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"Investigation on the Future of Enterprise Architecture in Dynamic Environments"

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LIST OF ABREVIATIONS

AAF	Agile Architecture Framework
ARIMA	Autoregressive integrated moving average
AT	Architectural Thinking
CAS	Complex Adaptive System
CRISP-DM	Cross Industry Standard Process for Data Mining
DA	Disciplined Agile
DAD	Disciplined Agile Delivery
DMSM	DeLone and McLean information system success model
DoDAF	Department of Defense Architecture Framework
DOI	Digital Object Identifier
DYA	Dynamic Architecture
EA	Enterprise Architecture
EAM	Enterprise Architecture Management
EAs	Enterprise Architects
ECA	Enterprise Coherence-governance Assessment
ECF	Enterprise Coherence Framework
ECG	Enterprise Coherence Governance
FEA	Federal Enterprise Architecture
GDP	Gross Domestic Product
GEA	General Enterprise Architecting
IoT	Internet of Things
IS	Information System
IT	Information Technology
LeSS	Large Scale Scrum
MDA	Model-Driven-Architecture
MDD	Model-Driven-Development
MRQ	Main Research Question

O-AAF	The Open Group Agile Architecture Framework
RQ	Research Question
SAFe	Scaled Agile Framework
SDA	Software Defined Architecture
SDN	Software Defined Network
TOGAF	The Open Group Architecture Framework
VUCA	Volatility, Uncertainty, Complexity and Ambiguity

1 INTRODUCTION

1.1 MOTIVATION

In today's economy, constant change has become the new normal. Since 1960, the average lifespan of companies on Standard & Poor's 500 has decreased from more than 60 to less than 20 years (Satell 2014), which serves as one vivid indicator of a business world with increasing dynamics. An important driver for this development is technical progress, which is accelerating. Moore's law is a prominent observation of this acceleration, which outlines that the number of transistors in a dense integrated circuit doubles approximately every two years and hence is exponentially growing (Moore 1965). While the scope of Moore's law was initially restricted to the semiconductor industry, more recent publications, show that similar observations can be made for technical progress overall. For example, Kurzweil (Kurzweil 2004) shows that overall technological change is exponentially accelerating.

Digital transformation is one of the latest effects driven by technical progress which disrupts existing business models in various industries (Iansiti and Lakhani 2014; Porter and Heppelmann 2015). Examples range from the financial industry, where young, digital-first companies take away significant market share from long existing competitors with their online offerings, up to the transportation sector, where digital platforms enable entirely new business models such as car-sharing (Bughin and Zeebroeck 2017).

The increasing dynamics in both technology and economy impose significant challenges for enterprises since there is a constant need to adapt to changing conditions while ensuring internal alignment at the same time. Since the late nineteen eighties, the concept of Enterprise Architecture (EA) has evolved as a discipline and as a method to cope with these challenges and facilitate the management of information systems in alignment with corresponding business elements within complex organizations (Lapalme et al. 2016; Zachman 1987). Today, a variety of practices and frameworks are available, which help to manage existing architectures of enterprises and to support the transition from a given to a future state (Buckl and Schweda 2011; Matthes 2011; Schekkerman 2004). EA has been and still is an evolving discipline, which is shaped by social progress and technological advance as well as learning outcomes (Romero and Vernadat 2016).

The initial idea to apply architecture in the context of enterprises to describe, understand, represent and design different dimensions has been developed and made popular simultaneously by different groups in the late nineteen eighties and early nineties (Kotusev 2016; Romero and Vernadat 2016). As a consequence, several EA frameworks have emerged (Schekkerman 2004), which is also a reason for the plurality of definitions on EA (Saint-Louis, Morency, and Lapalme 2017). One frequently referenced basis, the ISO/IEC/IEEE 42010 standard, defines architecture as: ''The fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution.'' (ISO/IEC 2011). This definition can be applied to EA by viewing an enterprise as a "system". The result is a commonly used definition for EA, which is for example embraced in the TOGAF framework. TOGAF is one of the most popular EA frameworks (Matthes 2011; The Open Group 2013).

This thesis also embraces the ISO/IEC/IEEE 42010 definition and considers EA as a discipline which manages the architecture of an enterprise resulting in the following definition:

"Enterprise Architectures is a discipline which manages the fundamental organization of an enterprise, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution."

Based on the definition of EA above, this thesis investigates how the discipline and its methods can be applied in current times of increasing dynamics.

Information technology takes a unique role within digital transformation since it is a core enabler for this transformation. Lately, various approaches have emerged in information technology, which help to cope with the more rapidly changing business world. Some examples are:

Agile software development - The implementation of IT projects in short iterations with the goal to release a first version of the product as soon as possible (Beck et al. 2001);

DevOps - A practice to bring software developers and IT operations personnel closer to each other in order to enable a more rapid and more frequent release of software (Debois 2009);

Cloud Computing - The delivery of IT as a service over the internet on a pay per use basis, which increases flexibility (Armbrust et al. 2010).

One key objective of Enterprise Architecture is to keep the different facets of an organization aligned, which includes business interests and the underlying information systems. Therefore, in a more flexible and more rapidly changing IT world, also the approaches to Enterprise Architecture must be revised.

Considering the example of agile software development, it will hardly be possible to define the entire architecture upfront. At the same time, a lack of Enterprise Architecture in agile environments will likely lead to several problems such as unnecessary rework, inconsistent communication and especially locally focused architecture, design and implementation (Gill 2015).

Concerning DevOps practices, there is also a clear dependency to EA. First of all, to implement and run an organization in a DevOps manner, certain architectural preconditions need to be fulfilled, such as the availability of suitable tools and platforms. Moreover, when transforming existing traditional organizations to a DevOps setup and hence restructuring development and operations teams, also the future organizational setup of architecture teams needs to be addressed (Bass, Weber, and Zhu 2015).

Cloud Computing is another example of a concept which is supposed to increase agility and flexibility in IT. However, this comes at a cost because in order to leverage these advantages long-term, organizations need to ensure effective governance of cloud services by addressing architectural challenges for example related to integration and security (Janulevicius et al. 2017). These challenges present a typical remit for EA. However, due to the significant paradigm shift introduced by cloud computing, it needs to be ensured that suitable EA approaches and methods are selected (Ebneter et al. 2010).

The presented approaches from IT are reasonable attempts to cope with the increasing dynamics of the business world. However, in order to produce sustainable results, not only short-term flexibility needs to be pursued, but also long-term strategic alignment. EA has the potential to play a significant role in these new realities of increasing dynamics by enabling organizations to manage and transform their architectures effectively. However, to do so, the discipline EA itself needs to evolve and adapt to the changing conditions. This evolution of EA is investigated in this thesis.

1.2 PROBLEM OUTLINE AND OBJECTIVE

We live in times of increasing dynamics. The effects of digital transformation enable new companies to be founded and grow swiftly. At the same time, existing organizations have to adapt more quickly than ever to changing conditions in order to remain successful (Bughin and Zeebroeck 2017).

The increasing dynamics in economy, in technology and IT have a substantial impact on transformation activities of enterprises and thereby affect how EA needs to be practiced. This challenge has been recognized by both scholars (Korhonen et al. 2016; Lapalme et al. 2016) and practitioners (Matthijssen 2016; O'Neill, Macgregor, and Livadas 2017). At the same time, the discipline EA is still relatively immature (Lapalme 2012). Consequently, immaturity can also be observed for the implementation of EA in many organizations. (van Steenbergen 2011; Winter, Legner, and Fischbach 2014). The presented observations lead to the conclusion that the discipline EA will likely need to change in the upcoming years to be useful in the future, which presents the foundational problem for the research presented in this work.

Individual authors have come up with first suggestions on how EA should be practiced given these changing conditions. In the early 2000s years, with the growing hype around agile methodologies (Beck et al. 2001), first authors have published research to describe how EA could adopt agile practices and hence become more effective in dynamic environments (Wagter et al. 2005). Moreover, very recently there is an increasing interest the subject with various authors publishing individual research results (Hinkelmann et al. 2016; Korhonen et al. 2016; Korhonen and Halen 2017; Lapalme et al. 2016).

However, a holistic and integrative view on how to practice EA in dynamic and environments is still missing. At the same time a recent study by Drews (Drews et al. 2017) asks for further empirical research on the subject.

In order to address these gaps, this thesis takes an integrative view and aims to validate, consolidate and potentially enhance existing recommendations. Moreover, the goal is to present them in an actionable for practitioners so they can be quickly implemented in actual enterprises.

In conclusion, the objective of this thesis is to describe a future-proof approach to practice enterprise architecture in increasingly dynamic environments.

1.3 RESEARCH DESCRIPTION

The research presented in this thesis addresses one main research question (MRQ), which is:

"How can Enterprise Architecture evolve to be effective in times of increasing dynamics?"

The underlying observation is that economic and technological dynamics are overall increasing which requires a different way than the current one of working in EA to be effective.

In order to find a solution to the MRQ the influence of increasing dynamics on the discipline EA needs to be formally understood and described. Afterwards, different approaches can be identified and assessed, which enable and ensure the effectiveness of EA in the light of these changing conditions.

Going forward this work applies a structured approach to address the MRQ considering the as-is as well as the desired to-be situation of the discipline of EA. Similar approaches are commonly applied in EA to develop and implement architectures (The Open Group 2013). However, in the case of this thesis, it is applied not to an enterprise or a part of it, but the discipline of EA. The structured approach considers two parts with related individual research questions (RQ), see also Figure 1:

I. The *current state* of EA focusing on the discipline itself as well as its implementation and usage in practice
II. The *future state* EA considering potential scenarios on how the discipline can evolve to cope with increasing dynamics

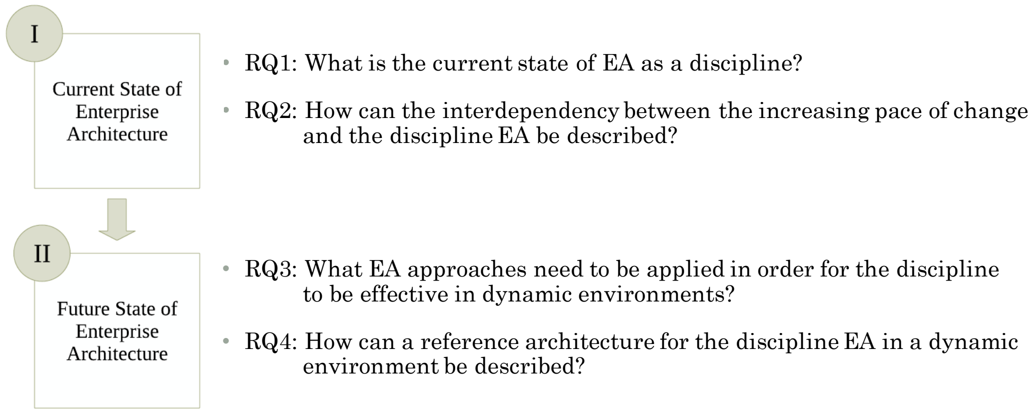

Figure 1: Research Structure of this Thesis

Each of the two parts – current state and future state – is further addressed with individual research question RQ1 – RQ4, which are presented below.

The first research question (RQ1) is: *"What is the current state of Enterprise Architecture as a discipline?"* The first research question of this work focuses on the overall current state of EA and has the objective to consider the history of the discipline as well as its current developments. The underlying idea is to provide a broad foundation for the subsequent analysis in this thesis including a sufficient repository of relevant literature.

The second research question (RQ2) is: *"How can the interdependency between the increasing pace of change and the discipline EA be described?"* The objective is to understand and describe the relationship between increasing dynamics and the discipline of EA. Therefore, first, the effects of a changing pace are more closely considered. Different related concepts, such as dynamic environments as well as interdependencies between technological and economic change, are defined and observed over time. In a second step the effects of these changing conditions on EA are analyzed and summarized in a research model.

The third research question (RQ3) is: *"What EA approaches need to be applied in order for the discipline to be effective in dynamic environments?"*. Based on the results of the overall current state analysis and the identified interaction between increasing dynamics and EA, the future of EA is investigated. Different approaches which have the potential to increase the effectiveness of EA in dynamic environments, are identified and assessed.

The fourth research question (RQ4) is: "*How can a reference architecture for the discipline EA in a dynamic environment be described?*". The objective is to summarize a reference architecture with a set of recommended approaches and practices, which organizations can apply in order to run EA effectively in dynamic environments.

The combination of the results from current state analysis (I) and future state analysis (II) will deliver a response to the main research question of this work by describing a future-proof approach which considers how enterprise architecture can be run in increasingly dynamic environments.

1.4 STRUCTURE OF THE DISSERTATION

The structure of this dissertation reflects the previously presented research approach. Figure 2 depicts a graphical overview, which maps the two parts concerning the current state and future state to the individual chapters of this dissertation. Moreover, the figure indicates the results presented within the different chapters as well as the applied research strategies and scientific methods.

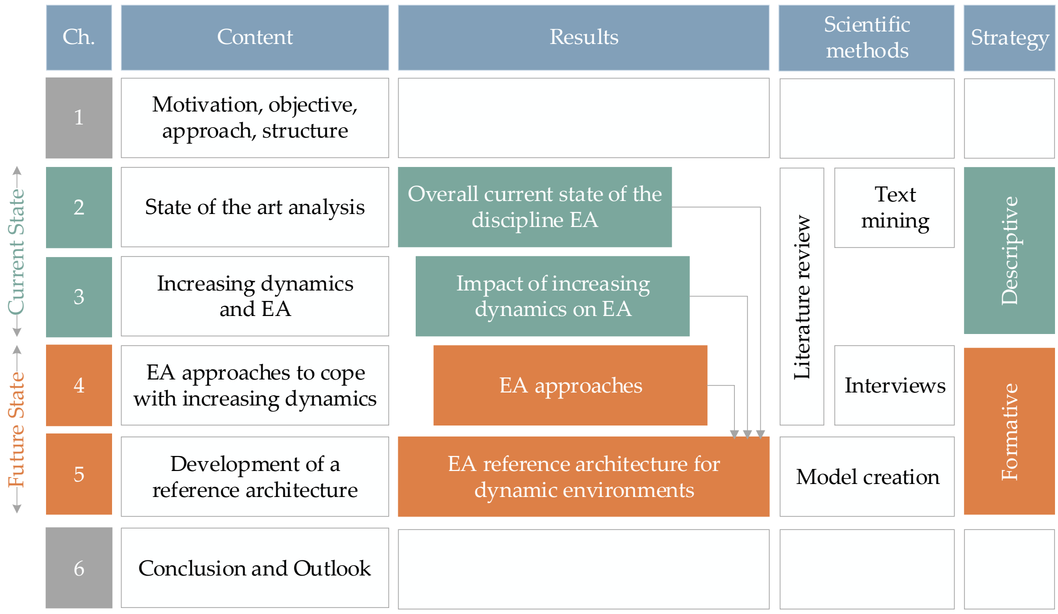

Figure 2: Graphical Overview of Dissertation Structure

Chapter 2, which is following this introduction, presents the analysis of the overall current state of EA addressing RQ1. First, a systematic review is conducted to determine the overall current state of the discipline. To cope with the vast body of knowledge, which has been generated in about 30 years of EA research, text mining techniques are utilized to support the systematic review. A particular emphasis is put on current trends related to the discipline. They are considered especially important for the investigation of this thesis since they are currently influencing EA and therefore likely affect the future of the discipline.

In chapter 3, a closer look is taken at the effect of increasing dynamics and its interaction with the discipline of EA. A formal understanding and description of how economic and technologic dynamics are currently changing are established. Subsequently, models for EA effectiveness are considered focusing on the question how the discipline creates value within organizations. As the last step in chapter 3, the formal description of increasing dynamics and models for EA effectiveness are combined to assess how increasingly dynamic environments are impacting EA effectiveness. The resulting research model is used as a foundation for the following parts of the thesis

The future state analysis, which is addressed in RQ3 and RQ4, is presented in chapter 4 and 5 of this work.

In chapter 4, approaches for EA to cope with increasingly dynamic environments are derived from various sources, such as scientific literature, existing frameworks as well as industry reports. These approaches are consolidated and structured using qualitative content analysis. Afterwards, initial validation and further exploration of these approaches are conducted based on expert interviews with EA practitioners from various industries and geographies. The results are structured and consolidated into a list of applicable EA approaches for dynamic environments.

In order to provide a better consumable format of the identified approaches for practitioners, chapter 5 presents them in from of a domain reference architecture. This reference architecture summarizes the approaches and shows their dependencies. Moreover, it includes graphical representations as well as formal models using the EA modelling standard ArchiMate.

The final chapter 6 of this thesis presents a conclusion of the work as well as an outlook including suggestions for future research.

2 CURRENT STATE OF ENTERPRISE ARCHITECTURE

This chapter presents an overall current state analysis of the discipline Enterprise Architecture and thereby lays the foundation for the following steps of this work presented in subsequent chapters. The following research question is addressed within this chapter (RQ1): *"What is the current state of Enterprise Architecture as a discipline?"*

This chapter provides an overall state of the art analysis regarding the discipline EA to identify the research status as well as current trends which drive the evolution of the subject.[1]

The first section of this chapter provides a definition of EA which sets the scope for the state-of-the-art review. The following two sections describe how this work's state of the art review is planned and structured (section 2.2 and 2.3). Afterward, the information retrieval is explained and how content from various sources is consolidated (section 2.4). The results of the review are presented subsequently (sections 2.5 and 2.6). Finally, a discussion and conclusion are given which also puts the results into the overall context of this thesis (section 2.7).

2.1 DEFINING ENTERPRISE ARCHITECTURE

In order to conduct a state-of-the-art review a crucial first step is to define the subject which should be reviewed. As already pointed out, this study embraces the ISO/IEC/IEEE 42010:2011 (ISO/IEC 2011) definition and considers EA to be a discipline that manages the architecture of an enterprise, thereby resulting in the following definition: *"Enterprise Architecture is a discipline that manages the fundamental organization of an enterprise, which is embodied in its components, their*

[1] The content of this chapter has been partly published within the September 2018 issue of Computers in Industry (Gampfer et al. 2018).

relationships to one another and the environment, and the principles that govern its design and evolution."

While the previously presented definition of EA based on the ISO/IEC/IEEE 42010 standard is commonly referenced and accepted by scholars and practitioners, a major difference can be found in how the scope of EA is interpreted. Based on the definition above, EA appears to be specifically concerned with the level of an entire organization where business aspects are included. However, EA is not supposed to solely create a holistic and detailed model of the entire enterprise but relies on various architecture subdomains, which deliver aggregates (Aier, Riege, and Winter 2008; Fischer and Winter 2007). Therefore, a main concern of EA is to integrate the various architectural domains on which it depends (Jonkers et al. 2006). Other architectural disciplines such as Information Systems (IS) Architecture and Information Technology (IT) Architecture perform similar integrative tasks on lower levels and therefore can be considered parts of an extended EA. Figure 3 summarizes the described narrow and extended views of EA and outlines how they relate to different architectural subdomains.

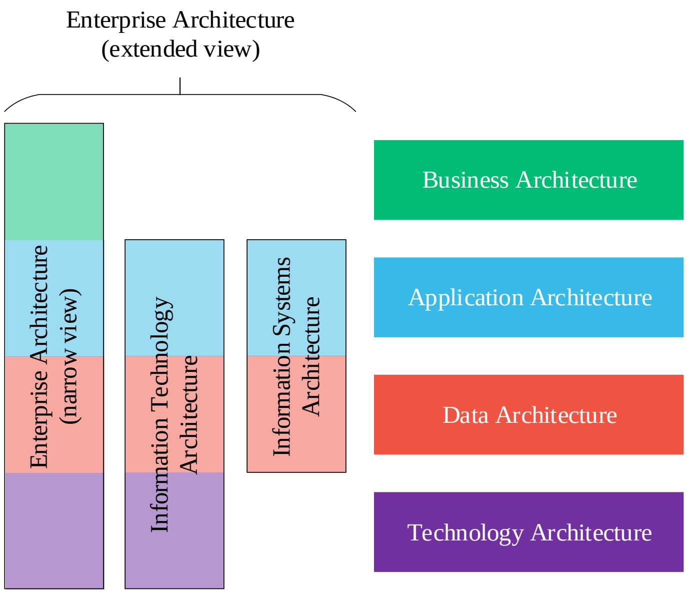

Figure 3: EA definition, narrow and extended views

Lapalme (Lapalme 2012) similarly describes the current differences in the interpretation of EA scope and purpose of EA summarizes the major schools of thought regarding EA, see Table 1.

The school with the narrowest scope is called *Enterprise IT Architecting*. It considers EA only for the alignment of IT with the business of an enterprise. The *Enterprise Integrating* school of thought presents a more extended view of EA which includes all facets of an enterprise where enterprise IT is just one facet. Lapalme describes a further extended perspective of EA as school of *Enterprise Ecological Adaption*, which includes all facets of an enterprise including its relationship to its environment. Since a central element of this thesis is the effect of the technological and economic pace of change, which is external to an enterprise, this thesis embraces the school of Enterprise Ecological Adaption for EA as presented by Lapalme.

Table 1: Schools of thought regarding enterprise architecture (Lapalme 2012)

	Scope	**Purpose**
Enterprise IT Architecting	The enterprise-wide IT platform, including all components (software, hardware, and so on) of the enterprise IT assets	Effectively execute and operate the overall enterprise strategy for maintaining a competitive advantage by aligning the business and IT strategies such that the proper IT capabilities are developed to support current and future business needs
Enterprise Integrating	The enterprise as a sociocultural, techno-economic system, including all facets of the enterprise (where enterprise IT is just one facet)	Effectively implement the overall enterprise strategy by designing the various enterprise facets (governance structures, IT capabilities, remuneration policies, work design, and so on) to maximize coherency between them and minimize contradictions
Enterprise Ecological Adaptation	The enterprise in its environment, including not only the enterprise but also its environment and the bidirectional relationship and transactions between the enterprise and its environment	Help the organization innovate and adapt by designing the various enterprise facets to maximize organizational learning throughout the enterprise

2.2 PLANNING THE STATE-OF-THE-ART REVIEW

Ever since the introduction of the discipline, many publications have been written related to EA. Among the scientific publications are already a few state-of-the-art reviews which attempt to summarize and structure the work which has been done on the subject. These existing reviews are a starting point for the state-of-the-art analysis in this thesis.

There are several reviews which address the subject EA overall. The origins of EA are analyzed and presented by Kotusev (Kotusev 2016). Buckl and Schweda (Buckl and Schweda 2011) provide a detailed and at the time of publishing comprehensive review on EA, which focuses on EA frameworks and how they compare to each other. In contrast, Aier et al. (Aier, Riege, and Winter 2008) present a condensed view of current literature and practices related to EA. Saint-Louis and Lapalme (Saint-Louis and Lapalme 2016) have recently published a systematic mapping study on EA to address the current situation of diverse perspectives on EA. They provide an in-depth analysis of about 200 publications. Moreover, Saint-Louis, Morency and Lapalme (Saint-Louis, Morency, and Lapalme 2017) provide a structured analysis with a similar scope comparing various definitions of EA.

In addition to the work that addresses the discipline as a whole, there are the various state of the art reviews available, which focus on specific aspects of EA: Niemi (Niemi 2006) focuses on the review of EA benefits in literature and practice. Stelzer (Stelzer 2009) considers EA principles in closer detail and evaluates how they have been addressed in scientific publications. A review of available work on critical issues in EA is provided by Lucke et al. (Lucke, Krell, and Lechner 2010). Further publications offer literature reviews on specific aspects of EA like EA evaluation by Andersen and Carugati (Andersen and Carugati 2014), EA implementation methodologies have been described by Rouhani et al. (Rouhani et al. 2015), EA analysis in combination with network thinking by Santana et al. (Santana A., Fischbach K., and Moura H. 2016) and EA measurement by Abdallah et al. (Abdallah, Lapalme, and Abran 2016).

Both publications lead by Saint-Louis mention as a limitation that they only cover a limited number of articles from selected journals. This can be confirmed by querying for "Enterprise Architecture" on academic databases which shows that far more scientific contributions on the subject exist[2].

At the time when this work was conducted, there was no state-of-the-art review available which includes the extended amount of publications on EA. Therefore, such a review has been created as part of this thesis and the results are presented here. In the state-of-the-art review, the previously introduced extended view of EA is taken as a basis, which is in line to provide a holistic view of EA as a discipline.

2.3 STRUCTURING THE STATE-OF-THE-ART REVIEW

The state-of-the-art review presented in this thesis provides an extended view of enterprise architecture by analyzing about 4.000 related journal articles and conference proceedings. The goal is to reveal additional findings of the dynamics of the discipline that have not been mentioned in earlier EA reviews and especially develop an understanding of the overall current state of the subject to address RQ1 of this thesis.

Due to the vast amount of publications, the methodology applied within the review leverages artificial intelligence technologies such as text mining or natural language processing (Moreno and Redondo 2016) in combination with traditional full-text reading approaches. By applying text mining techniques multiple questions concerning the past, the present as well as to some extent the future of scientific research on EA can be systematically addressed. The focus of this state-of-the-art review are academic contributions. However, due to the interdependency of academic research and the way the discipline is practiced (Marrone and Hammerle 2016), also a comparison with practitioner trends is considered valuable for the context of this thesis. To investigate the future development of the subject an approach integrating academic and practitioner viewpoints is taken.

[2] For example, a query for "Enterprise Architecture" at Web of Science on 07.11.2017 returns 1876 results (http://webofknowledge.com) and the same query at ScienceDirect returns 1432 results (http://www.sciencedirect.com)

This work's state of the art review is structured by using two research questions which build upon RQ1. This approach ensures a telic review which is aligned with the overall goal of the thesis.

The first research question of the state-of-the-art analysis is (RQ1.1): "*What is the current focus of Enterprise Architecture research and how did it develop over time?*" RQ1.1 considers subtopics related to EA and their development since the discipline has been introduced in the 1980s.

The second research question addressed by the state-of-the-art analysis is (RQ1.2): *"What are current and future Enterprise Architecture research trends?"* RQ1.2 focuses on today's EA research trends. The goal is to identify current trends that appear to have a significant impact on the discipline EA. The analysis is supposed to focus on how they have developed in recent years and to predict how they will evolve in the future. RQ1.2 does not only consider on the academic side of EA but also the practitioner point of view. For example, recently introduced and trending industry practices might potentially influence EA in the future. Therefore, the Gartner hype cycle for enterprise architecture (Blosch and Burton 2017), which determines practitioner EA trends, is taken as an additional input and compared with the findings from academic sources.

2.3.1 Classifying the State-of-the-Art Review

Fettke suggests a classification scheme for literature reviews and applies it to several examples in the area of business informatics (Fettke 2006). To investigate how the text mining based approach compares to traditional literature reviews, this review is classified according to Fettke's classification scheme. The results are depicted in Table 2 and the classification of this review is marked in green.

The major difference between the approach of this work and other manual literature reviews is reflected in Fettke's attribute *type*. All business informatics literature reviews investigated by Fettke are based on *natural language*, which means that the reviewers read and interpret the content of publications. Fettke's second option for the *type* is *mathematical-statistical*. This type of review is not reflected in the reviews investigated by Fettke. However, he considers his work to be *mathematical-statistical*. This work's text mining based literature review approach can be considered a combination of both types suggested by Fettke. This work applies Natural Language Processing (Moreno and Redondo 2016) to deduct statistical data from natural language which can, later on, be analyzed using mathematical methods.

Table 2: Classification of the review according to Fettke's scheme

Review Characteristic		**Classification Results (this review marked in green)**			
Type		natural language		mathematical-statistical	
Focus		research results	research method	theory	experience
Target	Formulation	not explicit		explicit	
	Content	integration	Criticism	central topics	
Perspective		neutral		position	
Literature	Selection	not explicit		explicit	
	Extensiveness	foundations	representative	selective	complete
Structure		historical	Thematically	methodical	
Target Group		common public	practitioners	common research	specialized researcher
Future Research		not explicit		explicit	

Given the confirmation that there is a significant difference between the approach of this work and manual literature reviews in business informatics when it comes to the way the analysis is conducted, a process model is suggested to guide the research methodology which is presented in the next subsection and applied throughout the review.

2.3.2 Conduction a Text Mining Supported State-of-the-Art Review

In the late 1990s, the first researchers started to apply text mining to support their literature reviews. The approach was especially popular in the area of medicine and biology (Andrade and Bork 2000) when it was first introduced. Today, text mining technologies are more commonly used to support systematic reviews across various research areas.[3] However, they are certainly not yet fully established in practice (Thomas, McNaught, and Ananiadou 2011).

The methodology applied in this work leverages the learnings from previous studies which use text mining to support systematic reviews: Felizardo et al.

[3] See Appendix A.1 for an overview of the text mining methods applied within this work.

describe an approach which combines classical methods for the initial phases of a review with text mining support for the later stages (Felizardo et al. 2010). Thomas et al. describe that search and analysis phase of a literature review can be supported by text mining (Thomas, McNaught, and Ananiadou 2011). Therefore, traditional literature review methodologies (Petersen et al. 2008) are combined with state of the art text mining approaches (Fan et al. 2006) into a process model, which is used for the analysis described in this work.

Chapman et al. point out a general approach for text mining in their publication, the CRISP-DM model (Chapman et al. 2000). The CRISP-DM model identifies business understanding as the initial starting point. Clearly defined research questions are the basis for data understanding which complements the selection process. The following steps comprise data preparation and modelling. These repetitive activities improve their results in each iteration. The results later lead to evaluation and deployment into business practices or they lead back to the business understanding to cycle input variables until the results meet the requirements.

The process model of this work leverages the iterative text mining practices of the CRISP-DM model and derive the methodology presented in Figure 4.

First, after the alignment of objectives, the review activities are kicked-off at stage *'Review Initiation'*. Based on the objectives and focus points, the research is discussed. When goals, research questions and scope are fixed, the information retrieval process can be started at stage *'Search for Publications'*. Once the selection of the proper corpus of documents is completed, the iterative text mining process is started.

The iterative part starts with planning the iteration, which includes setting the goal of the current analysis as well as choosing appropriate text-mining methods, which pre-defines how subsequent steps like data preparation need to be executed, i.e., in which format data need to be pre-processed. Afterward, the data pool is adjusted and transformed accordingly. In the third phase, the analysis is conducted. Finally, in the fourth phase, the results are interpreted, and it is decided whether goals have been achieved or whether further iteration processes are required.

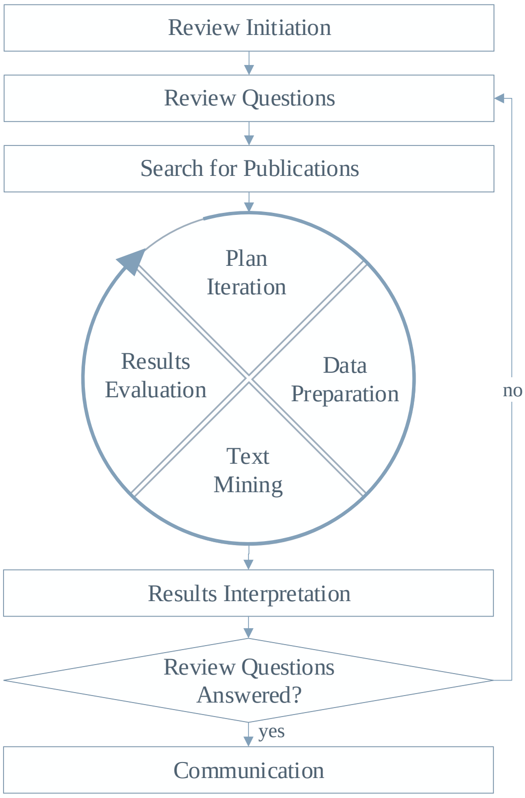

Figure 4: A process model for applying text mining in systematic reviews

After the results are evaluated, the interpretation starts. Subsequently, it needs to be verified that the results which have been obtained correctly address the previously defined review questions. If this is not the case, it is necessary to go back in the process. Consequently, the review questions and the search for publications should be assessed and potentially adjusted, which likely requires another text mining iteration as well. If the review questions are finally correctly addressed, the results are visualized and prepared for publication in an appropriate way for the audience at the last stage '*Communication*'.

The presented process model has been applied throughout the entire review presented in this thesis. Based on the experiences within this work, the approach can be recommended for similar analyses.[4]

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[4] The presented process model as well as the learnings which resulted from its application have been incorporated in a separately published journal article (Rudiger Buchkremer et al. 2019)

2.4 DISCOVERING AND CONSOLIDATING THE BODY OF ACADEMIC ENTERPRISE ARCHITECTURE KNOWLEDGE

The search for scientific publications which serve as input to the state-of-the-art review is done in multiple relevant databases. The results are consolidated, a selection process is applied to include only publications that are relevant for the work described in this thesis and data items that could corrupt the results of the analysis, such as duplicate publications, are excluded.

The text mining analysis is based on the title, abstract and tags of the publications. The full text of the publications is deliberately not analyzed. Schuemie et al. show that the information density is highest in abstracts compared to other sections of a publication (Schuemie et al. 2004). Moreover, this approach enables to avoid two issues: First, linguistic specifics of abstracts and full texts are different and would require separate analytical methods (Cohen et al. 2010). Second, copyright, licensing and lawful access to scientific full-text content for text mining is difficult (O'Mara-Eves et al. 2015), especially since records from multiple sources are supposed to be combined. Finally, due to the purpose and scope of this analysis, which is about categorization, topic identification and trend analysis, the decision is taken that the information contained in title, abstract and tags are sufficient for this current work.

To retrieve relevant publications, the following databases have been queried on November 1st, 2016:

- IEEE Xplore (http://www.ieee.org/web/publications/xplore/)
- Science Direct – Elsevier (http://www.elsevier.com)
- Springer Link (http://www.springerlink.com)
- Web of Science – Thomson Reuters (http://webofknowledge.com)
- ACM Guide to Computing Literature (http://dl.acm.org/)

For all databases, the following combined search string was used: *"enterprise architecture" OR "information systems architecture" OR "information technology architecture" OR "business-IT alignment"*. In recent years, the term "Enterprise Architecture" has been well-established and has been used throughout scientific and practitioner communities to identify the subject. However, especially in the early years of the discipline, other terms have been used, which explains the extension of the search string with queries that include "information systems architecture" and "information technology architecture". EA has been primarily called "Information Systems (IS) Architecture" in its early years (Zachman 1987). "Information Technology (IT) Architecture" is a part of EA, which is addressed individually in some cases (Jeanna W. Ross and Westerman 2004) but also in the full context of EA. "Business-IT Alignment" is a closely related subject, which is considered to be part of EA. While EA considers all aspects of an organization combined, the alignment between business and IT is a relevant part of this (Buckl and Schweda 2011; van Steenbergen 2011).

