visualizations do you work with?
	GQ8: On a scale of 1 to 5, how much experience do you have with AR glasses?
	GQ9: Why are you participating in this evaluation?
Post-Questions	PQ1: What is your first impression of the prototype?
	PQ2: Which functions do you consider useful?
	PQ3: Which features are missing?
	PQ4: How can features be revised to improve work processes?
	PQ5: In how far is this tool understandable and can it be learned easily?
	PQ6: How did you perceive the control?

seemed to be relevant, and provided each a summarizing description. The descriptions were subject of constant change in order to produce descriptions that share the meaning of many excerpts. In a second step, we connected related open codes and then described a new set of connected open codes by so called axial codes. Lastly, these axial codes were again connected and described by new codes, called selective codes.

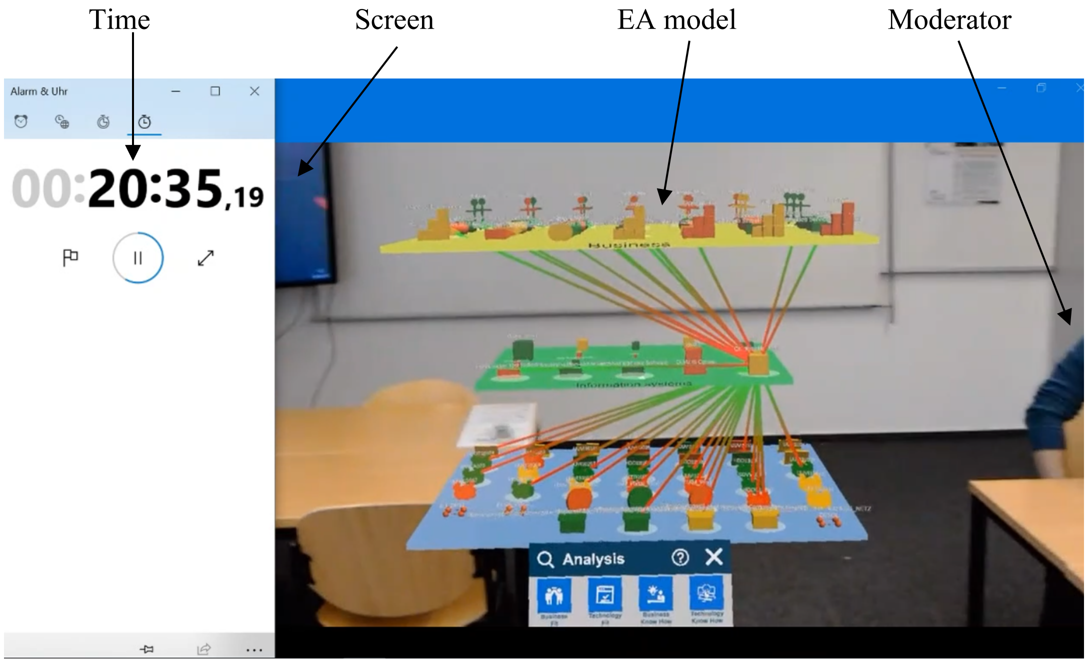


Figure V-3. Exemplary view on EA model from user perspective

4 Results

In the following, we will report on our results from a quantitative user performance (subsection 4.1) and a qualitative user experience (subsection 4.2) perspective. The detailed results are moved to the appendix.

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 answered all the tasks' instructions. The results are shown in Figure V-4. In the following, we explain how the users performed in each class of EA task: visualizing, analyzing, and filtering.

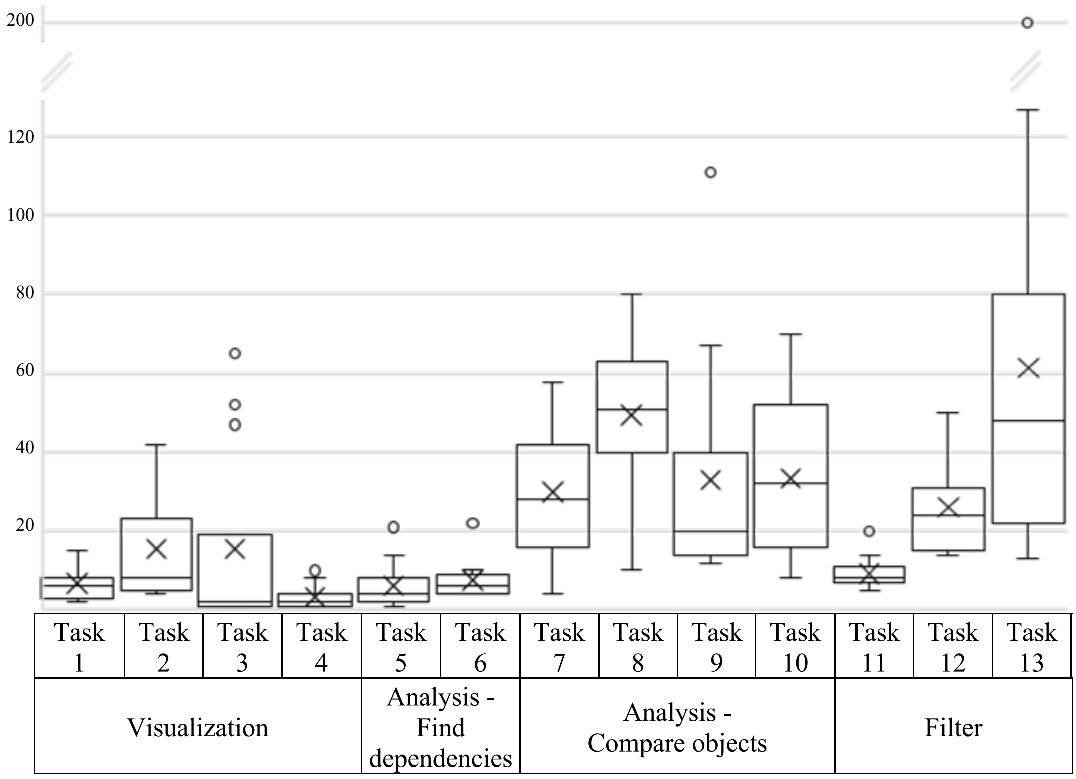


Figure V-4. Completion time in seconds for each task represented in a box-plot chart

Visualization: Overall, the participants quickly learned how to interact with the visualization but at first had difficulties in applying the gestures correctly. 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 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 incorrect application of the gestures resulted in longer completion time for task 2 (M=8sec; SD=14sec) and less for task 3 (M=2sec; SD=23sec). Task 4 (M=2sec; SD=3sec) posed no problems 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. However, they sometimes struggled to read the names of the objects, or the objects were hidden behind other objects which meant the experts had to adjust their perspective on the model. Experts 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 due to the fact that we did not provide proper definitions of each analytic function. The experts 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 experts 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.

Filter: Filtering the 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 experts 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. It is based on the statements that the participants mentioned while performing the EA tasks, as well as on open questions that were asked after the evaluation. We categorized users' statements into five main classes, namely general, device, analysis, interaction, and visualization. Moreover, we subdivided each statement into sub-classes, namely assessment, improvement, and problem. Table V-4 provides an overview of the amount of identified statements. For precision, we mark in parenthesis participants' statements with reference to the IDs of those who made the points.

Table V-4. Overview of identified unique statements during evaluation

Class	Sub-class	Number of unique statements	Total
General	Assessment	58	71
	Improvement	9	
	Problem	4	
Device	Improvement	1	22
	Problem	21	
Analysis	Assessment	26	73
	Improvement	31	
	Problem	16	
Interaction	Assessment	50	90
	Improvement	10	
	Problem	30	
Visualization	Assessment	28	101
	Improvement	20	
	Problem	53	
			357

General: In general, most experts assessed the prototype 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 prototype was also perceived as being "touchable" (*2,5,7,9*) which increases the understandability of the EA and, hence, makes it a useful tool to introduce EAM within a company (*2*). Four participants mentioned that the 3D visualization might be useful for communicating EAs to stakeholders, e.g. to customers, departments, or other groups of people (*2,5,7,11*). Looking to the future, another participant commented that collaborative work on EAs can be positively influenced by the application of the evaluated prototype (*11*).

However, the evaluated prototype might not be relevant for enterprise architects, as they need more detailed analysis capabilities (*2*). Only one participant was convinced that a 3D visualization of the EA yields no benefit for a company (*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 is a standard missing that regulates the use of HMDs in the industrial context (*2*). The usability in large offices should be tested first (*11*).

Device: Besides generally being enthusiastic about interacting with the HMD, the experts reported several physical issues about the hardware. 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 perceived it as being 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 might be related to the weight of the HMD (*3,10*). It seemed to be challenging for the participants to use their hands only within the defined frame of activity that the HMD could capture. This was perceived as inhibiting (*4,9,12*).

Beside the hardware limitations, the experts 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 a shaking model (*1,12*), cursor (*3,12*), or text (*5*) that could be avoided by relocating the model to a different place. When placing the model on top of a table, sometimes the model "fell" under the table (*4,5*) which meant that the participant needed to search for the model and move it back to the table. Also, parts of the model disappeared when the experts moved too close to it (*3,4,12*). This withheld users from standing "inside" the model or getting closer to objects of interest.

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 (*6*) and considerably better suited to present connections than doing so using, e.g., network plans or listings (*7,8,11*). One expert compared the prototype 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 ArchiMate notation, using ArchiMate as the basic modelling language simplified the adoption (*4*). The accompanying main menu is easy to understand (*9,12*).

Due to the 3D representation of the three-layer model, 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 changing the user's position or by moving and rotating the model. One way of overcoming this issue is for the individual to change the distance between the layers in the model (*4*). This might explain an assessment that this model is not well-suited for very large EAs. According to the experts, including further EA aspects like projects, or increasing the number of objects itself, can create a too big visualization that overwhelms users (*7,10,11*). 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. For instance, 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*). While conducting task 12, 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*). 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, the prototype could benefit from adding a navigation menu 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*), especially the visualization of the connections between EA objects (*3,4,6-13*). The prototype offered different object sizes 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 for examples to reduce the amount of visualized EA objects was perceived to be helpful (*3,4,5,6,8*).

Even though 12 out of 13 participants immediately understood the different colors while investigating the results of an analysis, many experts 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 (*1,4,7*) 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 HMD (*1,3,6,7,10,11,13*) and that it was fun to use (*2,5,6,9,10*). Only one participant explicitly asked for a joystick to use instead of gestures (*3*). Regarding the handling of the prototype, a large portion of the experts 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 during the evaluation.

Even though the gestures were accepted and worked well during the evaluation, some participants had serious 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 experts, 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 experts as 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 (Microsoft.github.io., 2019) sometimes appeared to be too distant or too small (*6,7,11,12*), which made it difficult for the user to enter keywords.

The experts 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.

5 Discussion

5.1 Suitability of AR for Analyzing and Communicating EAs

The evaluation revealed that the participants learned how to interact with a layer-based visualization of an illustrative EA in AR after completing a familiarization phase and, moreover that mostly, they understood the presented analysis results. Overall, the average completion time for analyzing connections within an EA was substantially low. Due to the signal colors we used, the experts could also rapidly identify and interpret analysis results. This was in spite of the prototype falling short in defining the analysis features (e.g. “risk”, “business know-how”) and not explaining the colors by e.g. using a legend next to the visualization. Both the latter aspects would most likely have resulted in higher completion times. 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. This understanding was positively influenced by the experts 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 required user interactions for (e.g.) creating, moving, and rotating a model, showing connections starting from specific objects, or viewing analysis results. Hence, we claim that considering the third dimension for EA visualization presented in AR, enables users to include diverse EA objects more easily. This leads to more comprehensive overall representations without a negative influence on the analytical capabilities of a broad range of observers. This makes AR a great tool for communicating EAs to stakeholders with different kinds of IT and business know-how.

5.2 Design Recommendation for AR Apps

Design recommendations for AR HMD apps are rare. Recently, Berkemeier et al. (2019) comprehensively derived meta requirements, design principles, as well as a framework in order to support the design and implementation of AR HMD-based information systems. More broadly in terms of the used device, Quandt et al. (2018) focused on general requirements based on a literature review for industry applications in the area of AR. Another example is from Mirbabaie and Fromm (2019), where they derived five AR design recommendations in the area of emergency management and highlight that AR hardware (head-mounted vs. hand-held) needs to fit to the specific use case. Based on our observations and participants’ feedback, we can add design recommendations for similar information visualizing AR prototypes, as shown in Table V-5.

Table V-5. General design recommendations for information visualizing AR apps

Design Recommendation	Rationale
An AR application should preferably be designed to enable working while standing.	We observed that in 79% of the time the participants stand while performing the tasks.
A user rights management system for or integrated with the AR application is needed to facilitate collaboration.	Statements indicate that working in groups might require to differentiate between a moderator and viewers.
Users must be able to change individual visual preferences to address visual impairments like e.g. color-blindness.	Organizations endeavor to integrate all their employees; hence, visual impairments need to be considered.
After performing gestures, recognizable audio, visual, or haptic feedback should follow.	Many of our participants were confused when they performed an air tap but did not receive any feedback.
Distinguishable object sizes and colors are suitable for presenting results of analyses.	Our results show that different object sizes as well as using signal colors enhance the understanding of analyses.
Arrows and lines should never pass through other objects without a reason.	All objects along an arrow are perceived to be connected.
Introducing HMDs to a new user reuires them to practice the gestures first.	Interacting with a HMD is a new experience and needs practice in order to gain acceptance for specific AR apps.

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 (Rehring, Greulich, Bredenfeld, & Ahlemann, 2019), we conducted an evaluation of user experience with 13 EA experts, 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 experts from EAM or related fields. 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 experts to participate in the evaluation. However, we assumed a point of saturation due to repeatedly getting the same feedback and answers, and therefore stopped inviting more potential candidates. Third, we did not question the quality of the underlying EA data. We excluded a discussion of the difficulties involved in obtaining high quality EA data, also because we worked almost completely with real-world data. Fourth, we have to assume that some participants might have been overly positive in their assessment of the prototype due to some form of technology bias.

Future research could aim to extend this work by adding more diverse visualizations to the prototype. Investigating the collaborative use of EA AR 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 use metaphors that seem to be very promising in getting stakeholders to develop an understanding of EA visualization (Rehring, Brée, Gulden, & Bredenfeld, 2019).

References

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and virtual environments*, *6*(4), 355–385.

Berkemeier, L., Zobel, B., Werning, S., Ickerott, I., & Thomas, O. (2019). Engineering of Augmented Reality-Based Information Systems - Design and Implementation for Intralogistics Services. *Business & Information Systems Engineering*, *61*(1), 67–89.

Corbin, J., & Strauss, A. (1990). Grounded theory research: procedures, canons, and evaluative criteria. *Qualitative Sociology*, *13*(1), 3–21.

Deck, C., & Jahedi, S. (2015). The effect of cognitive load on economic decision making: A survey and new experiments. *European Economic Review*, *78*, 97–119. https://doi.org/10.1016/j.euroecorev.2015.05.004

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, *18*(1), 7–22. https://doi.org/10.1007/s10956-008-9119-1

Foorthuis, R., Steenbergen, M., Brinkkemper, S., & Bruls, W. A. (2016). A theory building study of enterprise architecture practices and benefits. *Information Systems Frontiers*, *18*(3), 541–564.

Greenberg, S., & Buxton, B. (2008). Usability evaluation considered harmful (some of the time). *Proceeding of the Twenty-Sixth Annual CHI Conference on Human Factors in Computing Systems - CHI '08*, 111. Florence, Italy: ACM Press. https://doi.org/10.1145/1357054.1357074

Hiekkanen, K., Korhonen, J. J., Collin, J., Patricio, E., Helenius, M., & Mykkänen, J. (2013). Architects' Perceptions on EA Use – An Empirical Study. *2013 IEEE 15th Conference on Business Informatics*, 292–297. https://doi.org/10.1109/CBI.2013.48

Kortekamp, S.-S., Werning, S., Thomas, O., & Ickerott, I. (2019). THE FUTURE OF DIGITAL WORK - USE CASES FOR AUGMENTED REALITY GLASSES. *ECIS 2019*. Gehalten auf der Sweden. Sweden. Abgerufen von https://aisel.aisnet.org/ecis2019_rp/165

Lam, H., Bertini, E., Isenberg, P., Plaisant, C., & Carpendale, S. (2012). Empirical Studies in Information Visualization: Seven Scenarios. *IEEE Transactions on Visualization and Computer Graphics*, *18*(9), 1520–1536. https://doi.org/10.1109/TVCG.2011.279

Lee, K. (2012). *Augmented Reality in Education and Training*. *56*(2), 9.

Löhe, J., & Legner, C. (2014). Overcoming implementation challenges in enterprise architecture management: a design theory for architecture-driven IT Management (ADRIMA). *Information Systems and E-Business Management*, *12*(1), 101–137. https://doi.org/10.1007/s10257-012-0211-y

Meola, A., Cutolo, F., Carbone, M., Cagnazzo, F., Ferrari, M., & Ferrari, V. (2017). Augmented reality in neurosurgery: a systematic review. *Neurosurgical Review*, *40*(4), 537–548. https://doi.org/10.1007/s10143-016-0732-9

Merino, L., Bergel, A., & Nierstrasz, O. (2018). Overcoming issues of 3D software visualization through immersive augmented reality. *2018 IEEE Working Conference on Software Visualization (VISSOFT)*, 54–64. Madrid, Spain.

Microsoft.github.io. (2019). Mixed Reality Toolkit Documentation. Abgerufen 23. Juli 2019, von https://microsoft.github.io/MixedRealityToolkit-Unity

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies*, *2351*(11), 282–292.

Mirbabaie, M., & Fromm, J. (2019). REDUCING THE COGNITIVE LOAD OF DECISION-MAKERS IN EMERGENCY MANAGEMENT THROUGH AUGMENTED

REALITY. *ECIS 2019*. Gehalten auf der Sweden. Sweden. Abgerufen von https://aisel.aisnet.org/ecis2019_rip/50

Olshannikova, E., Ometov, A., Koucheryavy, Y., & Olsson, T. (2015). Visualizing Big Data with augmented and virtual reality: challenges and research agenda. *Journal of Big Data*, *2*(1), 1–27.

Quandt, M., Knoke, B., Gorldt, C., Freitag, M., & Thoben, K.-D. (2018). General Requirements for Industrial Augmented Reality Applications. *Procedia CIRP*, *72*, 1130–1135. https://doi.org/10.1016/j.procir.2018.03.061

Rehring, K., Greulich, M., Bredenfeld, L., & Ahlemann, F. (2019). *Let's get in touch - Decision making about Enterprise Architecture using 3D Visualization in Augmented Reality* (S. Proceedings of the 52nd annual Hawaii International Conference on Systems, Hrsg.). Hawaii, USA.

Rehring, Kevin, Brée, T., Gulden, J., & Bredenfeld, L. (2019). Conceptualizing EA Cities: Towards Visualizing Enterprise Architectures as Cities. *Proceedings of the 27th European Conference on Information Systems (ECIS)*. Gehalten auf der Twenty-Seventh European Conference on Information Systems (ECIS 2019), Stockholm & Uppsala, Sweden.

Rehring, Kevin, Greulich, M., Bredenfeld, L., & Ahlemann, F. (2019). Let's Get in Touch - Decision Making about Enterprise Architecture Using 3D Visualization in Augmented Reality. *Proceedings of the 52nd Hawaii International Conference on System Sciences*.

Roth, S., Zec, M., & Matthes, F. (2014). *Enterprise Architecture Visualization Tool Survey 2014*. Germany: epubli GmbH.

Sommerauer, P., & Müller, O. (2014). Augmented reality in informal learning environments: A field experiment in a mathematics exhibition. *Computers & Education*, *79*, 59–68. https://doi.org/10.1016/j.compedu.2014.07.013

Steffen, J., Gaskin, J., Meservy, T., & Jenkins, J. (2017). The Missing Framework for Virtually Assisted Activities. *Thirty Eighth International Conference on Information Systems*. Gehalten auf der Seoul. Seoul.

Tamm, T., Seddon, P. B., Shanks, G., & Reynolds, P. (2011). How does enterprise architecture add value to organisations. *Communications of the Association for Information Systems*, *28*(1), 141–168.

The Open Group. (2009). *TOGAF® Version 9*. Van Haren Publishing.

The Open Group. (2012). *ArchiMate® 2.0 Specification*. van Haren Publishing.

Vovk, A., Wild, F., Guest, W., & Kuula, T. (2018). Simulator Sickness in Augmented Reality Training Using the Microsoft HoloLens. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 209. ACM.

Wang, X., Love, P. E. D., Kim, M. J., & Wang, W. (2014). Mutual awareness in collaborative design: An Augmented Reality integrated telepresence system. *Computers in Industry*, *65*(2), 314–324. https://doi.org/10.1016/j.compind.2013.11.012

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education*, *62*(Supplement C), 41–49. https://doi.org/10.1016/j.compedu.2012.10.024

Appendix

Appendix V-1: Task Completion Time in Seconds

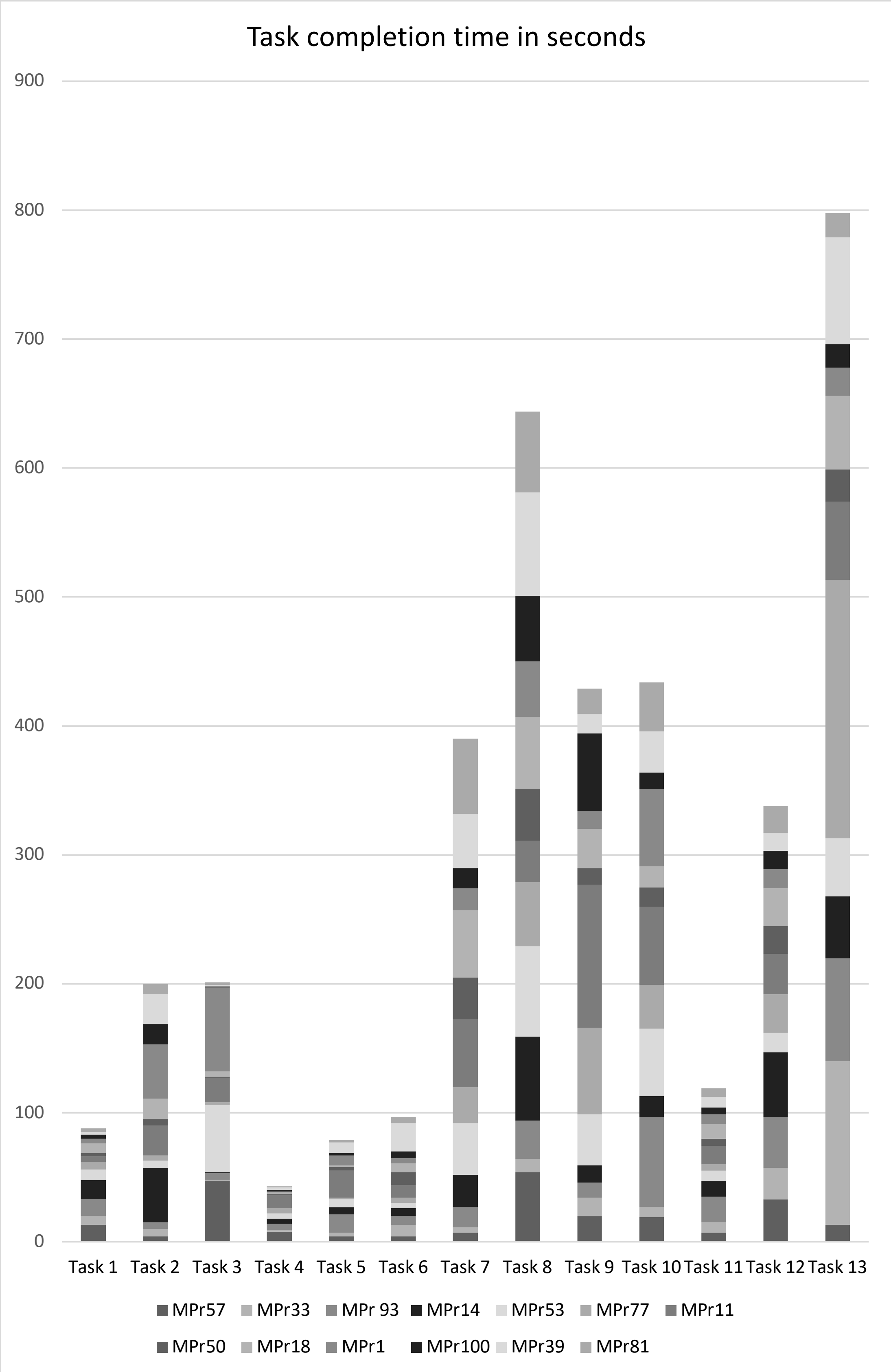
In seconds	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 9	Task 10	Task 11	Task 12	Task 13
MPr001	4	42	65	1	8	4	17	43	14	60	8	15	22
MPr011	4	23	19	10	21	10	53	32	111	61	14	31	61
MPr014	15	42	1	4	6	6	25	65	13	16	12	50	48
MPr018	7	16	4	1	1	7	52	56	30	16	11	29	57
MPr033	7	6	1	1	3	9	4	10	14	8	8	24	127
MPr039	2	23	1	2	8	22	42	80	15	32	8	14	83
MPr050	3	5	1	1	3	10	32	40	13	15	6	22	25
MPr053	8	6	52	4	6	4	40	70	40	52	8	15	45
MPr057	13	4	47	8	4	4	7	54	20	19	7	33	13
MPr077	6	4	2	4	1	4	28	50	67	34	5	30	200
MPr081	3	8	2	1	2	5	58	63	20	38	7	21	19
MPr093	13	5	5	5	14	7	16	30	12	70	20	40	80
MPr100	3	16	1	1	2	5	16	51	60	13	5	14	18

Average	6,8	15,4	15,5	3,3	6,1	7,5	30,0	49,5	33,0	33,4	9,2	26,0	61,4
Standard deviation	4,4	13,7	23,2	3,0	5,8	4,9	17,9	18,7	29,8	21,2	4,2	11,0	53,0
Minimum	2,0	4,0	1,0	1,0	1,0	4,0	4,0	10,0	12,0	8,0	5,0	14,0	13,0
Maximum	15,0	42,0	65,0	10,0	21,0	22,0	58,0	80,0	111,0	70,0	20,0	50,0	200,0
Min/Max Gap	13,0	38,0	64,0	9,0	20,0	18,0	54,0	70,0	99,0	62,0	15,0	36,0	187,0

Minimum	2,0	4,0	1,0	1,0	1,0	4,0	4,0	10,0	12,0	8,0	5,0	14,0	13,0
Q1	3,8	5,0	1,0	1,0	2,8	4,0	16,8	38,0	13,8	16,0	7,0	19,5	24,3
Average	6,5	7,0	3,0	3,0	5,0	6,5	30,0	52,0	17,5	33,0	8,0	26,5	52,5
Q3	9,3	23,0	26,0	4,3	8,0	9,3	44,5	63,5	32,5	54,0	11,3	31,5	80,8
Maximum	15,0	42,0	65,0	10,0	21,0	22,0	58,0	80,0	111,0	70,0	20,0	50,0	200,0

Q1-Minimum	1,8	1,0	0,0	0,0	1,8	0,0	12,8	28,0	1,8	8,0	2,0	5,5	11,3
Q1	3,8	5,0	1,0	1,0	2,8	4,0	16,8	38,0	13,8	16,0	7,0	19,5	24,3
Median-Q1	2,8	2,0	2,0	2,0	2,3	2,5	13,3	14,0	3,8	17,0	1,0	7,0	28,3
Q3-median	2,8	16,0	23,0	1,3	3,0	2,8	14,5	11,5	15,0	21,0	3,3	5,0	28,3
Maxi-mum-Q3	5,8	19,0	39,0	5,8	13,0	12,8	13,5	16,5	78,5	16,0	8,8	18,5	119,3

Appendix V-2: Bar Chart Describing Task Completion Time in Seconds



Appendix V-3: Average Duration of Interactions in Seconds

In seconds	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 9	Task 10	Task 11	Task 12	Task 13
MPr001	2	21	33	1	8	2	9	22	7	30	3	3	3
MPr011	2	12	10	10	21	5	27	16	56	31	5	6	8
MPr014	8	21	1	4	6	3	13	33	7	8	4	10	6
MPr018	4	8	2	1	1	4	26	28	15	8	4	6	7
MPr033	4	3	1	1	3	5	2	5	7	4	3	5	16
MPr039	1	12	1	2	8	11	21	40	8	16	3	3	10
MPr050	2	3	1	1	3	5	16	20	7	8	2	4	3
MPr053	4	3	26	4	6	2	20	35	20	26	3	3	6
MPr057	7	2	24	8	4	2	4	27	10	10	2	7	2
MPr077	3	2	1	4	1	2	14	25	34	17	2	6	25
MPr081	2	4	1	1	2	3	29	32	10	19	2	4	2
MPr093	7	3	3	5	14	4	8	15	6	35	7	8	10
MPr100	2	8	1	1	2	3	8	26	30	7	2	3	2

Appendix V-4: Detailed Results of Coding Approach

Selective code	**Axial code**	**Open code**	**Unique reference**
Analysis	Assessment	answers superficial questions	2
Analysis	Assessment	colors must fit to analysis	11
Analysis	Assessment	sizes better than colors	1
Analysis	Assessment	combination of analysis features good	2,13
Analysis	Assessment	different object sizes helpful	4,13
Analysis	Assessment	analysis function helpful	4,9,13
Analysis	Assessment	filter function helpful	3,4,5,6,8
Analysis	Assessment	connection between objects helpful	3,4,6,7,8,9, 10,11,12,13
Analysis	Improvement	indirect connections should be visualized	10
Analysis	Improvement	maintenance not covered	2
Analysis	Improvement	missing definition of analysis functions	2
Analysis	Improvement	enable data drill down	2,11
Analysis	Improvement	missing selection information	7,13
Analysis	Improvement	standard reports needed	2,3
Analysis	Improvement	More details needed	2,4,11
Analysis	Improvement	missing legend	1,2,7,8,10, 11,12,13
Analysis	Problem	3D hinders comparison of different sizes	10
Analysis	Problem	data value unknown	1
Analysis	Problem	color gradient unclear	1,11
Analysis	Problem	different object sizes hardly noticeable	1,4,7
Analysis	Problem	connections through objects difficult to understand	6,8,12,13

Selective code	Axial code	Open code	Unique reference
Device	Improvement	unclear about usability in large offices	11
Device	Problem	dry eyes	3
Device	Problem	hard to attach to head	4
Device	Problem	head pain	12
Device	Problem	limited frame annoying	12
Device	Problem	pressure points on skin	2
Device	Problem	gestures have to be within a frame	4,9
Device	Problem	hardware limitation	10,11
Device	Problem	pressing on nose	5,7
Device	Problem	weight too high	3,1
Device	Problem	neck pain	2,4,12
Device	Problem	lack of comfort	3,8,10,12
General	Assessment	Good idea	2
General	Assessment	no benefit for companies	3
General	Assessment	prototype useful for collaboration	11
General	Assessment	using 2D EA visualization unsatisfactory	13
General	Assessment	audio-supported tutorial would be nice	11
General	Assessment	beneficial for analysis	12
General	Assessment	companies generally use reports	11
General	Assessment	connect to wearables	2
General	Assessment	good overall experience	2
General	Assessment	HMD suitable for teaching	13
General	Assessment	mix between audio and visualization beneficial	8
General	Assessment	more types of EA objects make EA complex	11
General	Assessment	not ready for market	3
General	Assessment	organizational change management needed	13
General	Assessment	prototype introduces EAM	2
General	Assessment	prototype makes EA exciting	2
General	Assessment	prototype not useful for architects	2
General	Assessment	standing is more comfortable than sitting	13
General	Assessment	would use at work when maturity high	4
General	Assessment	application of prototype depend on organization	7,9
General	Assessment	better than expected	2,6
General	Assessment	implementation depends on cost-benefit-analysis	8,13
General	Assessment	mix between 3D and 2D probable	11,12
General	Assessment	prototype useful for communication	2,5,7,11
General	Assessment	architecture is touchable	2,5,7,9
General	Assessment	provides good EA overview	3,4,7,8,12
General	Improvement	development could be expensive	3
General	Improvement	development should be cheap	2
General	Improvement	more visualizations needed	11
General	Improvement	user management needed	11