The results retrieved from all databases have been exported and consolidated in BibTeX format. The information of the individual results is validated and completed using the Digital Object Identifier (DOI) lookup.

After the consolidated results from various literature databases are present, a selection process based on inclusion and exclusion criteria is performed. English peer-reviewed publications of the type of Conference Proceedings and Journal Article, which are related to the subject Enterprise Architecture are included. Only those published in or after 1987 are included since it is commonly regarded as the year in which EA became popular with Zachman's publication on EA (Zachman 1987). Any publication not in English is excluded since the clear majority of publications is in English and other languages would need to be treated as separate data sets in the text mining analysis. Also, duplicates, as well as records without abstract, are excluded since the abstract is needed for the text mining analysis.

Based on the inclusion and exclusion criteria, the following selection process is applied, see also Figure 5.

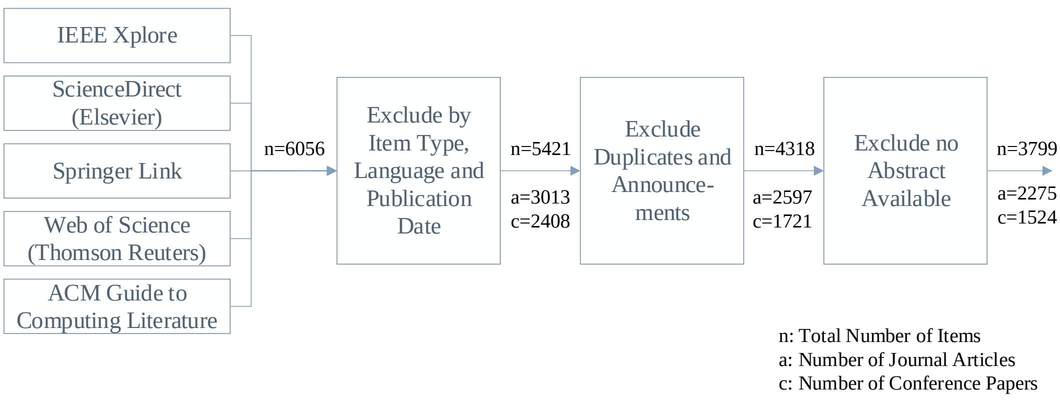

Figure 5: Publication search and selection process for state-of-the-art analysis

1. Consolidate results from all selected sources
2. Exclude by item type, language and publication date
    a. Exclude any item which is not of type Conference Proceeding or Journal Article
    b. Exclude any item which is not in English
    c. Exclude any item which is not published after 1987
3. Exclude duplicates and announcements
    a. Exclude duplicate studies
    b. Exclude items which contain no actual research results (like announcements of an issue)
4. Exclude no abstract available
    a. Exclude any items for which there is no abstract available

Finally, 3799 records are selected as input data for the text mining analysis. For validation purposes, 10% randomly selected publications are reviewed to ensure that the data corpus resembles articles that are compliant with the extended view on enterprise architecture, as described in section 2.1. To further validate the extended view of enterprise architecture, the dataset was split into two clusters – one that is compliant with the narrow view of EA (1517 publications; 40% of the corpus), from now on called “narrow EA”, and one that consists of the remaining data, which is called “not-narrow EA”. To confirm that the contents of clusters narrow EA and not-narrow EA are in line with the proposed EA terminology, clustering analysis is performed based on maximum entropy classifiers. It is confirmed that the articles that do not specifically mention EA are driven by the following descriptive terms: “Information Systems Architecture”, “Information System Architecture” and “Information Technology Architecture”. These preliminary analytical results support the extended text-mining-based approach since 1) the number of articles that specifically mention EA is sufficiently high to justify an automated review and 2) the articles that do not specifically mention EA can be considered as part of an extended EA and hence serve as a basis for the objective of providing a view beyond the horizon.

The dataset, especially the distribution of publications throughout the years, can be used as first observations about the history of EA and the scientific relevance of the topic; see Figure 6. From 1987 to 2015, the number of peer-reviewed publications on EA increased by 21% per year on average. In comparison, the total number of scientific publications has grown by approximately 3% per year on average (Jinha 2010), while the number of IT publications has grown by approximately 5%[5]. Therefore, it can be concluded that EA has remained a topic of interest since it was first introduced in 1987. Moreover, the scientific interest in EA has grown significantly more than that in IT overall.

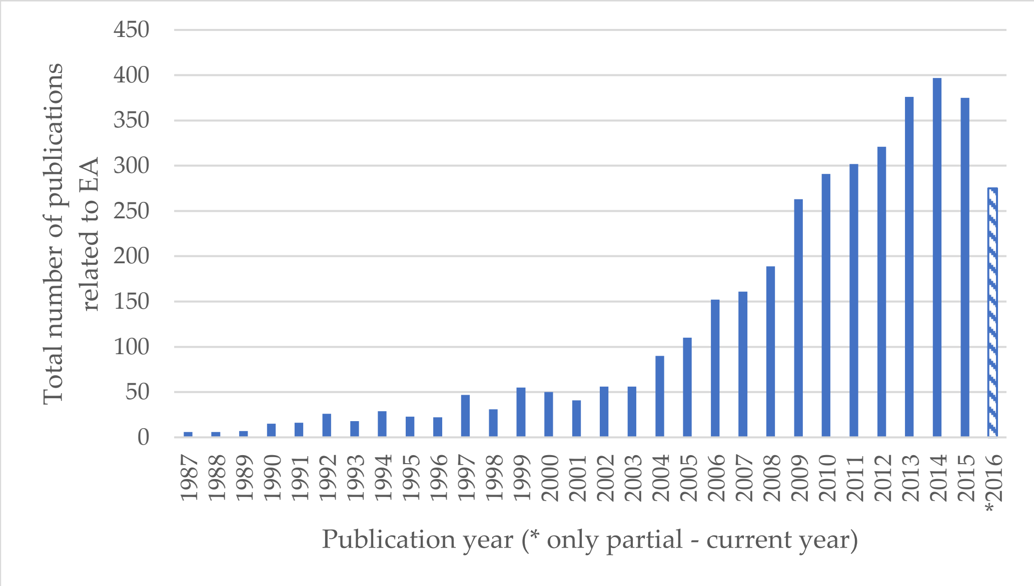

Figure 6: Overview of publications related to EA by publication year

2.5 HISTORICAL DEVELOPMENT OF ENTERPRISE ARCHITECTURE UP TO TODAY

This subsection presents the result to the first research question of the state-of-the-art analysis is (RQ1.1): "*What is the current focus of Enterprise Architecture research and how did it develop over time?*"

A semi-supervised learning approach is applied to get a holistic view and to evaluate how the focus of EA research has changed over time. Classification schemes and related search queries that have been selected according to earlier reviewers are used to support this part of the analysis.

[5] Based on a query of Web of Science for IT publications on 14.03.2017 (Thomson Reuters 2017)

2.5.1 A Taxonomy for Enterprise Architecture Research

As an additional input to this work, already existing EA literature reviews are considered. These reviews have also been presented in section 2.2 of this thesis (Aier, Riege, and Winter 2008; Andersen and Carugati 2014; Buckl and Schweda 2011; Lucke, Krell, and Lechner 2010; Niemi 2006; Rouhani et al. 2015; Santana A., Fischbach K., and Moura H. 2016; Stelzer 2009).

We used existing reviews to derive a taxonomy with two categorization hierarchies for structuring the whole topic of EA. The taxonomy is used as part of the analysis to classify available publications and analyze changes throughout the past years. The following main categories of EA research are defined:

- *EA Understanding* refers to architecture content and how it can be represented. Key concepts of this subcategory are the definition of architectural building blocks, their interdependencies, views and viewpoints as well as reference architectures.
- *EA Modelling* refers to the creation and management of architecture models. Key concepts of this subcategory are EA modelling languages, modelling tools which support the creation of EA models, modelling concepts as well as modelling deliverables.
- *EA Management* refers to how EA as a discipline is applied and managed. Key concepts of this subcategory are the development and implementation of architectures, their lifecycle, EA governance and development of the EA competency.

For each of the three main categories, four subcategories are identified, see Figure 7 below. The tag data available from the EA publications, which have been collected, is used to validate the applicability of the taxonomy. Each tag which is used in more than 20 documents of the data set is assigned it to the matching subcategory. This validates the relevance of each subcategory by confirming that there is related data within the dataset.

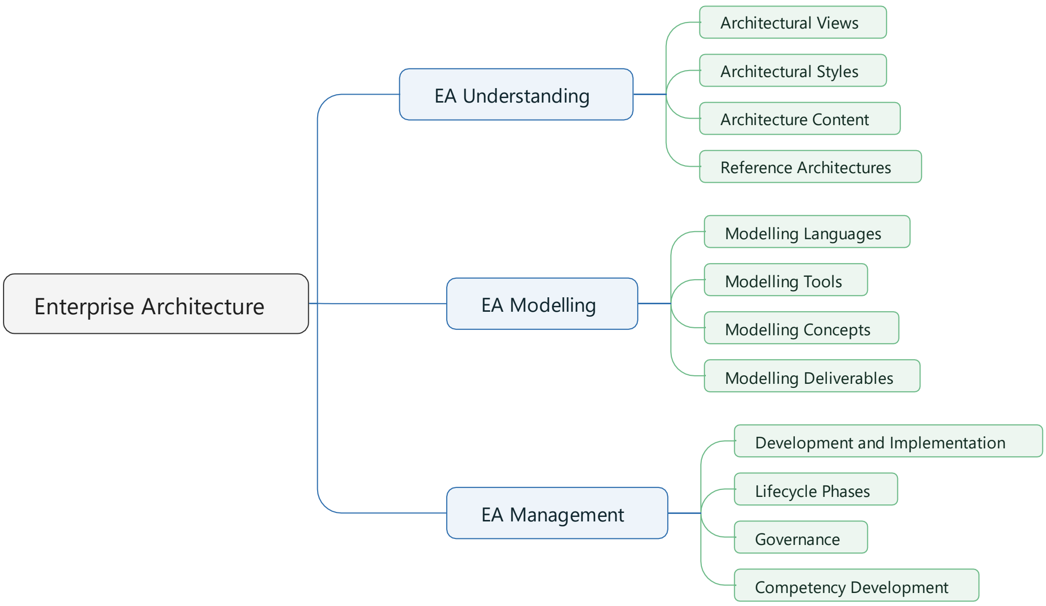

Figure 7: A taxonomy for EA research

Another essential reference for structuring the subject EA is the structure of EA frameworks. The presented taxonomy, which is derived from previous literature reviews, can be mapped to the structure of EA frameworks. This is demonstrated using the TOGAF framework as an example since it is one of the most popular EA frameworks (Matthes 2011), see Table 3. The successful mapping confirms the validity of the developed taxonomy and can be valuable for readers familiar with the TOGAF framework to better understand the approach of this work.

Table 3: Mapping of the work's EA taxonomy to the TOGAF framework

Taxonomy Subcategory	**Related TOGAF Parts**
EA Understanding	Part IV Architecture Content Framework Part V Enterprise Continuum & Tools
EA Modelling	Part VI TOGAF Reference Models
EA Management	Part II Architecture Development Method Part III ADM Guidelines and Techniques Part VII Architecture Capability Framework

It is worth noting that the TOGAF framework is not primarily focused on EA Modelling. This work's category EA modelling encompasses significantly more than described in "Part VI TOGAF Reference Models". For example, The Open Group, owner of the TOGAF framework, maintains the EA Modelling language ArchiMate separate from the TOGAF framework. The research focused on ArchiMate and other EA Modelling languages are considered part of the category EA Modelling.

2.5.2 The shift from EA to EA Management

To conduct the analysis, first manually 10% of the records were categorized. This equates 380 EA publications which are randomly selected from the consolidated dataset. The documents are manually categorized by reading them and assigning them to the most suitable category of the presented taxonomy. These manually categorized records serve as a test and training data set within the text mining analysis.

Both an unsupervised and supervised learning approach has been applied using the software products SAS Content Categorization Studio (SAS Institute Inc. 2017) and Rapidminer (RapidMiner Inc. 2017). As an input for the text mining processor, the title, the tags and the abstract of the publication are supplied. Unsupervised learning does not yield acceptable results, which is reflected in high classification errors (>40%) that can be traced back to the fact that automatically selected categorization terms are not meaningful from a content perspective but rather related to linguistic differences between texts written in different years – in this case, 30 years. These deficiencies of unsupervised learning can be addressed in a supervised approach, which is why this kind of method is selected for the first review question. The graph in Figure 8 shows the analysis results.

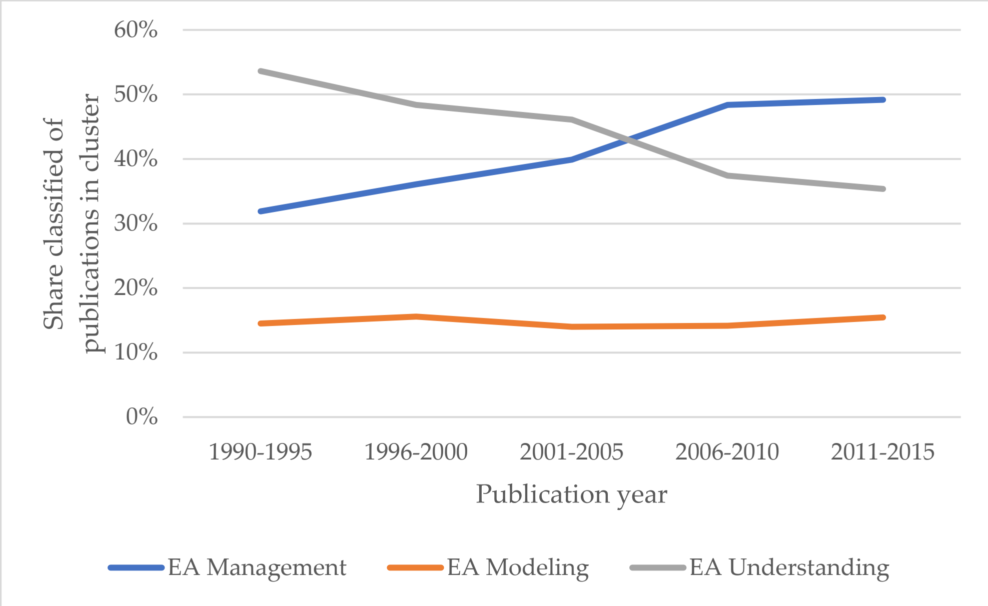

Figure 8: History of EA research focus

From the analysis results, it is evident that in the first years after the introduction of EA, publications focused on EA Understanding. This is reasonable since it was essential first to understand how various concepts such as EA building blocks and their dependencies need to be defined. In recent years, the focus has shifted from EA Understanding to EA Management. This is also reflected in the fact that many publications talk about "Enterprise Architecture Management" (EAM) instead of solely "Enterprise Architecture" (EA). Various challenges in today's EA do not relate to the definition of EA and its parts anymore; they instead focus on the questions how EA can be successfully applied and managed in the context of organizations to deliver value. These kinds of challenges are addressed in the papers focused on EA Management, see for example Foorthuis et al. (Foorthuis et al. 2016). The shift within the discipline from EA Understanding to EA Management is also described by Lankhorst (Lankhorst 2013) and Steenbergen (van Steenbergen 2011). The results of this analysis confirm their statements based on the comprehensive data set of this review.

Nevertheless, a significant amount of current publications is still focused on EA Understanding and addresses challenges related to the plurality of definitions on EA, which to a certain extent still exists today. Lapalme reviews the different schools of thought regarding EA in a recent publication (Lapalme 2012).

According to the analysis of this work, EA modelling has continuously remained to be a portion of the publications on EA, which is significantly less than EA Understanding and EA Management though. However, the share of publications on EA Modelling has not declined over time as assumed by Steenbergeben (van Steenbergen 2011). This category of EA research has still relevance today, which is reflected in the work that is done around the EA modelling language ArchiMate for example. Also, the current general trend of analytics and artificial intelligence fosters the recent interest in EA Modelling. Several current studies address the machine readability of EA models to assess them automatically and derive relevant information for decision making, see for example Hinkelmann et al. (Hinkelmann et al. 2016).

2.6 CURRENT AND FUTURE TRENDS IN ENTERPRISE ARCHITECTURE

This subsection addresses the second research question of the state-of-the-art analysis (RQ1.2): *"What are current and future Enterprise Architecture research trends?"* In case a particular area of EA receives increased attention, more articles will be published within a time frame. This is defined as a trend. Text-mining based trend detection (Kontostathis et al. 2004) is leveraged to identify and measure these areas of increased attention. Afterward, trends with the most substantial impact are investigated in closer detail by considering individual publications. Moreover, a comparison of this work's results with those of the Gartner Hype Cycle for Enterprise Architecture is conducted to understand the relationship of academic and practitioner EA trends better.

For the subsequently presented EA trend analysis, an approach combining supervised and unsupervised learning is applied. First, a partly supervised topic identification method is used to identify and investigate various trends. In a second step, a fully unsupervised cluster analysis is used to assess the context of the identified trends. The results of both steps are used to investigate trends with the strongest impact in closer detail afterward.

2.6.1 Identifying, Measuring and Forecasting of Current EA Trends

In the first step of this analysis, trends need to be identified which is done by applying a partly supervised topic identification, using the software products SAS

Content Categorization Studio (SAS Institute Inc. 2017) and R (The R Foundation 2017). The data set is separated into two groups: documents published recently (2015-2016) and those published earlier (2002-2014). Publications from before 2002 are excluded since this part of the analysis focuses on current trends. Therefore, documents released more than 15 years ago are considered to be neglectable here. First, characteristic terms which distinguish recent from earlier documents are identified to conduct the analysis using maximum entropy classifiers, for details on the method see appendix A.1. This results in the following list of terms: *adapt, agenda, agile, big data, cloud, complexity theory, consensus, consumer, cyber, distribution, entrepreneurial, message, objectives, preliminary, publishing, quickly, similarity, smart, statistical, sustainable, things.* In the second analysis step, the resulting terms and related documents are manually reviewed to identify content-wise relevant subjects. Terms which could not be mapped to a subject have been excluded from the subsequent analysis. Table 4 shows the results.

Table 4: Characteristic terms of recent EA publications and identified trends

Identified Terms	**Related Subject / Trend**
cloud	Cloud Computing and Enterprise Architecture
complexity theory	Complexity Theory and Enterprise Architecture
agile OR adapt	Agile or Adaptive Enterprise Architecture
big data	Big Data and Enterprise Architecture
things	Internet of Things (IoT) and Enterprise Architecture
entrepreneurial	Entrepreneurship and Enterprise Architecture
smart	Smart Machines and Enterprise Architecture
sustainable	Sustainability and Enterprise Architecture

Over time, the number of documents related to each of the identified trends is considered relative to the total number of publications of a given year. In addition to evaluating the past development of the identified trends, prognosis is determined using an Auto ARIMA Model (Asteriou and Hall 2015) up to 2020. The results are depicted in Figure 9.

According to the analysis and forecast, Cloud Computing is and will remain the trend with the most substantial impact on scientific EA publications. The trend with the strongest growth in impact, according to the forecast, is Internet of Things (IoT).

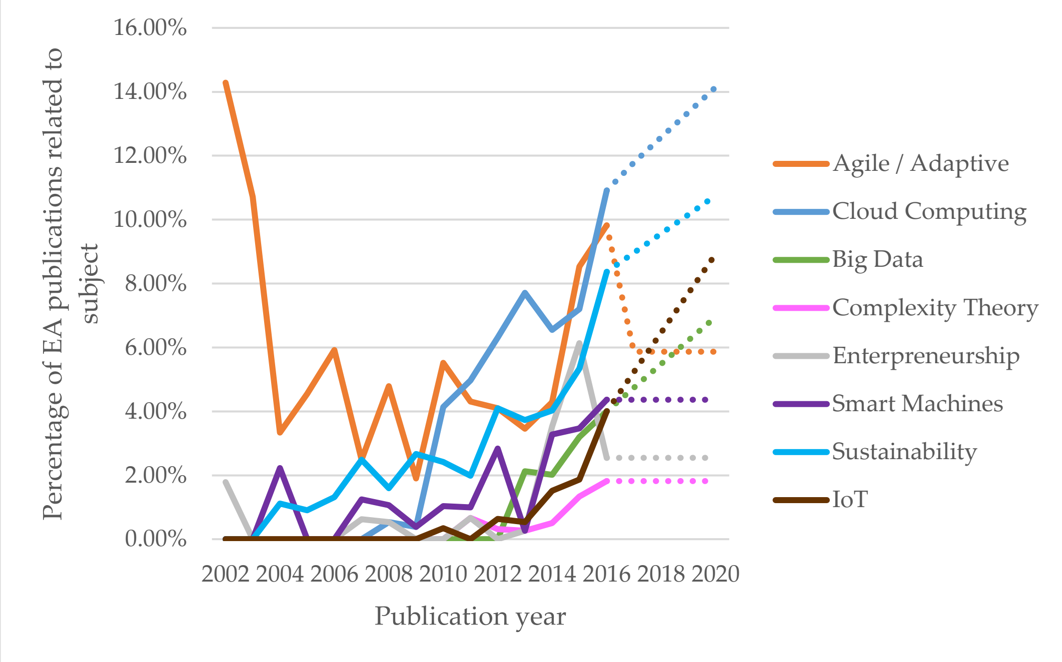

Figure 9: History and forecast of research trends in scientific EA literature

To better understand the relationships of EA with the identified trends, also the extent to which these trends appear in the clusters "narrow EA" or "not-narrow EA" is investigated, which are described in section 2.4. According to Table 5, six trends are significantly present in each cluster with minor quantitative differences. Entrepreneurship is significantly present only in the "not-narrow EA" cluster, complexity theory is almost exclusively present in the "narrow-EA" cluster, and all other trends are present in both clusters.

Table 5: Distribution of Trends that are Related to Articles in Clusters "narrow EA" and "not-narrower EA"

	Number of Publications Related to Trend		
Trend	**Total**	**Narrow EA**	**Not-Narrow EA**
Agile / Adaptive	180	90 (50%)	90 (50%)
Cloud Computing	161	66 (41%)	95 (59%)
Big Data	39	14 (36%)	25 (64%)
Complexity Theory	17	16 (94%)	1 (6%)
Entrepreneurship	50	7 (14%)	43 (86%)
Smart Machines	61	17 (28%)	44 (72%)
Sustainability	117	36 (31%)	81 (69%)
IoT	29	7 (24%)	22 (76%)

2.6.2 Understanding the Context of Current EA Trends

To better understand the context of the identified trends, an unsupervised cluster analysis for topic detection is applied. The text mining software Rapidminer (RapidMiner Inc. 2017) is used for this part of the analysis. The basis for this step is the same corpus including the publications from 2002 – 2016.

The idea is to split the documents into timely hierarchical groups and identify clusters in each document group. Comparing the clusters and their descriptive terms provide an idea of how the discipline EA has developed over time. For details on the applied text mining techniques refer to Appendix A.1 of this work.

The Davis Bouldin Index indicates how precisely the cluster centers differ from each other and therefore offers an excellent measure to optimize the cluster count. The optimized Davis Bouldin Index for 0 – 20 cluster centers is considered. The documents are split into three corpora: A) 2002-2006, B) 2007-2011, C) 2012-2016. The optimal count of clusters is derived from counting the Davis Bouldin Index of each document group. The lowest average index was found at cluster count of seven. Based on this optimization of cluster counts the 10 most important descriptive terms are exported. This is done for seven clusters in each document group. Appendix A.2 shows the full results. Afterward, the descriptive terms can be compared to understand whether and how the clusters changed over time.

Only some topics are present in multiple document sets. It is noteworthy that the topic "Healthcare" is constantly present in all periods (see clusters A7, B5, C7). Healthcare comes up as a topic also in similar cluster analysis for other IT related research area (Lu and Liu 2016; Rekik et al. 2018). This is presumably because healthcare related publications include distinctive language which separates them from the rest. When looking at the individual papers of the healthcare clusters, it can be observed that these are for example case studies or specific reference models for the medical sector. The same observation can be made for another application area of EA – "Manufacturing". It is represented in clusters A3, B2, C2. Based on these observations and given the previously identified trend around EA and Entrepreneurship a closer look is taken at EA application areas, see results in section 2.6.3.7.

Many further observations can be made from the results of the unsupervised cluster analysis. However, often these raise various questions when considered separately. Therefore, this work does not rely only on this part of the analysis only but combines it with the findings presented earlier. Thus, a comprehensive view of EA trends can be obtained.

2.6.3 A Closer Look at Individual EA Trends

In the next step of the analysis, the results of the partly supervised topic identification are combined with the observations of the cluster analysis to investigate various trends in a broader context. Each trend is considered in a separate section below.

In addition, the findings are cross-checked with the results of the Gartner Hype Cycle for Enterprise Architecture, which is available for the years 2010 to 2017 (Blosch and Burton 2017). Gartner's Hype Cycle is a structured, qualitative analytical tool for trend analysis, which is based on surveys and expert judgment (Fenn, Raskino, and Burton 2017). Even though Gartner's research has a dominant position in practice, it has so far received limited attention from academics (Dedehayir and Steinert 2016; O'Leary 2008). As previously argued this work seeks to understand the relationship of the results, derived from academic sources, with EA in practice and therefore refers to the Hype Cycle. Moreover, from the comparison of this work's results with the ones from the Gartner Hype Cycle provide interesting insights since both use a different methodology and have a different focus but apply to the same subject (see the comparison in Table 6).

Table 6: Comparison of this work's trend analysis with the Gartner Hype Cycle

	This Work's Trend Analysis	**Gartner Hype Cycle for EA**
Methodology	Data Analysis	Surveys and Expert Judgement
Focus	Scientific	Industry
Subject	Enterprise Architecture	Enterprise Architecture

2.6.3.1 Cloud Computing and Enterprise Architecture

According to this work's analysis, Cloud Computing (Armbrust et al. 2010) is currently and will be the trend until 2020 with the strongest impact on scientific EA publications. This is plausible since it has changed the way services can be designed, build, operated and consumed. Therefore, it has a major impact on all layers of an EA (Ebneter et al. 2010).

The relevance of the trend Cloud Computing for EA is not restricted to the scientific space only. It can be confirmed for practitioners as well, considering the Gartner Hype Cycle. Cloud Computing comes up within the Hype Cycle from 2011 and is considered a strong trend ("At the Peak" within the Hype Cycle) up to 2016. In 2017 Cloud Computing is first ranked as "Sliding Into the Trough". It is worth noting that the trend is entirely missing in Gartner's EA hype cycles before 2011 while scientific publications pick it up in 2008 already. In 2010, 4.14% of scientific EA publications addressed Cloud Computing.

The findings of the cluster analysis demonstrate that "security" and "privacy" is closely related to EA Cloud Computing. In general, security and privacy are prominent topics for Cloud Computing because services are commonly consumed via the public internet, which allows traffic to be intercepted (Zissis and Lekkas 2012). Moreover, the fact that data of cloud services are typically not stored at the consumer´s site but the provider presents a challenge considering data privacy regulations, especially in international setups. Enterprise Architecture can help to address these challenges of Cloud Computing in a systematic, vendor-neutral way (Janulevicius et al. 2017).

2.6.3.2 Adaptive or Agile Enterprise Architecture

Another trend appears to be prominent that proposes a reconceptualization of EA so that the discipline and the resulting architectures are more adaptive to changes (Korhonen et al. 2016). The trend is driven by the increasing pace of change in and in the convergence of both business and IT (Lapalme et al. 2016). Different authors and publications refer to the topic either as Adaptive (Korhonen et al. 2016; Zimmermann et al. 2014) or Agile EA (Gill 2015).

Considering the results of this work's trend analysis, it is noteworthy that this trend has already received significant attention since 2002 and has been addressed continuously throughout recent years. In 2015 and 2016 there is another spike in the share of EA publications which address the subject. Earlier papers address the subject especially for the manufacturing industry in the context of "agile manufacturing" and "virtual enterprise" which were popular around 2002 (Aerts, Szirbik, and Goossenaerts 2002; Zhou and Nagi 2002). More recent publications address the topic not only for the manufacturing industry but in a more general manner (Hinkelmann et al. 2016).

Adaptive Enterprise Architecture is considered in the Gartner Hype Cycle only once, in 2016. Gartner describes "Situationally Adaptive Behavior" as an EA trend being on the rise. However, in 2017 it is not mentioned anymore.

2.6.3.3 Sustainability and Enterprise Architecture

The trend analysis shows that the EA trend Sustainability has grown in importance. There is an increase in the number of EA publications that address sustainability over the last fifteen years, from zero documents in 2002 to more than 8% of the publications on EA in 2016.

Sustainable development is regarded as one of the grand challenges for our current society to increase the wellbeing of present and future generations as well as to protect the planet from degradation by sustainably managing natural resources (United Nations 2015). One view of Enterprise Architecture is the systems-in-environment perspective, which does not only regard the architecture of an organization but also how it interacts with its environment (Lapalme 2012). When taking this perspective, EA needs to address concerns of the environment and therefore also the question of how sustainable development can be achieved (Lapalme et al. 2016). EA and its methodologies can be used to understand the dependencies and implications of sustainable development better, see, e.g. Villarreal for an analytical framework (Villarreal 2014).

Looking at the publications which address sustainability and EA, there is a clear overlap between this trend and the one around adaptive EA presented earlier. An obvious conclusion is that an adaptive architecture is more sustainable since it can adapt to changing conditions rather than requiring a replacement (Laverdure and Conn 2012).

The Gartner Hype Cycle for EA does not mention Sustainability at all. However, there is a separate Hype Cycle focused directly on sustainability. While there is an overlap between the trends mentioned in both Hype Cycles, there is no direct connection made between EA and Sustainability.

2.6.3.4 *Smart Machines and Enterprise Architecture*

This work's analysis indicates that there is a trend around Smart Machines and Enterprise Architecture which is prominent in the most recent year of the analysis, 2016, reflected in the fact that about 4 % of the EA publications address this subject. The term "Smart Machines" refers to machines which are supported by cognitive technologies and hence can support or even replace human labor (Davenport and Kirby 2016).

When looking at the original EA publications more closely, two specific examples are Smart City (Mamkaitis, Bezbradica, and Helfert 2016) and Smart Grid (Razo-Zapata, Mihaylov, and Proper 2016). Introducing a Smart Machine and smartly redesigning an existing system can be a significant transformation activity. Enterprise Architecture methodologies can be applied to support this transformation considering both the business as well as the information systems view.

Smart Machines or artificial intelligence are not being addressed in the Gartner Hype Cycle for Enterprise Architecture.

2.6.3.5 *Internet of Things and Enterprise Architecture*

According to this work's analysis and forecast, the Internet of Things (IoT) is the EA trend where the most substantial growth until 2020 is expected. The trend is represented significantly in the documents which were analyzed from 2012. IoT describes a significant increase in the number of physical devices which connect to each other and primarily communicate via the internet. Examples range from electronic health to connected cars up to intelligent manufacturing, sometimes referred to as "industry 4.0" (Gubbi et al. 2013).

From an EA perspective, IoT means a massive increase in the diversity of architectural building blocks and respective integrations, which need to be managed. Due to these changing conditions, EA approaches and concepts such as meta-models need to be extended. However, EA methodologies can also help to manage the transformation related to the Internet of Things better (Zimmermann et al. 2015).

The Gartner Hype Cycle confirms the findings of this work's analysis for the practitioner space. IoT is represented in the Hype Cycle for EA from 2012 and considered to be at the peak 2017.

2.6.3.6 Big Data and Enterprise Architecture

Beginning in 2011, the general trend around Big Data has boomed and resulted in various scientific publications addressing the subject (Lu and Liu 2016). The trend analysis shows that EA publications started addressing Big Data two years later, in 2013. There are two major streams of thought in the articles which have been analyzed:

1) EA can be applied to develop, implement and manage Big Data architectures to ensure alignment and value creation (Vanauer, Bohle, and Hellingrath 2015; Zimmermann et al. 2013).
2) Big data methodologies can be applied to support enterprise architecture activities. Specifically, analytics and artificial intelligence technologies can be used to analyze and optimize architecture models (Hinkelmann et al. 2016).

Big Data is represented in the Gartner Hype Cycle for EA from 2012 until 2016. Hence, Gartner had highlighted this trend one year before scientific publications addressed the subject. Interestingly, Gartner do not include Big Data or analytics in their 2017 Hype Cycle for EA anymore. However, this work's forecast indicates that the topic will still receive significant attention until 2020.

2.6.3.7 Entrepreneurship and Enterprise Architecture

This work's trend analysis indicates a trend around Entrepreneurship in scientific EA publications. From 2014 a significant share of the documents that have been analyzed refers to entrepreneurial settings, such as small and medium enterprises (SMEs) or even start-ups. SMEs often face several problems due to a lack of structure and overview within the company. EA can be used as an extended setup to address these issues and ensure alignment (Bernaert et al. 2014). Similar challenges apply to start-ups in slightly different conditions. Start-ups have the advantage that they are typically operating in a greenfield setting and therefore do not need to deal with the integration of legacy systems, which reduces complexity. At the same time, it is a challenge that activities in a start-up need to be pragmatic and practical. This applies to EA as well. Therefore, an EA approach for a start-up needs to be tailored to these conditions (Bischof dos Santos et al. 2015).

The cluster analysis shows various application areas of EA in the past including the manufacturing industry, healthcare and government. An analysis can be performed based on the existing dataset how these traditional EA application areas compare to the use of EA in entrepreneurial settings. The results are depicted in Figure 10. Before 2014, EA publications focused on the traditional application areas, with the government being the most popular. Since 2014 entrepreneurial settings have been addressed to a similar extent as traditional application areas in the publications which have been analyzed.