Selective code	Axial code	Open code	Unique reference
General	Improvement	prototype should enable architecture reviews	10,13
General	Improvement	integration in existing EA tool needed	2,7
General	Problem	din norm required	2
General	Problem	gestures do not work every time	4
General	Problem	loading time too long	4
General	Problem	need to fix my head to watch entire model	12
Interaction	Assessment	gestures worked as expected	6
Interaction	Assessment	interaction depends on users behavior	7
Interaction	Assessment	joystick needed	3
Interaction	Assessment	navigation good	3
Interaction	Assessment	no need for further gestures	2
Interaction	Assessment	no voice control needed	2
Interaction	Assessment	should be similar to desktop use	2
Interaction	Assessment	sitting is more difficult than standing	8
Interaction	Assessment	easy to learn	6,13
Interaction	Assessment	easy to understand	7,13
Interaction	Assessment	gestures not comprehensive enough	11,12
Interaction	Assessment	gestures are intuitive	8,9,12
Interaction	Assessment	easy to interact	1,3,7,10,11
Interaction	Assessment	using prototype is fun	2,5,6,9,10
Interaction	Assessment	requires practice	2,3,5,6,7,8, 9,10,12
Interaction	Improvement	audio should stop when speaking	3
Interaction	Improvement	function should stop automatically	2
Interaction	Improvement	looking at object could replace air tab	12
Interaction	Improvement	more interaction besides gestures and voice required	12
Interaction	Improvement	should be easier	2
Interaction	Improvement	use haptic instead of voice	12
Interaction	Improvement	voice could improve interaction	11
Interaction	Improvement	cursor hover can enhance understanding	7,11
Interaction	Problem	audio too loud	3
Interaction	Problem	hand-eye coordination difficult	7
Interaction	Problem	meaning of cursor unclear	6
Interaction	Problem	operating is unpleasant	8
Interaction	Problem	rotate model is difficult	10
Interaction	Problem	selection leads to a fade out instead of fade in	11
Interaction	Problem	zooming is difficult	4
Interaction	Problem	gestures are difficult to perform	6,1
Interaction	Problem	interaction requires high effort	4,8,10
Interaction	Problem	air tab is difficult	3,7,8,11
Interaction	Problem	keyboard difficult to use	6,7,11,12
Interaction	Problem	missing feedback	1,2,6,7,9, 11,12,13

Selective code	**Axial code**	**Open code**	**Unique reference**
Visualization	Assessment	free moving of model helpful	4
Visualization	Assessment	used colors beneficial	4
Visualization	Assessment	3D shows connections well	7
Visualization	Assessment	color and sizes easy to recognize	7
Visualization	Assessment	cursor moves with shape of object	12
Visualization	Assessment	easy object identification	1
Visualization	Assessment	many information are presented	6
Visualization	Assessment	modification of model helpful	4
Visualization	Assessment	perspective influences readability of model	11
Visualization	Assessment	quick understanding of model	4
Visualization	Assessment	use of ArchiMate helpful	4
Visualization	Assessment	visualizing indirect connections helpful	12
Visualization	Assessment	walk a lot	4
Visualization	Assessment	good layer visualization	7,11
Visualization	Assessment	highlighting selected EA objects good	10,13
Visualization	Assessment	user menu easy to understand	9,12
Visualization	Assessment	view from different perspectives possible	3,5
Visualization	Assessment	3D better than 2D	6,8,11
Visualization	Improvement	arrows should glow	2
Visualization	Improvement	change distance between layers	4
Visualization	Improvement	click on object should jump to different model	11
Visualization	Improvement	color and contrast should be changeable	3
Visualization	Improvement	cursor in model visible for others	4
Visualization	Improvement	further colors could be used	2
Visualization	Improvement	icons should glow	2
Visualization	Improvement	missing navigation menu	10
Visualization	Improvement	model looks old	3
Visualization	Improvement	text size should be changeable	3
Visualization	Improvement	use of different architecture language	10
Visualization	Improvement	navigation missing	7,11
Visualization	Improvement	transitions between changed models needed	3,8,12
Visualization	Improvement	difference between user groups	2,3,11,12
Visualization	Problem	arrows hide text	9
Visualization	Problem	color changes with distance	8
Visualization	Problem	cursor disappears on user menu	9
Visualization	Problem	info box disappears in model	12
Visualization	Problem	keyboard disappeared	9
Visualization	Problem	many information are overexerting	6
Visualization	Problem	missing cursor in user menu	4
Visualization	Problem	need to stand far away from model	12
Visualization	Problem	perspective influences perception of object sizes	11
Visualization	Problem	shaking text	5
Visualization	Problem	small objects are too small	8
Visualization	Problem	symbols visualizing EA objects unclear	9

Selective code	**Axial code**	**Open code**	**Unique reference**
Visualization	Problem	user menu might be to complex	10
Visualization	Problem	user menu too far away	11
Visualization	Problem	user menu too small	12
Visualization	Problem	view on model depends on position	5
Visualization	Problem	keyboard too small	2,9
Visualization	Problem	large architecture cannot be proper visualized	7,1
Visualization	Problem	lost model while working	4,5
Visualization	Problem	shaking cursor	3,12
Visualization	Problem	shaking model	1,12
Visualization	Problem	user menu sometimes disappears	8,11
Visualization	Problem	missing focus on accessibility	2,7,8
Visualization	Problem	model disappears when too close	3,4,12
Visualization	Problem	low resolution	1,3,4,10,12
Visualization	Problem	text difficult too read	3,4,7,8, 11,12

VI

COMPARING EA VISUALIZATIONS AND VISUALIZATION TECHNOLOGIES - A TAXONOMY FOR THE DEVELOPMENT OF RESEARCH DESIGNS

Abstract

Enterprise Architectures (EA) provide a time-dependent holistic view on the structure of an organization. Desktop environments and, more recently, Augmented Reality (AR) and Virtual Reality (VR) technologies are used to visualize EAs in various forms such as diagrams, models, and charts. The interplay between EA visualization on the one hand and its underlying technology on the other hand support fact-based decision-making. Both research and practice evaluate various technology settings and EA visualizations to determine when they are most applicable, effective, or efficient. However, cross-technology comparisons are reasonable only to a limited extent, as the various technologies differ so extensively, for example, in the way users apply the associated interaction devices or how immersive users perceive the visualizations. Consequently, we claim that EA visualizations' distinctive characteristics and the required visualization technology should be considered when developing comparative research designs. Based on a literature review, this paper suggests a taxonomy consisting of 13 dimensions intended to support developing future comparative analyses of EA visualizations and their corresponding technologies. The taxonomy's applicability is demonstrated with two examples. First, it supports researchers in developing suitable research designs, and second, it provides a unified structure for describing comparative analyses.

Keywords: *Enterprise Architecture, Evaluations, Research Design Taxonomy*

Table of Contents

List of Figures

List of Tables

1 Introduction

Organizations are complex systems, encompassing a wide range of associated objects such as business goals, organizational structures, business processes, information systems (IS) and technical infrastructure (Ahlemann, Stettiner, Messerschmidt, & Legner, 2012, p. 3). Enterprise Architecture Management (EAM) is a management discipline that deals with these diverse organizational aspects (Aier, 2013, p. 645). EAM establishes, maintains, and develops Enterprise Architectures (EAs), which are high level representations of an enterprise that include the business and Information Technology (IT) perspective (Ahlemann et al., 2012, p. 20; Tamm, Seddon, Shanks, & Reynolds, 2011, p. 142). EAs can be visualized in many ways, e.g. in the form of texts, diagrams, charts, special models, maps, and metaphors (Roth, Zec, & Matthes, 2014, p. 46; Rehring, Brée, Gulden, & Bredenfeld, 2019, p. 1). However, earlier research indicates a low perceived usefulness of EA visualizations due to its complexity (van der Raadt, Schouten, & Vliet, 2008, p. 20), lack of focus (Buckl, Ernst, Matthes, & Schweda, 2009, p. 4), an inappropriate level of abstraction (Nowakowski et al., 2017, p. 4854; Vieira, Cardoso, & Becker, 2014, p. 245), or insufficient tool support (Nowakowski et al., 2017, p. 4854). Both research and practice have addressed these limitations by introducing technology that intends to decrease cognitive load and increase general understanding of complex EAs, e.g. through visualizing EA in Virtual Reality (Oberhauser, Sousa, & Michel, 2020) or Augmented Reality (Rehring, Greulich, Bredenfeld, & Ahlemann, 2019). While some technologies are appropriate in some situations or for certain tasks, other technologies might be more appropriate in other situations or for other tasks. The challenge lies in cross-technology evaluations as these are difficult to realize due to the diverging characteristics of the individual technologies. In fact, researchers interested in comparing technologies for EA visualizations face multi-dimensional research settings that varying not only in terms of settings, but also of device properties, interaction techniques, and visual features. In this paper, we propose a taxonomy that takes the diversity of the above-mentioned aspects into account. The taxonomy aims to guide researchers starting out with designing research settings to evaluate and, hence, compare various technologies available for visualizing EAs. In doing so, our taxonomy solves striking problems: first, it highlights the relevant and mandatory aspects of each research design in this research domain. Second, it provides a general framework for classifying existing research. We pursue the goal to answer the following research question: *How can we compare various EA visualization technologies?*

Our taxonomy's design is based on the taxonomy development method Nickerson et al. (2013) proposed, as well as on a literature review influenced by vom Brocke et al. (2015). It highlights the research setting, devices, interaction, and visualization aspects and intends to support researchers in framing planned studies.

The following section provides an overview of technologies employed to visualize EAs. Section 3 describes the research design. We present the resulting taxonomy in section 4, while section 5 elaborates two exemplary implementations. Section 6 gives a discussion of the findings. The last section summarizes the main findings, mentions limitations, and suggests further research opportunities.

2 Theoretical Foundation

Various technologies are used to visualize EAs. In this section, we introduce and describe the applied technologies mentioned in the literature which are desktop environments, augmented reality, and virtual reality.

In visualizing EA objects, the technology primarily used is the desktop environment (Roth et al., 2014). Desktop environments are sometimes referred to as Desktop Virtual Environment (DVE) (Marshall & Nichols, 2004). Usually, this system consists of a desktop screen, a computer mouse, and a keyboard and it follows the basic principle of point-and-click graphical user interfaces (Lee, Isenberg, Riche, & Carpendale, 2012, p. 2689; Hoppe, van de Camp, & Stiefelhagen, 2017, p. 136). This principle eventually relies on apps with various user menus and multifaceted control panels in desktop environments designed for use by single persons (Lee et al., 2012, pp. 2694–2695). Touchscreens represent a different approach, enabling users to perform tasks by touching an object of interest on the screen with their fingers or hand instead of using a computer mouse (Findlater, Froehlich, Fattal, Wobbrock, & Dastyar, 2013, p. 343). Virtual keyboards on touchscreens like smartphones or tablets enable writing in apps (Kim, Aulck, Bartha, Harper, & Johnson, 2014, p. 1406). With only a few exceptions, EA visualizations are designed to be used on desktop environments that include using the computer mouse and a keyboard (Roth et al., 2014). Figure VI-1 exemplifies an EA represented in a desktop environment using a computer mouse and a keyboard.

Figure VI-1. Exemplary EA visualization in a desktop environment presented in Oberhauser et al. (2020, p. 16)

Augmented Reality (AR) is a technology that combines the real and the virtual worlds (Azuma, 1997, p. 2). It creates an immersive and interactive environment by superimposing virtual objects onto the real world that interact with it in real time (Azuma, 1997, p. 2). Cameras, mirrors, microphones, head and body movement detection sensors, and further sensors provide users with AR capabilities (Milgram, Takemura, Utsumi, & Kishino, 1994, p. 286; Kortekamp, Werning, Thomas, & Ickerott, 2019, p. 1). Several devices can give access to AR. On the one hand, head-mounted displays (HMD) are attached to the head, providing users with AR capabilities via direct view on the real world by using mirrors and further optics (optical see-through HMDs) or by indirect view using manipulated video signals (video see-through HMDs) (Milgram et al., 1994, p. 284). HMDs give users hands-free experiences (Azuma, 1997, p. 31; Kortekamp et al., 2019, p. 1). In contrast, handheld devices like tablets and smartphones are similar to video see-through HMDs, but have to be held in one or in both hands, which limits users' interaction possibilities and, hence, their AR experience (Dunleavy, Dede, & Mitchell, 2009, p. 8; K. Lee, 2012, p. 14). AR has been applied in EAM for visualizing EA in the form of a three layered object (Rehring, Greulich et al., 2019) and a city (Rehring, Brée et al., 2019). Different research scopes aim for visualizing specific architectures, e.g. for software architectures (Merino, Bergel, & Nierstrasz, 2018). Figure VI-2 presents an exemplary EA visualized in layers in AR.

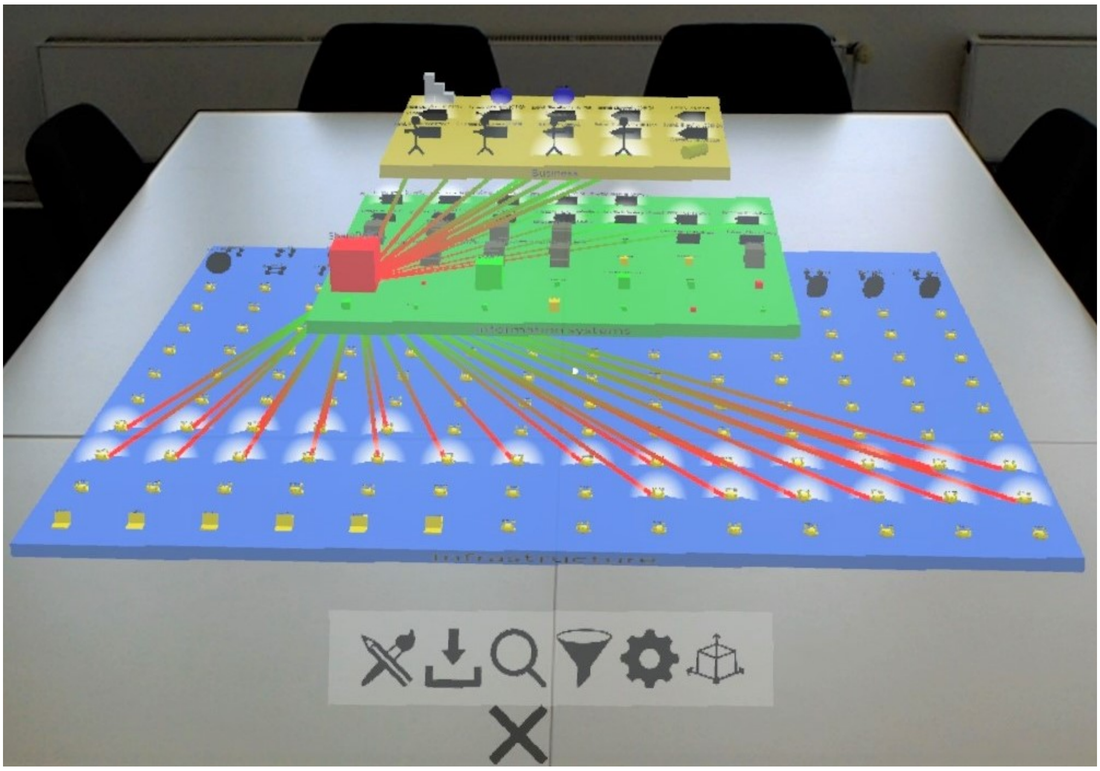


Figure VI-2. Exemplary EA visualized in layers in AR by Rehring, Greulich et al. (2019, p. 1774)

Virtual Reality (VR) allows users to interact in a completely virtual environment (Milgram et al., 1994, p. 287). VR users perceive the computer-generated environment as another reality due to a perfect immersive sensory illusion (Biocca & Delaney, 1995, p. 63). As VR consists of virtual elements only, access to VR is limited to occlusive video HMD devices (Biocca & Delaney, 1995, p. 59; Sherman & Craig, 2002, p. 86). Small screens or virtual retina displays (VRD) are built into HMD devices to suppress the real world and enable a fully immersive perception of the VR (Biocca & Delaney, 1995, p. 59; Sherman & Craig, 2002, p. 86). Head-motion sensors, position and body tracking, and input devices like joysticks enable interaction in a VR environment (Sherman & Craig, 2002, p. 89). In the EA context, Figure VI-3 shows how an exemplary EA designed with the modelling language ArchiMate and with Business Process model and Notation (BPMN) is represented in VR (Oberhauser & Pogolski, 2019). Also, VR is used to extend existing EA tools with VR capabilities (Oberhauser et al., 2020).

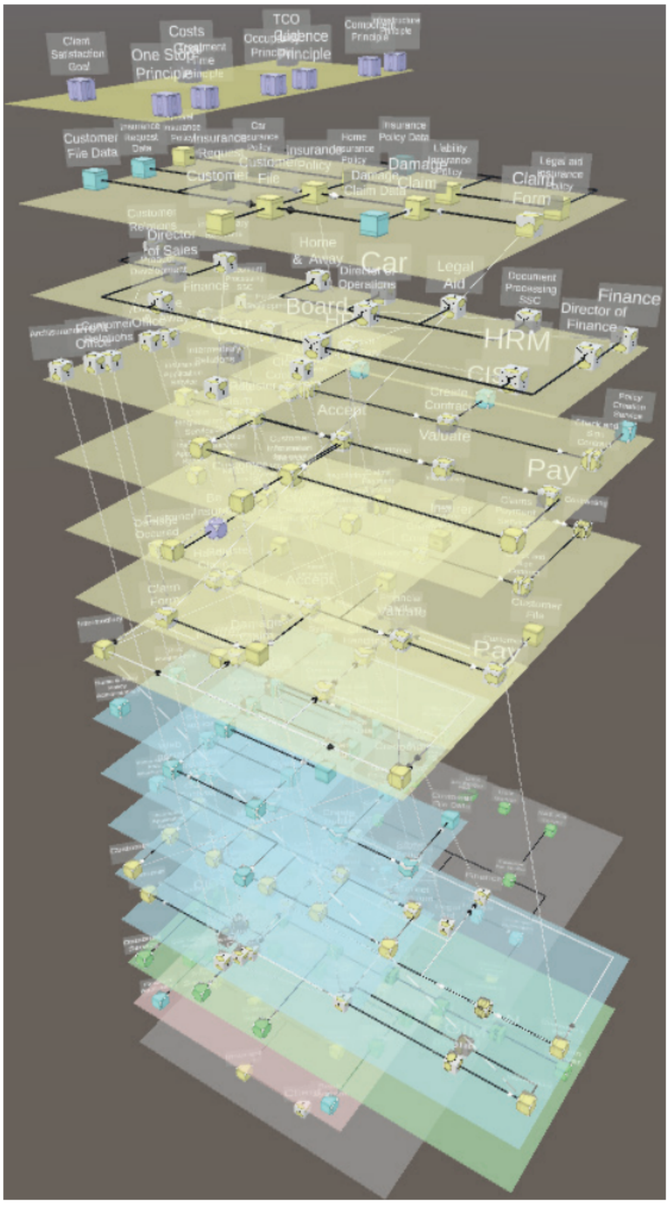


Figure VI-3. Exemplary EA visualized in layers in VR by Oberhauser & Pogolski (2019, p. 10)

3 Research Design

This paper's goal is to develop a conceptual model in the form of a taxonomy that supports the development of a research design that compares technologies for EA visualization. To achieve this, we applied Nickerson et al.'s (2013, pp. 342–347) iterative taxonomy development method, which is frequently used in the IS discipline. This method provides a step-by-step approach aimed at guiding researchers in the development of useful taxonomies. In doing so, their method proposes an empirical-to-conceptual, as well as a conceptual-to-empirical approach to designing new taxonomies. Figure VI-4 provides an overview of each taxonomy development step.

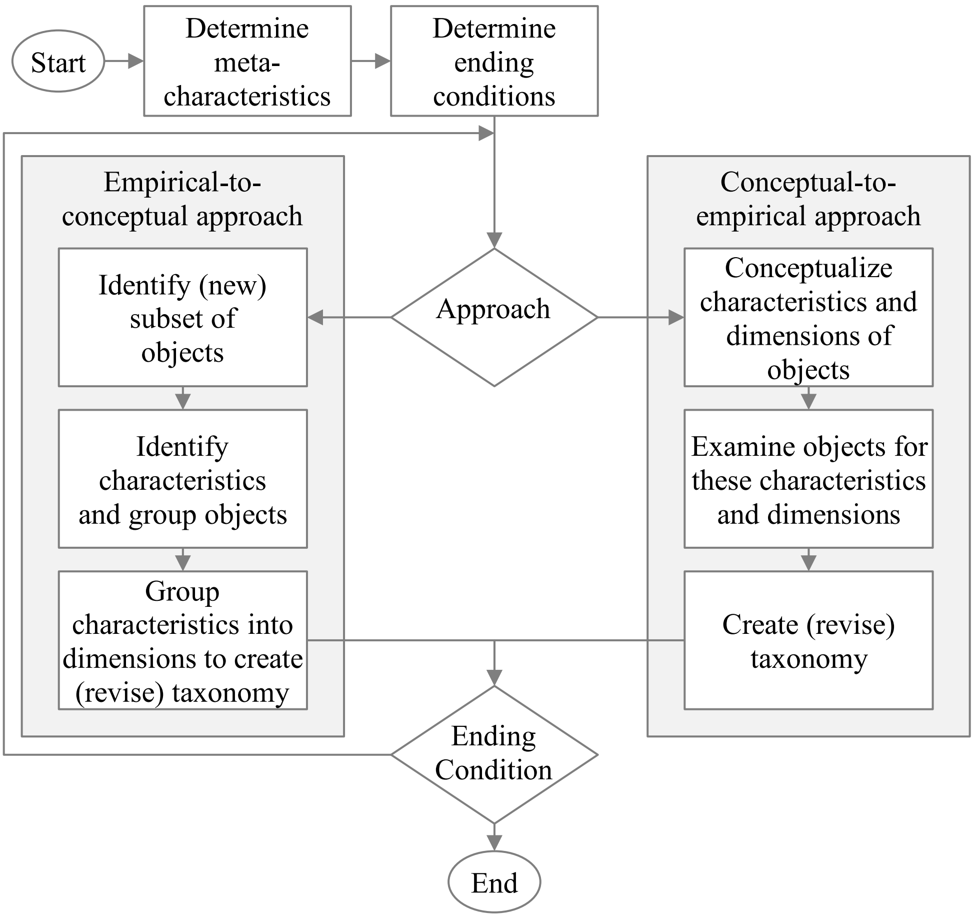


Figure VI-4. Research approach for developing taxonomies proposed by Nickerson et al. (2013, pp. 342–347)

The first and crucial step is to define the object of interest's meta-characteristics. Basically, each characteristic in a taxonomy is a logical consequence of the meta-characteristic. The meta-characteristic is based on a taxonomies' purpose and expected use by a group of stakeholders, who in this case, are primarily researchers. As illustrated in the introduction, the purpose of our taxonomy is to compare EA visualization technologies. Our taxonomy should support researchers in designing comprehensive research settings for technology comparisons in the domain of EA visualization. Hence, we define the meta-characteristics of our taxonomy as follows: Comparing EA visualization technologies.

The second step defines objective and subjective conditions that determine when to stop developing a taxonomy. We defined three objective ending conditions that we believe are suitable for our purpose. First, we check whether a new iteration reveals changes in the taxonomy in terms of its dimensions and characteristics. This condition assumes the achievement of a theoretical saturation, which means that adding more data will not bring further changes to a research artefact or, in this case, a taxonomy. Second, we require unique dimensions and characteristics to avoid overlapping interpretations and, hence, possible redundancies. Third, we ensure that all dimensions and characteristics are terminologically unique. This condition avoids the assignment of notions to more than one dimension or characteristic. In terms of subjective ending conditions, we considered the five recommendations Nickerson et al. (2013, p. 341f) proposed. First, to remain properly applicable, IS taxonomies should limit the number of dimensions and associated characteristics they use. Second, the extent of a taxonomy in terms of its dimensions and characteristics should cover enough objects to be interesting and useful, but at the same time be distinctive. Third, when developing conceptual taxonomies, the classification should preferably be as comprehensive as possible and suitably appropriate to describe an object of interest. Fourth, the taxonomy should be extendable and consider new or modified dimensions and characteristics when changes occur. Lastly, a taxonomy should explain an object of interest through insightful classification rather than describing every tiny detail. Table VI-1 provides an overview of the considered objective and subjective ending conditions.

Table VI-1. Overview of the objective and subjective ending conditions for taxonomy development

Objective ending conditions	Saturation	A new iteration hasn't revealed changes in the taxonomy
	Uniqueness	The description of dimensions and characteristics are preferably do not have multiple interpretations.
	Differentiation	Notions of dimensions and characteristics are exclusive.
Subjective ending conditions	Concise	The dimensions are sufficient to describe an object.
	Robust	The appropriate dimensions and characteristics differ from one another.
	Comprehensive	All the relevant aspects have been considered.
	Extendible	The taxonomy can easily be extended.
	Explanatory	The taxonomy provides explanations rather than descriptions of an object.

After determining the meta-characteristics as well as the ending conditions, we were able to start developing the taxonomy by iteratively conducting the empirical-to-conceptual or conceptual-to-empirical approach. Which approach we selected, depended on (a) the availability of data about the object of interest, and (b) our existing knowledge about the domain of interest. The empirical-to-conceptual approach is most suitable when sufficient data is available, whereas the conceptual-to-empirical approach seems to fit when researchers have enough available knowledge about the domain of interest.

Our data gathering approach is based on the author's prior knowledge, but more importantly on a literature review. We identified the papers that evaluate a single technology or multiple technologies mentioned in chapter 2, used to visualize complex information, and provide data analysis capabilities. Following vom Brocke et al.'s (2015) recommendations, our sequential procedure was (a) gathering literature, (b) analyzing text, and (c) documenting the findings. We considered the Association for Computing Machinery (ACM) database as it is known for peer-reviewed and highly rated IS journals and conference proceedings. Also, the database has a record of EAM publications and regularly includes research articles on technology artefacts with a special focus on innovative technologies. We considered all papers published between 1990 and 2020 in our literature review. Our set of keywords were *desktop environment, desktop virtual environment, augmented reality, AR, virtual reality,* and *VR* in combination with *evaluation* or *assessment* or *comparing*. This setting revealed 110 potentially relevant papers without any duplicates, which did not come as a surprise because we had considered only one database. Next, we checked every title, abstract, and keyword. We chose those papers that describe the evaluation of two or more visualization technologies or considered interaction techniques that describe the evaluation approach in detail, explain its research setting's characterizing features, and tend to focus on any form of data analysis even though the latter is an optional criterion. After carefully reading the 25 papers that remained, we were left with eight papers that fit the criteria. A subsequently performed backward and forward search resulted in a final set of 12 relevant papers. Figure VI-5 gives an overview of the above-mentioned process and its results.

We analyzed the selected papers with the well-suited coding technique Corbin and Strauss (1990) endorsed. This approach facilitates extraction of relevant aspects from each paper. While reading them, we tagged all relevant phrases and attached a quick description to each. This phase is termed "open coding" as the tagging process is independent of already conducted tagging. Afterwards, we categorized these short descriptions to connect similar phrases. This ongoing process is necessary as these so-called axial codes could be subject to change every time a new paper provides new data. Eventually, we summarized the axial codes again in selective codes to describe the "what happens" perspective on given phenomena. To develop the taxonomy, we considered the selective codes for the taxonomy, and the axial codes for the taxonomy's characteristics. We included all codes until we had met the end conditions of the taxonomy development method. In total, we conducted five iterations of the empirical-to-conceptual approach and three iterations of the conceptual-to-empirical approach, thus completing eighty iterations in all. As the final taxonomy rather than the development process was of research interest, we do not describe the taxonomy's individual development steps in detail; however in Table VI-2 we provide an overview.

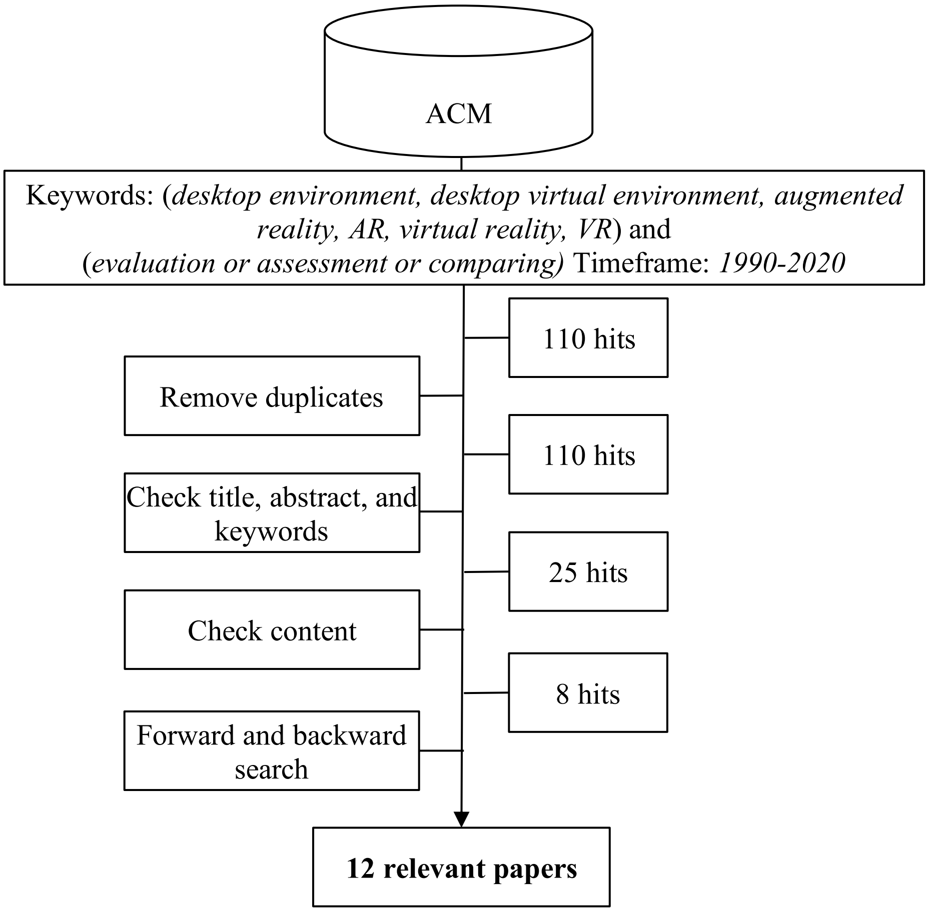


Figure VI-5. Literature research process and results

Table VI-2. Development of the suggested taxonomy

Iteration No.	Approach	Taxonomy
1	conceptual-to-empirical approach	T_1 = { Interaction (Gestures, Control, Voice, Body, Touch), Input type (Computer mouse, Keyboard, Pen), Device (Video HMD, See-through HMD, Mobile device, Screen, Touchscreen, whiteboard), Use case (single user, multiple user) }
2	empirical-to-conceptual approach	T_2 = { Interaction (Gestures, Control, Voice, Body, Touch), Input type (Computer mouse, Keyboard, Pen), Device (Video HMD, See-through HMD, Mobile device, Screen, Touchscreen), Output (Visual, Acoustic, Haptic), Dependent Variable (Interaction, Performance, Experience, Readability, Effectiveness, Cognitive Load, Mental load), Use case (single user, multiple user), Situation (Analog only, Analog/digital, virtual only) }
3	empirical-to-conceptual approach	T_2 = { Interaction (Gestures, Control, Speech, Body Movement, Touch), Interaction task (Pointing, Dragging, Crossing, Steering), Input device (Computer mouse, Keyboard, Pen, None), Device (Video HMD, See-through HMD, Mobile Device, Screen, Touchscreen), Visualization types (), Tasks (), Stakeholder (Business experts, Enterprise architects), Output (Visual, Acoustic, Haptic), Dependent Variable (Interaction, Performance, Experience, Readability, Effectiveness, Cognitive Load, Mental load), Use case (single user, multiple user), Use case (Single user, Multiple user), Situation (analog only / face to face, analog/virtual, virtual only) }
4	conceptual-to-empirical approach	T_4 = { Research setting [Dependent Variable (Interaction, Performance, Experience, Readability, Effectiveness, Cognitive Load, Mental load), Use case (Single user, Multiple user), Stakeholder (Management, Business experts, IT experts, Enterprise architects), Reality (Real-world, Mixed Reality, Virtual Reality), Environment (analog only / face to face, Mixed, Digital)], Device [Hardware (Video HMD, See-through HMD, Mobile, Screen, Touchscreen), Input (Computer mouse, Keyboard, Pen, None)] , Interaction [Interaction (Gestures, Control, Speech, Touch, Body Movement), Interaction task (Pointing, Dragging, Crossing, Steering)], Visualization / Analysis [Visualization types (2D, 3D), Tasks (Create, Analysis, Filter) , Output (Visual, Acoustic, Haptic)] }
5	empirical-to-conceptual approach	T_5 = { Research setting [Dependent Variable (performance, experience, effectiveness), Use case (Single user, Multiple user), Stakeholder (Management, Business experts, IT experts, Enterprise architects), Reality (Real-world, Mixed Reality, Virtual Reality), Environment (analog only / face to face, Mixed, Digital)], Device [Hardware (Desktop system, Video HMD, See-through HMD, Handheld device, Touchscreen), Input (Computer mouse, Keyboard, Pen, Body), Output (Visual, Acoustic, Haptic)], Interaction [Interaction (Gestures, Control, Speech, Touch, Body Movement), Interaction task (Pointing, Dragging, Crossing, Steering)] , Visualization / Analysis [Visualization types (Matrix/Table, Cluster map, Timeline, Flow diagram, List,