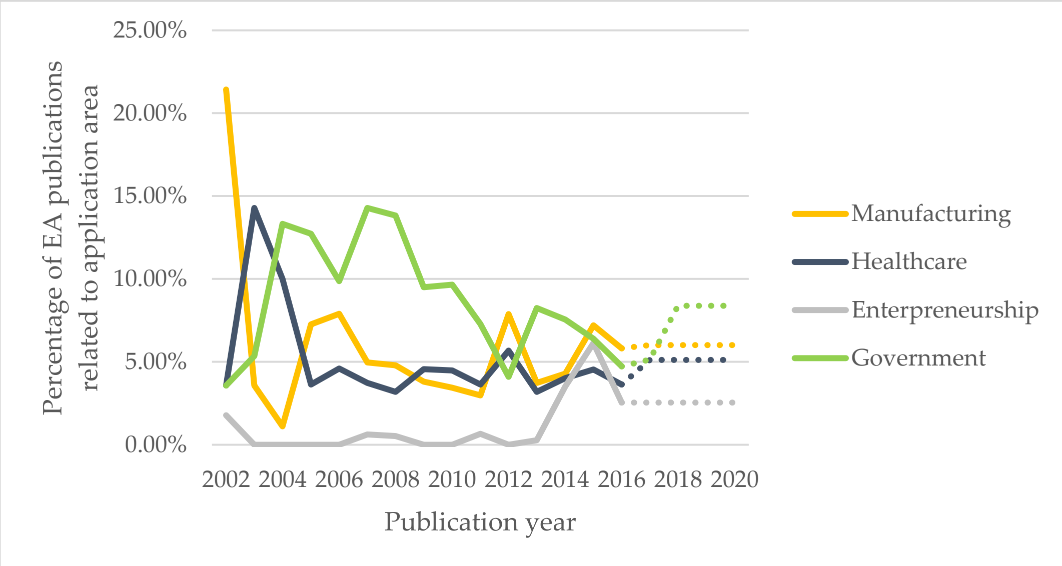

Figure 10: History and forecast of EA application areas in scientific EA literature

Entrepreneurship, SMEs and start-ups are not being addressed in the Gartner Hype Cycle for Enterprise Architecture.

2.6.3.8 *Complexity Theory and Enterprise Architecture*

From 2014 the analysis shows an increasingly prominent trend regarding Complexity Theory and Enterprise Architecture. Complexity Theory presents a framework for understanding based on concepts such as non-linear systems and network theory. It can be applied in various areas including social sciences (Byrne and Callaghan 2013). For EA, Complexity Theory can be applied to understand and model architectures as well as to measure attributes such as their complexity (Fu et al. 2016; Schütz, Widjaja, and Kaiser 2013).

Moreover, findings and methods from Complexity Theory can be used to optimize given architectures. There is a link to the trend around Big Data presented earlier since an architecture assessment and optimization based on Complexity Theory likely requires an analytics solution to perform the required computations (Hinkelmann et al. 2016).

An especially prominent part of Complexity Theory for EA presents Complex Adaptive Systems (CAS) thinking. CAS can be applied as a theoretical model to conceptualize enterprises. Consequently, CAS ideas and methods can be considered for EA, see for example (Schilling et al. 2017).

Complexity Theory and CAS are not being addressed in the Gartner Hype Cycle for Enterprise Architecture.

2.6.4 Practical Relevance of Academic EA Trends

When comparing results of the trend analysis with the Gartner Hype Cycle, which is especially popular with practitioners (Dedehayir and Steinert 2016), there is a clear difference between "conceptual" and "technology" trends. Table 7 provides a comparison between the work's analysis and the Gartner Hype Cycle regarding the trends which have been identified. It is striking that the Gartner Hype Cycle reflects only the technology trends identified by this thesis.

Table 7: Comparison of the trend analysis with the Gartner Hype Cycle

	Our Trend Analysis	**Gartner Hype Cycle**
Cloud Computing	From 2010 to 2017	From 2011 to 2017
Complexity Theory	From 2014 to 2017	N/A
Agile or Adaptive EA	From 2002 to 2017	N/A
Big Data	From 2013 to 2017	From 2012 to 2016
Internet of Things	From 2012 to 2017	From 2012 to 2017
Entrepreneurship	From 2014 to 2017	N/A
Smart Systems	From 2004 to 2017	N/A
Sustainability	From 2004 to 2017	N/A

However, Gartner also identifies trends for EA, including conceptual ones, which do not come up as a result of this work's trend analysis. For example, "DevOps" and "Design Thinking" are at the peak in the 2016 Hype Cycle for EA. When explicitly checking for these topics in the data set, it can be found that they are not significantly represented (e.g., there are two articles in total mentioning DevOps and three with Design Thinking).

The differences between the results of this work's analysis and those of the Gartner Hype Cycle present an interesting observation and potential starting point for future research. These findings raise the question of whether there is a mismatch between academic EA work and EA in practice. Moreover, in general – and not only restricted to the subject EA – the relationship of Hype Cycles, such as the one from Gartner, and academic research presents an opportunity for further investigation.

2.7 IMPLICATIONS OF THE STATE-OF-THE-ART FOR THIS THESIS

This work's state of the art analysis presents the first comprehensive review on a large body of academic knowledge which has been created in the last 30 years of research on EA. The fact that this analysis is based on this large dataset presents an advantage but also a limitation since it is not possible to perform a holistic review and do an in-depth analysis of individual articles at the same time. Therefore, as an overall result of the state-of-the-art analysis and as an input for the subsequent parts of this thesis the findings of the holistic review are considered in combination with other more focused reviews. Table 8 provides an overview of the relevant reviews.

The state-of-the-art analysis conducted in the context of this work is regarded as a "view beyond the horizon" meaning that a higher degree of variety for search terms at the initial stage of this work's review is allowed. The analysis can demonstrate that the large surplus that was found compared to many existing literature reviews is still significant concerning enterprise architecture and confirms that it has become a highly dynamic discipline with growing scientific interest.

This work's trend analysis provides strong guidance regarding the impact of specific topics such as sustainability, cloud computing, internet of things, smart machines or complexity theory on the discipline of EA. A major advantage of the extended approach compared to others is the fact that it is possible to quantify the impact of trends on a large scale and present forecasts subsequently.

Table 8: Overview of Existing Reviews on EA

Review	Specific Focus	Docs Reviewed	Year
Kotusev		75	2016
Buckl and Schweda		150	2011
Aier, Riege, and Winter		54	2008
Saint-Louis and Lapalme		206	2016
Saint-Louis, Morency, and Lapalme		110	2017
Niemi	EA Benefits	32	2006
Stelzer	EA Principles	19	2009
Lucke, Krell, and Lechner	EA Issues	71	2010
Andersen and Carugati	EA Evaluation	45	2014
Rouhani et al.	EA Implementation Methodologies	46	2015
Santana A., Fischbach K., and Moura H.	EA Analysis and Network Thinking	24	2016
Abdallah, Lapalme, and Abran	EA Measurement	16	2016

In conclusion of the state-of-the-art analysis, the discipline EA has substantially grown over the last thirty years since its first introduction. Nevertheless, it is still a young discipline which offers excellent potential for researchers to contribute and grow the maturity of the discipline. This is reflected in the ever-growing amount of publications written on EA. The subject understanding of EA has evolved, but there is still misalignment within the EA community regarding the definition and scope of EA as also pointed out by Saint-Louis and Lapalme (Saint-Louis and Lapalme 2016). Hence, this thesis presents a detailed view on the definition of EA in section 2.1 which is used throughout the entire work.

As an additional result of the review on EA history, a significant current challenge certainly appears around successfully applying EA in the context of organizations, which is reflected in the increasing amount of publications which can be found to be focused on EA management.

The analysis of current and future trends shows various topics with an impact on EA that will shape the discipline in the future. Hence, the results may present the foundation for future studies and support authors during the selection of their research topics and questions.

For the context of this thesis, two of the identified trends are considered particularly relevant:

First, the trend around adaptive or agile EA since these approaches directly address the challenges in dynamic environments. Moreover, since EA initially gained popularity before agile concepts did, early EA aligns mostly with traditional, waterfall approaches. After the release of the agile manifesto in 2001 (Beck et al. 2001) however, there is a significant number of scientific EA publications addressing the subject. While this number decreased again after 2004, there is recently a visible spike again from 2015 (Gampfer et al. 2018), see also Figure 11. One reason for this could be the increasing mainstream adoption of agile practices (Puppet and Dora 2017; VersionOne Inc. 2017).

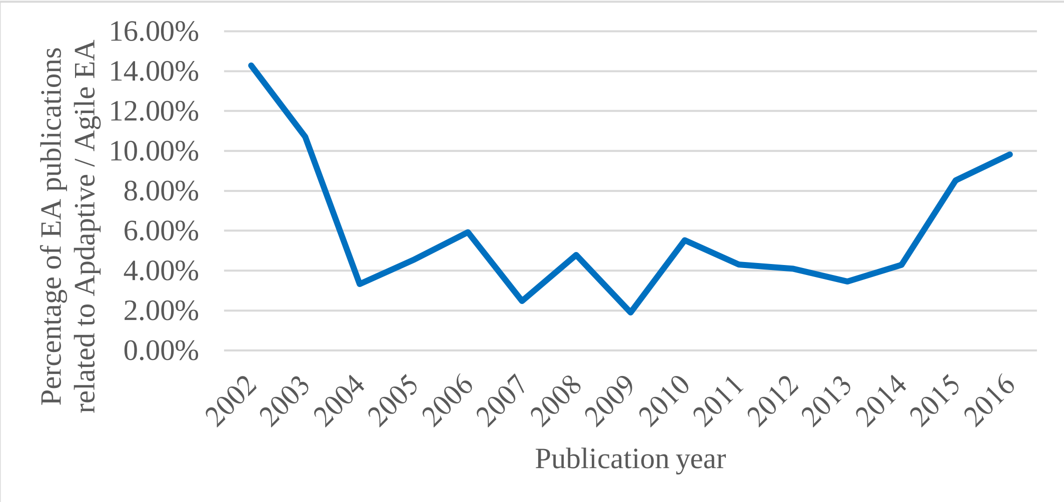

Figure 11: Share of EA publications related to agile concepts over time (adapted from (Gampfer et al. 2018))

Second, the trend on EA and complexity theory presents a suitable scientific basis for the subsequent analysis. Therefore, both the concepts as well as the existing underlying research which has been retrieved for the state-of-the-art review will be leveraged in the following parts of this thesis.

3 DYNAMIC ENVIRONMENTS AND ENTERPRISE ARCHITECTURE

This chapter is focused on the second research question of this thesis (RQ2) which asks: *"How can the interdependency between the increasing pace of change and the discipline EA be described?"*. The goal is to understand better, describe and formalize the problem in the current state, which is the basis for the development of the future state described in the subsequent chapters of this work.

Therefore, a closer look is taken at the effect of increasing dynamics and its interdependency with the discipline of EA. First, an understanding and description of how economic and technologic pace of change have evolved and are currently changing are established in section 3.1. It is investigated how the development affects businesses. In the subsequent section 3.2, it is examined how EA creates value within organizations and what determines its effectiveness to derive a model of EA effectiveness. As the last step in this chapter, the results of 3.1 and 3.2 are combined in section 3.3. The description of increasing dynamics and models for EA effectiveness are combined to assess how increasingly dynamic environments are impacting EA effectiveness.

3.1 PACE OF ECONOMIC AND TECHNICAL CHANGE

Technological progress and related economic change have been a constant companion throughout the past centuries. Innovations such as the steam engine, electric light and the telephone mark some examples which have revolutionized our economy and society (Buchanan 2001). Today, we are in the middle of just another revolution enabled by information technology, which drives the digital transformation of almost every industry (Bughin and Zeebroeck 2017).

In today's digital economy it seems to be a natural conclusion that things are moving more quickly than ever. Advances in computation and communication allow faster generation and exchange of information, which enables faster technical progress. The observation that "the pace of change is accelerating" is made for example by Eric Schmidt and Jonathan Rosenberg who have been part of the

Google leadership team (E. Schmidt and Rosenberg 2014). For Schmidt and Rosenberg this development is primarily related to three technology trends: The Internet, Mobile Devices and Cloud Computing. All these developments have enhanced communication as well as computation.

Recent advances in information technology are remarkable in many ways and have enabled digital business models, such as car-sharing and crypto-currency trading, which would not have been possible a few years ago (Bughin and Zeebroeck 2017). However, this is so far only an indication of the fact that technical progress has reached a new milestone and not a confirmation of the conclusion that its pace is accelerating. Therefore, this section of the thesis takes a closer look at the idea of an accelerating pace of change. Different technological, economical and sociological dimensions are considered in order to describe and understand change and its velocity better especially in current times. The following subsection 3.1.1 considers the definition of the pace of change and describes how it is understood in the context of this thesis. Afterwards subsection 3.1.2 considers the economic and technological pace of change.

3.1.1 Defining Pace of Change

In order to build the necessary foundation for the discussions presented in this and subsequent chapters of this thesis, this subsection takes a look at the definitions regarding change and its pace. The Oxford English Dictionary (Oxford University Press 2018) defines "Change" and "Pace" as:

Change: *"An act or process through which something becomes different"*

Pace: *"Speed in walking, running, or moving"*

Consequently, the "Pace of Change" is the rate at which things are becoming different. The 'something' that is becoming different needs a closer definition as well. Technology and business are two central aspects of Enterprise Architecture and therefore present the two major dimensions of change which are more closely considered in this subsection. Moreover, the scope of this change deserves consideration as well since there might be significant differences depending on the environment which is being considered.

3.1.1.1 Technological Change and Economic Growth

Technological change is a phenomenon which has been heavily studied in macroeconomics since it represents one of the primary drivers of human development (Romer 1990; Solow 1956). Technological change in macroeconomics is defined as the link between capital K, labor L and production output Y. As depicted in Formula (1) technological possibilities can be represented by a production function F, which have K and L as inputs (Solow 1956). Depending on the technological possibilities, production output from a given amount of capital and labor can be more or less. Hence, technological change is the change of F, which typically increases production output.

$$Y = F(K, L) \tag{1}$$

Therefore, on a macroeconomic scale, it can be stated that technological change drives economic growth. Vice versa, there is a dependency as well. Economic growth delivers resources, which can be used for technology development that drive additional technological change (UNDP 2001), see also Figure 12.

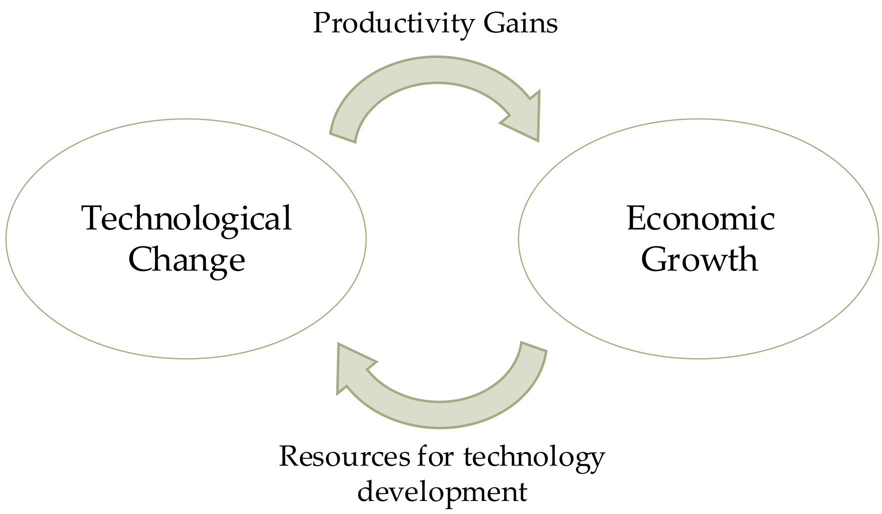

Figure 12: Technological Change and Economic Growth, adapted from (UNDP 2001)

The macroeconomic dependency of technological change and economic growth is applicable to the level of individual organizations as well and hence it can be transferred to microeconomics. For enterprises, the same logic applies.

Technological change drives the growth of the business. Additional resources delivered by business growth can be used to fund new technological change.

In conclusion, there is a strong dependency between technology and economic change. Hence, for the consideration of the pace of change in this thesis, both dimensions of change need to be jointly considered.

3.1.1.2 Change and Dynamic Environments

In the context of change and its pace, dynamics is a closely related term. The Oxford English Dictionary (Oxford University Press 2018) defines "Dynamics" as:

Dynamics: *"The forces or properties which stimulate growth, development, or change within a system or process."*

Hence, dynamics drive change. Adapted to the context of this thesis, dynamics are the underlying forces which stimulate technological and economic change within an enterprise and in its environment. As a result, the degree of dynamics which is present in the environment of a given enterprise can be used to relate to the pace of change it is facing. Collyer and Warren (Collyer and Warren 2009) describe dynamism as a non-binary dimension that applies in varying degrees to all environments, which reflects the view of this work. Figure 13 summarizes the dependencies of the introduced concepts around the pace of change and dynamic environments as well as their dependencies.

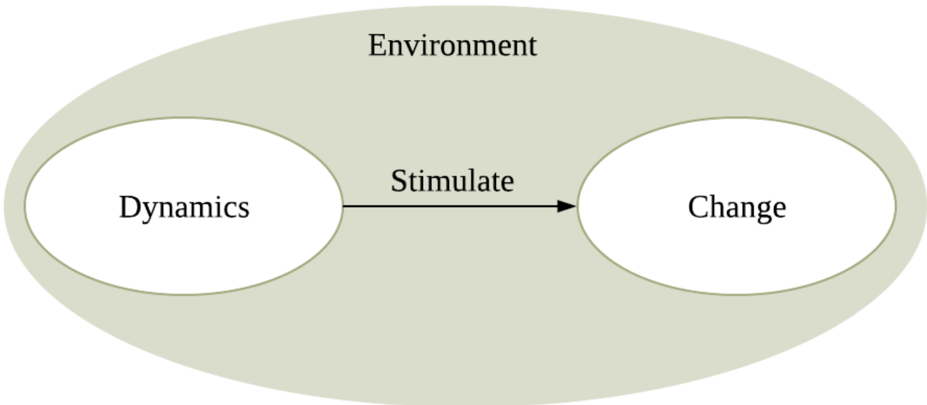

Figure 13: Dependencies of Dynamics and Change

Strictly speaking, there is no such thing as the "dynamic" or "non-dynamic" environment; for the sake of simplicity, however, this work considers an environment dynamic when it is subject to higher than normal pace of change. The effects, challenges and approaches discussed subsequently are most relevant to such a highly dynamic environment. However, they might be applied moderate dynamic environment as well depending on the context.

3.1.2 Observing Pace of Change

Based on the observations made in the previous subsection 3.1.1, this thesis considers a combination of technological and economic change and its impact on the discipline of Enterprise Architecture. According to the context of this thesis, this work primarily considers the technological and economic development within the past three decades – reflecting the time in which Enterprise Architecture has been practiced. The goal is to understand how conditions for the discipline might have changed in the past and to grasp the implications for the immediate future.

The idea of an accelerating pace of change driven by technological advances is not new. As early as 1910 the architect and urban designer Daniel Burnham wrote "a mighty change having come about in fifty years, and our pace of development having immensely accelerated, our sons and grandsons are going to demand and get results that would stagger us." (The Royal Institute of British Architects 1910). Ever since various scientists have investigated the effect for the past as well as its projection for the future (Bishop and Hines 2012).

While many studies and publications mention the effect of an accelerating pace of change for both technology and the economy, there are much fewer which provide measures to confirm the development long term. Lord Kelvin, the physicist known for determining the value of absolute zero, has prominently described problems of such an approach: "When you can measure what you are speaking about and express it in numbers, you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind."

Therefore, this subsection strongly focuses on measures to describe the development of economic and technological pace of change to provide hard facts, which can be built upon in the subsequent parts of this thesis. Moreover, a closer look will be taken at the human perception of these changes since this strongly influences the way we deal with them.

3.1.2.1 Technological Pace of Change

Technological change and its acceleration have been observed and described by various authors. Rothwell and Zegveld (Rothwell and Zegveld 1985) went so far as to say that we are in the midst of a technology explosion which they have strikingly note stated in contemporary times – but already in 1985. Similarly, Perrino and Tipping (Perrino and Tipping 1991) noted in 1991: "The pace of technology is accelerating, raising the stakes and penalties for managing innovation, and requiring early warning and a shorter response time to capture opportunities."

Probably the most prominent measure vividly illustrating an accelerating technological pace of change over the past century is Moore's law. It was originally formulated to outline that the number of transistors in a dense integrated circuit doubles approximately every two years and hence is exponentially growing (Moore 1965). Moore's law was first publicly stated in 1965 considering integrated circuits and their development until 1975, see Figure 14. The original graph presenting Moore's law and typically all similar illustrations feature a logarithmic scale to visualize the exponential growth in an appropriate manner.

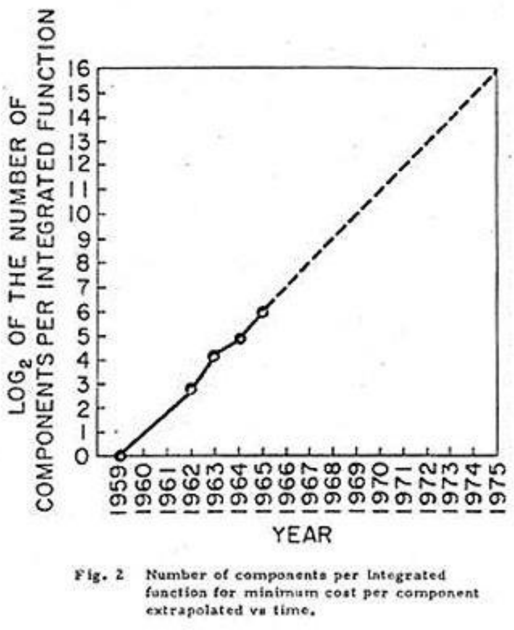

Figure 14: Moore's Original Graph: 'The Number of Components per Integrated Function' (Moore 1965)

Over the past decade it has turned out that, the logic of Moore's law can be applied much more broadly than in its original scope. The law with its original formulation has proven to be relatively accurate even until today. Transistors in an integrated circuit have continued to double every 18 to 24 months, see Figure 15.

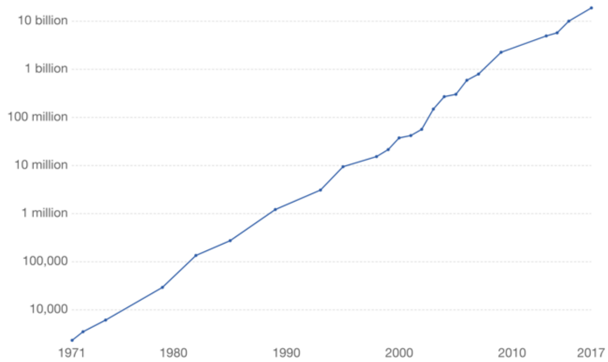

Figure 15: Moore's original law observed until today (Roser and Ritchie 2018)

Due to its long-term applicability, Moore's law has become a prominent metric, which is applied by scientists as well as practitioners in the semiconductor industry. By now, in the view of some critics, it has converted from an empirical observation to a self-fulfilling prophecy since both producers and consumers of chips have started to rely on it for their planning (Waldrop 2016). Producers leverage Moore's law to plan their R&D and production efforts while consumers use it to forecast the availability of computing resources (Simonite 2016). However, whether it is considered an observation only or even self-fulfilling prophecy, Moore's law clearly shows exponential growth for a core technology of IT over the past decades. Therefore, it presents a first indication for the fact that technological change has recently not occurred linearly but exponentially and can, therefore, be considered to be accelerating.

Since the early 2000s, different studies have predicted the end of Moore's law referring to physical restrictions of semi-conductors and predominantly unsolvable heating problems which arise into dense integrated circuits (Kish 2002). This effect is already observable for the clock speed of processors, which has not been growing further for the past couple of years (Waldrop 2016). However, while this might indicate the end of Moore's original law in a narrower sense, for the context of this thesis, it is worth taking a step back and considering the larger picture as well. This has been recognized by Ray Kurzweil in 2004 (Kurzweil 2004), who has taken

Moore's law to a different level of abstraction by not considering the sole technical metric of transistors in an integrated circuit but instead considering the calculations per second per constant dollar. This metric is more outcome-focused since it reflects the availability of computing capacity which presents the foundation for most IT related technological change.

Kurzweil's adaption of Moore's law has an additional striking feature. It does not only help to project the logic of Moore until today and potentially further into the future; it also proves to be applicable for the time before Moore's law was formulated in 1965. Since Kurzweil's version does not only consider integrated circuits, it can be applied for previous technologies such as transistors, vacuum tubes, relays and even mechanical computers. Observation of different examples shows that it can be used for the time until 1900, see Figure 16 for an overview.

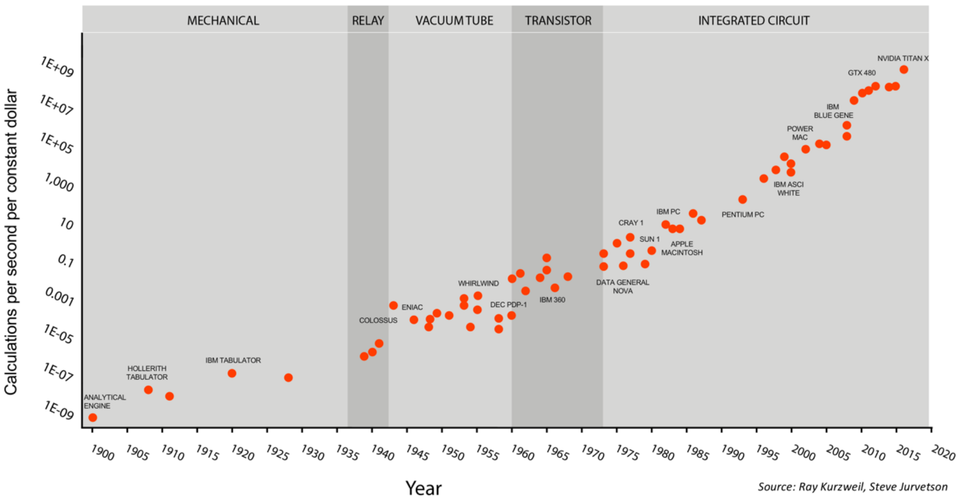

Figure 16: Moore's law over 120 Years – calculations per second per constant dollar (Jurvetson 2016)

Ray Kurzweil has not only generalized Moore's law but has further dealt with the phenomenon of an accelerating pace of change in close details, most prominently in his publications "The Law of Accelerating Returns" (Kurzweil 2004) and "The Singularity is Near" (Kurzweil 2005). Kurzweil shows that exponential growth can be shown in other areas of technological change as well. For example, he finds that technology adoption has accelerated exponentially considering, e.g. the adoption of the telephone which took half a century versus the adoption of the cell phone, which took only a decade. Figure 17 illustrates the pace of technology adoptions for different vital technologies in the past century and confirms the acceleration described by Kurzweil (Dediu 2013).

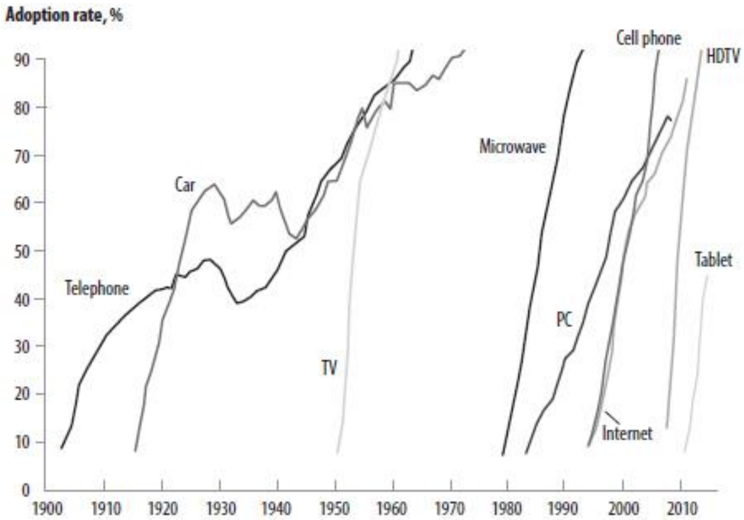

Figure 17: Acceleration of Technology Adaption (Dediu 2013)

A similar increase in the pace of change can be observed for the growth of devices connected to the internet. Observed initially by Kurzweil in 2005, this measure continues to grow exponentially even a decade later. Recently, especially the trend around the Internet of Things (IoT) is driving this growth (Lucero 2016), see also Figure 18.

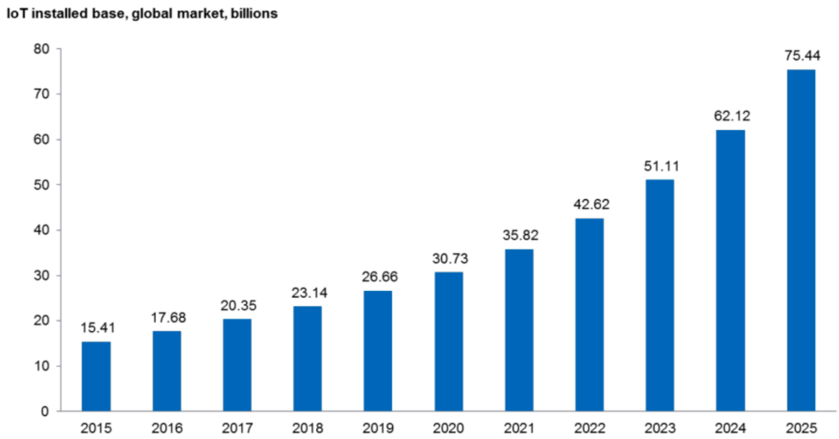

Figure 18: Internet of Things (IoT) connected devices installed base worldwide 2015 -2025 (Lucero 2016)

In total, Kurzweil presents more than 15 data sources which confirm the exponential growth of technological change in various areas on a long-term basis.

He derives a mathematical representation of the development for which he considers three variables (Kurzweil 2005):

- *V*: Velocity (that is power) of computation measured in calculations per second per unit cost
- *W*: World knowledge as it pertains to designing and building computational devices
- *t*: Time

The following first mathematical representation shows that World knowledge grows exponentially with time, see Formula 2.

$$W = W_0 e^{c_1 c_2 t} \tag{2}$$

Kurzweil further states that based on the data he has gathered, the growth can be considered double exponential, arguing that not only Velocity itself is changing but that there is interdependency between Velocity and World Knowledge which leads to the fact that more and more resources are available, which can drive technological change. This can be reflected in a formula where the exponent is exponential as well (Kurzweil 2004), see Formula 3.

$$W = \exp\,(e^t) \tag{3}$$

As a result of this growth, Kurzweil predicts what he calls the "Singularity" for mid of this century. This is, according to his definition "a time when the pace of technological change is so rapid, its impact so deep, that human life irreversibly transformed" (Kurzweil 2005).

Kurzweil's work has several critics. These deal predominantly with his long-term predictions and his view of the Singularity. For the context of this work, however, primarily his observations of technological change are relevant. There are a few publications which present a different view than Kurzweil's one in this matter. For example, Korotayev states that the growth might, in fact, be not exponential but hyperbolic (Korotayev 2018). However, most experts agree with the view of an exponential rate (A. Lopes, Tenreiro Machado, and Galhano 2016), which has also recently been empirically confirmed by Potapov (Potapov 2018).

In summary, this thesis concludes that the development of technological change is in fact exponential. Consequently, the technological pace of change is accelerating and therefore today faster than it has ever been before.

3.1.2.2 Economic Pace of Change

As previously pointed out, there is a strong interlink between technological and economic change. Therefore, when considering the pace of change, both domains and their dependencies need to be considered. Since technological change is in many cases the driver for economic change, one might assume that an increase in the pace of technological change will also lead to an increase in the pace of economic change. This development was already observed more than half a century ago by Max Ways, then editor of the Fortune magazine, who noted:

"Change has always been a part of the human condition. What is different now is the pace of change and the prospect that it will come faster and faster, affecting every part of life including personal values, morality, and religion, which seem almost remote from technology. […] So swift is the acceleration, that trying to 'make sense' of change will become our basic industry." (Ways 1964)

Similar to the observation of technological change, many publications, especially non-scientific ones, only mention the fact that pace of economic change is faster than ever but do not back up their views with data and metrics (Cornish 2004). While some at least refer to examples, this still makes it difficult to judge the development long-term. Therefore, similar as in the section on technological change, this thesis will strongly focus on metrics to provide an objective view of the developments.

Especially macroeconomics has a long history of observing and tracking all sorts of metrics. This kind of data is most readily available and can, therefore, be an excellent foundation to measure and subsequently understand the overall economic pace of change. The gross domestic product (GDP) is the primary metric this thesis will consider more carefully. The GDP represents the overall productivity of a country. Hence, the growth of the GDP can be used to measure the overall economic change and its pace. Two factors need to be excluded for a sensible measurement: First, the metric needs to be measured in constant currency to avoid inflation effects. Second, the metric should be viewed per-capita, so the effects of population growth are not included. The resulting metric is presented in Figure 19 for the United States.