		Graph, ER diagram, bar chart, BPMN, UML, Bubble chart, Tree view, Pie chart, Dashboard, Radar chart, EPC, Archimate, Line chart, Scatter chart, Geographic, Canvas, Gauge, Tree map, Tag cloud, 3D visualization, Sunburst chart, Metaphor), Tasks (Create, Analysis, Filter), Layer of architecture (Business, Application, Data, Infrastructure)] }
6	empirical-to-conceptual approach	T_6 = { Research setting [Dependent variable (performance, experience, effectiveness), Unit of analysis (individual, group), Target audience (EA expert, EA experienced)], Device [Hardware (static screen, touch-enabled screens, video-see-through HMD, optical see-through HMD, video occlusive HMD), Input device (computer mouse, 3D device, sensors, pointer, touchpads), output (visual, acoustic, haptic)], Interacti on [Input task type (2D, 3D), interaction technique (gestures, voice, touch, body movement, operation of device), interaction task (navigation, selection, manipulation / transformation, system control)], Visualization [EA visualization (text, diagram, chart, model, map, metaphor), EA perspective (business, data, application, technology)] }
7	conceptual-to-empirical approach	T_7 = { Research setting [Dependent variable (efficiency, experience, usability), Data gathering method (), User group (individual, collective), Target audience (EA expert, EA experienced)], Device [Hardware (static screen, touch-enabled screens, video-see-through HMD, optical see-through HMD, video occlusive HMD), Input device (computer mouse, 3D device, sensors, pointer, touchpads), output (visual, acoustic, haptic)], Interaction [Input task type (2D, 3D), interaction technique (gestures, voice, touch, body movement, operation of device), interaction task (navigation, selection, manipulation, system control)], Visualization [EA visualization (text, diagram, chart, model, map, metaphor), EA perspective (business, data, application, technology)] }
8	empirical-to-conceptual approach	T_8 = { Research setting [Dependent variable (efficiency, experience, usability), User group (individual, collective), Target audience (EA expert, EA experienced), Research Method (questionnaire, time measurement, distance measurement, count measurement, subjective measurement)], Device [Hardware (static screen, touch-enabled screens, video-see-through HMD, optical see-through HMD, video occlusive HMD), Input device (computer mouse, 3D device, sensors, pointer, touchpads), output (visual, acoustic, haptic)], Interaction [Input task type (2D, 3D), interaction technique (gestures, voice, touch, body movement, operation of device), interaction task (navigation, selection, manipulation, system control)], Visualization [EA visualization (text, diagram, chart, model, map, metaphor), EA perspective (business, data, application, technology)] }

4 Conceptual Taxonomy

The challenge of comparing many EA visualizing technologies lies in the expected multi-dimensional research setting. One reason for this is that EA visualization technologies differ in terms of their device properties, interaction techniques, and visual features, which makes it particularly difficult to conduct cross-technology assessments. Our research goal is to develop a taxonomy that will guide researchers in designing future research settings to evaluate EA visualization technologies. Further, we need to remind that this taxonomy is open to future changes, as Nickerson et al. (2013, p. 341) suggested.

To achieve this, we designed a taxonomy influenced by Nickerson et al.'s (2013, pp. 342–347) taxonomy development method and we conducted a literature review to identify the specific dimensions and characteristics that need to be considered when evaluating technologies suitable for EA visualizations. Hence, the resulting taxonomy T consists of a set of n dimensions D_i (i = 1, …, n) each comprising k_i ($k_i \geq 2$) non-mutually exclusive but jointly exhaustive characteristics C_{ij} (j = 1, …, k_i), meaning that a technology under consideration has one or many characteristics C_{ij} for each dimension D_i. The idea is that the more characteristics C_{ij} selected in each dimension $D_{i,}$ the more complex the research setting will be. In contrast, for each dimension D_i at least one characteristic C_{ij} should be selected to ensure the research setting's consistency.

As presented in Table VI-3, our proposed taxonomy consists of four categories: Research setting, device, interaction, and visualization. The research setting describes the main general conditions that need to be defined before evaluating various technologies and EA visualizations. Our findings revealed four main dimensions that have to be considered: the dependent variable, the unit of analysis, the target audience, and the data gathering research method. As hardware devices' characteristics vary considerably, our taxonomy recommends that researchers should at least focus on the specific hardware, the required input devices, and the expected output of each technology. The latter seems to be counterintuitive as it also includes the non-visual acoustic and haptic outcomes. However, currently available visualization devices integrate corresponding hardware features, and ongoing research is increasingly interested in observing the usefulness of these additional output variants. Regarding the interaction category, we consider the input task type, the respective interaction technique, and the considered interaction task. The last category comprises the EA-related visualization aspects that are under investigation. This category distinguishes between the EA visualization and the considered EA perspective dimension. The following subsections will explain each dimension and their characteristics in detail. We further propose a template to describe evaluations that consider our taxonomy, as presented in Table VI-4.

Table VI-3. Proposed taxonomy for technology evaluations of EA visualizations

Research setting						
Dependent variable	Efficiency	Experience	Usability			
User group	Individual	Collective				
Target audience	EA expert	EA experienced	Others			
Research method	Questionnaire	Time measurement	Distance measurement	Count measurement	Subjective measurement	
Device						
Hardware	Static screen	Touch-enabled screens				
	Video see-through HMD	Optical see-through HMD	Video occlusive HMD			
Input devices	Computer mouse	3D device	Sensors	Pointer	Touchpads	
Output	Visual	Acoustic	Haptic			
Interaction						
Input task type	2D	3D				
Interaction technique	Gestures	Voice	Touch			
	Body movement	Operation of device				
Interaction task	Navigation	Selection	Manipulation	System Control		
Visualization						
EA visualization	Text	Diagram	Chart	Model	Map	Metaphor
EA perspective	Business	Data	Application	Technology		

Table VI-4. Proposed template to describe evaluations considering our taxonomy

Our research evaluates the [*dependent variable*] of [*input device*] using [*visualization device*] regarding the [*output*] output each has for [*unit of analysis*] who are [*target audience*] users that consume EA visualizations. We collect data by applying [*research method*]. The interactions to be observed perform [*input task type*] [*interaction task*] interaction tasks employing [*interaction technique*]. The EAs visualized [*EA perspective*] architectures using [*EA visualization type*] visualization.

4.1 Research Setting

The most important technology evaluation characteristic depends on the general research setting's design. First, a researcher should define the dependent variable of interest. This is influenced by the phenomena under investigation. Second, the unit of analysis describes the objects of study. Third, the EA research focus depends on the main target audience and their experiences with EA. Lastly, the research needs to define in which reality it will be conducted. In the next sections we explain the four important research setting characteristics.

Dependent variable

Our literature review revealed three main dependent variables: efficiency, user experience, and usability. Measuring the efficiency or performance is a favored dependent variable among researchers. It is considered to evaluate how quickly participants can conduct pre-defined tasks with a specific input device and interaction technique, e.g., in measuring task completion time or speed (Krichenbauer, Yamamoto, Taketomi, Sandor, & Kato, 2017, p. 1038; Hoppe et al., 2017, p. 133f; Gribnau & Hennessey, 1998, p. 234) and error rate (Sun, Stuerzlinger, & Riecke, 2018, p. 2; Dang, Tavanti, Rankin, & Cooper, 2009, p. 157). Task-efficient interaction techniques are measured, e.g., by how fast users grasp, move, and transform virtual objects (Werkhoven & Groen, 1998, p. 432).

There are different ways of investigating usability. First, research can be interested in how users access and understand a visualization, e.g. in order to test new IS (Butterworth, Davidson, Hench, & Olano, 1992, p. 135). Second, user experience has become an independent object of research as it seems to significantly influence individual performance (Hoppe et al., 2017, p. 134). Prior research claims that how users perceive and put technology to use might influence user engagement (Krichenbauer et al., 2017, p. 1046).

Studying the usability of visualization technologies can be measured by participants' efficiency and accuracy (Sun et al., 2018, p. 2), perceived degree of exhaustion, perceived workload (Besançon, Issartel, Ammi, & Isenberg, 2017, p. 4727), as well as ease of learning, coordinating, and device persistence and acquisition (Zhai, 1998, p. 50). Some researchers argue that the perceived level of comfort while using a technology to visualize information, influences user satisfaction (Krichenbauer et al., 2017, p. 1043); others mentioned a general subjective satisfaction toward using a specific technology (Besançon et al., 2017, p. 4728).

Unit of analysis

Defining the unit of analysis is one of the most important research settings. This decision sets the scene for the resulting research approach. In the considered literature, we found evidence that many authors focus on single user studies. Such studies are characterized by asking individual participants to conduct specific tasks, which are then evaluated (Besançon et al., 2017, p. 4730; Krichenbauer et al., 2017, p. 1044; Hoppe et al., 2017, p. 133f; Sun et al., 2018, p. 2; Werkhoven & Groen, 1998, p. 433; Gribnau & Hennessey, 1998, p. 234).

Our literature review did not reveal evaluations that focus on groups of participants. However, past empirical research suggests that EA visualization techniques might differ between groups and single user involvement, e.g. regarding who manipulates EAs and how, or how to design the various interfaces (Rehring & Ahlemann, 2020, p. 11). Consequently, we add 'collective' to the taxonomy to indicate a group of individuals that share the same outcome.

Target audience

Prior research often distinguishes between advanced or experienced and unsophisticated or inexperienced participants (Butterworth et al., 1992, p. 138; Besançon et al., 2017, p. 4733). For EA visualization, research has revealed that specific EA visualizations are more supportive to specific target audiences than others, hence, users' degree of experience should be considered (Rehring & Ahlemann, 2020, p. 14). Many evaluations are based on studies that including students and other academic staff (e.g. Krichenbauer et al., 2017, p. 1044).

Research method

We identified five kinds of data gathering approaches. First, researchers use questionnaires to collect data from evaluations with users. Questionnaires can consist of open qualitative questions (Sun et al., 2018, p. 2) or quantitative x-point Likert scales (Dang et al., 2009, p. 156), or both (Besançon et al., 2017, p. 4730; Sadri et al., 2019, p. 97). Depending on the use case, participants can be asked to answer a pre-questionnaire to retrieve demographic information (Besançon et al., 2017, p. 4730), and a questionnaire at the end of the evaluation (Sun et al., 2018, p. 2), or after each round of testing (Krichenbauer et al., 2017, p. 1044).

Second, the task execution can be evaluated in terms of time. Commonly measured in seconds, researchers aim to assess the time participants needed to complete one or many pre-defined tasks (e.g. Gribnau & Hennessey, 1998, p. 18; Werkhoven & Groen, 1998, p. 437; Sun et al., 2018, p. 437) or the time users needed to perform specific interaction techniques (Sadri et al., 2019, p. 97). A solid description of the starting and ending conditions is recommended (Krichenbauer et al., 2017, p. 1044; Werkhoven & Groen, 1998, p. 437)

Third, as visualizations can be processed in 3D, some research settings require a virtual object to be placed at a previously determined position. Measuring the distance between where a user placed a virtual object and its expected position in 3D space is another data gathering method. This can be calculated in absolute distance (Sun et al., 2018, p. 4), the Euclidean distance (Besançon et al., 2017, p. 4731), or "along the horizontal, vertical, and depth axes" (Werkhoven & Groen, 1998, p. 437).

Fourth, counting the number of successfully and unsuccessful completed tasks can support researchers in calculating the deviation of performance metrics. Many evaluations do not consider events of not finishing a task successfully in the research setting. Hence, only a few papers consider the number of errors in their research (e.g. Dang et al., 2009, p. 157).

Finally, subjective measurements in the form of thought experiments or researchers' empirical observations are often considered as data acquisition approaches. Thought experiments could be used to describe, e.g., pros and cons of specific input devices determined by asking potential users, without considering empirical data (Zhai, 1998, p. 50). However, more commonly, during an evaluation a moderator takes notes, which they then use in answering research questions (Besançon et al., 2017, p. 4730). Alternatively, researchers less formally interview experts (Hinckley, Pausch, Goble, & Kassell, 1994, p. 215; Rhienmora, Gajananan, Haddawy, Dailey, & Suebnukarn, 2010, p. 98).

4.2 Device

There are three perspectives on selecting devices, referred to as hardware, input, and output. This category in the taxonomy intends to support the selection of a suitable technological configuration. The hardware perspective consists of largely delimitable technologies that users can employ to visualize EAs. The input perspective identifies commonly used interaction technologies required to interact with EA models, whereas the output perspective addresses the form of feedback the considered technology gives. In this section, we explain these three device aspects in detail.

Hardware

Many different hardware devices that provide access to EA visualizations are available. Static screens, or so-called stationary monitors (Werkhoven & Groen, 1998, p. 432), are displays without touching capabilities. Static screens are part of a desktop environment that comprises of one or many screens, a computer mouse, and a keyboard.

Touch-enabled screens are displays with touching capabilities, which allow users to touch virtual objects on a surface (Hoppe et al., 2017, p. 133). Examples are touchscreens (Besançon et al., 2017, p. 4729) or mobile devices such as smartphones or tablets (Hoppe et al., 2017, p. 132). Commonly, researchers provide further information about the screen features like, resolution, refresh-rate, angle of view, and whether a monoscopic or stereoscopic display was used in an evaluation (Besançon et al., 2017, p. 4729).

As introduced and explained in chapter 2, HMDs, occasionally referred to as headsets (Sun et al., 2018, p. 3), are hardware devices attached to the user's head (Milgram et al., 1994, p. 284). Briefly, HMDs can be classified into three classes, identified as video occlusive or VR HMDs, video see-through HMDs, and optical see-through HMDs. Video occlusive HMDs operate in VR (Biocca & Delaney, 1995, p. 59; Sherman & Craig, 2002, p. 86) where "powerful image generators create the illusion of moving and looking around in a virtual environment" (Werkhoven & Groen, 1998, p. 432). Video see-through HMDs are equipped with cameras either by default (Rhienmora et al., 2010, p. 98) or as an extension to video occlusive HMDs to interact in AR (Krichenbauer et al., 2017, p. 1043). Optical see-through HMDs consist of mirrors and optics (Milgram et al., 1994, p. 284) and also enable interaction in AR.

Input devices

The design, development, and operation of 3D environments relies on input devices (Sun et al., 2018, p. 1). Research and practice haven't identified an input device that fits all interaction purposes, but the claim that the interaction goal and application domain influence the selection of a suitable input device, persists (Sun et al., 2018, p. 1; Besançon et al., 2017, p. 4727). There are various input devices that enable users to interact with EA visualizations. Researchers should, therefore, select one or many input devices for intended technology comparisons.

The most common and well-known input device is the computer mouse (Zhai, 1998, p. 50; Sun et al., 2018, p. 1), sometimes referred to as the traditional or classical 2D mouse (Krichenbauer et al., 2017, p. 1038; Hoppe et al., 2017, p. 131), as a mouse in 2D user interfaces (Sun et al., 2018, p. 1), or simply as a mouse (Besançon et al., 2017, p. 4727; Zhai, 1998, p. 50). A 2D computer mouse tracks the 2D movement relative to a surface. Using a computer mouse always enforces a reference point in the field of view, e.g. by using a mouse pointer (Krichenbauer et al., 2017, p. 1043). This technology is not aligned with a user's hand and usually operates outside a users' field of view (Krichenbauer et al., 2017, p. 1042; Sun et al., 2018, p. 1). Although computer mouses are designed for 2D desktop applications they are applied in 3D immersive environments, too (Sun et al., 2018, p. 3). Further implementations aim to improve 3D modelling capabilities, e.g. by working with two computer mouses simultaneously, adding more buttons, adding rollers, or changing the devices' shape to enable rotation and tilting to expand one or two dimensions of interaction (Hoppe et al., 2017, p. 131f; Zhai, 1998, p. 50). The research papers we considered do not focus on keyboards, but these are commonly presented in connection with computer mouses (Besançon et al., 2017, p. 4727; Sun et al., 2018, p. 4).

Interaction can be performed through the use of 3D input devices, often referred to 3D 6DOF (six degrees of freedom) (Krichenbauer et al., 2017, p. 1038), 6D input devices (Sun et al., 2018, p. 2; Werkhoven & Groen, 1998, p. 432), 6 DOF controllers (Hoppe et al., 2017, p. 132; Zhai, 1998, p. 50), handheld controllers (Sadri et al., 2019, p. 93), free-space 3D user interfaces, or spatial input (Gribnau & Hennessey, 1998, p. 233; Hinckley et al., 1994, p. 213). Support for the movement of virtual objects forward and backward, up and down, left and right, as well as the rotation of an object around a normal, transverse, and longitudinal axis comes via 3D input devices (Sun et al., 2018, p. 1). The 3D input devices are generally distinguishable between isotonic free-moving and isometric or elastic stationary hardware (Hoppe et al., 2017, p. 132; Zhai, 1998, p. 50f). Free-moving 3D input devices use tracking capabilities to measure a device's position and orientation in space (Hoppe et al., 2017, p. 132), e.g. through measuring the impacting force while moving (Werkhoven & Groen, 1998, p. 433) or changing the magnetic alignment during orientation (Gribnau & Hennessey, 1998, p. 233). These 3D input devices can be shaped in various ways, e.g. in the form of custom-made 3D printed cases with a pistol grip including four buttons (Krichenbauer et al., 2017, p. 1043), wireless handheld controllers (Sun et al., 2018, p. 1; Dang et al., 2009, p. 155), handheld cardboard-based cuboctahedrons (Besançon et al., 2017, p. 4729), or 6D 2-button handheld mouses (Butterworth et al., 1992, p. 136). Non explicit handheld 3D input devices are, e.g., gloves worn on hands without substantially restricting free movement (Werkhoven & Groen, 1998, p. 433). However, gloves are also used to grasp physical objects represented in VR (Hinckley et al., 1994, p. 215). Stationary 3D input devices do not move a great deal but they provide 3D manipulation techniques by measuring force or its deviation relative to a baseline position (Hoppe et al., 2017, p. 132). Examples are table-bound input devices that stay on a surface but provide moveable controllers operated with the hands (Werkhoven & Groen, 1998, p. 432; Krichenbauer et al., 2017, p. 4). Various 3D input devices further provide haptic capability, e.g., to simulate touching virtual objects (Rhienmora et al., 2010, p. 97).

Special sensors enable the interaction with objects by tracking parts of the human body, like the head (Werkhoven & Groen, 1998, p. 432; Sun et al., 2018, p. 3), hands (Butterworth et al., 1992, p. 136; Sadri et al., 2019, p. 95), fingers (Hoppe et al., 2017, p. 132), and feet (Sadri et al., 2019, p. 95). Other sensors, like gyroscopes, are used to measure the orientation of a device such as a smartphone (Hoppe et al., 2017, p. 132) or a 3D input device (Gribnau & Hennessey, 1998, p. 233). Microphones capture the spoken words of one or many users and enable voice-based commanding (Dang et al., 2009, p. 155; Sadri et al., 2019, p. 95). In some cases, various kinds of sensory data are combined to perform specific system behavior e.g. by using voice and head movement (Sadri et al., 2019, p. 95).

Touchpads or trackpads are technology-equipped surfaces that translate the position and 2D movement of a user's finger to an output device such as a screen. Touchpads can be found on any laptop but also on 3D input devices (Sun et al., 2018, p. 2). The surfaces differ in size, feature, and style of operation. Laptop based touchpads are usually operated by the index finger, whereas other devices might require the use of other fingers (Sun et al., 2018, p. 7).

Pointer input devices are commonly shaped in the form of a pen (Dang et al., 2009, p. 155; Zhai, 1998, p. 50). Pointers can be equipped with buttons to provide additional functionality (Dang et al., 2009, p. 155). Such devices can be used to interact with graphical user interfaces through touch-based screens (Dang et al., 2009, p. 155).

Output

Our literature review revealed three classes of EA outcomes, identified as visual, acoustic, and haptic. Not surprisingly, in evaluating, researchers and users attribute high importance to visual aspects. Visualization technologies can be assessed in terms of how users deal with virtual objects in a mixed or virtual environment (Krichenbauer et al., 2017, p. 1038; Rhienmora et al., 2010, p. 97). Additionally, a common visual representation is a cursor that moves virtually through space depending on the movement of input devices (Werkhoven & Groen, 1998, p. 433). Some implementations provide specific visual support for users in performing a task, like highlighting objects (Butterworth et al., 1992, p. 136) or indicating an application's special mode change (Sadri et al., 2019, p. 95).

Users interacting with visualized EAs, can also use acoustic features. EA visualization technologies might afford acoustic feedback to report on a system state or to accept a command. We did not find empirical evidence for this in the literature, but we suggest considering this aspect.

In addition, haptic feedback provides force feedback functionality, which can be found in mechanical arms (Hoppe et al., 2017, p. 132) or specially equipped 3D input devices (Rhienmora et al., 2010, p. 97). Haptic rendering gives a user the feeling of touching a virtual object in AR or VR when they use virtual tools (Rhienmora et al., 2010, p. 97). Grasping and moving real-world physical objects represented in AR or VR also provide haptic feedback (Hinckley et al., 1994, p. 216) and enable interaction with EA visualizations.

4.3 Interaction

Various technologies differ in how they facilitate interaction with EA visualizations. Comparing technologies that include similar interaction approaches increase the validity of the research. Likewise, comparing similar technologies with various interaction approaches can also positively influence validity. Hence, researchers should define the kind of interaction in which they are interested as their research object. Further, the concrete interaction tasks should be defined. In the following sections we describe both aspects in detail.

Input type

Prior research indicates that different input devices perform differently regarding the task to be processed (Hoppe et al., 2017, p. 130; Butterworth et al., 1992, p. 135). Researchers should consider the specific capabilities of a manipulation technique when they compare various forms of interaction technologies (Hoppe et al., 2017, p. 130). Factors such as the distance between user and object, size of object, required amount of interaction, and object density can influence efficiency and adequacy of manipulation techniques (Hoppe et al., 2017, p. 130; Werkhoven & Groen, 1998, p. 435f). For example, the sliding algorithm works well with 2D input devices (Sun et al., 2018, p. 2), whereas the rockin' mouse works better for 3D positioning tasks (Zhai, 1998, p. 51). Hence, evaluating EA visualization technologies and their corresponding EA visualizations should consider the EA's 2D or 3D features.

Interaction technique

Users can interact with EA visualization through gestures, voice, touch, body movement, and operating specific devices. They use hand gestures to interact with virtual content by performing context-specific movements with hands and fingers (Hoppe et al., 2017, p. 132; Sadri et al., 2019, p. 97). Using gestures allows for an intuitive and, hence, natural interaction as it does not require the use of hand-held input devices. Examples of gestures are grabbing and moving objects using a natural closing-the-hand gesture (Hoppe et al., 2017, p. 132), or performing a pre-defined grab gesture like an opening-the-hand gesture (Werkhoven & Groen, 1998, p. 432), or raising an index finger (Sadri et al., 2019, p. 95). Gestures are commonly processed either by special sensors (Sadri et al., 2019, p. 95) or by gloves users wear on the hands (Werkhoven & Groen, 1998, p. 432).

Interaction can be conducted by relying on a users' voice. Commonly, developers implement a small number of easy to learn pre-defined commands to enable voice control, such as rotate left, rotate right, rotate up, rotate down, zoom in, zoom out, or stop (Dang et al., 2009, p. 155). Voice commands are further used to change the system's behavior (Sadri et al., 2019, p. 95)

Interacting can be performed by touching a touch-enabled surface with one or many fingers (Hoppe et al., 2017, p. 132). Users can draw commands on a graphical interface to perform pre-defined operations (Dang et al., 2009, p. 155f). The application consists of a recognition system that detects a user's input and interprets the drawing (Dang et al., 2009, p. 155f).

Users can interact with virtual objects by moving parts of the object's body. More commonly, moving the head can result in a moving cursor, which aims to select objects that depend on the head position (Sun et al., 2018, p. 4), or the head movement changes the user's viewing angle on a virtual object (Milgram et al., 1994, p. 284).

Depending on an input device's shape, various specific ways of operating an input device are possible. Clicking or pushing buttons is a widespread and dominant approach to operating an input device (Zhai, 1998, p. 50; Sun et al., 2018, p. 3f; Gribnau & Hennessey, 1998, p. 234; Dang et al., 2009, p. 155). This approach is especially notable when users handle computer mouses (Besançon et al., 2017, p. 4727). Some devices imitate the shape of well-known physical objects to give users an easy way of interacting with virtual content, such as pen-like input devices (Dang et al., 2009, p. 155; Zhai, 1998, p. 50). Additionally, depending on the input device's characteristics, it can be rotated and moved to perform a pre-defined function such as pointing or rotating (Sun et al., 2018, p. 4; Rhienmora et al., 2010, p. 97). Usually, such devices must be held in one or both of a user's hands; however, other devices need to be held with the fingers only (Gribnau & Hennessey, 1998, p. 233)

Interaction tasks

Bowman and Wingrave (2001, p. 149) propose four universal interaction tasks in virtual environments, which we adapt to either mixed or real environments, identified as navigation, selection, manipulation, and system control.

Navigation tasks describe how users move through an environment from a cognitive perspective (how to find a way) and from a motor perspective (how to travel) (Bowman & Wingrave, 2001, p. 149). Our literature review did not disclose any aspects of the cognitive perspective. The motor perspective refers to (1) walking, where a user can literally walk in 3D space, (2) flying, where a user can travel in a non-real-world environment by using a cursor and/or specific buttons, and (3) grabbing, where a user can attach virtual objects to a cursor and move the object toward themselves (Butterworth et al., 1992, p. 136).

Selection tasks aim to choose one or more real or virtual objects from a set of available objects (Bowman & Wingrave, 2001, p. 149). Before selection can happen, some researchers report the need to be able to point to objects (Sun et al., 2018, p. 4). Users commonly select one or many objects by means of an interaction technique, e.g. by pressing a button on a 3D input device (Gribnau & Hennessey, 1998, p. 234). Marked objects can be used for further functionalities (Butterworth et al., 1992, p. 137).

Manipulation tasks encompass all the activities that change an object's specification (Bowman & Wingrave, 2001, p. 149). Examples of evaluated manipulation tasks abound. Changing the position and orientation of a single virtual object or group of virtual objects is a task frequently evaluated (Krichenbauer et al., 2017, pp. 1038 & 1043; Butterworth et al., 1992, p. 137; Besançon et al., 2017, p. 4727; Werkhoven & Groen, 1998, p. 435; Dang et al., 2009, p. 155f). Translating and rotating virtual objects is considered to be a basic task in 3D user interfaces, which involves the repositioning of virtual objects (Sadri et al., 2019, p. 94; Sun et al., 2018, pp. 1 & 4). Further, an object's size can be transformed regarding its scale in space (Krichenbauer et al., 2017, p. 1038; Sadri et al., 2019, p. 94) in just the same way as a user's scale can be transformed relative to their space (Butterworth et al., 1992, p. 136; Dang et al., 2009, p. 155). Rotating, translating, and scaling, often summarized as RTS tasks (Hoppe et al., 2017, p. 130).

System control tasks cover actions of changing a system state or mode of interaction. This includes, e.g., graphical user interfaces that provide access to further application functionalities (Bowman & Wingrave, 2001, p. 149). Such systems have many different names, e.g. toolbox (Butterworth et al., 1992, p. 136) or UI (Sadri et al., 2019, p. 95). User interfaces are designed for a specific purpose and, hence, differ in terms of their functionality, appearance, and behavior. Functionalities of user interfaces could be, e.g. enabling or disabling specific references to objects like coordinate axes (Butterworth et al., 1992, p. 136) or providing cutting, copying, pasting, and deleting features (Butterworth et al., 1992, p. 137). User interfaces can be organized in cells and contain 3D icons that represent a tool, a command, a toggle, or a grouping of these (Butterworth et al., 1992, p. 136). In terms of behavior, some user interfaces are attached to a user or can be moved to and placed in a specific area (Butterworth et al., 1992, p. 136).

4.4 Visualization

Various EA visualization approaches have evolved over time, each with special characteristics that might be more or less suitable for individual EA tasks. Thus, researchers should define which type of EA visualization they want to investigate. Depending on the scope of research, they might also determine which tasks should be supported by the visualization. Also, in many cases only certain levels of architectures should be part of the research and, hence, need to be specified. In the following sections, these three dimensions will be explained.

EA Visualization types

The research domain of EAM has generated extensive knowledge about this management discipline and associated phenomena in various areas. In an extensive publication, Roth et al. (2014) have summarized the most common forms of EA visualization applied in contemporary organizations.

First, EAs can be represented in the form of text, either in how they describe EAs with complete sentences or with single highlighted words like tag clouds (Roth et al., 2014, p. 70). Second, EA visualizations can come as diagrams, which can be, e.g., Gantt diagrams to visualize project roadmaps (Roth et al., 2014, p. 49), flow diagrams to represent business process steps or data flow (Roth et al., 2014, p. 50), Entity-Relationship (ER) diagrams to describe structural elements and their relationships (Roth et al., 2014, p. 53), and Event-Driven Process Chain (EPC) diagrams to show business-related information (Roth et al., 2014, p. 62). Third, often-considered EA visualizations are charts that represent timelines (Roth et al., 2014, p. 49), quantitative data in the form of bars (Roth et al., 2014, p. 54), bubbles (Roth et al., 2014, p. 57), pies (Roth et al., 2014, p. 59), radar (Roth et al., 2014, p. 61), lines (Roth et al., 2014, p. 64), scatter plots (Roth et al., 2014, p. 65), and sunbursts (Roth et al., 2014, p. 72). Fourth, EA can encompass business processes' descriptions using the Business Process model and Notation (BPMN) (Roth et al., 2014, p. 55), picture structures and their relationships to the Unified Modeling Language (UML) (Roth et al., 2014, p. 56), design business models with the help of the Business Model Canvas (Roth et al., 2014, p. 67), and, more importantly, describe EAs in a unified way supported by the EA modelling language ArchiMate (Roth et al., 2014, p. 63). Fifth, EA visualizations can cover maps that can be expressed through cluster maps, which represent hierarchical relationships (Roth et al., 2014, p. 48), geographic maps, which relate EA objects to locations (Roth et al., 2014, p. 66), and tree maps, which display hierarchical data in relation to a quantitative dimension (Roth et al., 2014, p. 69). Lastly, metaphors for visualizing EAs or parts of EAs are occasionally mentioned in the literature. Well-known metaphors to visualize organizations are those of an organism, the brain, culture, or a political system (Morgan, 1986). In the EA domain, this metaphor is considered for visualizing software architectures (Panas, Berrigan, & Grundy, 2003; Wettel, Lanza, & Robbes, 2011), application architectures (Guetat & Dakhli, 2009), and entire EAs (Rehring, Brée et al., 2019).

EA perspective

EAs are described in various aspects, domains, views, or layers, which can be examined individually, in combination, or as a whole. An EA representation commonly follows a hierarchical "IT-follows business" (Winter & Fischer, 2006, p. 2) approach, whereas an EA explanation begins with a business-driven strategic point of view, continues with a business processes supporting information system, and ends with considering the underlying IT infrastructure (Winter & Fischer, 2006, p. 2). Currently, the EAM Framework TOGAF provides a widespread accepted subdivision of EAs, which also serves as a basis for the EA modelling language ArchiMate (Matthes, 2011, p. 68). TOGAF's metamodel proposes four EA layers, namely business architecture, data architecture, application architecture, and technology architecture (TOGAF, 2018). All business-related components of an organization such as business operation, organization structure, and business capabilities are encapsulated in business architecture. The data architecture consists of data entities that are processed in an organization along the business processes. Data is created, processed, and shared using applications that are represented in the application architecture. The technology architecture covers all logical and physical technology assets that are needed to realize application and data solutions (TOGAF, 2018).