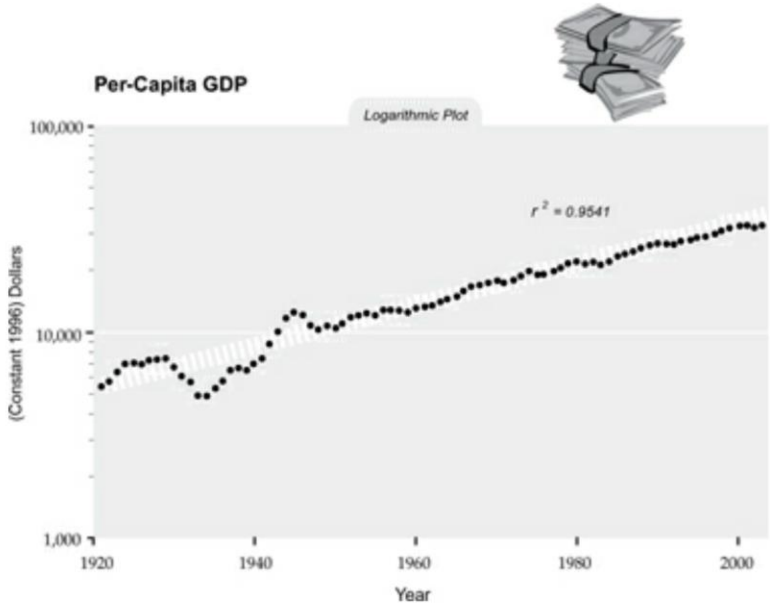

Figure 19: Development of Per-Capita GDP in the US (Kurzweil 2005)

The per-capita GDP presented in Figure 19 reflects exponential growth for the last century in the US. Some deviations from the trendline are visible which are due to special effects, in this case, economic recessions and the second world war. However, the overall trend snaps back to the exponential growth afterward. (Kurzweil 2005). Similar developments can be observed for per-capita GDP of other western countries such as the UK, France or Germany. For developing countries like China or India, the exponential growth is even stronger (World Bank Group 2018).

For the context of this thesis, not only the macroeconomic view is relevant but especially what happens on the level of enterprises. Appropriate measures are harder to obtain and more difficult to compare since especially on the level of individual enterprises numbers would be prone to all sorts of special effects. Nevertheless, there are a few studies which consider a more detailed level as well. One such study has recently been conducted by the economist (The Economist 2015) in which they compared key measures from various sources such as Bloomberg, Thomson Reuters, S&P, etc. of American companies over the past decade. Figure 20 provides a summary of the results and shows how these numbers have developed from 2005 to 2015.

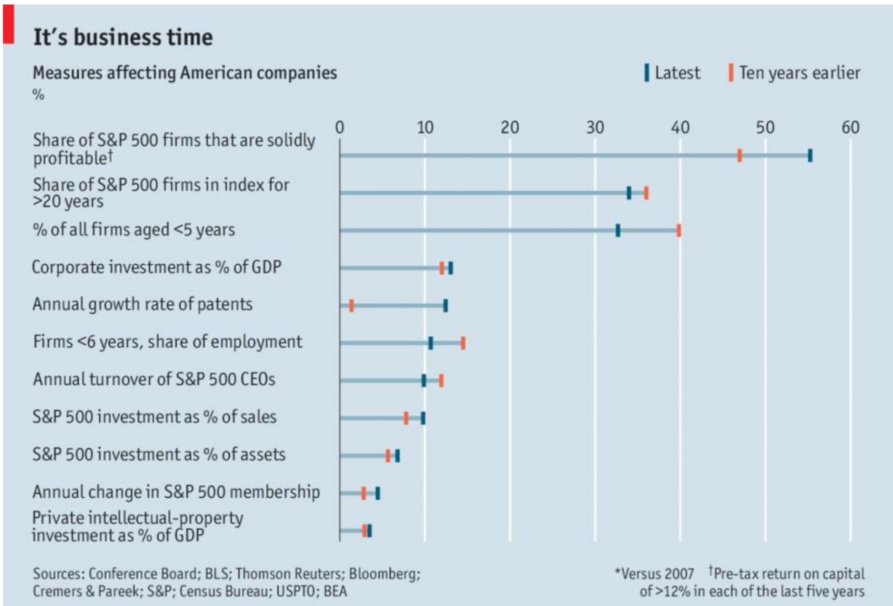

Figure 20: Measures affecting American companies over the past decade (The Economist 2015)

As pointed out previously in this thesis, the S&P 500 index, which lists the biggest US companies, provides a strong indication that the lifetime of big companies has strongly declined within the past decades (Satell 2014). This becomes visible in the results of the economist as well by the decreasing share of S&P 500 firms in the index for >20 years. Hence, it can be concluded that the market of the biggest enterprises is changing more swiftly than it has before.

However, there are also measures that provide a slightly different indication. For example, the number of S&P 500 companies which are solidly profitable has increased and their CEO turnover has declined. Therefore, it seems like some of the biggest US companies are getting more stable. This increased stability is also reflected on the financial market since the average duration of corporate bonds has increased from ten years in the 1990s to 17 years in 2015 indicating that companies behind these bonds are increasingly pursuing long-term strategies. Finally, the percentage of firms aged less than five years has significantly decreased, which shows that the number of successful independent startups is declining. While some of the effects shown in the study of the economist can be explained by a recent increase in mergers and acquisitions, this also raises the question whether talking about frantic acceleration only for the economic pace of change might be too simple (The Economist 2015).

An environment often connected with the ability to work at an outstanding pace of change by, e.g. achieving billion-dollar evaluations in a small number of years, are Silicon Valley startups. Examples range from tech companies like Google to Uber and Airbnb, which were able to disrupt existing markets driven by technological advantages (Bughin and Zeebroeck 2017). At the same time, there are industries which are much less or even not at all affected by digital disruption. Therefore, it seems like the effects of the increasing technological pace of change are different depending on the environment. This can be observed in the financial measure of different industries as well (Price and Toye 2017).

As presented in Figure 21, margin differences between top and least performing companies have recently been amplifying. Hence, the performance gap between winners and losers is amplifying which is one result of the increased frequency and speed at which incumbents are overthrown. As a result, we are overall facing a more volatile business environment than ever (Sinha, Haanaes, and Reeves 2015).

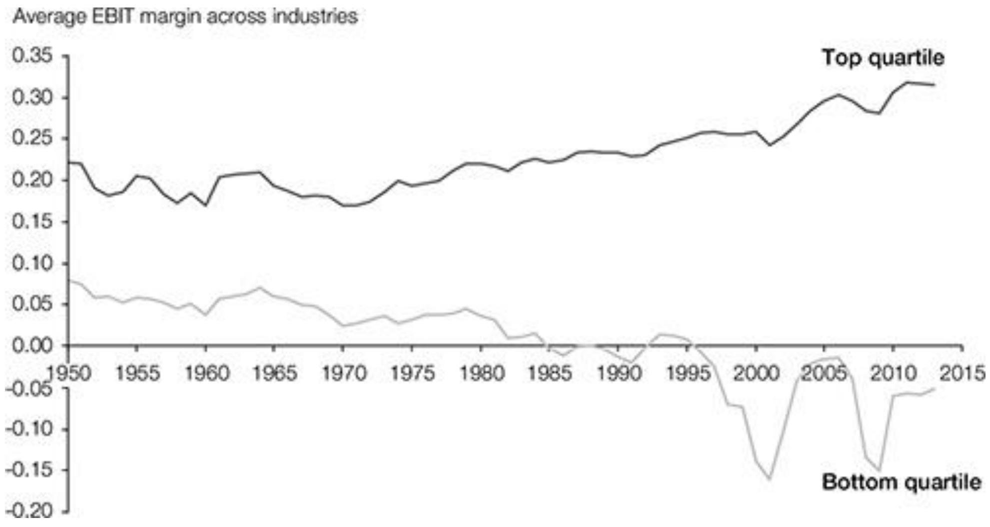

Figure 21: Average EBIT margins - top vs. bottom quartile (Sinha, Haanaes, and Reeves 2015)

When breaking this down, looking at margin differences for specific verticals, it becomes clear that the magnitude of this effect is different depending on the vertical.

Figure 22 shows the average margins for selected industries and the margin differences between the peers in these industries. High margin differences can mainly be observed in software and IT services as well as the media industry. Changing business conditions and the ability to react to them are likely a reason for the substantial performance differences in some of the verticals (Sinha, Haanaes, and Reeves 2015). Therefore, these measures support the thesis that the economic pace of change is strongly dependent on the business environment.

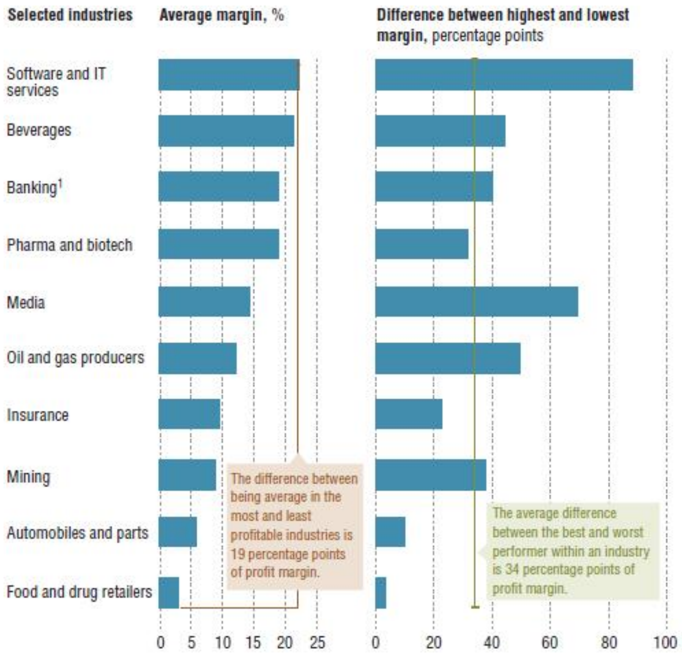

Figure 22: Average margins and margin differences for selected industries (Price and Toye 2017)

Similar trends as shown for margin differences can also be shown for the development of market capitalization. Until the 1980s, less than a third of industries in the US experienced regular turbulences. Today it is roughly two thirds, driven by accelerated technological change (Sinha, Haanaes, and Reeves 2015). Figure 23 shows the average five-year rolling standard deviation of firm market capitalization growth by sector, weighted by firm market capitalization as an indicator of unpredictability. Again, the IT industry stands out as an impacted industry. However, since the early 2000s also previously stable verticals such as health care and utilities show substantial unpredictability.

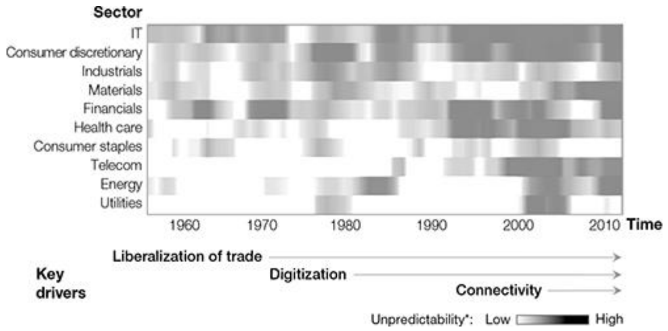

Figure 23: Increasing unpredictability of returns, based on all public US companies (Sinha, Haanaes, and Reeves 2015)

The effect of an increasing economic pace of change can be observed based on the presented measures. Driven by the exponential development of technological change, business environments are changing. However, this does not equally apply to every company and especially there are strong differences between verticals. Hence, companies are in environments with different degrees of dynamics. Therefore, they need to choose the right speed in order to be successful. Otherwise, they risk running into an acceleration trap – trying always to go as fast as possible – but consequently damaging their business in the long run (The Economist 2015).

To better describe the different facets of the increasing economic pace of change, recently the acronym VUCA has been introduced into business lexicons. VUCA stands for Volatility, Uncertainty, Complexity and Ambiguity and describes today’s business environments, which are challenging to handle with classical management styles. Volatility refers to unstable change, which is frequent and unpredictable. Agility is needed to address it effectively. Uncertainty describes the lack of knowledge about the environment and requires information to be addressed. Complexity refers to the increasing number of interconnected parts in companies and their environment but not necessarily involving change. Restructuring is required to address complexity. Finally, Ambiguity refers to a lack of knowledge regarding basic rules as well as cause and effect in changing business environments. Experimentation is required to overcome this. While VUCA is to some extent a marketing instrument of consulting firms, it also presents the parameters and vocabulary to understand better what is explicitly changing in certain environments (Bennett and Lemoine 2014).

While VUCA presents a concept to describe environmental changes in today's business world, there are additional approaches to structure a different kind of strategies, which can be followed as a reaction.

Since the 1990s, the concept of dynamic capabilities has started to receive an increasing amount of attention (Barreto 2010). The underlying idea is that VUCA environments require enterprises to develop specific capabilities which enable them to better react to changing conditions in their environment. These capabilities are comprehensively summarized for the first time in the dynamic capabilities framework presented by Teece et al. (Teece, Pisano, and Shuen 1997). Since then, various authors have contributed to the research area of dynamic capabilities.

A recent contribution building up on the idea of dynamic capabilities is the strategy classification scheme called the strategy palette by Sinha et al. (Sinha, Haanaes, and Reeves 2015). Their work is applicable for VUCA environments and is supposed to help practitioners to understand the conditions they are operating under and choose a suitable strategy accordingly. Sinha et al. state that today's business environments differ along three dimensions: Predictability (Can you forecast it?), malleability (Can you, either alone or in collaboration with others, shape it?), and harshness (Can you survive it?). According to Sinha et al. combining the dimensions into a matrix reveals five distinct environments, each of which requires a distinct approach to strategy and execution, see Figure 24.

The resulting strategies are described as follows in the strategy palette: In a predictable, classical environment strategic advantage is based on scale, differentiation or capabilities, which are achieved through comprehensive analysis and planning. Because planning does not work under conditions of rapid change and unpredictability, adaptive environments require continuous experimentation. In a visionary setting, firms win by being the first to create a new market or to disrupt an existing one. Firms can collaboratively shape an industry to their advantage by orchestrating the activities of other stakeholders in a shaping environment. Finally, under the harsh conditions of a renewal environment, a firm needs to first conserve and free up resources to ensure its viability and then go on to choose one of the other four approaches to rejuvenate growth and ensure long-term prosperity (Sinha, Haanaes, and Reeves 2015).

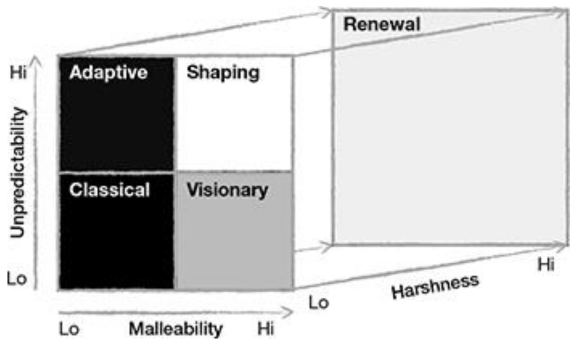

Figure 24: The strategy palette: five environments and approaches to strategy (Sinha, Haanaes, and Reeves 2015)

The strategy classification scheme by Sinha et al. fits the view of this thesis as it describes how environments are affected by different conditions and therefore require distinct strategies as a reaction for the companies to be successful. Moreover, the unpredictability dimension in the strategy palette reflects the effect caused by the increasing pace of change. The trend around VUCA indicates that the number of increasingly volatile and uncertain environments is growing; however, not every business is affected. Therefore, companies need to carefully choose their strategies according to their context and environmental conditions. The same is true for an EA strategy.

The EA concepts and approaches subsequently presented in this work are especially relevant for highly dynamic environments.

3.1.2.3 Human Perception of an Increasing Pace of Change

One might expect that – since the development of technological and economic pace of change have already been studied thoroughly for at least one century – today people and companies they represent should be ready to act accordingly. However, there is another factor which requires consideration to understand the interdependencies: The human perception of these changes and developments (Kurzweil 2005; The Economist 2015).

The exponential growth of technological change has been going on for decades and has also been observed by different researchers. Therefore, it should be no surprise and people in different roles should be used to dealing with this phenomenon – including Enterprise Architects. However, we seem to have a structural problem when it comes to exponential developments (Kurzweil 2005).

When it comes to planning new projects, we often rely on our experience from the past, e.g., when planning a new initiative, we rely on our experience from the last time we did something similar. Such an approach is only valid for linear developments. This can be especially painful at a later point in time since at the beginning linear and exponential developments can be very similar while at a later point in time the difference is significant, see Figure 25.

In addition to our understanding of the developments itself, it is also worth considering how we learn about changes. Especially since the speed and volume of this information has significantly increased recently. The trend known as Big Data describes that volume, velocity and variety of data has grown to an immense extent (Mcafee and Brynjolfsson 2012).

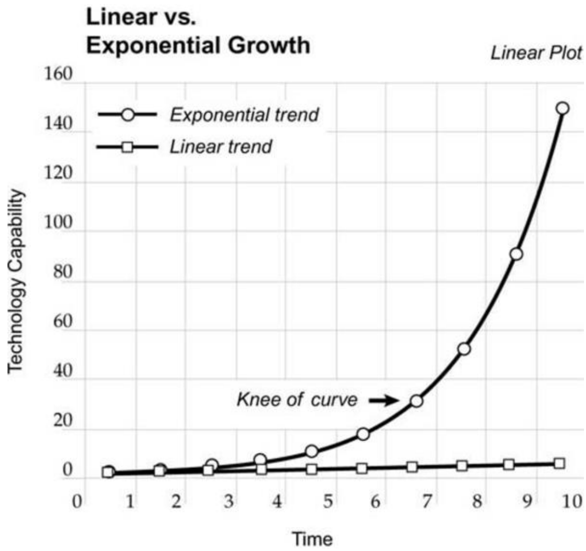

Figure 25: Linear vs. Exponential Growth (Kurzweil 2005)

Big Data has not only implications from a technical point of view but also on many aspects of our daily lives as humans. For example, while in the last century, emails were mostly a niche technology, the average manager today receives 200-400 of them. Similarly, we receive more information faster from a variety of sources such as social media. The Economist (The Economist 2015) even argues that this explosion of information leads to the fact that we overestimate the current economic pace of change. While overestimation is subject to discussions, it is undoubtedly true that the increase in available information has certainly an impact on our perception of the world.

It has been proven multiple times that human decision making is never wholly rational and that this can be a deciding factor in economic systems (Ariely 2010). Behavioral economics has become a substantial research area to understand this effect further. In this section, two examples are presented on how our perception can influence the way we react to changes in our environment. Therefore, considering measures only to determine the impact of an accelerating pace of change to a discipline like EA will not be enough. While this thesis will not provide an in-depth behavioral analysis for Enterprise Architects, it will highlight the areas where this is particularly relevant also providing an opportunity for future research.

3.2 BENEFITS AND EFFECTIVENESS OF ENTERPRISE ARCHITECTURE

The overall goal of this thesis is to understand and describe how EA can be practiced successfully in dynamic environments. In order to do that, one needs to understand first what success means for the discipline of EA. Therefore, this section takes a closer look at the benefits of EA and the way these are realized in organizations.

As previously mentioned, there are different views regarding the scope and purpose of EA (Lapalme 2012). In order to talk about EA benefits and how they are realized, the scope and purpose of EA need to be defined. This thesis follows the view of Enterprise Ecological Adaptation considering the enterprise and its environment for EA. Consequently, the benefits are derived.

The remainder of this section is structured according to the general theoretical framework for EA practices and benefits by Foorthuis et al. (Foorthuis et al. 2016), which summarizes how EA is creating value in organizations, see Figure 26. First, different EA approaches and related success factors are discussed to understand what needs to be done at which level to generate value from EA (Lange, Mendling, and Recker 2012). Second, the link between EA approaches and benefits is described considering direct and indirect benefits as well as the contextual factors, which influence the correct use of EA (Foorthuis et al. 2010, 2016). Finally, the benefits of EA are investigated. Operational and strategic benefits are considered as well as the effects on different organizational levels such as individual projects and for the organization as a whole (Boucharas 2010; Jeanna W. Ross, Weill, and Robertson 2006).

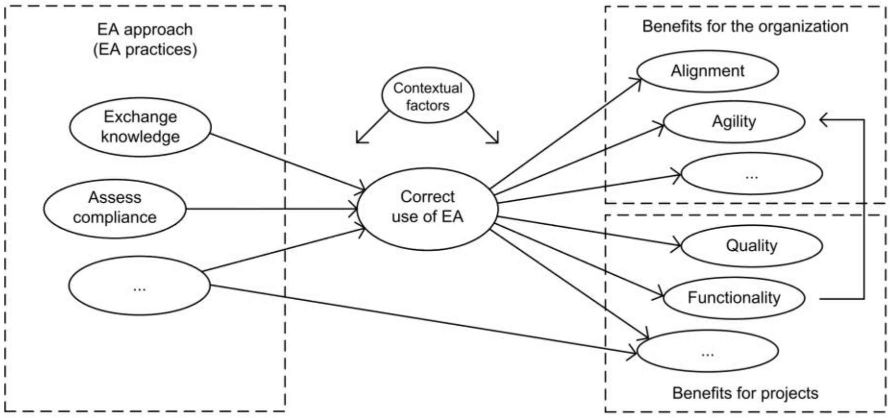

Figure 26: General theoretical framework for EA practices and benefits (Foorthuis et al. 2016)

3.2.1 EA Approaches and Success Factors

According to the definition provided earlier in this thesis, EA is a discipline which manages the organization of an enterprise. EA includes methods, tools and frameworks, which result in a set of activities conducted by people (Lankhorst 2013). The way these activities are organized and executed is considered an EA approach. Choosing the right EA approaches for a given setting, strongly determines how successful EA as a discipline is and the amount of value it generates for an organization.

Within the publication on the general theoretical framework for EA practices and benefits, Foorthuis et al. (Foorthuis et al. 2016) describe the following ten EA approaches (T1 – T10) structured into five areas, which are linked to the benefits of the discipline:

First of all, by ensuring management involvement, organizations can ensure that EA is formally approved, that the choices within EA are linked to overall goals and that the discipline as well as its value are propagated throughout the organization (Lankhorst 2013). EA should enable the achievement of strategic business goals and this kind of management involvement will help to make sure that EA is working in the right direction and is received with the required amount of approval (Morganwalp and Sage 2004).

The second area is related to assessing EA conformance. By running EA compliance assessments for new and ongoing projects, organizations are enabled to run required corrective actions and therefore ensure that EA principles are implemented in the real world (C. Schmidt and Buxmann 2011).

Another significant area for EA success is knowledge exchange. Particularly in larger organizations multiple enterprise architects and involved stakeholders will need to collaborate in order to ensure that benefits of EA are being realized. This includes knowledge exchange between different types of architects but also exchange between architects and other project members. Moreover, especially if there is a centralized EA team, architects from this team should be actively involved in projects when defining solutions and applying EA norms (Lange, Mendling, and Recker 2012).

The fourth area is related to the value of project artifacts. EA alignment can be primarily driven early in the project. Therefore, defining a project start architecture that adheres to EA norms can be essential to ensure alignment throughout the implementation phase of the project. In general, document templates are considered essential when it comes to applying EA in the context of individual projects. Standard architecture templates help in the knowledge exchange between architects and projects while simultaneously providing guidance to project stakeholders on how to comply with EA (Wagter et al. 2005).

Finally, the fifth area considers financial incentives and disincentives. By tying financial implications to EA conformance or non-conformance, specific behavior can be supported. For example, costs associated with EA conformance could be covered by the central EA program instead of the individual project budget (Lange, Mendling, and Recker 2012).

Table 9 provides a summary of the EA approaches and related areas presented by Foorthuis et al. (Foorthuis et al. 2016).

A similar analysis regarding EA approaches and benefits is presented by Lange et al. (Lange, Mendling, and Recker 2012), who describe a set of success factors for four different dimensions of EA, see Figure 27 for a summary. Three of the four dimensions presented by Lange et al. are aligned to the popular, more general DeLone and McLean information system success model (DMSM) (DeLone and McLean 1992, 2003), which serves as a foundation for their work.

Table 9: EA approaches determining benefits (Foorthuis et al. 2016)

Area	**EA Approaches**
Ensure management involvement in EA	T1 Formal approval of EA T2 EA choices linked to the organization T3 Management propagation of EA
Assess EA conformance	T4 Compliance assessments
Create an active community for EA knowledge exchange.	T5 Knowledge exchanges between architects T6 Knowledge exchanges between project members and architects T7 Architects assist and are actively involved in projects
Leverage the value of project artifacts	T8 Project Start Architecture (PSA) T9 Document templates
Use compensation or sanctioning for stimulating conformance	T10 Finance (dis)incentives

EA product quality refers to the output of EA, namely the EA products. The quality of these products determines how they can be used to support decision-making. The foundation on which EA is run is described by the dimension EA infrastructure quality. EA service delivery refers to the way EA is executed and received by different stakeholders. Finally, EA cultural aspects, which are not based on the DMSM model, refers to informal "soft" conditions in which EA is operated.

There is an overlap with the previously discussed approaches presented by Foorthuis et al. – especially regarding the importance of management support, the value of EA artifacts and EA knowledge exchange. Compared to Foorthuis et al., Lange et al. have a broader scope and include foundational aspects such as tools, skills and resources required to run EA in practice successfully. Foorthuis et al. focus on actual practices instead, which can be operationalized immediately to generate value. Going forward, this thesis will leverage a combination of the approaches presented by Lange et al. and Foorthuis et al. since for dynamic environments both foundational and operational aspects are considered necessary.

EA Product Quality	**EA Infrastructure Quality**	**EA Service Delivery Quality**	**EA Cultural Aspects**
PQ1 As-Is Architecture	IQ1 EA mandate	SQ1 EA communication	CA1 Top-management support
PQ2 To-Be Architecture	IQ2 Extent of centra-lization	SQ2 EA management support	CA2 EA awareness
PQ3 Roadmap	IQ3 EA governance formalization	SQ3 EA project support	CA3 Common under-standing
	IQ4 EA framework		
	IQ5 EA tool support		
	IQ6 EA reference architectures		
	IQ7 EA principles		
	IQ8 EA skills		
	IQ9 EA resources		

Figure 27: Overview of EAM success factors (Lange, Mendling, and Recker 2012)

3.2.2 The Link between EA Approaches and Benefits

Executing the previously discussed EA approaches is supposed to yield benefits on a per-project level as well as on the overall organizational level. However, there is not always a direct link between approaches and benefits, especially for central functions such as EA. Therefore, this subsection focuses on the question how benefits are realized, and what intermediate steps need to be taken in order to do so.

The DeLone and McLean information success model (DMSM) (DeLone and McLean 1992, 2003) presents a widespread and validated theoretical foundation for the review of how EA benefits are realized. While the DMSM has originally a much broader scope and slightly different focus by considering the overall success of the information systems within organizations, its structure and approaches can be applied to the discipline of EA as well (Lange, Mendling, and Recker 2012).

The DMSM describes different criteria of an information system, namely system quality and information quality. These criteria determine how a system is used as well as the satisfaction of the users. Moreover, there is a dependency between use and user satisfaction. Increased user satisfaction can lead to increased use while more users make the system more relevant; therefore, user satisfaction can be increased. If a system is used and the users are satisfied, this will have a positive impact on the individual user and consequently lead to benefits on the organizational level. See Figure 28 for a summary of the DMSM.

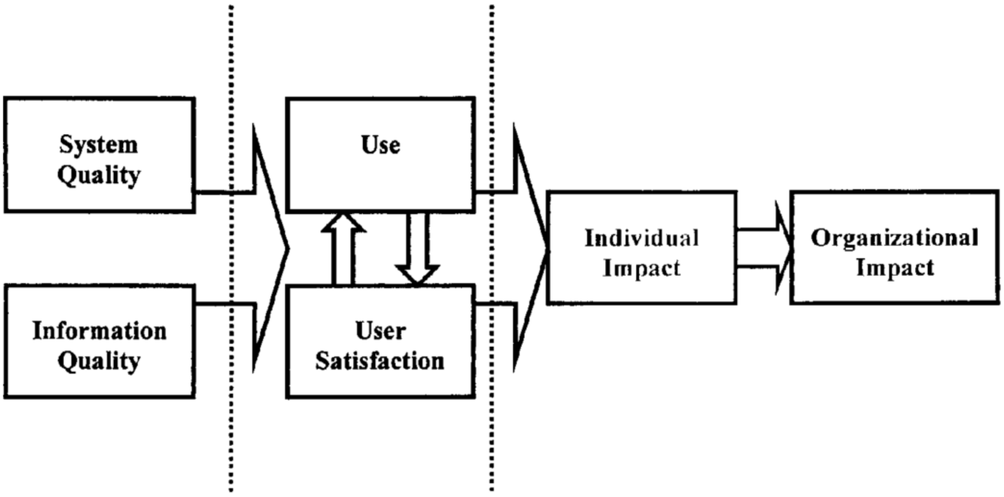

Figure 28: DeLone and McLean information system success model (DeLone and McLean 1992, 2003)

As pointed out previously, Lange et al. have taken the general DMSM and adapted it for the context of EA, see Figure 29. They adjusted the input criteria on the left-hand side of the model by aligning the different aspects specifically to the discipline of EA. The rest of the DMSM is re-used as-is, which is reasonably argued: For an Enterprise Architecture, it is essential that it is not only initially created and maintained but also that it is actively used. Otherwise, very limited value is generated. Hence, user stratification is a crucial aspect to ensure that it is applied and consulted by different stakeholder groups and, moreover, that future intention to use is stimulated. The different quality criteria of EA and related cultural aspects are driving intention to use and user satisfaction.

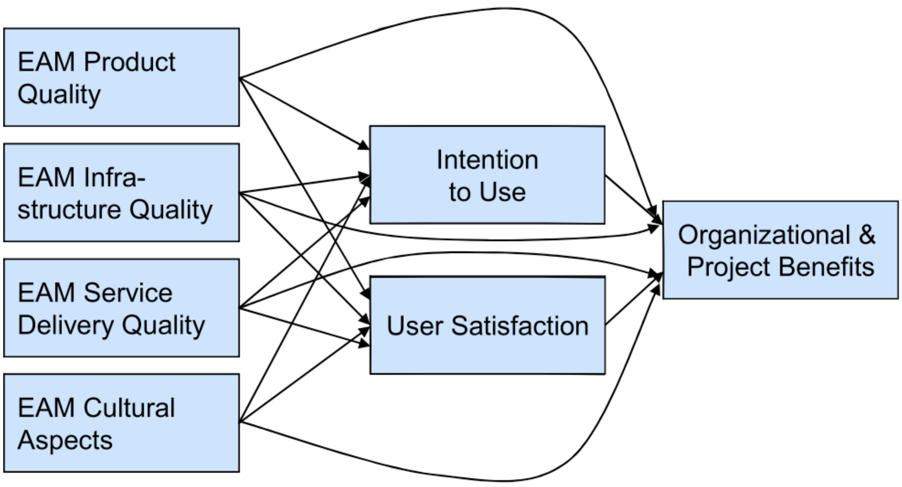

Figure 29: The EAM benefit realization model (Lange, Mendling, and Recker 2012)

Moreover, there can be direct benefits on the project or even an organizational level. However, primarily benefits are generated from an actively used EA. Hence, with high intention to use and to high user satisfaction the most benefits are realized (Lange, Mendling, and Recker 2012).

The model presented by Foorthuis et al. (Foorthuis et al. 2016) outlines similar dependencies, with a slightly different view. They also point out that EA approaches can directly result in benefits. However, in their overall model, they describe "correct use of EA" as the key link between EA approaches and benefits. "Correct use of EA" describes the level of accordance between real-world behavior and products on the one side and predefined EA norms on the other (Foorthuis 2012). This basically reflects a measure of the extent to which an EA is actually used within an organization.

As part of their research contribution in 2016, Foorthuis et al. elaborate further on the correct use of EA presenting a more detailed and broken-down view of this abstract construct, see Figure 30.

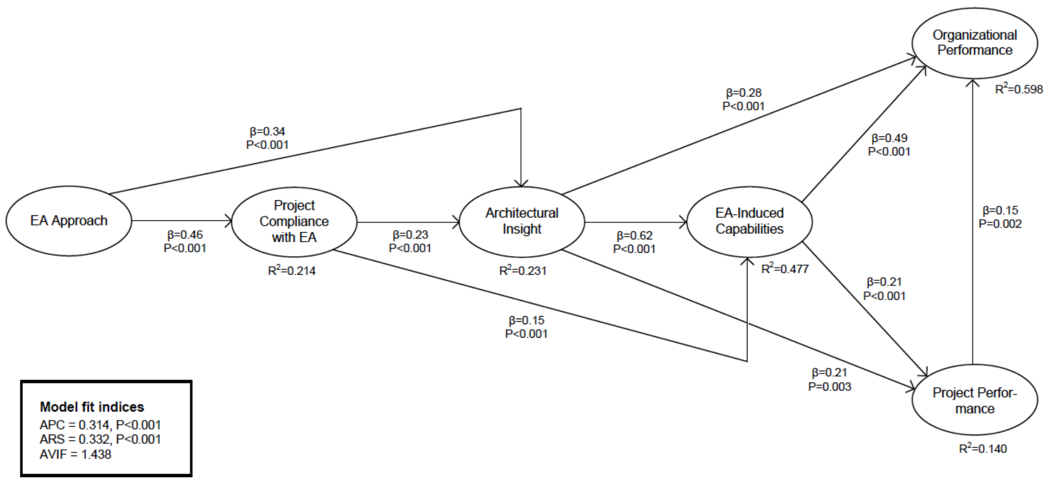

Figure 30: Link between EA approaches and benefits (Foorthuis et al. 2016)

According to Foorthuis et al., the first step in the causal model form approaches towards benefits is to achieve project compliance with EA as it will help to reduce complexity and simplify integration across the enterprise while it enables subsequent benefits as well. Practicing an EA that is complied with will then lead to architectural insights, providing a foundation for communication and decision support. Achieving the end goals of increased project and organizational performance is to some extent a direct result of architectural insight. However, a substantial part of EA takes an intermediate role enabling other internal capabilities, which will then lead to real benefits (Schryen 2013).

The models of Lange et al. and Foorthuis et al. both provide a different perspective on the way EA approaches generate benefits. Lange et al. describe a model which is based on rather leading indicators such as the intention to use and user satisfaction. This perspective allows measuring results already early in the process. However, these indicators can be challenging to measure. Foorthuis et al. in contrast focus on lagging indicators reflecting more tangible results such as the degree of compliance and the availability of architectural insights.

The critical aspect both models and further researchers (Schryen 2013; van Steenbergen 2011) emphasize is the indirect link between EA approaches and benefits. A substantial share of results is delivered in an intermediate fashion by EA. The resource-based theory can be used to describe the foundation of this causal relationship in more detail (Lux, Riempp, and Urbach 2010).