5 Evaluation

The following section discusses two potential applications of the suggested taxonomy. Both examples are illustrative scenarios that apply our taxonomy to real-world objects (Szopinski, Schoormann, & Kundisch, 2019, p. 11). The first example outlines an evaluation of two HMDs representing a three-layer EA Model regarding its user performance. The second example sketches the comparison between a screen and a video occlusive HMD while interacting with an EA following a 3D city metaphor.

5.1 Exemplary Research Setting for EA Layer Visualizations

We present an exemplary study which aims to determine the most appropriate HMD for visualizing a three-layer EA model as Rehring, Greulich et al. (2019) suggested. Hence, our research evaluates the *efficiency* of s*ensors* using *video see-through HMDs and video occlusive HMDs* regarding the *visual* output each has for *individuals* who are *EA experienced* users that consume EA visualizations. We collect data by applying *time and counting measurements*. The interactions to be observed perform *3D navigation, selection, manipulation, and system control* interaction tasks employing *gestures*. The EAs visualized *business, application, and technology* architectures using a *three-layer model* visualization. Table VI-5 presents the configuration, and we explicate it in the following sections.

This exemplary research setting focuses on the comparison between two different HMDs that visualize an EA three-layer model regarding its efficiency. More specifically, the efficiency will be determined by how fast users complete pre-defined tasks, measured by task completion time, as well as how many mistakes users make, measured by error rate. The former will be measured in seconds, while the latter will be measured in the average number of errors per minute. The expected results will indicate which HMD visualization technology will be more suitable in terms of task processing while working with a three-layer EA model. This research focuses on individual task performance; hence, we will not investigate any group dynamics, nor will we require special collaborative mechanisms. Participants have to be experienced with EA to ensure a basic understanding of the tasks and the corresponding visualizations.

As mentioned, two different HMDs will be tested: a video see-through HMD for AR and a video occlusive HMD for VR. The two HMDs share some characteristics such as the helmet-like wearing style, the interrupted direct view on the real world, and the use of small screens to present the visualization content (Milgram et al., 1994, p. 284). However, the video see-through HMD uses cameras to capture and provide the user with the real-world scenario in real time, whereas the video occlusive HMD does not capture the surrounding real environment but provides computer generated visualizations. This setting enables task performance

Table VI-5. Exemplary research setting to compare AR and VR efficiency visualizing an EA in a three-layer model

Research setting						
Dependent variable	Efficiency	Experience	Usability			
User group	Individual	Collective				
Target audience	EA expert	EA experienced	Others			
Research method	Questionnaire	Time measurement	Distance measurement	Count measurement	Subjective measurement	
Device						
Hardware	Static screen	Touch-enabled screens				
	Video see-through HMD	Optical see-through HMD	Video occlusive HMD			
Input devices	Computer mouse	3D device	Sensors	Pointer	Touchpads	
Output	Visual	Acoustic	Haptic			
Interaction						
Input task type	2D	3D				
Interaction technique	Gestures	Voice	Touch			
	Body movement	Operation of device				
Interaction task	Navigation	Selection	Manipulation	System Control		
Visualization						
EA visualization	Text	Diagram	Chart	Model	Map	Metaphor
EA perspective	Business	Data	Application	Technology		

observation with similar visualization devices that differ in how they provide access to a users' real-world scenario. Further, only sensory information will be processed to avoid using specialized input devices such as a computer mouse, 3D devices, a pointer, or touchpads. Only the visual output will be assessed, hence, audio and haptic outcomes will be dismissed.

In this scenario, the EA visualization under observation is displayed in 3D, hence, the participants must perform tasks in depth-aiding augmentation, too. Interaction with the EA visualization can only be conducted by processing users' gestures. Those gestures will be captured by pre-built HMD sensors. To avoid incompatible interaction techniques, we have to ensure that both HMDs process the same gesture information. The research will focus on navigation, selection, manipulation, and system control tasks. We assume that pointing, grabbing, and moving are reasonable gesture techniques.

The visualization we planned to be evaluated is a three-layer EA model consisting of technical architecture, application architecture, and business architecture. The technical architecture contains all physical IT infrastructure components, such as servers, computers, and routers, as well as logical IT infrastructure components, such as virtual servers, middleware, and operating systems. The application architecture encompasses all software and groups of software that are run to support business processes. The business architecture includes all business-related EA components, such as domains, business processes, roles, capabilities, and stakeholders. The EA visualization can provide further analysis results in the form of connecting lines that represent dependencies, as well as various sizes and colors of visualized EA components to add contextual meaning.

5.2 Exemplary Research Setting for EA City Visualizations

We suggest another example with a research goal to evaluate the usability of an EA city metaphor using static screens and optical see-through HMDs for decision-making. This example is based on Rehring, Brée et al. (2019). Hence, we describe the research setting of this example as follows: Our research evaluates the u*sability* of *a computer mouse* in a *desktop environment* and with *optical see-through HMDs* regarding the *visual* output each has for *individuals* who are *EA experts and EA experienced* users that consume EA visualizations. We collect data by applying *questionnaires and subjective measurement methods*. The interactions to be observed perform *3D navigation, selection, manipulation, and system control* interaction tasks employing *operation of device and gestures*. The EAs visualize *application* architectures using *city metaphor* visualization. Table VI-6 presents the configuration and we explain it in the following sections.

This exemplary research setting focuses on the comparison between two different visualization hardware, namely static screens for a desktop environment and optical see-through HMDs for AR, regarding the usability of an EA city visualization for EA decision-making. This is a crucial aspect of EAM as one of its main purposes is to provide EA artefacts to support EA decision-making. In particular, usability can be measured in this research setting by perceived ease of learning, perceived workload, and perceived degree of tiredness. These results might indicate how effective the considered EA city representation is in EA decision-making processes. The unit of analysis is single individuals. The participants have to answer questionnaires presented before, during, and after they executed pre-defined tasks. The participants are expected to have prior knowledge of EA. This study will further investigate whether there is a

Table VI-6. Exemplary research setting to compare AR and screen usability visualizing an EA visualization with city metaphor

Research setting						
Dependent variable	Efficiency	Experience	Usability			
User group	Individual	Collective				
Target audience	EA expert	EA experienced	Others			
Research method	Questionnaire	Time measurement	Distance measurement	Count measurement	Subjective measurement	
Device						
Hardware	Static screen	Touch-enabled screens				
	Video see-through HMD	Optical see-through HMD	Video occlusive HMD			
Input devices	Computer mouse	3D device	Sensors	Pointer	Touchpads	
Output	Visual	Acoustic	Haptic			
Interaction						
Input task type	2D	3D				
Interaction technique	Gestures	Voice	Touch			
	Body movement	Operation of device				
Interaction task	Navigation	Selection	Manipulation	System Control		
Visualization						
EA visualization	Text	Diagram	Chart	Model	Map	Metaphor
EA perspective	Business	Data	Application	Technology		

difference in the perceived usability of the different hardware, on the one hand, for less experienced EA participants and, on the other hand, for EA experts with a solid EA background. The assumption is that the evaluated EA visualization is more appropriate for less experienced EA individuals. A moderator prepares notes based on their observation, which are later used for analysis. This illustrative research setting compares two disparate visualization technologies. The first device is a 2D static screen without touching capability. Although such screens are manufactured in various sizes, this research will use a 24-inch desktop screen. The second device is an optical see-through HMD that has to be worn on the head. This device uses mirrors and sensors to superimpose virtual objects onto a participant's real-world view. Both devices are capable of visualizing virtual 3D objects; however, the screen projects 3D content on a 2D surface and the HMD uses advanced technology to virtually place 3D content onto a user's real-world view. The ways of visualizing 3D content can differ; yet, both devices seem to be suitable for 3D representation. In order to streamline this research and reduce the amount of complexity, this evaluation is built on a single input method using a computer mouse. Operating a computer mouse is so familiar that participants will most likely have no problems interacting with such an EA visualization. As this research setting focuses on visual processing, no audio and haptic features will be part of this research.

The visualized EA runs in 3D, which therefore requires three-dimensional interaction with the virtual object. As mentioned, this research requires users to operate a computer mouse to navigate, select, manipulate, and use a control system of which it can be assumed that the general public knows how it works.

The visualization under investigation represents EAs in the form of a city as Rehring, Brée et al. (2019) suggested. The city is divided into districts that are compared to business departments. The city' streets represent existing data connections and moving cars the flow of data. These cars link buildings that exist in various shapes. Each type of building, e.g. government building, conference center, or residential building, portrays an EA artefact, such as business rules, events, or software applications.

6 Discussion

We have contributed to EAM research, especially concerning EA visualization, by suggesting a taxonomy that supports researchers in developing research designs to compare EA visualizations and required visualization technologies. We further contribute to the body of knowledge by providing a generic structure for summarizing and, hence, classifying existing research in this area. Two examples presented in section 5 show the possible applicability of our taxonomy using exemplary real-world objects in illustrative scenarios (Szopinski et al., 2019, p. 11). By applying the taxonomy, we were able to briefly frame possible research settings, even though we did not test them empirically. The guidance we provided ensured that relevant aspects would get due consideration. The proposed template for the description of evaluations of our taxonomy as presented in Table VI-4 gives quick access to the research project. In addition, readers can benefit from a table-like representation of the research setting, as we did in Table VI-5 and Table VI-6, as this enables a quick understanding of the content. Based on the generic high-level research designs, researchers can continue refining the planned research in a subsequent step of applying the suggested taxonomy.

Notably, this work provides a first overview of key factors of future research designs. The taxonomy does not summarize the current state of research, e.g. in the human-computer interaction (HCI) discourse or software visualization discipline. Rather, it focuses on the current EA use cases. We assume that our taxonomy generally provides the relevant required aspects that should be considered in designing EA comparison research settings. As these facets at first sound limiting, Nickerson et al. (2013, p. 341f) noted that taxonomies should tolerate new or modified aspects. If required, the taxonomy can be extended to serve individual needs. This can entail a change in category, dimension, or associated characteristics.

The existing literature has given some hints as to how far the taxonomy can be extended. The category research setting in our taxonomy offers some areas of improvements. Especially the characteristics of the dependent variable could be adjusted. Variables such as readability, cognitive and mental load, or user trust might be of interest to researchers. These characteristics could be linked to the existing variables (efficiency, effectiveness, usability); however, depending on the research focus, it might be useful to specify the dependent variable. In addition, it might be reasonable to extend the category. Differentiating the types of reality that make up the real world, mixed reality, or virtual reality might profit from a comparative study. On the same note, it might also be fruitful to focus on the environment in which a group of individuals operate. Research environments can differ across a continuum, from a point where all people see each other face-to-face, to a digital context in which all people are integrated in a fully virtual environment.

Our proposed taxonomy features devices that have explicitly been used to visualize and interact with EAs. However, the taxonomy can be extended in favor of further visualization approaches like a novel three-dimensional printing and a consistent use of pen and paper. The 3D printing, also known as additive manufacturing (Chen et al., 2019, p. 661), could be a novel and unique approach to visualizing EAs, in that 3D printing machines manufacture physical objects based on computer-generated 3D models (Gibson, Rosen, & Stucker, 2010, pp. 1–2). The final object is produced by adding material in layers, "that are formed on top of each other" (Ngo, Kashani, Imbalzano, Nguyen, & Hui, 2018, p. 172). The selected material depends on the planned characteristics of the physical model and the intended production process, e.g. accuracy of the layers, material and mechanical properties, production time, required postprocessing, size of the printing machine, and production costs (Gibson et al., 2010, p. 2). Physical models are commonly perceived as being superior to conceptual designs like drawings and other renderings in terms of building understanding (Gibson et al., 2010, p. 3). 3D printing has been applied in various industries such as construction, rapid prototyping, and biomechanics (Ngo et al., 2018, p. 172). In EA, 3D model building has been applied in a financial institution. Researchers employed 3D modelling to visualize their IT architecture. The goal was to understand the interdependencies between various EA objects to address the growing complexity of their heterogeneous service landscape (Finextra, 2017). Pen and paper are another heavily used approach to conceptually designing EAs. These 'napkin drawings' or 'paper sketches' consist of only a few high-level symbols and serve to reduce a model's complexity and to design easily understandable models (Fox, 2018, p. 1). Stakeholders frequently use a piece of paper, flipcharts, and whiteboards to draw basic EA models (Nowakowski et al., 2017, p. 4851f; ter Doest et al., 2017, p. 259). These drawings address the need to visualize EA models that support a specific decision scenario (Riempp & Gieffers-Ankel, 2007, p. 370). Extending the proposed taxonomy could be done to focus on its internal dependencies, too. Characteristics of technologies and techniques could be mapped and applied to the taxonomy. Integrating dependencies could add constraints that limit the number of options and, hence, streamline the design of research settings. For instance, processing gestures for EA visualization manipulation require the use of any sort of gestures-identification technology such as sensors. In such cases, hardware input devices like 3D devices or pointers might not be applicable. Another future study could focus on using the voice as interaction technique, which is commonly not linked to static screens. In addition, some characteristics might be strictly mutually exclusive, e.g. the voice and operating a device could be incompatible.

7 Conclusion

We developed and applied a taxonomy to support researchers in comparing visualization technologies for EAs. Based on a literature review and streamlined by the EA visualization research, the proposed taxonomy consists of four categories with 11 dimensions and a number of associated characteristics. Two exemplary illustrative scenarios show the conceptual applicability of the taxonomy. Our research contributes to the IS research discourse in that, first, our proposed taxonomy can be applied to design research settings and, second, can serve as a theoretical lens to summarize and classify similar research. Previous and future research can be classified and categorized to access and summarize the existing body of knowledge.

This paper is not without limitations, which future research projects could address. First, as this paper suggests a preparatory and practical approach, it is not based on a cross-disciplinary encompassing analysis of the current body of knowledge. It is noticeable that the resulting taxonomy might miss possible dimensions or characteristics. A further in-depth comparison of the unique characteristics of each technology and its characteristics, as well as a comprehensive description of the testing environment is mandatory to design favorable research settings. As comparing various EA visualization technologies include the study of human behavior, researchers need a precise explanation of the research environment, including detailed discussions of aspects like the participant selection process, the layout of the testing scenery, and the considered data gathering methods. Second, our review of the literature and the subsequently developed taxonomy cover desktop environments as a commonly used technology dealing with EA visualizations. There is a high probability that many research papers do not explicitly mention or recognize desktop systems or desktop environments as the underlying visualization technology in title, abstract, or keywords. As a result, such papers were not considered in our literature review. However, we are convinced that our taxonomy contains all the crucial aspects needed for a solid research setting when evaluating EA visualization technologies. Third, we did not examine already existing taxonomies, as this approach was not the subject of this paper. Potential areas for suitable taxonomies could be the software visualization discipline or the human computing interaction discourse. Insights from these fields of research can be added through another empirical-to-conceptual iteration following Nickerson et al.'s (2013) taxonomy building method. Finally, we did not empirically test our taxonomy in a real-world scenario. Future research should address this concern by applying our taxonomy as a basis for designing an EA visualization comparison study or by considering the taxonomy for information aggregation studies such as systematic literature reviews. Findings from these research activities could be beneficial for further improving our taxonomy.

References

Ahlemann, F., Stettiner, E., Messerschmidt, M., & Legner, C. (2012). *Strategic Enterprise Architecture Management: Challenges, Best Practices, and Future Developments*. Berlin; New York: Springer.

Aier, S. (2013). Understanding the Role of Organizational Culture for Design and Success of Enterprise Architecture Management. In R. Alt & B. Franczyk (Eds.), *Proceedings of the 11th International Conference on Wirtschaftsinformatik (WI 2013)* (Vol. 1, pp. 879–894). Leipzig.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators and Virtual Environments*, *6*(4), 355–385.

Besançon, L., Issartel, P., Ammi, M., & Isenberg, T. (2017). Mouse, tactile, and tangible input for 3D manipulation. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 4727–4740.