In addition to the causal model itself, also the context in which EA is practiced should be considered. Depending on contextual factors such as the economic sector and organizational size, effects of EA approaches and compliance might vary. According to earlier studies, in particular the economic sector is known to be an important factor since various industries are known to attach different priorities and consequently funds to EA, which effects the outcomes (Foorthuis et al. 2016; van Steenbergen 2011).

Especially for this thesis, contextual factors which affect the way EA benefits are realized are considered to be essential. As pointed out in the previous section, there is a significant difference in the development of technological and economic pace of change depending on the environment. These environmental differences can be covered in contextual factors going forward.

3.2.3 EA Benefits

As previously pointed out, EA has an intermediate nature of generating benefits. By ensuring alignment of projects and enabling several capabilities, ultimately the overall goals of the organization are supported – such as reducing IT costs, increasing IT responsiveness, improving risk management, increasing management satisfaction and enhancing strategic business outcomes (Jeanna W.

Ross, Weill, and Robertson 2006). At the same time, EA requires investments in order to operate successfully. Due to the resulting indirect link between investments and potential benefits in combination with the increasing popularity of EA, this area has been studied substantially within the past decade to understand the dependencies better and provide guidance to practitioners. This subsection provides a summary of the identified benefits.

EA benefits are multifold and can be found on multiple levels. Recent scientific contributions predominantly distinguish between overall organizational benefits and those of individual projects (Boucharas 2010; Jeanna W. Ross, Weill, and Robertson 2006). Ultimately, these benefits can mostly be associated with improved efficiency, better effectiveness and increased flexibility (Lange, Mendling, and Recker 2012; C. Schmidt and Buxmann 2011). Efficiency increases are predominantly related to improved re-use and therefore reduced costs. Better effectiveness is primarily based on better alignment, which leads to enterprise-wide instead of locally-optimized solutions. Flexibility is improved by providing transparency and therefore the means to manage complexity.

Foorthuis et al. (Foorthuis et al. 2016) provide a more detailed overview of 18 benefits in total (see Table 10) which are aligned with the structure of the previously introduced benefits model, see Figure 30.

Taking a detailed look at each benefit is not the focus of this work and therefore beyond the scope of what can be presented in this section. Since the area of EA benefits has been substantially studied in the recent past, there are several publications which can be consulted for further details[6]. However, there is one area of benefits that needs to be considered more closely for the context of this thesis which is increased agility and flexibility.

[6] The following publications provide further details on EA benefits (Foorthuis et al. 2016; Lange, Mendling, and Recker 2012; Jeanna W. Ross, Weill, and Robertson 2006)

Table 10: Organizational and project benefits from EA

Area	**EA Benefits**
Architectural Insight	B3 Understand organizational complexity B9 Guide change initiatives with clear image of future B10 Improve communication
EA-Induced-Capabilities	B2 Improve business-IT alignment B4 Control organizational complexity B5 Improve integration, standardization B8 Facilitate external co-operation
Organizational Performance	B1 Pursue enterprise-wide goals B6 Control costs B7 Increase agility
Project Performance	B12 Save project resources B13 Save project time B14 Improve project risk management B15 Improve project quality B16 Improve project functionality B17 Control project complexity B18 Improve speed of project initialization

Teece et al. (Teece, Pisano, and Shuen 1997) point out that in order to operate successfully in dynamic environments, organizations need dynamic capabilities. Agility and flexibility are considered dynamic capabilities. Therefore, it can be concluded that already in its basic form, EA should help organizations to become more successful in dynamic environments. EA can achieve this by providing transparency to identify required changes and therefore allowing organizations to deal with their environment effectively and adjust quickly (Lange, Mendling, and Recker 2012). However, in order to generate these benefits, a correctly used EA needs to be in place, which depends on contextual factors as pointed out previously. Hence, it is not enough to implement EA as usual in dynamic environments and automatically assume that by doing so required agility and flexibility will be generated.

This concludes the section on the benefits and effectiveness of EA. For the subsequent analysis in this thesis, there are two key takeaways:

1. EA benefits are yielded in an intermediate fashion and on multiple levels within an enterprise. This includes the level of individual projects as well as multiple intermediate capabilities which are enabled through EA. Ultimately, also benefits for the overall enterprise are being generated.
2. EA benefits and how they are generated are subject to contextual factors. Depending on the environment, specific EA approaches can be more or less successful.

The next section connects the findings of the two previous sections to derive a research model which is used to answer the main research question of this thesis.

3.3 IMPACT OF INCREASING DYNAMICS ON ENTERPRISE ARCHITECTURE[7]

This section of the thesis will bring together the results of the two previous sections, combining the current developments regarding the economic and technological pace of change with the way EA generates benefits in organizations. The goal is to derive a research model which describes the key constructs and dependencies relevant for the thesis and can, therefore, be used to determine how EA can be practiced effectively in dynamic environments.

At the time this thesis is written, there was no recent study available which explicitly considers the conditions EA faces in dynamic environments. However, there are two closely related scientific contributions which are consulted to build up the research model for this thesis:

First of all, Collyer and Warren (Collyer and Warren 2009) describe project management approaches for dynamic environments in their work. While they

[7] The content of this section has been partly presented at the Bled eConference in 2018 and was subsequently published as part of the related conference proceedings (Gampfer 2018a).

consider a completely different discipline – project management instead of EA – the underlying research approach and structure is quite similar. Collyer and Warren draw comparable conclusions like this thesis in section 3.1. They find that specific environments are more dynamic than others and therefore require different project management approaches in order to be successful.

Second, Schilling et al. (Schilling et al. 2017) provide a review of information systems complexity taking a Complex Adaptive Systems (CAS) perspective. CAS theory has recently become increasingly popular in EA research, see also section 2.6.3.8 of this work. The key result from the work of Schilling et al. for this thesis is that by applying the CAS perspective, they find a formal way to describe the impact of environmental changes on the discipline of EA. Therefore, the CAS theory is applied similarly in this thesis.

The following subsection will introduce CAS and take a closer look at how CAS is related to EA. Afterwards the subsequent subsection presents the resulting research model considering CAS theory as well as the results presented previously in this chapter.

3.3.1 Complex Adaptive Systems Theory and its Link to EA

CAS is grounded in complexity theory, which presents a framework for understanding based on concepts such as non-linear systems and network theory. It can be applied in various areas, including social sciences (Byrne and Callaghan 2013). The CAS perspective describes a complex system, such as an Enterprise Architecture, as a "dynamic network of interdependent, interacting agents (e.g., cells, species, individuals, firms, and nations) bonded by common goals, views, and needs that act in parallel, and that constantly act and react to the actions of other agents" (Vessey and Ward 2013).

Based on this idea of a dynamic network, CAS can be applied to EA, in order to understand, measure and optimize the structure of architectures, e.g., to reduce complexity (Fu et al. 2016; Schütz, Widjaja, and Kaiser 2013). Moreover, it is relevant for the methodological level of EA. CAS has been described to be a suitable theoretical lens to analyze the emergence of order in complex socio-technical systems as a result of individual actions (Anderson 1999). Therefore, the CAS perspective is applied within this thesis to build up the research model similar to the way it is done by Schilling et al. (Schilling et al. 2017).

The work of Schilling et al. focuses on the complexity of Information Systems (IS). Within their CAS based model, they derive four types of IS complexity:

1. *Structural Technological Complexity*, reflecting the interdependence of IT systems and the variety of the underlying technological platform
2. *Structural Organizational Complexity*, reflecting the diversity of stakeholders in projects and organizations
3. *Dynamic Technological Complexity*, reflecting the frequency of changes in the technological infrastructure and development methodologies
4. *Dynamic Organizational Complexity*, reflecting the frequency of changes in the organizational structure and business processes

In the context of this thesis, the differentiation between dynamic and structural complexity is worth taking a closer look at. Structural complexity is related to the number and diversity of parts in a system. The more significant and more diverse a system is, the higher is its structural complexity. However, this statically considers the system only. Changes of the system are covered by dynamic complexity. A higher frequency of changes results in higher dynamics complexity, which needs to be managed.

The conceptualization of the interdependencies between change frequency and dynamic complexity is a perfect fit for the research model of this thesis and is therefore used subsequently.

3.3.2 Research Model

One key result of the current state analysis within this thesis is a model which describes the influence of dynamic environments on EA effectiveness. This model is depicted in Figure 31. It combines the general theoretical framework for EA practices and benefits by Foorthuis et al. (Foorthuis et al. 2016) with the ideas presented by Schilling et al. (Schilling et al. 2017) around dynamic complexity.

Changes in both business and technology result in dynamic complexity for EA. The faster things are changing, the higher is the dynamic complexity which needs to be handled. In contrast to Schilling et al. this thesis does not solely consider dynamic organizational complexity but dynamic business complexity instead. This is due to the focus on EA instead of IS. In the context of EA, the business side does not only generate output in the form of organizational changes, which need to be handled. Instead, the business architecture is something which is actively managed. Therefore, it is considered as dynamic business complexity.

In terms of the overall model, EA approaches create benefits for organizations and projects by delivering an EA which is correctly used. This means that an EA is defined and used in the organization. Multiple contextual factors influence the correct use of EA. The research model of this work considers both dynamic business complexity and dynamic technological complexity as contextual factors which influence the correct use of EA.

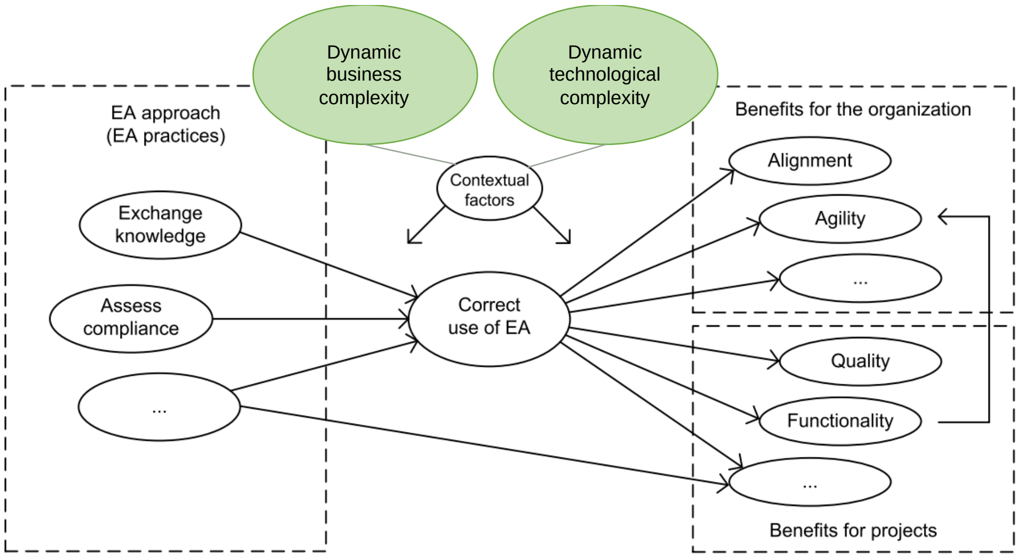

Figure 31: Impact of dynamic environments on EA – based on (Foorthuis et al. 2016)

The next step within this research is to collect and consolidate approaches which improve the effectiveness of EA in environments with high dynamic complexity. A series of expert interviews will support this step. Afterwards the identified approaches are assessed based on the given research model in order to define a reference architecture for the EA capability in environments with high levels of dynamic complexity. The resulting reference architecture will present guidance to EA practitioners on how EA can be applied for current digital transformation initiatives.

4 EA APPROACHES TO COPE WITH DYNAMIC ENVIRONMENTS

As pointed out by Teece et al. (Teece, Pisano, and Shuen 1997) enterprises require dynamic capabilities in order to be successful in dynamic environments. This applies to the overall organizational level and can be broken down to individual disciplines. EA is certainly a relevant discipline in this context since it provides the framework for dynamically creating, extending or modifying resources, structures and values (Helfat et al. 2009).

The major challenge for EA in a dynamic environment is the tension between agility and coherence (Barbazange et al. 2018; Wagter et al. 2005). While the original job of EA is to ensure coherence throughout the enterprise and most commonly between business and IT, dynamic environments ask for capabilities which allow organizations to quickly adapt to new circumstances. One example could be the need to quickly introduce a new business service because of a competitor who is taking away market share with a certain offering. Running through classical EA processes to determine business, information systems and technical architecture might be not feasible in this case due to time constraints. However, dealing with a non-coherent architecture in the long run is a problem as well. Ensuring such agility while maintaining coherence at the same time presents the foundational challenge for EA in dynamic environments.

The question of how EA can address the tension between agility and coherence is summarized in the third research question (RQ3) of this thesis. RQ3 asks: *"What EA approaches need to be applied in order for the discipline to be effective in dynamic environments?"* The goal within this chapter is to address RQ3 by exploring EA approaches which, once implemented, will help to address the challenges of managing EA in dynamic environments and ultimately enhancing the dynamic capabilities of enterprises. By interviewing several experts, the identified approaches will be enhanced and validated.

This chapter is structured in the following manner: The next section 4.1 provides an overview of the research strategy applied within this chapter. The results of the previously conducted state-of-the-art review, the identified literature as well as the derived research model will serve as a basis. Subsequently, different EA approaches are presented and reviewed in section 4.2. Finally, in section 4.3 the presented EA approaches are discussed and initially validated considering the results of the conducted expert interviews.

4.1 RESEARCH STRATEGY

The research strategy within this chapter encompasses a combination of a literature review and semi-structured expert interviews with industry professionals in the EA space. The rationale of this approach is that it covers both existing scientific knowledge as well as current challenges and potential solutions from practitioners. Moreover, this strategy has been successfully applied for similar research in the area of EA by Lange et al. (Lange, Mendling, and Recker 2012). The experience and findings by Lange et al. are used as a basis for the research strategy applied in this chapter.

Figure 32 provides a graphical overview of the research strategy applied for this part of the thesis.

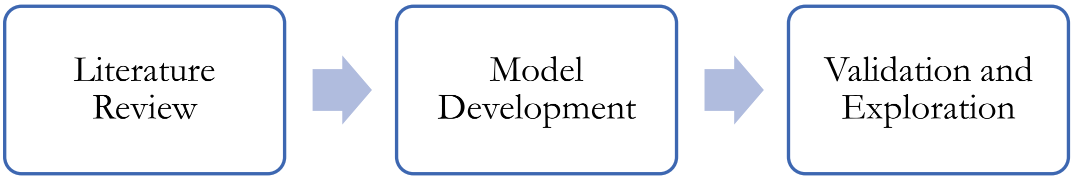

Figure 32: Research strategy to address Research Question 3 (RQ3)

Today, a limited number of scientific publications, which address certain parts of the research question RQ3, already exist. This knowledge needs to be considered and is used as a starting point. Due to the lack of an accepted research model for RQ3, a formative research strategy is chosen for this part of the thesis.

Philipp Mayring's qualitative content analysis (Mayring 2015) is used as a methodology to extract EA approaches from the available publications systematically. Specifically, an inductive category definition is applied, in which first, all approaches are extracted from the given material and in a second step paraphrasing, generalizing and reduction are used to summarize the content in a consumable manner. The extracted EA approaches are inductively clustered into a category system and the result is validated based on original material.

The clustered EA approaches present the basis for deriving the first version of a model which describes how EA can be run successfully in dynamic environments. However, considering only existing scientific knowledge would only provide a restricted overview.

Therefore, a series of expert interviews is conducted to validate and enhance the findings from the literature review. In particular, challenges and approaches raised within the interviews are considered to account for current developments and to include the practitioner point of view into the results on top of the theoretical perspective of literature. The interviews are run in a semi-structured fashion (Flick 2018) while the structure and questions are designed according to the results of the literature review.

Again, Philipp Mayring's qualitative content analysis methodology is applied to extract information from the results of the interviews. However, for the analysis of the interview results, a deductive categorization approach is chosen instead of an inductive one. The preliminary model is taken as a foundation to derive an initial structure. The answers provided in the interviews are used to validate the structure as well as to enhance its content.

The following subsections explain the individual steps taken during the literature review, the model development as well as the validation and exploration phase in more detail.

4.1.1 Literature Review

In the first step, the existing scientific literature which is related to running EA in dynamic environments is considered.

The literature identified in the first chapter of this thesis is used as a foundation. In particular, the publications linked to the trend 'adaptive' or 'agile' EA are considered since these are most closely related to applying EA in dynamic environments. Based on the previously identified search string in combination with the terms identified in the text mining analysis, a newly combined string is derived. Back and forward search reveals that besides looking for 'agile' and 'adaptive' EA, also 'dynamic' EA closely relates to the subject of the research question being addressed in this chapter. Therefore, 'dynamic' is included in the search string as well. Ultimately, the following combined search string is derived for the literature review presented in this chapter:

("enterprise architecture" OR "information systems architecture" OR "information technology architecture" OR "business-IT alignment") AND ("adaptive" OR "dynamic" OR "agile")

To retrieve relevant publications and also to ensure that recent publications are included, the previously introduced literature databases were queried once more on December 1st, 2018:

- IEEE Xplore (http://www.ieee.org/web/publications/xplore/)
- Science Direct – Elsevier (http://www.elsevier.com)
- Springer Link (http://www.springerlink.com)
- Web of Science – Thomson Reuters (http://webofknowledge.com)
- ACM Guide to Computing Literature (http://dl.acm.org/)

All these databases are queried using the new, combined search string to derive journal articles and conference proceedings which could contain approaches relevant to the research question of this chapter. The resulting list of literature from all databases is consolidated and duplicates are discarded. Afterwards, the title, abstract and conclusion of the publications are reviewed to discard any results which are not related to the research question of this chapter. In the end, a list of 55 publications is derived, which is used as input for the subsequent analysis,

Most of the identified publications present individual findings which address specific aspects of EA, e.g., they suggest EA approaches to better plan architectures for dynamic environments (Saat, Aier, and Gleichauf 2009). However, there is also a small number of scientific contributions which present or refer to complete frameworks on how to run EA in dynamic environments. These frameworks can be categorized into two groups:

1) EA frameworks which describe practices for dynamic environments
2) Agile frameworks which describe how agile development and operation practices can be applied on a large scale addressing a similar underlying challenge. These frameworks also include approaches to run architecture which are applicable for dynamics environments

Both groups of frameworks are more closely considered in the next two subsections.

4.1.1.1 Existing EA Frameworks for Dynamic Environments

On the basis of the existing scientific publications, a total of four frameworks have been identified, which attempt to summarize approaches to run EA in dynamic environments. The framework published first, namely in 2005, is the Dynamics Architecture (DYA) model by Wagter et al. (Wagter et al. 2005). The primary author of the DYA model, Roel Wagter, has subsequently also contributed to the Enterprise Coherence Framework (ECF), which includes some of the ideas from the DYA model (Wagter, Proper, and Witte 2014). The ECF was first published in 2012 and has been developed continuously since then. The third one among the frameworks considered relevant here is the Gill framework, which was first published in 2012 (Gill 2012). Today the third version of the Gill framework is available. A fourth framework which describes EA approaches for dynamic environments was released in 2018 by the Open Group: The Agile Architecture Framework (AAF) (Barbazange et al. 2018). The four frameworks are described subsequently.

4.1.1.1.1 Dynamic Architecture (DYA) Model

Wagter et al. (Wagter et al. 2005) are the first ones to describe a solution to address the challenges of EA in dynamic environments. Their framework is called the Dynamic Architecture (DYA) model.

Wagter et al. present a detailed description of the underlying challenge, which – from their point of view – comes down to the tension between agility and coherence. Businesses ask for an increasing pace of change, which is why engineers are forced to produce “quick and dirty” solutions. At the same time architects pursue coherence to align the different facets of the enterprise with one another. Whenever such a quick and dirty solution is not in alignment or even violates architectural principles, architects will likely not approve it and ask for adjustments. Due to the fact that engineers have to redo parts of their solution subsequently, the role of the architect will likely seem decelerating, see also Figure 33.

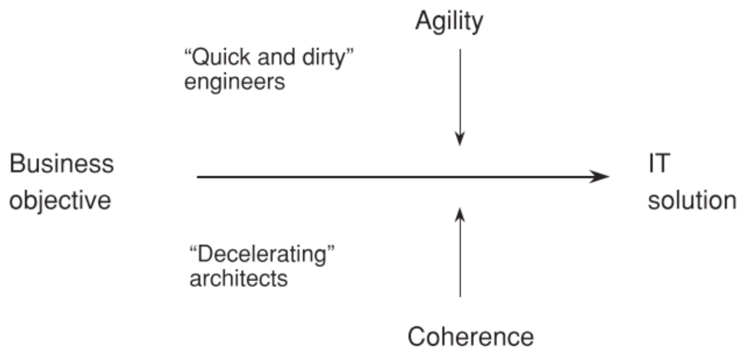

Figure 33: Tension between agility and coherence (Wagter et al. 2005)

With the DYA model Wagter et al. propose approaches to reduce the tension between agility and coherence. The core of the model are four processes, see Figure 34, which connect the dynamic architecture of an enterprise with its governance layer. The primary idea reflected within the DYA model is to support development with and without architectural support. Standard development should make use of established enterprise architecture practices to build solutions which are coherent and aligned with strategic goals of the enterprise. However, when it is mandatory to move fast for strategic reasons, the DYA model suggests an alternative way to build solutions without architectural coherence. The idea is to build these solutions first and tests their business viability. Later on, these solutions can be onboarded to the underlying enterprise architecture to ensure long term coherence.

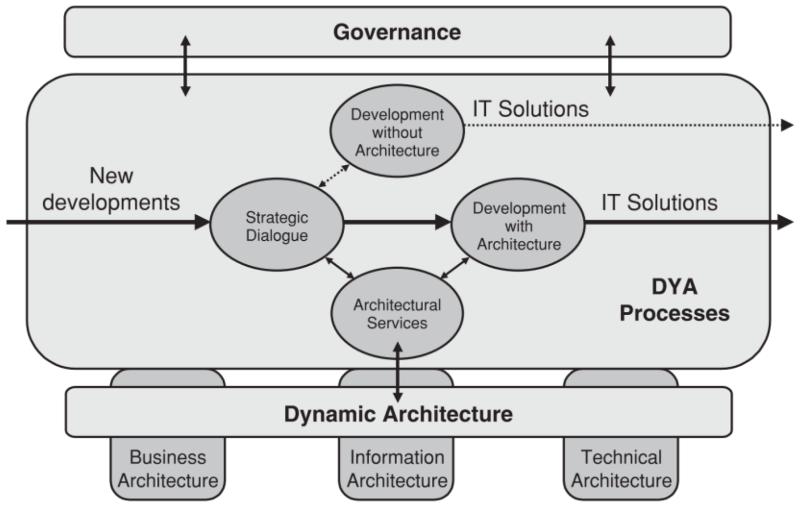

Figure 34: Dynamic Architecture (DYA) Model (Wagter et al. 2005)

The DYA model has a clear focus on the process perspective and does deliberately not discuss architecture content, i.e., the architectural artifacts which are required to build a dynamic architecture. Also, there are some light descriptions of organizational prerequisites and tools which need to be in place to support the DYA processes. However, the process side is the focus of the DYA model. In the early 2000s, there was a clear focus on processes also reflected within popular frameworks such as ITIL (Axelos 2019) or COBIT (ISACA 2019). Most likely, the process focus within the DYA model is related to its time of writing.

4.1.1.1.2 Enterprise Coherence Governance/Framework (ECG/ECF)

One of the shortcomings of the DYA model from today's point of view is its process-driven approach. Roel Wagter, one of the authors of the DYA model, recognizes this circumstance in one of his recent publications and describes that a modern EA approach needs to be performance-driven instead of process-driven. Therefore, Wagter has worked with different researchers and practitioners during the past couple of years within the General Enterprise Architecting (GEA) research program to develop a new architecture approach. According to the GEA, currently, the third wave of architecture is being adopted. This third wave is performance-driven and relies on enterprise coherence governance. The GEA program is the first example of this third wave according to Wagter et al. (Wagter, Stovers, and Krijgsman 2015), see also Figure 35.

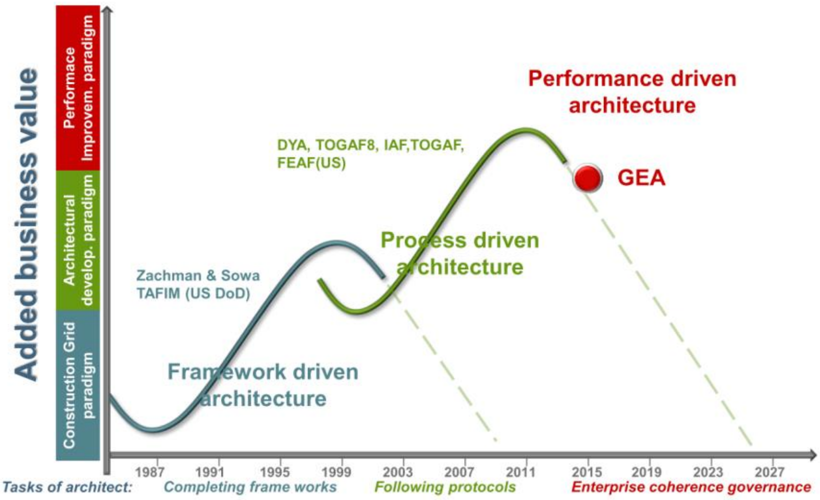

Figure 35: Architecture framework trends according to GEA (Wagter, Stovers, and Krijgsman 2015)

The GEA program attempts to reach a performance-driven architecture by focusing entirely on the business perspective as a starting point. Moreover, they stress "coherence" as a central goal of enterprise architecture instead of "alignment", which is more commonly used. From their point of view, alignment is generally associated with bringing only two concepts in line (e.g., business and IT). The word coherence, however, stresses the alignment of all critical aspects of an enterprise (Wagter, Proper, and Witte 2012).

By today, the GEA program has released various artifacts, which can be used to set up a performance-driven architecture. These artifacts include:

- Enterprise Coherence Framework (ECF) (Wagter, Proper, and Witte 2012), a practice-based framework which enables organizations to ensure coherence between key aspects such as business, finance, IT, etc., see also Figure 36
- Enterprise Coherence Governance (ECG) (Wagter, Proper, and Witte 2014), a governance approach, which offers organizations the instruments to guard/improve coherence during transformation
- Enterprise Coherence-governance Assessment (ECA), an assessment tool, which provides organizations with an indication of the degree to which they govern their coherence

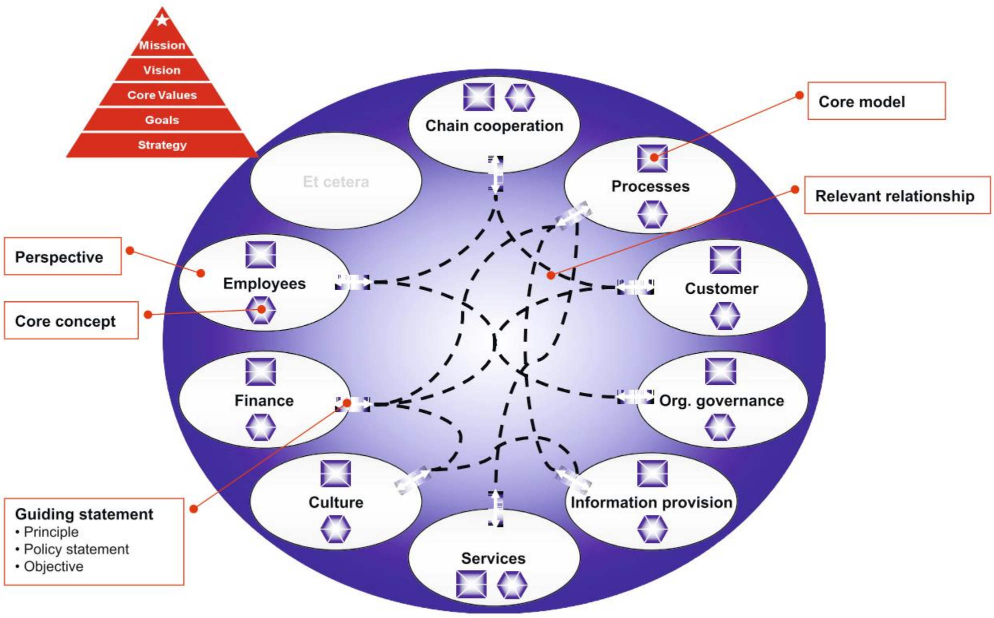

Figure 36: GEA coherence elements (Wagter, Proper, and Witte 2012)

In summary, the GEA offers a good description of current EA challenges, which are in line with the view presented in this thesis. However, even though the authors present their solutions as practice-based and actionable, the published documents rather present theoretical discussions and high-level guidelines. Moreover, some of the materials, especially recently, are presented in Dutch only, which limits the target audience.

4.1.1.1.3 Gill Framework

The Gill framework for Adaptive EA was first published in 2012 (Gill 2012) and has been available in its third version since 2015 (Korhonen et al. 2016). The author of the Gill framework, Asif Qumer Gill, has actively researched and published in the domain of EA throughout the past years.

Unlike other frameworks, Gill does not so much speak about dynamism or agility. The central idea within the Gill framework is adaptivity. According to Gill, an organization and its architecture need to have adaptive properties in current times in order to successfully react to changes.

The starting point within the Gill framework is adaption – Gill speaks about an “adaption first approach” (Gill 2019). The adapting capability within the Gill framework offers services which scan, sense, interpret, analyze, decide, respond to internal and external changes. As a result, projects are identified. The subsequent capabilities take care of defining, operating, managing and supporting identified projects as well as the resulting capabilities. Figure 37 presents a visual overview of the Gill framework.

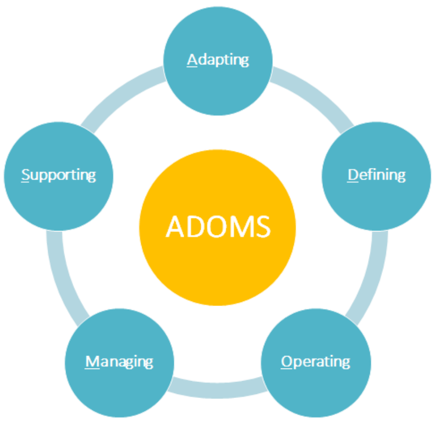

Figure 37: The Gill framework version 3 (Gill 2019)

The Gill framework considers many of the concepts which have been described previously in this thesis. The foundation according to Gill is "adaptive thinking", which includes agile thinking, design thinking, model thinking, resilience thinking, service thinking and systems thinking principles. Hence, from a theoretical point of view, there is some overlap with this thesis, which is why parts of the idea can be re-used throughout the last chapter.

One significant difference between Gill's work compared to the other frameworks presented in this section is the applicability. Gill considers his work as a meta framework, which can be used to develop frameworks. This fact is clearly shown in the structure and content of Gill's work. The theories and ideas presented are mostly considered from a high-level theoretical point of view. As a result, there are little to no approaches which can be directly translated into practice.

4.1.1.1.4 The Open Group Agile Architecture Framework (AAF)

In 2018, the Open Group, which is also the owner of the popular TOGAF framework, released a first white paper of a new Agile Architecture Framework (AAF). The tension arising when practicing EA in environments which also apply agile practices in development, operations, etc. is the core challenge addressed by the AAF. According to the whitepaper, the difficulty in such setups is to balance autonomy and alignment successfully. Maintaining proper autonomy of agile teams while at the same time avoiding chaos and ensuring alignment of the different parts of the enterprise.

The Open Group AAF formulates a vision, which is built around four core ideas (Barbazange et al. 2018):

- "When teams are not autonomous enough, it slows down continuous delivery which limits agility."
- "To avoid chaos, team autonomy must be balanced by alignment mechanisms that cannot rely on a command-and-control culture that otherwise would get in the way of autonomy."
- "New software architecture patterns deeply influence the evolution of Enterprise Architecture."
- "The digital enterprise needs a new architecture body of knowledge, new processes, and governance practices; architecture roles need to be redefined."

Based on the learnings from various case studies, the AAF describes a vision, theories and preliminary guidelines which can help organizations to implement suitable architecture practices for agile environments. However, until the time of this analysis, the published materials of the AAF include mostly the vision and only light coverage of actual approaches which can be directly leveraged. Moreover, the whitepaper from 2018 includes a call to action, which invites the community to contribute to the framework.

The authors of the AAF propose to develop their framework along three topics and describe a set of development epics which are supposed to structure their future work, see Figure 38:

- Autonomy, isolation, and alignment (red)
- Architecture process and roles (blue)
- Architecture body of knowledge (green)

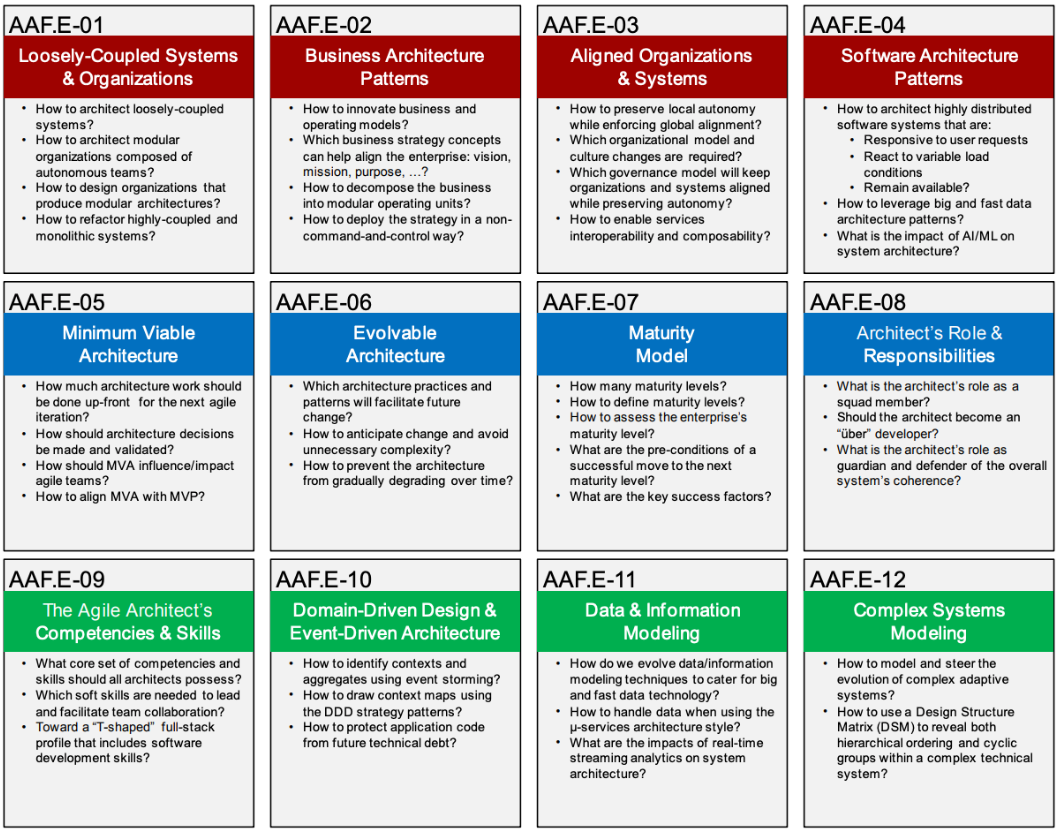

Figure 38: Agile Architecture Framework (AAF) Development Epics (Barbazange et al. 2018)

The AAF presents the framework, which is most closely aligned to the problem statement of this thesis. The fact that it is was published recently, presents an additional advantage since the latest developments are included. However, since the AAF presents mostly a vision until the time of this analysis and there is no actual content for each of its ideas yet, the framework is of limited use for this thesis. Still, especially the structure of the AAF provides valuable input for the model development discussed in the next subsection.

4.1.1.2 Existing Agile Frameworks which include an EA perspective[8]

Agile concepts are rooted in software development. With the Agile Manifesto released in 2001, the principles of agile development have been defined for and made accessible to a broader audience. *Agile methodologies,* refer to the implementation of projects in short iterations typically to release a first version of the product as soon as possible to receive feedback (Beck et al. 2001). They help organizations to accelerate delivery and to enhance the ability to manage changing priorities, which are critical capabilities for dynamic environments (Serrador and Pinto 2015).

Agile practices and the existing frameworks which attempt to summarize these practices cover various domains – and not only architecture. Since the roots of the agile movement are in software development, the starting point is often development practices, related project management approaches as well as principles for collaboration in development teams. However, as soon as projects become more prominent and need to be integrated into a larger environment, architecture quickly becomes a very relevant concern as well (Alzoubi, Gill, and Al-Ani 2015).

Due to the nature and principles of an agile project, the work of an architect in such an environment is significantly different. Madison (Madison 2010) describes and structures architectural interactions in an agile setup. He concludes that the main challenge for architects is to drive long-term outcomes using a series of short-term events. In order to achieve this, the architect needs to ensure his influence at the following critical interaction points: up-front planning,

[8] The content of this section has been partly published as part of the PVM 2018 conference proceedings (Gampfer 2018b).

storyboarding, sprint and working software (Madison 2010). Ultimately, architecture needs to be run in an agile fashion, which is why the term Agile Architecture is frequently used.

When applying Agile Architecture not only in the context of a single team but in an entire organization, there are further implications to be considered. Taking a look at different levels of architecture being practiced, these differ in terms of strategy and technology focus. EA has a long-term perspective by focusing on the strategy of an organization while not providing specific directions regarding individual technology decisions. Solution architects, which are often appointed for specific projects, consume the high-level guidelines provided by EA to drive design and make more specific technology decisions. Detailed design and implementation are the responsibility of technical architects, who have a strong technology focus. See Figure 39 for a graphical comparison of these different architecture roles (Mauersberger 2017).

Depending on the size and structure of an organization, there can be additional architecture roles such as data architect, application architect, etc. The unique characteristic of EA is that it represents the architecture discipline with the strongest strategy focus; it has the broadest scope and highest level of abstraction.

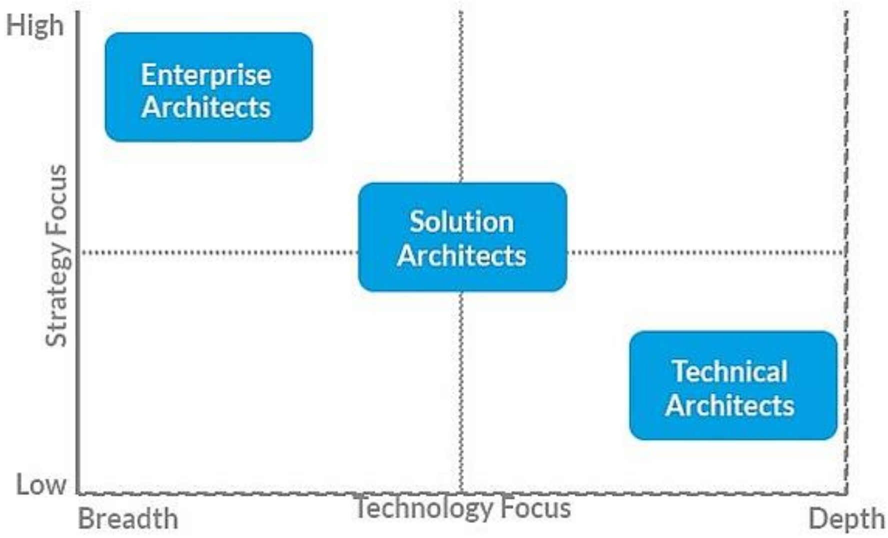

Figure 39: Comparison of architecture levels in terms of strategy and technology focus (Mauersberger 2017)

In order for EA to support agile environments, multiple facets need to be considered. As shown by Speckert et al. in 2013 the most popular EA frameworks back then, namely TOGAF, Zachman and FEA, had not yet incorporated or aligned with agile methodologies (Speckert et al. 2013). Therefore, agile frameworks have started to take the required steps to describe successful architecture practices from their point of view.

In contrast to the description from EA frameworks which tend to have a top-down view, the agile frameworks describe bottom-up solutions instead – i.e., how an organization can successfully manage the overall enterprise architecture on top of a set of distributed agile teams. The approaches described by Large Scale Scrum (LeSS), the Scaled Agile Framework (SAFe) and the Disciplined Agile (DA) toolkit are presented below.

4.1.1.2.1 Large Scale Scrum (LeSS)

Scrum in its basic form is one of the first agile frameworks. It is a process framework, which can be used to manage product development as well as other knowledge work. Scrum includes descriptions of values, principles and practices, which can be applied by a team to implement an agile way of working (Agile Alliance 2019).

The practices described by Scrum are designed to be applicable to the level of a single team – i.e., a group of people who develop a new product. However, as soon as multiple Scrum teams start working together, additional considerations and practices are required. This gap is addressed by the Large Scale Scrum (LeSS) framework. LeSS builds on top of Scrum and provides additional ideas, which help to manage Scrum on a larger scale. More precisely, "LeSS is Scrum applied to many teams working together on one product." (Larman and Vodde 2016).

The LeSS framework includes principles, structures as well as practices for technical excellence, adoption and management for up to eight Scrum teams. Moreover, there is an extension, called LeSS Huge, which is suitable for the adoption of LeSS by even larger organizations. Figure 40 provides a graphical overview of the framework.

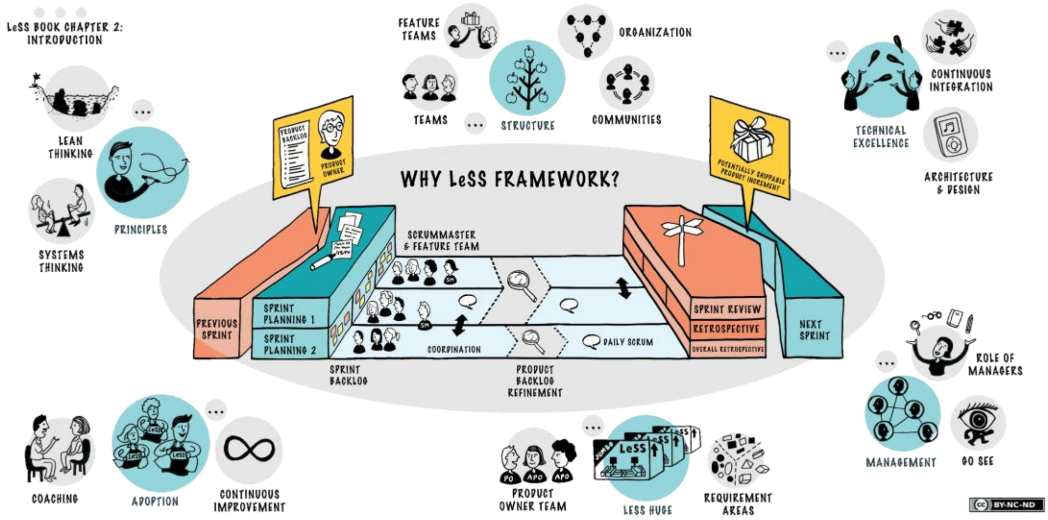

Figure 40: Graphical overview of the LeSS framework (LeSS Company 2019)

As part of the practices for technical excellence, LeSS includes guidance on how to run architecture and design in an organization which applies the LeSS framework.

LeSS claims that when developing and designing software today, the word "architecture" might not be the ideal metaphor. Because of its origins in building and city planning, it can promote misunderstandings: "Buildings are hard and static. Software is soft and dynamic." (LeSS Company 2019). Therefore, the LeSS framework encourages its users to think of (software) architecture differently.

LeSS calls for emergent design which is driven by a development culture involving short feedback cycles. In other words, the evolution of a design should be driven by the people working hands-on on the solution, which results in continues improvement. Vice-versa, anybody who holds an architect role should be, according to LeSS, actively working on the product and thus be involved in the emergent design process.

Also, LeSS actively promotes the idea of flexible design patterns which simplify changes to a platform and thus enables emergent design.

The primary value of architecture, design and related modelling is, according to LeSS, that it can help to drive communication and knowledge exchange between team members – especially between senior and junior team members – and thus enables a culture of learning. Consequently, LeSS promotes the idea of creating architectures and models in joint workshops using flip-charts and write-on walls. Closely related to this, LeSS describes a critical view for any software modelling tools and recommends their usage only for specific use-cases such as reverse engineering. In particular, a negative view of Model-Driven-Development (MDD) and Model-Driven-Architecture (MDA) is presented. MDA and MDD present concepts to automatically translate conceptual models into application code. LeSS claims that these do not yield sufficient benefits and that many MDA/MDD tool vendors do not even use their tools for their own development. (LeSS Company 2019)

In summary, LeSS presents a good number of ideas and approaches for design and architecture, which can be applied in environments applying agile development practices. However, for the context of this thesis, they are useable only to a limited extent since LeSS focuses on low-level (technical) architecture. There are no explicit approaches described to apply the concepts on a large-scale enterprise level. Still, some of the ideas, like flexible design patterns as well as the strong focus on communication and collaboration, are concepts which might help to increase the effectiveness of enterprise architecture in dynamic environments.

4.1.1.2.2 Scaled Agile Framework (SAFe)

The Scale Agile Framework (SAFe) was first published in 2011 with the mission to enable enterprises to build better software and systems. Today, in 2019, it is available in version 4.6 and has become one of the agile frameworks which is applied by large enterprises worldwide. In particular SAFe describes the means of how to apply agile practices not only at a team-level but at an enterprise scale (Scaled Agile Inc. 2019).

As also depicted in the graphical overview, see Figure 41, the current version of SAFe covers five major areas:

- *Lean-Agile Leadership* presents the foundation since advancing and applying lean-agile leadership skills on the management level is required to drive the significant organizational change envisioned by the framework.
- *Team and Technical Agility* describes technical practices such as built-in quality, behavior-driven development, agile testing and test-driven development, which can be applied on the operational level to drive agility.

- *DevOps and Release on Demand* shows how agility can be brought to operation teams by building the continuous delivery pipeline and implementing DevOps as well as release and demand practices.
- *Business Solutions and Lean Systems Engineering* describes engineering practices, which mainly apply to very large environments and enable enterprises to build the largest software applications and cyber-physical solutions.
- *Lean Portfolio Management* includes executing portfolio vision and strategy formulation, chartering portfolios, creating the vision, lean budgets and guardrails, as well as portfolio prioritization and road mapping.

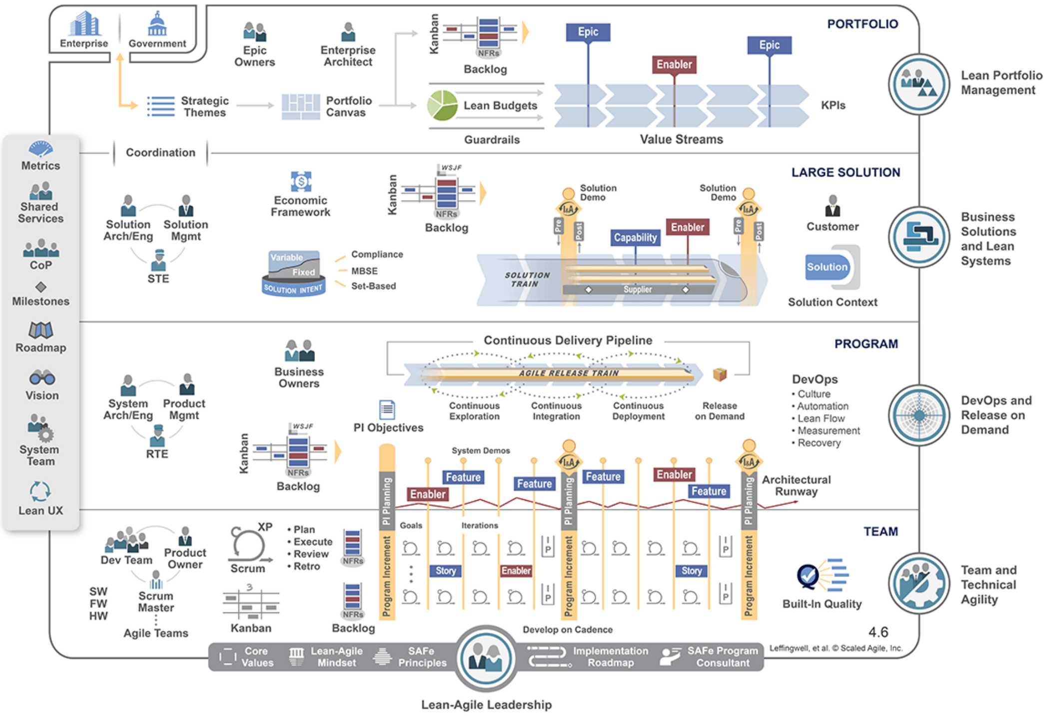

Figure 41: Overview of the scaled agile framework (SAFe) (Scaled Agile Inc. 2019)

In alignment with SAFe's Lean-Agile principles, the framework promotes the idea of Agile Architecture. Its core idea is an architecture style based on coaching, which fosters autonomous decision making.

Also, SAFe recognizes the critical role of architects in many of today's organizations when it comes to planning and implementing significant changes. Therefore, SAFe states that architects are an important group, which can help enterprises during an agile transformation, e.g. when adopting frameworks such as SAFe.

Similar to LeSS, the SAFe framework has its origins in and its focus on software development. Therefore, a lot of the ideas and practices presented relate to low-level technical architects, i.e., how to take architectural decisions in agile teams during development. Still, SAFe in its current version also includes a specific section on EA, which describes how EA can and should be practiced in an enterprise applying the SAFe framework. In particular, the key aspects of EA strategy are described for an agile environment. SAFe describes the following five key aspects, see also Figure 42 (Scaled Agile Inc. 2019):

- *Choice of technology and usage* – research, understand and choose appropriate technologies which are recommended to be used throughout the enterprise.
- *Solution architecture strategy* – ensure alignment between enterprise-wide and project level architecture
- *Infrastructure strategy* – work with system architects in order to provide an overall strategy for infrastructure, which is a shared technical platform for different stakeholders in the enterprise
- *Inter-program collaboration* – ensure alignment and enable collaboration across teams, e.g. by organizing joint design workshops and setting up communities of practice
- *Implementation strategy* – build the foundation for an agile implementation strategy which can be used by agile teams

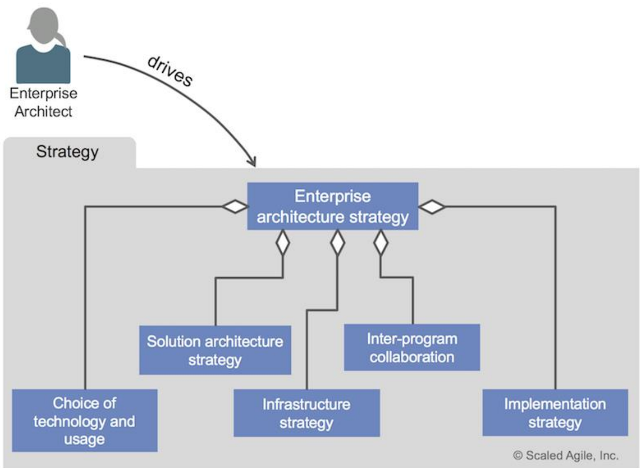

Figure 42: Five elements of enterprise architecture strategy according to SAFe (Scaled Agile Inc. 2019)

In summary, SAFe provides a good overview of the challenges for EA in agile environments and initial ideas on how to address them. Still, it is evident that the original focus of the framework is development and not EA. While the five aspects of EA strategy provide initial guidance on how to set up EA in an enterprise which applies SAFe, there is a minimal amount of recommendations which can be directly translated into actual EA practices. Therefore, the primary value of SAFe in its current version for an enterprise architect is advice on how EA could be integrated with agile practices in an enterprise overall.

It is worth noting though that the ideas around how to build an architecture practice based on coaching and autonomous decision making are in line with the core ideas presented by the LeSS framework There seems to be a pattern regarding the question how agile practitioners would like to shape the architecture profession.

4.1.1.2.3 Disciplined Agile (DA) Toolkit

The development of the Disciplined Agile (DA) toolkit was initially started in 2009 at IBM Rational with the goal to holistically describe different agile delivery practices and how they can be combined (Ambler 2010). In 2012 version 1.0, called the Disciplined Agile Delivery framework, was released and handed over to a consortium – the Disciplined Agile Consortium – which has maintained it ever since (Ambler and Lines 2012).

By today, version 4 of DA is released, which has an extended scope compared to the first version. While initially the focus was only software delivery practices, the current version also considers practices for operations, IT management as well as non-IT areas, see Figure 43 for a graphical overview. With this scope, DA shares similar objectives with LeSS and SAFe since all of them describe approaches on how agile practices can be brought from the development team level to the wider enterprise.

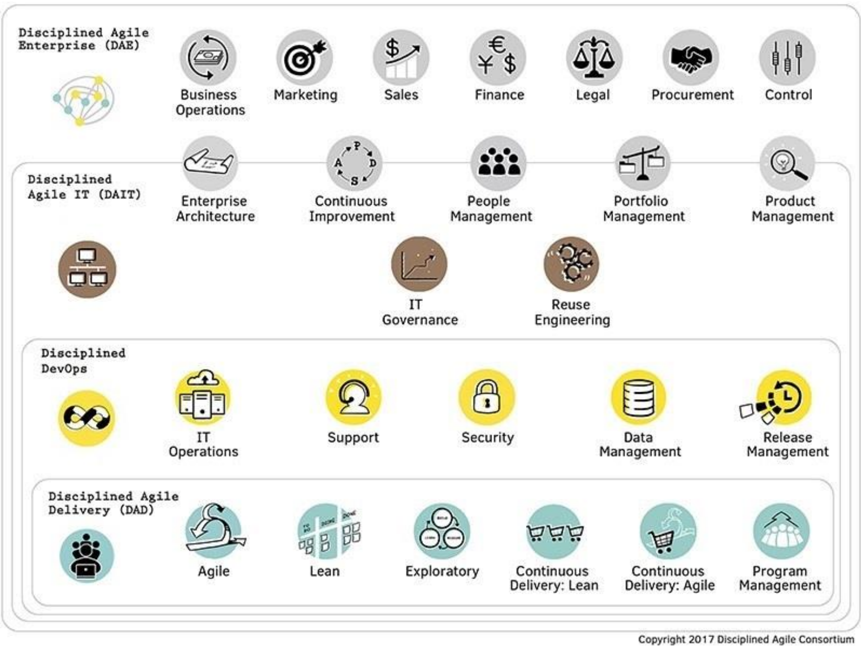

Figure 43: The Disciplined Agile (DA) toolkit (Lines and Ambler 2019)

Another recent change introduced with version 4 of DA is that DA does not consider itself a framework anymore but describes itself as a toolkit instead. According to the authors, the word "toolkit" characterizes the content of DA in a much better way, since DA does not prescribe what to do. Instead, it provides several options to choose from and presents only lightweight guidance (Lines and Ambler 2019).

The core of the latest DA toolkit is still focused on delivery and specifically software development. On top of this core, DA describes practices for DevOps, which can help organizations to transfer agile ideas from development to operations teams. The next level of DA describes how new enterprise IT functions can be covered with the same ideas. Finally, the fourth part of DA shows how agile practices can be applied to non-IT areas as well, see Figure 43.

DA also includes a section on architecture and specifically discusses EA as well. Compared to the other two agile frameworks investigated as part of this thesis, namely LeSS and SAFe, DA includes the strongest and most explicit coverage of EA. Figure 44 provides a graphical overview of the EA process according to DA.

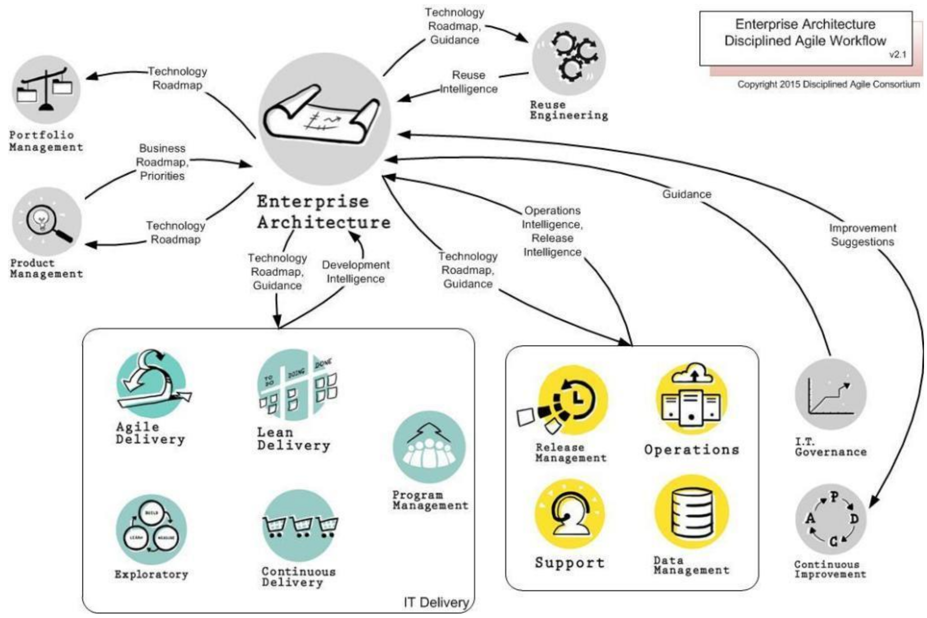

Figure 44: EA process according to Disciplined Agile (Lines and Ambler 2019)

The central message of DA regarding EA is that an Enterprise Architect working in an agile environment must be willing to work collaboratively and flexibly. There are various interactions with IT and non-IT teams for EA, which need to be maintained in this way, see also Figure 44. DA points out that the result should be an agile EA practice which creates flexible, easily extended and easily evolved architectures.

In order to achieve an agile EA, DA emphasizes the need for a new architectural mindset, which is much in contrast to the top-down, command and control orientation promoted by earlier EA frameworks. The core characteristic of an agile Enterprise Architects (EAs) mindset is collaboration. DA claims that agile EAs need to spend the majority of their time working actively with stakeholders in a learning-oriented and sharing way. In order to work effectively with various groups, they need to be multidisciplinary and business focused. DA also describes EAs as practical, pragmatic and technical so that they can actively engage with stakeholders (Lines and Ambler 2019).

While DA includes the strongest coverage of EA compared to the other agile frameworks considered in this thesis, it quickly becomes evident that the content does not provide a holistic picture of EA. To some extent this is due to the "toolkit" approach of DA – the descriptions of EA within DA are only semi-structured today and to some extent only in individual blog posts. Furthermore, DA references existing EA frameworks such as TOGAF or Zachman which can be leveraged. Therefore, it can be concluded that DA does not aim to replace existing EA frameworks, but much rather tries to point out the steps required to integrate them in a dynamic environment.

4.1.2 Model Development

By examining the 55 relevant publications as well as the seven previously presented frameworks, explicitly and implicitly described EA approaches were extracted which can be utilized to improve the effectiveness of EA in dynamic environments. Using line-by-line coding, approaches have been identified, such as "establish architectural thinking" or "build modular architectures".

At this point Philipp Mayring's (Mayring 2015) inductive categorization techniques are applied. In particular, paraphrasing, generalizing and reduction are used to summarize the content in a consumable manner. The extracted EA approaches are inductively clustered into a category system and the result is validated based on original material.

The qualitative data analysis tool NVivo 12 (QSR International Pty Ltd 2019) is used to extract, code and cluster the EA approaches. The reviewed publications and individual sections within them are tagged in NVivo. This results in a list of EA approaches with a preliminary frequency ranking, which states how often these approaches are presented within the documents.

Considering the EA approaches identified from the publications and the frameworks, there are some common topics and relationships, which can be recognized and thus present the foundation to develop an initial model within this thesis. The identified EA approaches are clustered into four dimensions:

- *EA Competency*, which considers the organizational setup of EA and, in particular, how the role of the architect needs to evolve in modern organizations. This dimension addresses the question of **who** in the organization is working on EA. There is a close link between EA competency and the organizational culture. This dimension is especially stressed in the ECF and various publications (Aier, Labusch, and Pähler 2015; Drews et al. 2017; Winter 2016).

- *EA Methodology*, which includes the architecture development and implementation processes as well as the architectural governance approach. This dimension addresses the question of **how** architecture is run in the organization. The methodology (i.e. process) perspective is called out by the DYA model and is represented as a domain within the vision of the AAF. Moreover, there is a number of individual publications which highlight this dimension (Abraham, Aier, and Winter 2012; Saat, Aier, and Gleichauf 2009).
- *EA Content*, which includes design principles, architecture patterns and blueprints which can be applied to build adaptive architectures and are thus more appropriate to react to changes. This dimension addresses the question of **what** is the output EA. EA content is a central element of the AAF and is also slightly touched by the DYA model. On a meta-level, it is also present in the Gill framework. Also, there is a number of individual scientific publications which focus on this dimension (Nadareishvili et al. 2016; Sturtevant 2017).
- *EA Tools*, which considers the conceptual and technological tools required to support modern EA approaches. This dimension addresses the question of **with what** architecture is being created and maintained. EA tools related approaches are highlighted by the AAF and by the Gill framework. Moreover, there are several individual publications which introduce ideas related to this dimension (Gill 2015; Trojer et al. 2015).

Further, during the extraction and clustering it was recognized that there are two groups of approaches: theoretical and practical. The focus of this chapter is practical approaches. However, the theoretical lenses identified are still deemed valuable since they can be considered the backbone of the practical approaches. Therefore, the theories are collected in a separate fifth dimension.

Figure 45 summarizes the discovered dimensions and presents the foundation for the model developed within this thesis.

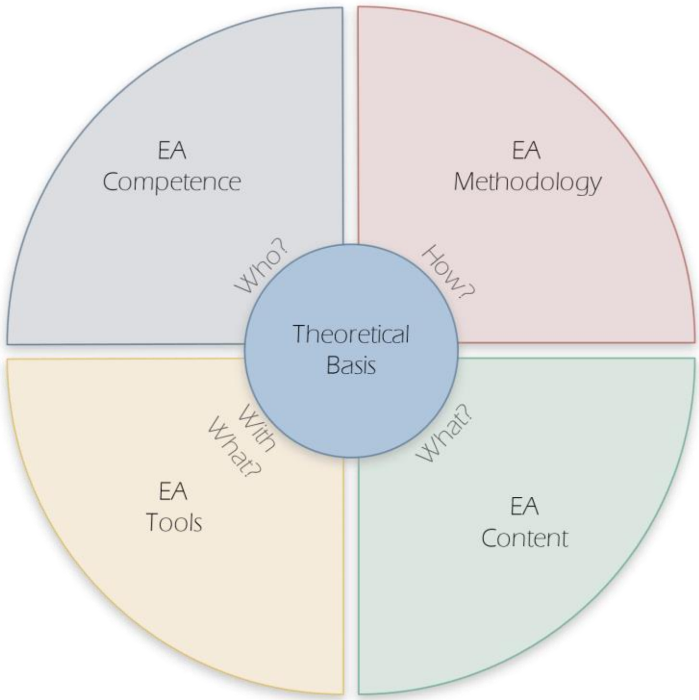

Figure 45: Summary of discovered dimensions

The theoretical approaches identified from literature are identified separately and are listed in Table 11 including the number of times they were mentioned in the articles considered. It is evident that chaos and complexity theory is by far the most popular theoretical lens in this domain, which serves as a confirmation of the research approach and model developed in chapter 3 of this thesis.

Moreover, this theoretical consideration reveals the potential for further research in the area of EA. Raphael Schilling (Schilling 2018) has recently published a paper structuring and presenting five theoretical lenses more closely to understand the dynamic nature of EA. These five are included in the list presented in Table 11. The additional approaches could be considered to extend the work of Schilling. However, the goal of this thesis is to provide actionable approaches for enterprises. A detailed theoretical consideration will not be provided at this point but presents much rather an opportunity for future research.

Table 11: Theories applied in analyzed literature

Theory	**Number of References**
Chaos and Complexity Theory	9
Open Systems Theory	4
Archetype Theory	3
Cooperative Learning Perspective	3
Living Systems Thinking	3
System-of-Systems Theory	3
Actor-Network Theory	2
Control Theory	2
Cynefin Framework	2
Dynamic Capabilities Framework	2
Institutional Theory	2
Resource-Based View	2
Service Science	2
Improvisational Capabilities	1
Morphogenetic Theory	1
Sensemaking Perspective	1

4.1.3 Validation and Exploration

In this subsequent step, the goal is to validate the identified approaches from literature and, furthermore, to explore additional approaches from the practitioner's point of view. Due to the formative nature of this goal, a series of semi-structed expert interviews is conducted with industry professionals (Atteslander 2010).

A total of 13 interview candidates were identified from expert groups on the social media platform LinkedIn as well as by announcing the interviews during a presentation at the IT-Enterprise Architecture Management 2019 in Vienna (Gampfer 2019). The interview candidates selected for this part of the research reflect opinions from both in house architecture, as well as external consultants who have run EA projects for multiple enterprise customers.

With the identified candidates, interviews were conducted up to the point when no additional information could be derived from additional interviews, hence up to the point of theoretical saturation (Glaser and Strauss 2010). This resulted in a total of seven conducted interviews, see details in Table 12.

Table 12: Overview of conducted expert interviews

Expert ID	Domain	Size of the Organization	Years of Experience with EA	Position in the Organization
Expert 1	Manufacturing	144000 Employees	14	Vice President IT
Expert 2	Manufacturing	46000 Employees	20	Senior EA Consultant
Expert 3	Finance	1000 Employees	12	Enterprise Architect
Expert 4	Oil and Gas	2000 Employees	7	Enterprise Architect
Expert 5	Various	Various	20	Senior EA Consultant
Expert 6	Education	Various	21	Senior EA Consultant
Expert 7	EA Tool Provider	Various	10	CEO

The interviews were run in a semi-structured fashion (Flick 2018). This approach was chosen in order to ensure that all the essential topics are covered. At the same time there was room left for open discussions with the experts

The structure of the interview was divided into six sections: one introductory section to validated demographics, one section to examine the expert's understanding of today's pace of change and how it affects the work of EA and finally four sections to cover the previously introduced dimensions, EA competence, EA methodology, EA content and EA tools. Table 13 provides an overview of the interview sections and the related questions. In advance of the interviews a summary of the questions was provided to the experts, so they had the opportunity to prepare, see appendix A.3 for the summary provided to the interviewed experts.

Table 13: Guiding questions for semi-structured interviews

Section	**Description**	**Questions**
A	Demographics	1. What is your (customer's) enterprise demographic? 2. What is your personal experience with EA?
B	Environment Dynamics and EA	3. If you consider the frequency of changes in your (customers) enterprise, has it accelerated throughout the past two decades? 4. What is changing in particular technology, business or both? 5. What is the impact of these changing conditions on EA in your opinion?
C1	EA Competence (Who?)	6. Which capabilities does an EA organization require to be successful given the conditions described in B? 7. How can this be implemented in your opinion?
C2	EA Methodology (How?)	8. What are the requirements towards an EA methodology which is successful given the conditions described in B? 9. What are the approaches which can address these requirements?
C3	EA Content (What?)	10. What are the requirements towards architecture content given the conditions described in B? 11. Which architectures can address these requirements?
C4	EA Tools (With what?)	12. Which tools are required to support the answers provided for sections C, D & E?

The interviews were recorded, transcribed and ultimately imported into the very same existing NVivo project. This approach allowed to code analyze the interviews side-by-side with the previously discussed literature. Based on Mayring's deductive categorization (Mayring 2015), the EA approaches were identified and added to the previously defined scheme.

From the interviews, it became evident that, while there are differences among the experts based on the industry, history and age of a company, there are nevertheless several standard views and related EA approaches, on which many interview partners agree. Also, there is agreement on the fact that there are enterprises which are already much better at effectively handling EA in dynamic environments. Namely the companies Netflix, Spotify and Zalando were mentioned multiple times in the interviews as a potential reference. Therefore, in addition to the facts and opinions derived directly from the expert interviews, case studies and reports from these companies were considered for the following exploration of EA approaches for dynamic environments.

The detailed results from the work on RQ3 is documented in the appendix of this thesis. Appendix A.4 provides the combined and complete coding results from the qualitative content analysis down to the node level.

4.2 EXPLORATION OF EA APPROACHES FOR DYNAMIC ENVIRONMENTS

The investigated literature revealed several EA approaches which present a foundation for the work in this chapter. In the interviews, these approaches could be initially validated from the practitioners' point of view and also extended with current views from experts in the field.