Biocca, F., & Delaney, B. (1995). Immersive Virtual Reality Technology. In *Communication in the Age of Virtual Reality* (p. 401). Routledge.

Bowman, D. A., & Wingrave, C. A. (2001). Design and evaluation of menu systems for immersive virtual environments. *Proceedings IEEE Virtual Reality 2001*, 149–156. Yokohama, Japan: IEEE Comput. Soc. https://doi.org/10.1109/VR.2001.913781

Buckl, S., Ernst, A. M., Matthes, F., & Schweda, C. M. (2009). How to make your enterprise architecture management endeavor fail! *Proceedings of the 16th Conference on Pattern Languages of Programs*. Presented at the Proceedings of the 16th Conference on Pattern Languages of Programs, Chicago, Illinois, USA.

Butterworth, J., Davidson, A., Hench, S., & Olano, M. T. (1992). 3DM: A three dimensional modeler using a head-mounted display. *Proceedings of the 1992 Symposium on Interactive 3D Graphics*, 135–138.

Chen, Z., Li, Z., Li, J., Liu, C., Lao, C., Fu, Y., … He, Y. (2019). 3D printing of ceramics: A review. *Journal of the European Ceramic Society*, *39*(4), 661–687.

Corbin, J., & Strauss, A. (1990). Grounded theory research: procedures, canons, and evaluative criteria. *Qualitative Sociology*, *13*(1), 3–21.

Dang, N. T., Tavanti, M., Rankin, I., & Cooper, M. (2009). A comparison of different input devices for a 3D environment. *International Journal of Industrial Ergonomics*, *39*(3), 554–563.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and Limitations of Immersive Participatory Augmented Reality Simulations for Teaching and Learning. *Journal of Science Education and Technology*, *18*(1), 7–22. https://doi.org/10.1007/s10956-008-9119-1

Findlater, L., Froehlich, J. E., Fattal, K., Wobbrock, J. O., & Dastyar, T. (2013). Age-related differences in performance with touchscreens compared to traditional mouse input. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 343–346.

Finextra. (2017). Rabobank constructs physical model to understand IT architecture. Retrieved April 13, 2018, from https://www.finextra.com/newsarticle/30988/rabobank-constructs-physical-model-to-understand-it-architecture

Fox, R. (2018). *Controlling the Chaos: A Functional Framework for Enterprise Architecture and Governance*. Technics Publications.

Gibson, I., Rosen, D., & Stucker, B. (2010). Development of additive manufacturing technology. In *Additive manufacturing technologies* (pp. 19–42). Springer.

Gribnau, M. W., & Hennessey, J. M. (1998). Comparing single-and two-handed 3D input for a 3D object assembly task. *Chi 98 Conference Summary on Human Factors in Computing Systems*, 233–234.

Guetat, S., & Dakhli, S. B. D. (2009). The Information City: A Framework For Information Systems Governance. *MCIS 2009 Proceedings*, 1377–1388.

Hinckley, K., Pausch, R., Goble, J. C., & Kassell, N. F. (1994). A survey of design issues in spatial input. *Proceedings of the 7th Annual ACM Symposium on User Interface Software and Technology*, 213–222.

Hoppe, A. H., van de Camp, F., & Stiefelhagen, R. (2017). Interaction with three dimensional objects on diverse input and output devices: A survey. *International Conference on Human-Computer Interaction*, 130–139. Springer.

Kim, J. H., Aulck, L., Bartha, M. C., Harper, C. A., & Johnson, P. W. (2014). Differences in typing forces, muscle activity, comfort, and typing performance among virtual, notebook, and desktop keyboards. *Applied Ergonomics*, *45*(6), 1406–1413.

Kortekamp, S.-S., Werning, S., Thomas, O., & Ickerott, I. (2019). THE FUTURE OF DIGITAL WORK - USE CASES FOR AUGMENTED REALITY GLASSES. *ECIS 2019*. Presented at the Sweden. Sweden.

Krichenbauer, M., Yamamoto, G., Taketomi, T., Sandor, C., & Kato, H. (2017). Augmented Reality vs Virtual Reality for 3D Object Manipulation. *IEEE Transactions on Visualization and Computer Graphics*, 1–10. https://doi.org/10.1109/TVCG.2017.2658570

Lee, B., Isenberg, P., Riche, N. H., & Carpendale, S. (2012). Beyond mouse and keyboard: Expanding design considerations for information visualization interactions. *IEEE Transactions on Visualization and Computer Graphics*, *18*(12), 2689–2698.

Lee, K. (2012). *Augmented Reality in Education and Training*. *56*(2), 9.

Levy, Y., & Ellis, T. J. (2006). A Systems Approach to Conduct an Effective Literature Review in Support of Information Systems Research. *Informing Science*, *9*.

Marshall, E., & Nichols, S. (2004). Interaction with a desktop virtual environment: a 2D view into a 3D world. *Virtual Reality*, *8*(1), 17–25.

Matthes, D. (2011). *Enterprise Architecture Frameworks Kompendium*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Merino, L., Bergel, A., & Nierstrasz, O. (2018). Overcoming issues of 3D software visualization through immersive augmented reality. *2018 IEEE Working Conference on Software Visualization (VISSOFT)*, 54–64. Madrid, Spain.

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1994). Augmented Reality: A class of displays on the reality-virtuality continuum. *Telemanipulator and Telepresence Technologies*, *2351*(11), 282–292.

Morgan, G. (1986). *Images of organization*. Beverly Hills, CA: SAGE Publications.

Ngo, T. D., Kashani, A., Imbalzano, G., Nguyen, K. T., & Hui, D. (2018). Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. *Composites Part B: Engineering*, *143*, 172–196.

Nickerson, R. C., Varshney, U., & Muntermann, J. (2013). A method for taxonomy development and its application in information systems. *European Journal of Information Systems*, *22*(3), 336–359. https://doi.org/10.1057/ejis.2012.26

Nowakowski, E., Farwick, M., Trojer, T., Häusler, M., Kessler, J., & Breu, R. (2017). Enterprise Architecture Planning: Analyses of Requirements from Practice and Research. *Proceedings of the 50th Hawaii International Conference on System Sciences*.

Oberhauser, R., & Pogolski, C. (2019). VR-EA: Virtual Reality Visualization of Enterprise Architecture Models with ArchiMate and BPMN. *International Symposium on Business Modeling and Software Design*, 170–187. Springer.

Oberhauser, R., Sousa, P., & Michel, F. (2020). VR-EAT: Visualization of Enterprise Architecture Tool Diagrams in Virtual Reality. *International Symposium on Business Modeling and Software Design*, 221–239. Springer.

Panas, T., Berrigan, R., & Grundy, J. (2003). A 3D metaphor for software production visualization. *Proceedings on Seventh International Conference on Information Visualization, 2003. IV 2003.*, 314–319. London, UK: IEEE.

Rehring, K., Greulich, M., Bredenfeld, L., & Ahlemann, F. (2019). *Let's get in touch - Decision making about Enterprise Architecture using 3D Visualization in Augmented Reality* (S. Proceedings of the 52nd annual Hawaii International Conference on Systems, Ed.). Hawaii, USA.

Rehring, Kevin, & Ahlemann, F. (2020). *Evaluating the User Experience of an Augmented Reality Prototype for Enterprise Architecture*. Presented at the 15th International Conference on Wirtschaftsinformatik, Potsdam, Germany.

Rehring, Kevin, Brée, T., Gulden, J., & Bredenfeld, L. (2019). Conceptualizing EA Cities: Towards Visualizing Enterprise Architectures as Cities. *Proceedings of the 27th European Conference on Information Systems (ECIS)*. Presented at the Twenty-Seventh European Conference on Information Systems (ECIS 2019), Stockholm & Uppsala, Sweden.

Rhienmora, P., Gajananan, K., Haddawy, P., Dailey, M. N., & Suebnukarn, S. (2010). Augmented reality haptics system for dental surgical skills training. *Proceedings of the 17th ACM Symposium on Virtual Reality Software and Technology*, 97–98.

Riempp, G., & Gieffers-Ankel, S. (2007). Application portfolio management: a decision-oriented view of enterprise architecture. *Information Systems and E-Business Management*, *5*(4), 359–378.

Roth, S., Zec, M., & Matthes, F. (2014). *Enterprise Architecture Visualization Tool Survey 2014*. Germany: epubli GmbH.

Sadri, S., Kohen, S., Elvezio, C., Sun, S., Grinshpoon, A., Loeb, G., … Feiner, S. (2019). Manipulating 3D Anatomic Models in Augmented Reality: Comparing a Hands-Free Approach and a Manual Approach. *2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 93–102. IEEE.

Sherman, W. R., & Craig, A. B. (2002). *Understanding Virtual Reality: Interface, Application, and Design*. Elsevier Science.

Sun, J., Stuerzlinger, W., & Riecke, B. E. (2018). Comparing input methods and cursors for 3D positioning with head-mounted displays. *Proceedings of the 15th ACM Symposium on Applied Perception*, 1–8.

Szopinski, D., Schoormann, T., & Kundisch, D. (2019). Because your taxonomy is worth it: Towards a framework for taxonomy evaluation. *EUROPEAN CONFERENCE ON INFORMATION SYSTEMS (ECIS) 2019 PROCEEDINGS*.

Tamm, T., Seddon, P. B., Shanks, G., & Reynolds, P. (2011). How does enterprise architecture add value to organisations. *Communications of the Association for Information Systems*, *28*(1), 141–168.

ter Doest, H. W., van Leeuwen, D., Fennema, P., van der Torre, L., Stam, A. W., Jacob, J., & Arbab, F. (2017). Tool Support. In *Enterprise Architecture at Work* (pp. 277–299). Springer.

TOGAF. (2018). The TOGAF Standard, Version 9.2 - Content Metamodel. Retrieved September 17, 2018, from http://pubs.opengroup.org/architecture/togaf9-doc/arch/chap30.html

van der Raadt, B., Schouten, S., & Vliet, H. van. (2008). Stakeholder Perception of Enterprise Architecture. In R. Morrison, D. Balasubramaniam, & K. Falkner (Eds.), *Software Architecture* (pp. 19–34). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-88030-1_4

Vieira, R., Cardoso, E., & Becker, C. (2014, September). *A Traceable Maturity Assessment Method Based on Enterprise Architecture Modelling*. 245–253. IEEE. https://doi.org/10.1109/EDOCW.2014.44

vom Brocke, J., Simons, A., Riemer, K., Niehaves, B., Plattfaut, R., & Cleven, A. (2015). Standing on the Shoulders of Giants: Challenges and Recommendations of Literature Search in Information Systems Research. *Communications of the Association for Information Systems*, *37*(1).

Werkhoven, P. J., & Groen, J. (1998). Manipulation performance in interactive virtual environments. *Human Factors*, *40*(3), 432–442.

Wettel, R., Lanza, M., & Robbes, R. (2011). Software systems as cities: A controlled experiment. *2011 33rd International Conference on Software Engineering (ICSE)*, 551–560. Honolulu, HI: IEEE.

Winter, R., & Fischer, R. (2006). Essential Layers, Artifacts, and Dependencies of Enterprise Architecture. *2006 10th IEEE International Enterprise Distributed Object Computing Conference Workshops (EDOCW'06)*, 30–30. https://doi.org/10.1109/EDOCW.2006.33

Zhai, S. (1998). User performance in relation to 3D input device design. *ACM Siggraph Computer Graphics*, *32*(4), 50–54.

Appendix

Appendix VI-1: Analysis Matrix 1

Analysis matrix 1/2	**Butterworth** et al. (1992)	**Sun** et al. (2018)	**Krichenbauer** et al. (2017)	**Besançon** et al. (2017)	**Zhai** (1998)	**Hoppe** et al. (2017)
Dependent variable						
» Efficiency	-	-	-	-	-	x
» Experience	-	x	x	-	-	-
» Usability	x	x	x	x	x	-
User group						
» Individual	x	x	x	x	x	x
» Collective	-	-	-	-	-	-
Target audience						
» EA expert	x	-	x	x	-	-
» EA experienced	x	-	-	x	-	-
» Other	-	-	x	-	x	x
Research method						
» Questionnaire	-	x	x	x	-	-
» Time measurement	-	x	x	x	-	x
» Distance measurement	-	x	-	x	-	-
» Count measurement	-	-	-	-	-	-
» Subjective measurement	x	-	-	x	x	-
Visualization devices						
» Static screen	-	x	-	-	-	x
» Touch-enabled screens	-	-	-	x	-	x
» Video see-through HMD	-	-	-	-	-	-
» Optical see-through HMD	-	-	-	-	-	-
» Video occlusive HMD	x	x	x	-	-	-
Input devices						
» Computer mouse	-	x	x	x	x	x
» 3D device	x	x	x	x	x	x
» Sensors	x	-	-	-	-	x
» Pointer	-	-	-	-	x	-
» Touchpad	-	x	-	-	-	-

Output						
» Visual	x	x	x	x	x	x
» Acoustic	-	-	-	-	-	-
» Haptic	-	-	-	-	-	-
Input task type						
» 2D	-	x	-	x	x	x
» 3D	x	x	x	-	x	x
Interaction technique						
» Gestures	-	-	-	-	-	x
» Voice	-	-	-	-	-	-
» Touch	-	-	-	-	-	x
» Body movement	-	x	-	-	-	-
» Operation device	-	x	x	x	x	-
Interaction tasks						
» Navigation	x		-	-	-	-
» Selection	x	x	-	-	-	-
» Manipulation	x	x	x	x	x	x
» System control	x	-	-	-	-	-

Appendix VI-2: Analysis Matrix 2

Analysis matrix 2/2	**Werkhoven &** Groen (1998)	**Rhienmora** et al. (2010)	**Gribnau &** Hennessey (1998)	**Hinckley** et al. (1994)	**Dang** et al. (2009)	**Sadri** et al. (2019)
Dependent variable						
» Efficiency	-	-	-	-	-	x
» Experience	x	-	x	-	x	-
» Usability	-	x	-	x	-	-
User group						
» Individual	x	x	x	x	x	x
» Collective	-	-	-	-	-	-
Target audience						
» EA expert	-	x	-	-	-	-
» EA experienced	-	-	-	-	-	-
» Other	x	-	x	x	x	x
Research method						

» Questionnaire	-	-	-	-	x	x
» Time measurement	x	-	x	-	x	x
» Distance measurement	x	-	-	-	-	-
» Count measurement	-	-	-	-	x	-
» Subjective measurement	-	x	-	x	-	-
Visualization devices						
» Static screen	x	-	-	-	-	-
» Touch-enabled screens	-	-	-	-	x	-
» Video see-through HMD	x	-	x	-	x	-
» Optical see-through HMD	-	x	-	-	-	x
» Video occlusive HMD	-	x	-	-	-	-
Input devices						
» Computer mouse	-	-	-	-	-	-
» 3D device	x	x	x	x	x	x
» Sensors	x	-	x	x	x	x
» Pointer	-	-	-	-	x	-
» Touchpad	-	-	-	-	-	-
Output						
» Visual	x	x	x	x	x	x
» Acoustic	-	-	-	-	-	-
» Haptic	-	x	-	x	-	-
Input task type						
» 2D	-	-	-	-	-	-
» 3D	x	x	x	x	x	x
Interaction technique						
» Gestures	x	-	-	x	-	x
» Voice	-	-	-	-	x	x
» Touch	-	-	-	-	x	-
» Body movement	-	-	-	x	-	x
» Operation device	-	x	x	x	x	-
Interaction tasks						
» Navigation	-	-	-	-	-	-
» Selection	-	-	x	x	-	x
» Manipulation	x	-	-	x	x	x
» System control	-	-	-	-	-	x

List of Abbreviations

Abbr.	**Explanation**
AR	Augmented Reality
AR HMD	Augmented Reality-enabled head-mounted display
AV	Augmented Virtuality
BPMN	Business Process Model and Notation
CFT	Cognitive Fit Theory
CoP	Community of Practices
DO	Design objectives
DSR	Design Science Research
EA	Enterprise Architecture
EAM	Enterprise Architecture
GQ	General question
HMD	Head-mounted display
IS	Information System
IT	Information Technology
LR	Literature review
M	Median
MR	Mixed Reality
PQ	Post-question
RQ	Research goal
RP	Research problem
RV	Reality-Virtuality
SD	Standard deviation
UML	Unified Modeling Language
VE	Virtual Environment
VR	Virtual Reality
VRD	Virtual Retinal Displays
3D	Three-dimensional