This section provides an overview of the approaches identified. The subsequent subsections are structured according to the dimensions identified – namely EA competence, EA methodology, EA content and EA tools. Each one of the identified EA approaches is logically mapped to one of the dimensions.

4.2.1 EA Competence

After performing the qualitative analysis, there are 74 codes assigned to the dimension EA competence, which have been clustered into four approaches for EA in dynamic environments. Figure 46 provides an overview of these approaches and their relative frequency considering references in the literature and interviews analyzed for this part of the thesis.

The approach of decentralizing EA competence and more generally architecture competence overall receives the highest level of attention in this dimension. The related idea of Architectural Thinking is strongly represented as well. It has the goal to build up competence not only in the form of specific individuals in the enterprise but broadly as a skill applied by different roles. For larger enterprises, especially those that have a traditional background, the approach of multi-speed EA is often referenced as well. Finally, the fourth approach considers the people level of architects. Dynamic environments seem to require a shift in the personal mindset of architects as well.

Each of the EA competence approaches is presented subsequently in detail.

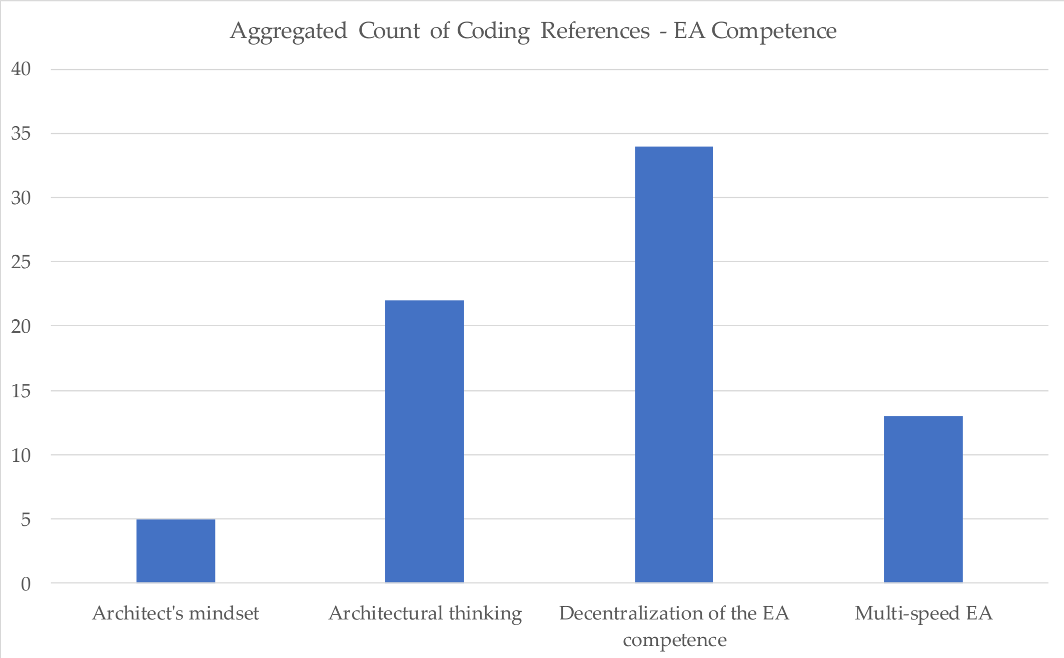

Figure 46: Overview of approaches in the dimension EA competence

4.2.1.1 Decentralization of the EA Competence

The general discussion around centralization and decentralization of management practices has been ongoing for several decades and is certainly not specific to the discipline of EA. Results from this discussion provide a foundation to understand the implications of a decentralized EA competence better. Siggelkow and Levinthal (Siggelkow and Levinthal 2003) present a scientifically well-recognized model based on complexity theory and complex adaptive systems (CAS) which analyzes the effect of centralization and decentralization on management effectiveness. Based on an extensive simulation, they conclude that neither complete centralization nor decentralization is most effective. Instead, organizations which can temporarily decentralize and re-integrate afterwards show the best performance results. Whenever there is a need to be responsive, decentral structures are more effective. At the same time, central structures can help to avoid local optimizations and unnecessary efforts while they also ensure alignment.

Traditionally, EA is considered and set up as a centralized function, for example, in the form of a global architect who runs EA in a command and control fashion. In such a setup, stakeholders need to present their proposals to the architects and he decides centrally for the entire organization whether proposals are approved or not. Considering the results from Siggelkow and Levinthal, this central management approach is not most effective – especially in dynamic environments. However, a complete decentralization is not most successful either.

Janssen and Kuk (Janssen and Kuk 2006) apply CAS theory to the question of whether central or decentral EA is more effective. They conclude that one key ingredient to a successful EA practice is finding the right balance of central and decentral layers. The characteristics of the environment have to be considered when determining this balance. The more responsive an organization needs to be, the more decentral the EA competence should be set up. For dynamic environments, this calls for a light-weight central EA practice and empowered teams which have the required skills, knowledge and mandate to take architectural decisions on their own. This is in line with the approach promoted by the agile framework SAFe, which states that one should"[c]entralize strategic decisions and decentralize everything else" (Scaled Agile Inc. 2019).

When considering the three reference organizations mentioned by the interviewed experts, namely Spotify, Netflix and Zalando, the theme of a decentral EA competence based on empowered teams is evident as well (Bloomberg 2014; Kniberg and Ivarsson 2012; Lemke, Brenner, and Kirchner 2017)

4.2.1.2 Architectural Thinking

For the current decade, the concept of Architectural Thinking (AT) has received increased attention. Ross and Quaadgras (Jeanne W. Ross and Quaadgras 2012) describe AT as the way of thinking and acting throughout an organization, which is specifically not restricted to architects and systems developers only. The core idea is that architectural aspects such as basic system design and evolution principles are included by everybody in their day-to-day decision making.

There is a dependency between AT and the previously presented idea of decentralizing EA competence. AT takes the idea of a decentral EA one step further by distributing the competence not only to architects and developers but to everybody in the organization.

According to Winter (Winter 2014), AT has a positive impact on the ratio of effort and impact when implementing and running EA. When trying to raise the maturity of EA above a certain threshold, EA without AT will likely produce much effort without sufficient benefits. This becomes particularly evident outside IT related stakeholder groups, e.g., there can be high enforcement efforts for EA to ensure that principles are followed by business groups. In contrast, an approach based on AT mainly addresses business and other non-architect stakeholders with a lightweight, less formalized and utility-centred approach which supports them to follow architectural guidelines with their decisions as well (Winter 2014). Table 14 depicts an overview of the differences between traditional EA and AT.

In order to successfully establish AT in organizations, there are several preconditions which need to be fulfilled. Most importantly this comes down to the cultural perception of architecture and particularly EA within the organization. Individual stakeholders need to be convinced that complying with EA raises their social status, makes them more efficient, is a strategic benefit for the overall enterprise while it is also transparent and useful to themselves (Winter 2016).

Table 14: Traditional EA and Architectural Thinking (Winter 2014)

Differences	Traditional EA	Architectural Thinking
Driver/Owner	Architects	Individual decision-makers
Hosting organizational unit	Primarily IT; sometimes corporate center	Business lines
Addressed stakeholders	Various (IT, corporate management, business lines)	Individual decision maker (= owner)
Benefit type	Enterprise-wide, long-term: "what's in it for the enterprise?"	Local utility, medium-term: "what's in it for me and why is it beneficial for all of us?"
Threads for benefit realization	'Ivory tower' → engage architects in change projects	'Local' architectures → bottom-up consolidation
Method support	Dedicated, sophisticated methods and tools: expert users!	Lightweight, pragmatic (e.g., principle catalogs, calculation templates, charts): users are not architecture experts!

Finally, if AT is successfully established, the benefits will be evident particularly in dynamic environments. Given that an EA competence based on AT is strongly decentral, organizations running AT are highly responsive while at the same time can avoid local optimizations with bottom-up consolidation.

4.2.1.3 Multi-Speed EA

In recent years, the idea of splitting enterprise IT organizations into two organizational parts which run two different delivery speeds – slow and fast – has received increased attention. Notably, the interest spiked when Gartner put the topic on their 2014 CIO agenda (Gartner 2014).

By now there are several real-life examples of this organizational setup, which is referred to as Two-Speed IT or Bimodal IT (Horlach, Drews, and Schirmer 2016). The core idea is to distinguish between traditional IT and digital IT.

Traditional IT is run stably and reliably to ensure that the most critical and central services of an enterprise are available. In contrast, Digital IT is run in an agile and fast-paced way in order to be competitive in the age of digital transformation. Table 15 provides a comparison of both approaches.

Table 15: Bimodal IT – Characteristics of Traditional and Digital IT (Horlach, Drews, and Schirmer 2016)

Traditional IT (mode 1, industrial / core IT)		**Digital IT (mode 2, agile IT)**
Stability	*Goal*	Agility & speed
IT-centric	*Culture*	Business-centric
Remote from customer	*Customer proximity*	Close to customer
Performance and security improvement	*Trigger*	Short term market trends
Performance of services	*Value*	Business moments, customer branding
Security & reliability	*Focus of services*	Innovation
Waterfall development	*Approach*	Iterative, agile development
Systems of records	*Applications*	Systems of engagement
Slow	*Speed of service delivery*	Fast

An overall two-speed or bimodal approach has substantial implications for EA as well. Interestingly, the underlying idea has been discussed in the domain of EA much earlier already. For example, Wagter et al. (Wagter et al. 2005) describe two approaches in the process perspective of their DYA model:

1) Development with architecture
2) Development without architecture

The ideas presented in the DYA model can be easily aligned with the overall idea of a two-speed IT. Traditional IT is developed in close alignment with EA (DYA, development with architecture) while Digital EA has the freedom of trying concepts and approaches which might be incompliant with current EA principles but are later onboard once they have proven to be viable from a business point of view (DYA, development without architecture).

By now, there are various scientifically-focused views as well as practitioner ones on how EA can be run in a two-speed fashion (Abraham, Aier, and Winter 2012; Drews et al. 2017). Mesaglio and Hotle (Mesaglio and Hotle 2016) take the idea one step further with their pace-layered application strategy and IT organizational design. They describe three instead of two speeds and differentiate: systems of record (slow pace), systems of differentiation (medium pace) and systems of innovation (fast pace). From the conducted expert interviews, it became evident that even three types of speed might not be enough in some cases. Therefore, EA needs to be able to support a multi-speed organization, which requires a multi-speed EA setup.

In the conducted expert interviews, the idea of multi-speed EA was mentioned several times. Depending on the situation and context of an enterprise, a multi-speed approach can be the only viable option, even when a dynamic environment is given. For example, the experts three and four from the finance and energy vertical stated that they would never run EA entirely in a fast-paced and agile way like streaming providers such as Netflix or Spotify. This is because traditional enterprises, especially in verticals like finance and energy, have a different context in which they operate EA. This context can include:

- traditional organization structures which cannot be changed to an agile setup on short-term basis.
- a technology stack which does not allow fast-paced changes.
- regulatory requirements which do not allow fast-paced and little controlled changes to the architecture.

These contextual factors need to be considered when designing or redesigning the EA discipline in traditional enterprises. As a result, also traditional approaches are likely valid in some areas. At the same time, other areas might benefit from a fast-paced approach. Therefore, a multi-speed EA approach holds much opportunity for these enterprises. It enables them to run fast-paced architecture in parallel to their traditional setup, try new ideas and therefore enables them to remain competitive with new competitors.

4.2.1.4 *Architects Mindset*

Dynamic environments have implications for EA in various areas. This thesis presents different considerations for EA competence, methodology, content and tools. Many of these approaches need to be designed, lead and run by architects. As particularly highlighted by experts one and six, since the changes will be fundamental in many cases, architects working successfully in dynamic environments will require new skills, knowledge and ultimately a different mindset than traditional architects.

In terms of skills required, the most substantial change is that architects need to feel comfortable in uncertain situations. They might not have 100% of the information and still need to be able to take decisions effectively. Traditional, upfront architecture is able to take a lot of time – i.e. multiple months – to perform thorough analysis and ultimately come to a decision. Given the available extensive timeframe, the work can be done by a small group or even by a single architect. In contrast, in dynamic environments and for related fast-paced architectures, this extensive time is not available. As a result, architects need to be able to think faster and, if required, involve multiple stakeholders to distribute the work. To ensure effective collaboration, architects in dynamic environments need to have strong communication and collaboration skills.

The knowledge required by architects in dynamic environment is different as well. Due to the need to take decisions more quickly, it is a major advantage if architects have relevant up-to-date knowledge directly available firsthand. This includes technical knowledge and business knowledge. In terms of technical knowledge, architects need to have a broad overview of available as well as upcoming technologies, standards and their maturity. This knowledge enables them to judge quickly whether new technical developments are suitable for their enterprise and whether the right time has come to invest in a certain technology. At the same time, a broad and up-to-date business knowledge is beneficial as well. This includes current information about their own enterprise but also latest market developments. Having this knowledge enables the architect to take faster and better decisions including the business perspective.

While both skills and knowledge are important pieces, the overall change for the architecture role goes one step further. Lines and Ambler (Lines and Ambler 2019) report on a new mindset which is required for enterprise architects in dynamic environments. Similarly, Crabb (Crabb 2018) points out a very different way of working. Probably the strongest shift is in the way in which architects interact with their peers and stakeholders in the enterprise. While in traditional setups, they are able to perform work in isolation, dynamic environments require architects to work much more openly and collaboratively.

4.2.2 EA Methodology[9]

When working in dynamic environments, architecture methods deserve special considerations as well. With the rise of agile software development and project management practices, some methods on the project level have significantly changed. While in traditional setups, e.g., applying waterfall methodologies, the architecture is defined upfront, it is developed and adjusted continuously when applying agile methodologies. Therefore, architecture in such environments requires different approaches (Madison 2010).

While there are several existing publications which already address the topic of Agile Architecture in the scope of individual projects, there are much fewer studies covering the topic from an overarching, enterprise point of view. In today's dynamic environments, it is essential more than ever, especially for large organizations, since a lack of Enterprise Architecture in these environments will likely lead to several problems such as unnecessary rework, inconsistent communication and locally focused architecture, design and implementation (Gill and Qureshi 2015).

After performing the qualitative analysis, there are 83 codes assigned to the dimension EA methodology, which are clustered into six approaches for EA in dynamic environments. The broadest coverage in this dimension concerns the idea of promoting self-organization and self-control. Moreover, the approach of integrating EA and agile software development practices is considerably covered as well. A third approach, that is repeatedly presented, is the idea of a lightweight EA process that is run by the central EA function. Also, decentralization plays a role in the methodological dimension as well. The question of how architectures in

[9] The content of this section has been partly published as part of the PVM 2018 conference proceedings (Gampfer 2018b).

a dynamic environment should be measured, presents another building block. Finally, the idea of emergent behavior and how it can be best-managed and exploited is covered as well.

Figure 47 provides an overview of these approaches and their relative frequency considering references in the literature and interviews analyzed for this part of the thesis.

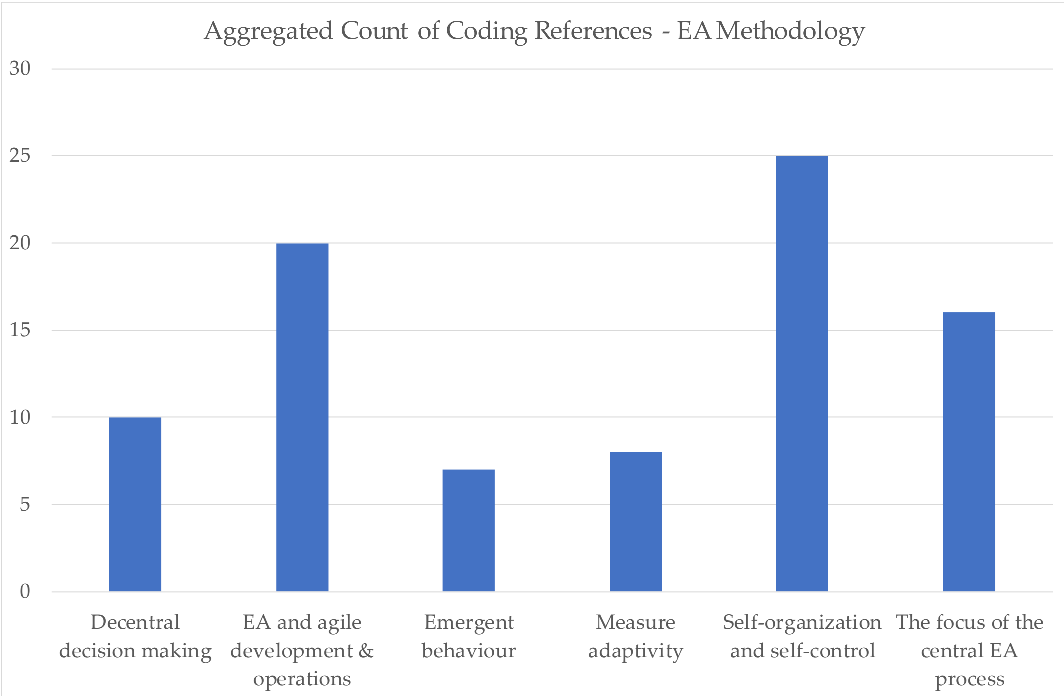

Figure 47: Overview of approaches in the dimension EA methodology

4.2.2.1 Self-Organization and Self-Control

Traditionally, EA is set up in a command and control fashion. When looking at the process, e.g., promoted by TOGAF (The Open Group 2013) the idea is to define architecture up front and to formally verify that projects are implementing it afterwards. For dynamic environments, both the literature as well as the interview results promote the importance of informal modes of control over formal ones.

Schilling et al. (Schilling, Haki, and Aier 2018) have systematically analyzed EA control mechanisms in a recent study. Their theoretical basis is control theory, which they apply to distinguish between formal and informal modes of control.

Moreover, they use the organizational sensemaking process as a foundation to consider how EA control mechanisms in an organization evolve based on a long-term case study. Schilling et al. find that with increasing maturity and adoption of EA in an enterprise, there is an increased emphasis on informal modes of control. At the same time, these informal modes of control lead to increased appreciation of EA, especially among non-architects. Hence, it can be concluded that a focus on informal modes of control can help to improve the perception of EA in the enterprise. As previously described, a positive perception of EA is a crucial ingredient to drive a distributed EA competence and organization-wide Architectural Thinking, which bears advantages in dynamic environments.

Ultimately, the goal is to achieve a culture of architectural self-organization and self-control. In this culture, individual teams have the competence and accept the responsibility to align their product or project with the overall architecture (Korhonen et al. 2016). However, this culture will not naturally emerge by itself. EA needs to foster this culture in order to exploit the advantages actively. The following actions can help to achieve this:

- Actively involve architects in product or project teams, which will help them speed up design as well as implementation (Drews et al. 2017) and consequently improve the perception of EA.
- Focus on recommendations instead of strict guidelines (Schilling et al. 2017), which empowers local decision-makers, therefore, encourages self-control.
- Enable teams so that they can take better decision on their own (Korhonen et al. 2016)

Moreover, the approaches presented subsequently on running the EA methodology in a dynamic environment can all foster the intended culture of self-organization and self-control.

4.2.2.2 EA and Agile Development / Operations

For the past two decades, agile practices have actively been on the rise in the enterprise context. According to the state of the agile report from 2017 (VersionOne Inc. 2017), 97% of organizations practice agile methods, while a quarter even runs all of their teams completely agile. The agile movement originally started in the software development area. Today, several organizations have decided to go one step further and extend agile ideas to operations teams resulting in the DevOps movement (Puppet and Dora 2017).

Especially for dynamic environments, it is an obvious choice to consider agile practices because they help to mitigate some of the critical challenges. Among these challenges, there are frequently changing conditions and requirements. Therefore, it is very likely that EA in dynamic environments will coexist with agile development and operation practices.

When enterprise architects and agile teams collaborate, there are interactions and potential conflicts between intentional architecture, defined by an overarching enterprise architect and the emergent design, which is driven by agile teams (Madison 2010), see also Figure 48. Initially, intentional architecture provides constraints on how a solution should be built. Throughout the execution of a project, the emergent design should correct any architectural constraints which are not viable in reality. Moreover, future intentional architecture should be inspired by the work of agile teams (Scaled Agile Inc. 2019).

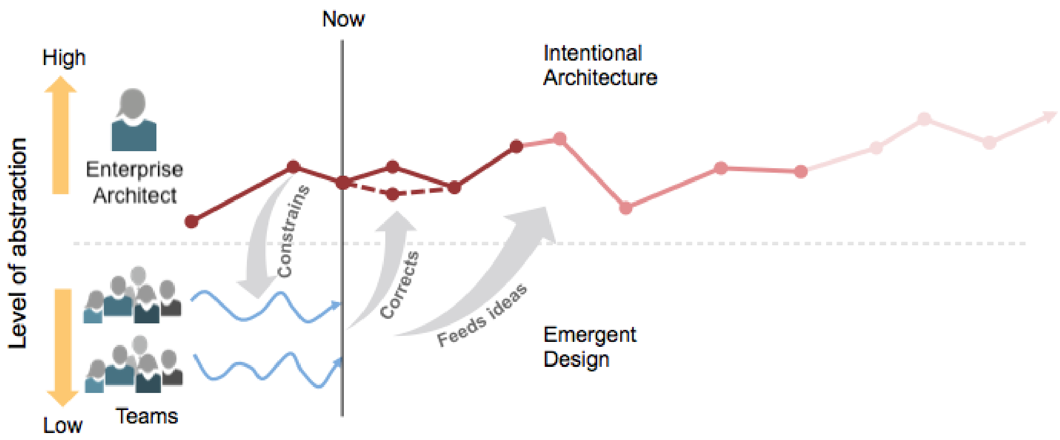

Figure 48: Intentional architecture and emergent design (adapted from (Scaled Agile Inc. 2019))

For enterprise architects working with agile implementation and operation teams, it is crucial to understand the kind of interaction and also potential areas of conflict in order to ensure a successful collaboration. Trying to enforce an entirely traditional EA approach in a setup with agile teams will likely cause issues. For example, teams may circumvent EA as much as possible because the processes are too slow for their approach. This will ultimately damage the reputation of EA and lead to a situation where EA becomes irrelevant within the enterprise. Therefore, it is essential to consider which overall approach is applied by the organization, i.e., agile, non-agile or a mix of both. The EA approach should be aligned accordingly – in dynamic environments, most likely with an agile approach.

In order to ensure a successful collaboration between EA and agile teams, the following should be considered:

- Enterprise architects need to have an understanding of agile practices. This includes knowing the overall organization of agile teams in the enterprise as well as the processes and methods they apply.
- Communication between EA and agile teams is best achieved by physically decentralizing architects and having them incorporate EA concerns at key interaction points, namely in up-front planning, storyboarding, during the sprint and when working software is available (Madison 2010).
- Current standard EA frameworks such as TOGAF are not aligned with agile practices. These frameworks may need to be customized accordingly (Hanschke, Ernsting, and Kuchen 2015).

Ultimately, the EA approach and the strategy for agile practices in an enterprise need to be aligned. This will lead to the correct use of EA and consequently yield benefits for projects and the overall organization.

4.2.2.3 The Focus of the Central EA Process

Given the underlying ideas of self-organization, self-control and decentralization, there is an obvious challenge concerning the enterprise-wide alignment of the architecture. Entirely without a central organizational unit and a shared EA process, alignment among individual teams cannot be achieved. As pointed out by Barbazange et al. (Barbazange et al. 2018), finding the right balance between autonomy and alignment regarding EA is one of the critical challenges for dynamic environments.

Madison (Madison 2010) describes that alignment among the decentral architects is best achieved by having a centralized EA practice and formal EA processes. However, the emphasis needs to be on the community of collaborating individuals, not just a process or a collection of artifacts.

Consequently, in order to ensure a sufficient level of central control while leaving room for autonomy at the same time, literature and experts agree:

- To-be architectures should be described and controlled as lightweight as possible by the central EA in order to enable decision making on a lower level.
- As-is architecture should be centrally documented to provide a basis for enterprise-wide decision making.

Such a central setup process also helps to improve the reputation of EA within the enterprise. One common criticism of implementation teams engaging with EA is that its processes and rules create too much overhead while providing too little value in return. Running a lightweight control process can help to address this concern and to drive the adoption of EA practices (Crabb 2018).

Wagter et al. (Wagter et al. 2005) describe a principle for EA, which outlines further how a lightweight EA process for to-be architecture can be run. They summarize their idea with the statement: "Just enough, just in time." This can be supported by keeping the architectural team small and, where necessary, expanding it with employees from other departments. According to expert six, this principle is still very relevant today, particularly in dynamic environments. Karanth (Karanth 2016) and Governor (Governor 2017) present a more recent interpretation of the same underlying idea, which they refer to as Minimum Viable Architecture (MVA).

While the guidelines for to-be architectures should be as lightweight as possible to enable local decision making, the central EA process can deliver significant value to projects and the overall organization by providing detailed insights into the as-is architecture. By providing a central architecture repository with proper documentation of the current landscape, EA can enable decision making and provide a basis for alignment. Moreover, this as-is picture provides the foundation to develop suitable high-level guidelines for the to-be architecture (Abraham, Aier, and Winter 2012).

4.2.2.4 Decentral Decision Making

One of the foundations for EA in dynamic environments is decentralization, as also presented previously from a competence point. In order to leverage the advantages of the decentral competence, it also needs to be ensured that decisions are effectively taken in a decentral manner. As a result, enterprises can be able to parallelize their activities and be more responsive.

Two questions quickly arise:

1) How can responsibilities be split in the best possible manner between different groups?
2) How can a sufficient level of alignment between the different groups be maintained?

In order to address the first question, the analyzed literature references the idea of domain-driven-design (Nadareishvili et al. 2016). While traditional EA approaches often focus on a layer-based view – i.e. application, business, data, etc., domain-driven-design considers a service-based view instead. When splitting responsibilities by service, individual teams are put in charge of a component which they own end-to-end. Figure 49, illustrates the ideas of domain-driven-design.

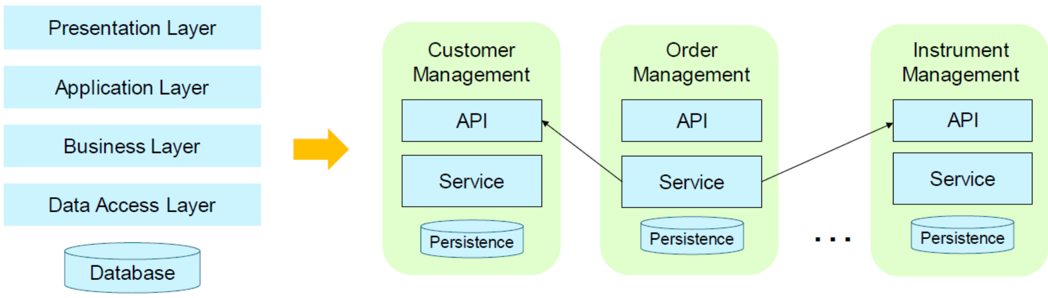

Figure 49: Domain-driven-design – from layers to services (Barbazange et al. 2018)

The importance of domain driven design is also stressed by expert six. Moreover, a particular strict implementation of this idea is presented by one of the reference organizations for dynamic environments, i.e., Zalando (Lemke, Brenner, and Kirchner 2017). Zalando follows an API first strategy, which allows teams responsible for individual services to take decisions on their own as long as the public interfaces are available in a documented and consistent manner.

The second question concerning how a sufficient level of alignment between the different groups can be maintained deserves a closer look as well. Since decentral decision making is a key characteristic of agile teams, agile practices and frameworks present a valuable source to address this methodological aspect. In agile organizations, decision-making is not enforced top-down but rather of the responsibility of the whole team. Taking group-based decisions can help to improve the quality of decisions and, consequently, the quality of the results. However, conducting them efficiently requires suitable practices as pointed out by Lopes and Junior (S. V. F. Lopes and Junior 2017). A key challenge for an EA methodology is how to ensure effectively distributed decision making, which aligns to the overall enterprise goals.

Speckert et al. (Speckert et al. 2013) introduce the idea of peer-to-peer validation for EA to increase the effectiveness of decentralized decision making. While in classical EA approaches typically a centralized architecture board oversees architectural decisions, a peer-to-peer review could be used to decentralize better and speed-up decision making.

In summary, the combination of domain-driven-design and peer-to-peer validation of architectural decisions present an opportunity to leverage decentral competence from a methodological point of view.

4.2.2.5 Measure Adaptivity

A critical requirement for any effective decision making is the availability of the required information. Measuring architecture compliance is a method applied by EA. This is not fundamentally different in dynamic environments – here measures are an important instrument as well. However, the measures should be different from a content point of view.

For EA in dynamic environments, multiple authors stress the importance of architecture adaptivity (Yu, Deng, and Sasmal 2012). Hence, defining and capturing related measures can help to support decision making. While adaptivity is, first of all, an abstract concept, it can be mapped to several indicators. Examples include time-to-market of new features, the average age of application – see also subsection 4.2.3 for a closer look at different architecture characteristics which are beneficial in dynamic environments.

In order to support decision making, relevant adaptivity indicators need to be measured and the resulting data should be made available throughout the enterprise. This will provide a feedback loop for architects on every level to validate their decisions (Abraham, Aier, and Winter 2012).

Moreover, Schmidt et al. (R. Schmidt et al. 2014) stress the importance of the real-time availability of this information. Relevant data about the architecture of the own enterprise as well as about the environment needs to be available quickly. Since the vital circumstance can quickly change in a dynamic environment, it is critical to ensure that all decision-makers are informed.

4.2.2.6 Emergent Behavior

The Agile Manifesto (Beck et al. 2001), which presents one of the central references for agile practitioners, includes a guiding principle for architecture, which states: "The best architectures, requirements, and designs emerge from self-organizing teams." This principle is in line with the ideas presented in this chapter and very much in contrast to traditional EA methodologies which rely on the architecture being defined upfront – often by single individuals – and are afterwards enforced throughout the delivery of a project.

For dynamic environments, emergent design, see also Figure 48, can become a key competitive advantage. However, especially for larger organizations, the question is: How can emergent behavior be effectively managed and leveraged?

In the recent past, the idea of nudge has become popular as a concept to influence decision making through positive reinforcement and indirect suggestions (Thaler and Sunstein 2012). Nudges present one possibility to steer emergent behavior.

Aier (Aier 2019) has applied the idea of nudge to EA and created, for example, a label for architecture compliance, which is supposed to be published for each domain within the enterprise, see Figure 50.

The measures shown in Figure 50 are not supposed to be used in a command and control fashion – i.e., resulting in penalties for a certain domain or team. Instead, this nudge is supposed to influence behavior simply by providing transparency and self-motivation to achieve better compliance.

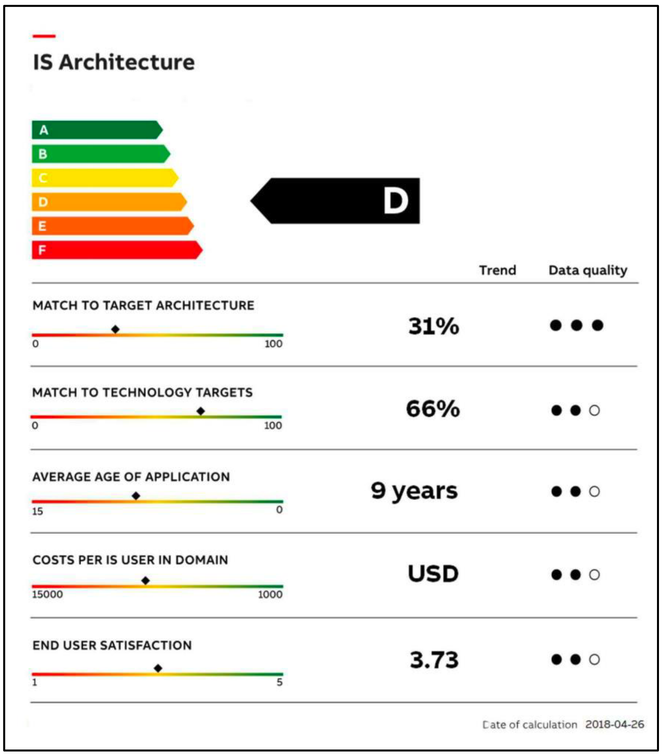

Figure 50: Label for architecture compliance inspired by energy labels (Aier 2019)

4.2.3 EA Content

The EA competency (the who) and the EA methodology (the how) present the foundation to build and maintain effective architectures for dynamic environments. As a next step, also the architecture itself (the what) deserves a closer look – this refers to the content, i.e., models and guidelines, which is produced by architects and is subsequently implemented within the enterprise.

For dynamic environments, various authors agree that a central goal should be for architectures to be more adaptive and hence more resilient to change (Gill 2012; Korhonen et al. 2016; Zimmermann et al. 2014). This general idea is decomposed further in this subsection to outline actual approaches that can be applied by architects.

Based on the qualitative analysis, there are 36 codes assigned to the dimension EA content, which are clustered into four EA approaches for dynamic environments. The broadest coverage in this dimension is on the idea of modularity, i.e., effective decomposer of large services into smaller ones, which are better manageable and more comfortable to change. Closely linked to the concept of modularity is the requirement for interoperability, which is addressed several times in the material analyzed. Especially for a decomposed and modular architecture, it is critical to ensure that individual components are effectively working together. The third approach in this dimension is flexibility, which concerns the internal design of individual modules. Designing with inherent flexibility on this level yields benefits as well. Finally, the fourth approach that receives coverage in the content dimension concerns the scope of EA. For dynamic environments, various sources argue that organizations need to consider not only the architecture of their enterprise but also one of their environments. By including the environment perspective, architectures can be assessed and aligned with changing conditions from the outside.

Figure 51 provides a graphical overview of the approaches in the dimension EA content and their relative frequency, considering references in the literature and interviews analyzed for this part of the thesis.

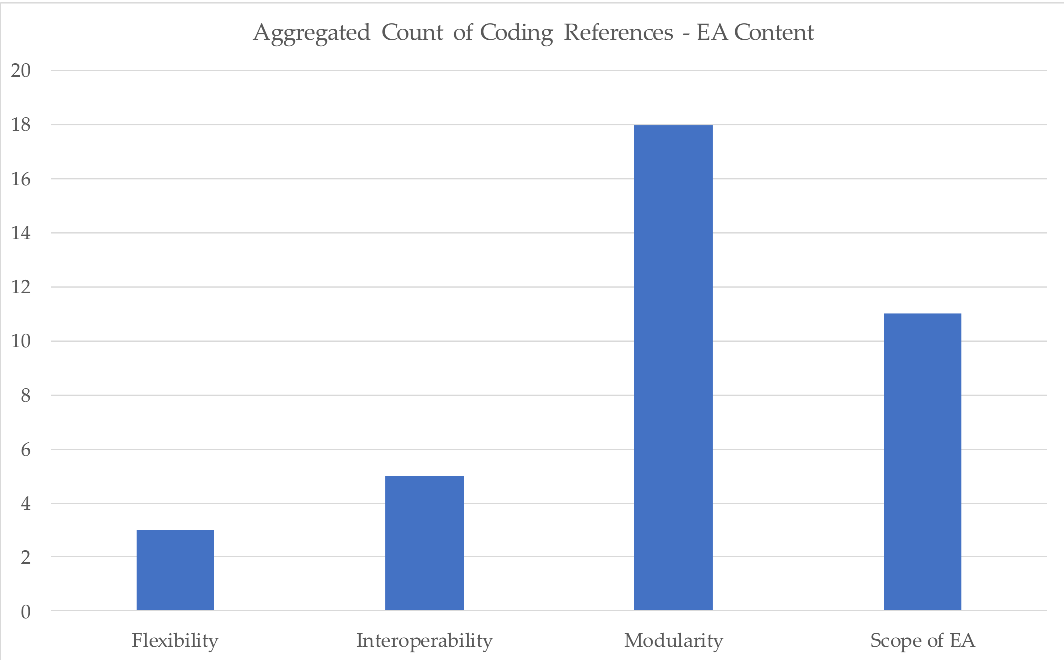

Figure 51: Overview of approaches in the dimension EA content

4.2.3.1 Modularity

The call for increased modularity of architectures is strongly reflected in the analyzed literature as well as in many of the interviews conducted. Related developments can already be observed in reality as well. While historically, architectures have focused on large monolithic systems – e.g., mainframes – there has been a trend to move towards loosely coupled systems made up of small and independent components primarily for the past two decades.

The major advantage is that modular applications or systems are broken down into autonomous building blocks which can be developed, maintained and changed independently of each other. As a result, changes to parts can be conducted more quickly as they are restricted to defined components. Some authors refer to this as the "Lego principle" (Wagter et al. 2005). It is quickly evident that the characteristics of this Lego principle are well aligned with the idea of decentral and autonomous teams.

Sturtevant (Sturtevant 2017) proves the advantages of modular architectures in a recent study. He shows that large monolithic systems often become too big to comprehend and therefore, changes are risky and slow. He recommends designing new systems in a modular fashion and even potentially redesigning (refactoring) existing systems accordingly to achieve increased agility. This agility is an advantage, especially in dynamic environments.

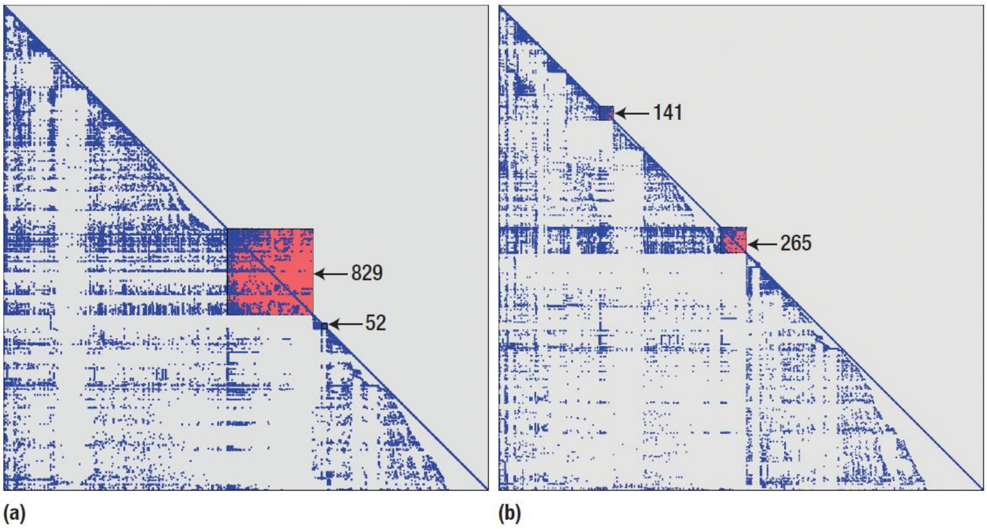

Figure 52: Design Structure Matrices for a commercial code base (a) before refactoring and (b) after refactoring (Sturtevant 2017)

Sturtevant (Sturtevant 2017) also provides a measure to assess the modularity of applications. By analyzing cyclic dependencies in code, he can show which parts of an application landscape are most monolithic. He suggests that these areas should be refactored or redesigned in a more modular fashion. Figure 52 shows a graphical representation created by Sturtevant for a commercial codebase before and after refactoring.

Designing new systems from scratch in a modular fashion is easier than refactoring existing non-modular applications. By today, various architecture options and related technologies which support and enable this are available. When looking at the application architecture concepts which have emerged over the past decades, a trend towards more modularity is also visible, see also Figure 53.

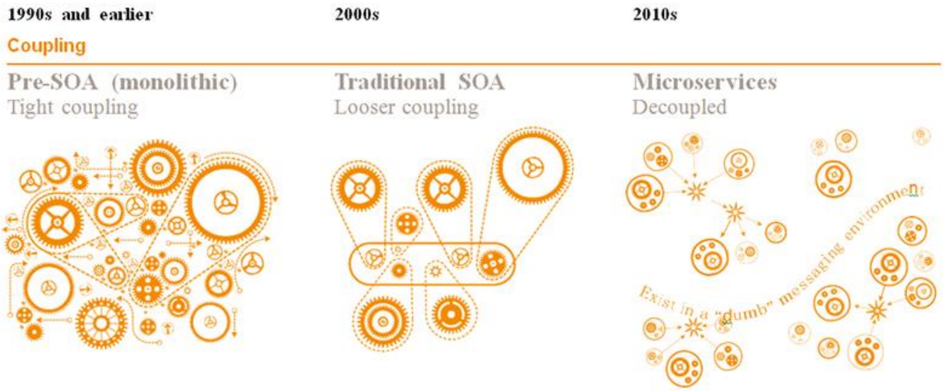

Figure 53: Evolution of service orientation (Morrison 2015)

In the 1990s and earlier, it was common to build applications in a monolithic way, i.e., large systems with lots of users and tasks which are tightly coupled – meaning a lot of internal dependencies.

The first step towards more modularity was the introduction of the Service Oriented Architecture (SOA) in the 2000s. In SOA modules or services are designed separately and integrated via a central services bus. While this already brings advantages because the services can be maintained independent of each other to some extent, the service bus itself still holds many characteristics of a monolithic system and therefore also the related disadvantages.

Since the 2010s there has been and still is a strong push towards micro-services architectures. Microservices are supposed to be designed in a truly modular way and decoupled from each other. There is no central integration layer. Hence, the messaging environment can be considered "dumb". Microservices allow for the highest degree of modularity and should, therefore, be strongly considered for dynamic environments (Morrison 2015).

Wolff (Wolff 2017) points out the advantages of microservices architectures, see also Figure 54. Among these, there are the ability to modularize and replace services which enable sustainable development. Moreover, a faster time-to-market is one characteristic of microservice architectures as well. Hence, some of the key advantages are in line with the requirements of dynamic environments.

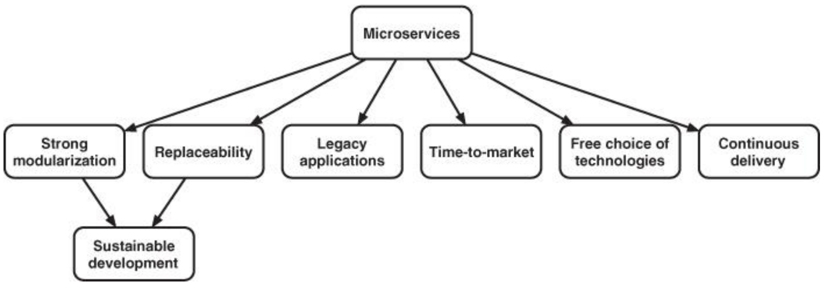

Figure 54: Advantages of Microservices (Wolff 2017)

Also, Irakli et al. point out (Nadareishvili et al. 2016) that microservices architectures can be perfectly combined with the approach of Domain Driven Design. First, services are split according to the identified domains. Second, the teams working on the services have a somewhat free choice of technology and therefore, a high degree of design freedom, which fits well to the idea of decentral decisions making and self-organization.

Despite the various benefits of microservices, especially for dynamic environments, there are also certain disadvantages of this architecture concept (Soldani, Tamburri, and Van Den Heuvel 2018):

1. Microservice architectures require experienced developers because in case problems arise, these tend to be more complex, e.g., contention issues between various microservices.
2. The overall complexity of a product can increase with a microservice architecture; therefore, e.g., integration testing tends to be more difficult because much alignment is required between the groups working on different services.

As a result, microservice architectures are not the one solution that works in every case. Therefore, the underlying idea of modularity needs to be considered on a more abstract level. While microservices might not work in some cases, very likely it still makes sense to logically separate different services or workloads (Sturtevant 2017).

In addition to modularizing and decoupling the individual services of applications, e.g., using SOA and microservices, the various layers of an architecture should be designed and implemented in a modular way. This applies to the platform and infrastructure layer. By providing well-defined services, development and operations of the infrastructure and platform can be decoupled from the application. This can be achieved by utilizing modern management concepts such as Cloudfoundry (Cloudfoundry Inc. 2019) or OpenStack (OpenStack Foundation 2019). As a result, similar benefits can be realized compared to the decoupling services of an application.

Moreover, decoupling the layers of architecture enables architectures to use cloud services such as Software as a Service (SaaS), Platform as a Service (PaaS) or Infrastructure as a Service (IaaS) more efficiently, see Figure 55. For example, in case a certain required platform cannot be provided in-house, it can be consumed from the cloud, which can improve flexibility and time-to-market. However, using these services becomes significantly more comfortable when the architecture is built in a modular way in advance.

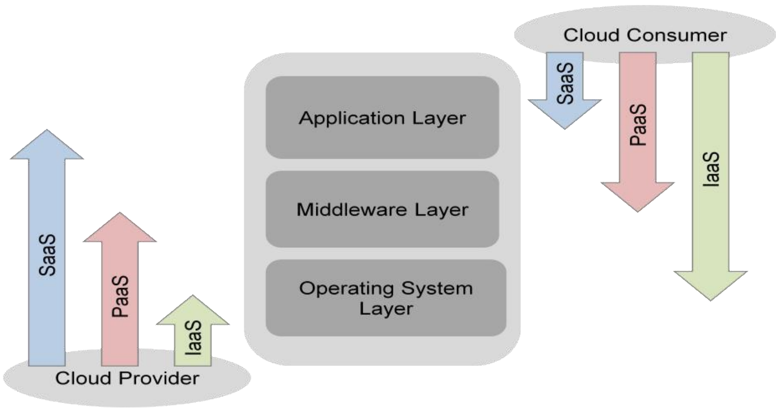

Figure 55: Modular services from the cloud (Liu et al. 2011)

Ultimately, in order to effectively leverage the advantages described for EA methodology and EA competence, architects need to ensure that architectures are built in a modular way for dynamic environments.

4.2.3.2 *Interoperability*

Similar to the tension between autonomy and alignment on the competence and methodological level, there is a related challenge for EA content as well: modularity and interoperability. While the previously discussed concept of modularity helps to foster the autonomy of individual teams, interoperability of the various components needs to be guaranteed so that products and services work end-to-end. The requirement for interoperability is raised in the analyzed literature and especially emphasized by experts one and three.

Chen et al. (Chen, Doumeingts, and Vernadat 2008) define: "interoperability is the ability for two systems to understand one another and to use functionality of one another. The word 'inter-operate' implies that one system performs an operation for another system. From the computer technology point of view, it is the faculty for two heterogeneous computer systems to function jointly and to give access to their resources in a reciprocal way." Interoperability needs to be considered on multiple levels (Jarwar et al. 2017):

- *Technical interoperability* is concerned with hardware and software components as well as the technical protocols used for communication between different modules, e.g., SOAP or REST.
- *Syntactical interoperability* considers data formats of messages exchanged between modules and components. This includes data schemes encodings, e.g., XML or JSON.
- *Semantic interoperability is* concerned with the understanding of data and the need to guarantee that messages are understood in the same way by sender and receiver.

In order to achieve interoperability on all these levels, EA needs to provide guidelines which the individual teams need to follow. These guidelines can be, e.g., in the form of reference models, blueprints or reusable patterns. The goal is that everybody follows the same rules and hence, interoperability is ensured.

Even though dynamic environments call for lightweight EA, interoperability requirements are one of the few areas which EA guidelines need to focus on in dynamics environments. This is visible, for example in the case of Zalando.

For their architecture content, the Zalando EA team describes three guidelines which all relate to interoperability (Lemke, Brenner, and Kirchner 2017):

- *Microservices*: All applications are service-oriented and each microservice provides precisely one function. This guideline relates to the idea of modularity as well as semantic interoperability.
- REST: All microservices communicate via the REST protocol. This guideline helps to ensure technical interoperability.
- API First: When designing and building a new microservice, its Application Programming Interface (API) needs to be specified before it is implemented. This guideline relates to all levels of interoperability.

From these guidelines, it is evident that for Zalando, there is a strong focus on interoperability. To ensure interoperability, they stress the use of open standards, which enable a plug and play architecture where individual components can be easily exchanged. Similar patterns can be observed for Netflix (Bloomberg 2014) and Spotify (Kniberg and Ivarsson 2012). Hence, it is concluded that ensuring interoperability is one of the focus areas for EA in dynamic environments.

4.2.3.3 Flexibility

In addition to building architectures in a modular and interoperable way, multiple sources, as well as the experts four and six, highlights the need to design individual components flexibly. This can be achieved by preferring concepts and technologies which allow changes to be conducted quickly during implementation and also once the solution has already been built (Drews et al. 2017).

One example of such a concept in the area of technology architecture is the Software Defined Architecture (SDA). In an SDA, the underlying hardware is generic and serves as a platform, which can be designed through software configurations. Hence, changes are easier because the architecture is completely decoupled from the infrastructure (Raghavan et al. 2012).

SDA was initially driven from the datacenter and networking area – referred to as Software Defined Network (SDN) (Kreutz et al. 2015). By today, the idea spans across the majority of datacenter services including, e.g., compute and storage. With an SDA, an organization can enable infrastructure as code (Morris 2016), which means that development teams can administer and configure their infrastructure through code changes, which can speed up implementation time of changes and consequently increases flexibility.

Flexible designs, such as SDA, are also an enabler for modularity. SDA allows designing modular services across the different layers of modern application architectures (i.e., infrastructure, platform and application layer). As a result, e.g., the generic infrastructure layer can be operated by a separate team entirely decoupled from the rest. The SDA infrastructure services should adhere to the principles of interoperability in order to provide services and interfaces based on open standards so that it is easily consumable by application and platform teams.

Ultimately the presented ideas of modularity, interoperability and flexibility are linked to a certain degree and enable each other. Modularity drives flexibility and vice versa. Both modularity and flexibility require interoperability so that their benefits can be leveraged in dynamic environments.

4.2.3.4 Scope of EA

Scope of EA is an often-debated topic in the EA community in general. Also, it is highlighted in the analyzed literature and stressed by expert seven. The reason is that in reality, EA is often very IT-focused only and for EA teams it is a challenge to break this pattern and become more relevant in the organization by covering, e.g., business architecture aspects as well. At the same time, various scholars agree that an extended scope of EA is required to increase the maturity and properly yield the benefits associated with the discipline (van Steenbergen 2011). This extended scope should include views of IT, the business and the environment of an enterprise. Lapalme describes this as the EA school of enterprise ecological adaptation (Lapalme 2012), see also section 2.1 of this thesis.

The importance of the scope consideration especially for dynamic environments, is highlighted by the analyzed literature (Korhonen et al. 2016; Korhonen and Halen 2017; Lapalme et al. 2016) as well as by experts one and six.

A too narrow scope of EA will likely result in problems within dynamic environments because many dynamic changes are triggered by the environment, see also section 3.1 of this thesis. If EA focuses on IT only, there is a risk of EA being run reactively only and therefore changes from the outside become nearly unpredictable. Instead, if EA includes views of the business and the environment, the need to change e.g. business process or IT architecture elements, can be detected early and adaptations of the architecture can be conducted in advance.

A comprehensive summary of the EA scope consideration and its link to adaptive capabilities is provided by Korhonen et al. (Korhonen et al. 2016). They conclude that an EA which focuses on IT only is maladaptive (Enterprise IT Architecting). If EA includes the business perspective, called Socio-Technical Architecture by Korhonen et al., adaptive capabilities improve (Enterprise Integrating). However, best adaptivity can only be achieved if EA also covers the environment of an Enterprise as well (Enterprise Ecological Adaptation), see Figure 56 for a summary of the different EA schools of thought and their related adaptive capabilities.

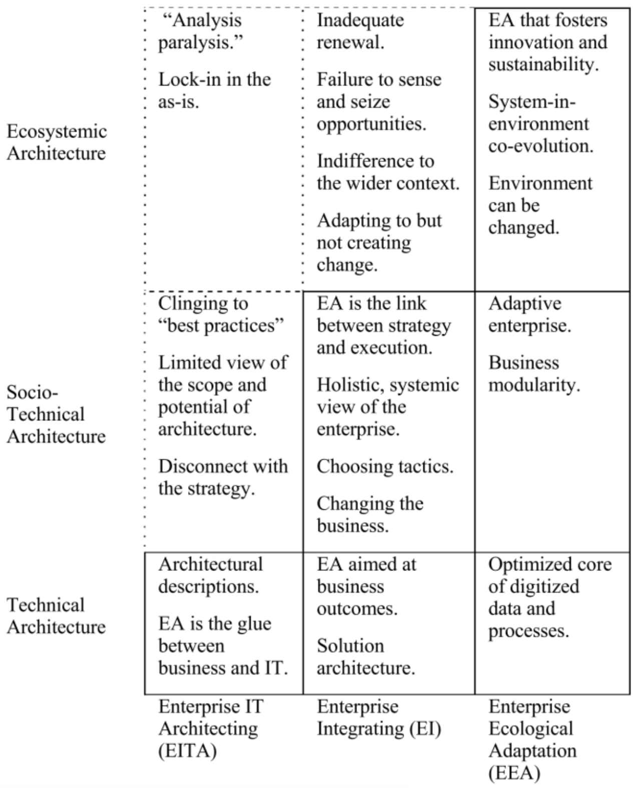

Figure 56: EA schools of thought and adaptive capabilities (Korhonen et al. 2016)

Therefore, in dynamic environments, it is especially important that the understanding of EA is in accordance with the school of enterprise ecological adaptation. As a result, architects are able to make their architectures more adaptive and consequently the discipline more effective in dynamic environments.

4.2.4 EA Tools

Software tools typically support the activities of EA. In the early years of EA, architects utilized mostly standard office products, e.g., to describe architecture guidelines or draw diagrams of architecture models. Office products were the choice mostly due to the lack of any alternative. However, using such generic tools has shortcomings, especially when trying to raise the maturity of the EA discipline. By today, the situation is different: A variety of EA tools is available, which range from simple modelling tools to sophisticated analysis and collaboration platforms (Searle and Kerremans 2018).

Dynamic environments impose specific requirements towards the EA tooling. For example, quickly changing configurations as well as the ideas of a distributed competence and the strong autonomy of individual teams ask for specialized functionality, which has been confirmed in the literature and the interviews.

Based on the qualitative analysis, there are 47 codes assigned to the dimension EA tools, which are clustered into three EA approaches for dynamic environments. The broadest coverage in this dimension is on the general idea of automation, which is applied in two areas: EA documentation and EA assessment. Therefore, for this analysis, two approaches are derived for each of the focus areas. Automated documentation considers the creation of architecture content, i.e., models and diagrams through automated discovery. The automated assessment covers the evaluation of architecture content to support decision making of architects. The third EA approach within the dimension EA tools revolves around collaboration and the idea to move away from architecture tools which are used by a few experts only and instead provide platforms which can be used by as many stakeholders as possible.

Figure 57 provides a graphical overview of the approaches in the dimension EA tools and their relative frequency, considering references in the literature and interviews analyzed for this part of the thesis.

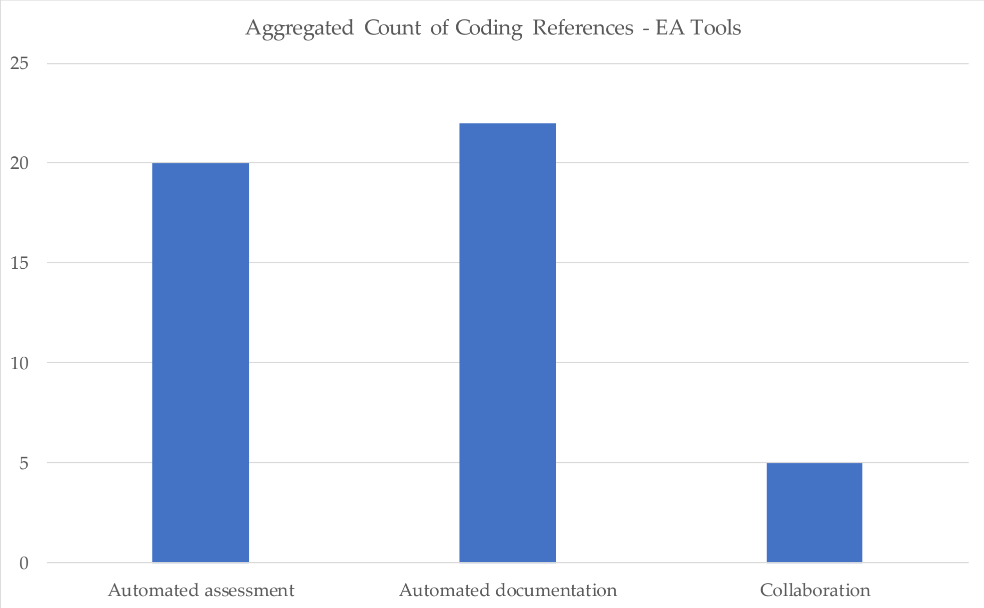

Figure 57: Overview of approaches in the dimension EA tools

4.2.4.1 Automated Documentation

Automated documentation and the closely related concept of automatic discovery of EA artifacts is stressed by multiple sources (Bogner and Zimmermann 2016; Drews et al. 2017) as well as by expert three. The primary goal is to achieve better documentation of the as-is architecture in real-time, which helps architects to take better decisions, especially in fast-changing environments. Moreover, as pointed out for EA methodology, see subsection 4.2.2, EA in dynamic environments should focus on providing an accurate view of the as-is state in order to provide maximum value to the rest of the enterprise. If EA documentation and discovery is done purely manually, there is a high risk that information is quickly outdated, which will hinder the acceptance of the EA discipline.

In order to provide automated documentation and discovery within EA, enterprises can and should leverage the results and data of related disciplines. The area of IT Service Management (ITSM) and in particular its discipline Configuration Management (CM) has the goal to provide accurate views of currently running configurations with a focus on technical artifacts such as infrastructure and software. By feeding relevant data from CM to EA tools, real-time views of the as-is architecture can be provided (Gama, Sousa, and da Silva 2013). Moreover, the disciplines which are in place to create new services and advance existing ones can deliver valuable data points for EA as well. Especially in organizations which utilize modern DevOps tooling to automate release and deployment, the required information for EA is likely available already (Drews et al. 2017).

On a more general level, the open group IT4IT reference architecture (The Open Group 2017b) provides a view on how different disciplines and related tooling can be integrated see Figure 58. The underlying service model, depicted in purple, shows how different stages of services are linked to disciplines. EA should leverage the relevant data from these different stages in order to provide a comprehensive view, which is as up-to-date as possible. Besides, EA will need to model specific parts by themselves, i.e., the business architecture. The data from other disciplines should be combined with the models created by EA in order to deliver a consistent and holistic view.

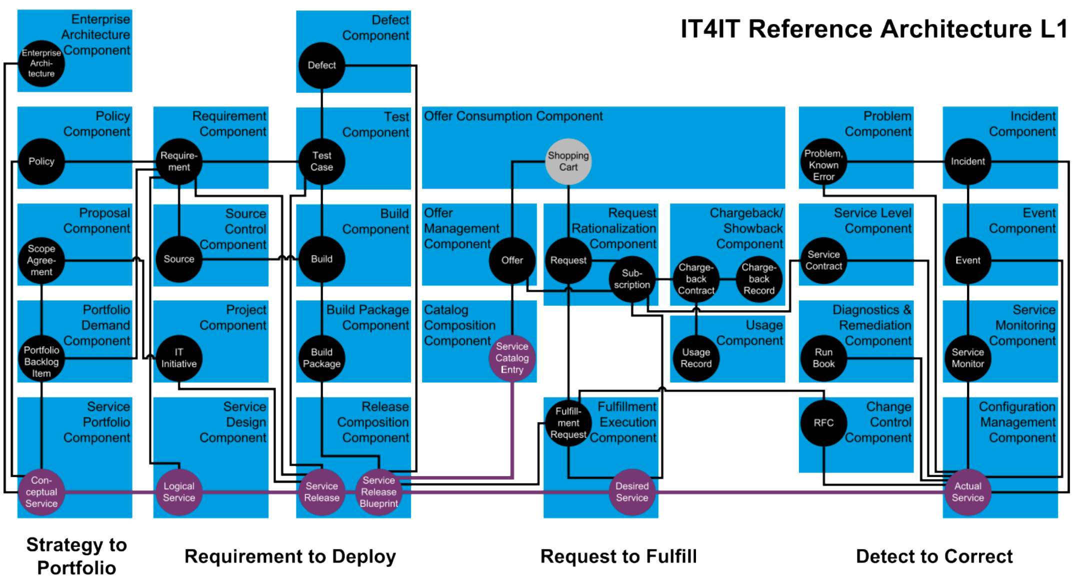

Figure 58: IT4IT Reference Architecture – functional components and data objects (The Open Group 2017b)

If EA can achieve to consolidate the architecture data from other disciplines in an automated way, the goal of automated discovery is likely already achieved. As a result, data is available in real-time and decisions can be supported with up-to-date information. Moreover, new use cases will be enabled, which can be supported by automation as well, see next subsubsection on automated assessment.

4.2.4.2 *Automated Assessment*

In the domain of EA, the trend around Big Data is one of the areas which currently receives increasing attention, see also subsection 2.6.3 of this thesis. The connection between Big Data and EA needs to be considered in two ways. On the one hand, EA can be applied to design Big Data solutions. On the other hand, Big Data solutions can be applied to support EA. For dynamic environments, the latter is interesting since Big Data can provide the means for an automated assessment of architectures.

The general idea of automated assessment is to leverage analytics, including machine learning techniques to automatically assess architecture data and provide recommendations to architects as a result. This point is highlighted by multiple of the analyzed sources, e.g. (Korhonen and Halen 2017; R. Schmidt et al. 2014) as well as by expert four.

The benefits of automated assessment are substantial when data from various sources is combined and analyzed. One example use case is technology risk assessment, which requires data from three sources[10]:

1. Discovered data from configuration management, such as hardware and software information including version numbers
2. Logical data from EA describing how business, application and technology architecture are linked and related to the discovered data from configuration management
3. IT asset data including version information to evaluate which systems are up-to-date and which are potentially outdated

By integrating these three sources, EA tools can generate reports which provide an overview of domains and applications that run into problems because they are using outdated technology components. As a result, architects and other decision-makers have the required information to start projects which address these risks. This is especially valuable in fast-changing and dynamic environments,

[10] As an example, the integration of the solutions Lean IX (LeanIX GmbH 2019) and Technopedia (Flexera Software LLC 2019) has been considered which provides technology risk assessment

since there is an increased likelihood of losing track of these risks with many moving parts.

Another example of Big Data-enabled EA use case is cloud transformation management[11]. By leveraging portfolio data from various cloud vendors in combination with discovery and architecture data, enterprises can automatically determine potentials and risks of moving applications and workloads to the cloud. Cloud transformation reports can help architects to determine which applications are most suitable for a migration to the cloud because they have the required architectural prerequisites. Moreover, with the portfolio data from cloud vendors, EA tools can provide recommendations on the question which vendor provides the most suitable solution for a particular area.

Ultimately, to assess as-is architectures and to derive the right steps for developing proper guidelines for a to-be architecture has always been a core task of EA. Automation of these assessments does generally not change this. However, the absolute advantage is the fact that decisions can be taken more quickly and be supported by better data, which is especially beneficial in dynamic environments.

4.2.4.3 Collaboration

The idea of collaboration through software has been one of the major themes within the past decades. Solutions in various spaces have moved from stand-alone installations operated by single experts to platforms which can be jointly utilized by various teams (Lanubile et al. 2010).

For dynamic environments, collaboration within EA tooling yields benefits in particular. This is highlighted by the analyzed literature as well as by experts three and six. Due to the ideas of decentralization and self-organization of individual teams, there is a strong need to foster transparency and alignment, which can be supported by suitable software tooling. The goal should be that as many people as possible consume architecture content through software and work on it collaboratively. A pattern that can be observed for EA tool implementations with limited success are solutions which are used by individual experts only and

[11] As an example for Cloud Transformation Management the solution txture (Txture GmbH 2019) has been considered

do not achieve wider adoption throughout the enterprise. On the contrary, successful tools focus on usability and are easy to access, also for non-EA stakeholders, who can leverage architecture reports for their decision making (Searle and Kerremans 2018).

One example of a change in EA tooling to support the idea of collaboration, is to move client-only installations to client-server setups, which allows multiple people to work on the same architecture repository. Moreover, the move from rich-clients to web-based clients allow easier onboarding of new users. These developments can be observed cross-vendor throughout the past years because they help vendors and their customers to increase adoption of their tooling throughout enterprises. To further extend the reach of architecture tooling to different teams, EA teams should also consider integrating with tools of others (Crabb 2018). A framework such as IT4IT can provide guidance on which integrations should be considered.

As highlighted before, this adoption is especially helpful in dynamic environments.

4.3 DISCUSSION AND VALIDATION OF APPROACHES

The approach taken to address research question three (RQ3) of this thesis relies on expert opinions derived from interviews. Such an approach is considered suitable to gather cognitive input as well as to analyze, compare and integrate different viewpoints (Korhonen et al. 2016), which also is the goal of this thesis.

Because, so far, only a qualitative research approach has been applied for RQ3, there is a limited possibility for a discussion and validation based on quantitative observations. Still, there are interesting observations, which can be made based on the codings derived and their relative amount.

Figure 59 shows the relative number of codings for the literature analyzed compared with the results from the interviews.

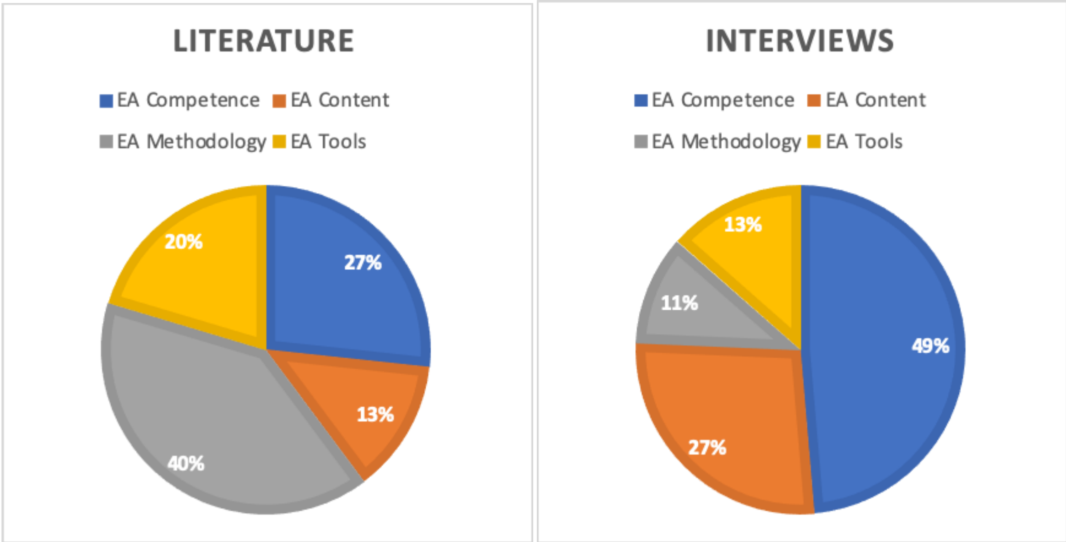

Figure 59: Comparison of codings - literature and interviews

From Figure 59 it becomes quickly evident that the emphasis is different. The investigated literature heavily focuses on the dimension EA methodology, which might be because methodologies are what is easiest to describe in written form. Instead, the interviews have the strongest emphasize on EA competence, which indicates that, in practice, this area might hold the most critical challenges. This mismatch is particularly interesting because when looking at the agile manifesto, it states precisely an emphasis on processes and tools is a significant risk for agility. Instead, the agile manifesto asks for a focus on individuals and their interactions (Beck et al. 2001).

However, due to the limited number of interviews, this is only an indication and not a formally confirmed observation so far which could be analyzed further in future research.

In general, while the expert interviews present a first form of validation for the approaches and the model derived within this thesis, this is not a scientifically formal validation yet. This validation needs to be conducted via further research.

One option could be, for example, a quantitative survey study among EA stakeholders. However, already within the preparation of the work for this thesis, it became evident that the group of addressable experts in this field is limited. Moreover, a survey at a single point in time holds limited value because for a holistic consideration, surveys would need to be conducted within the same environment (or enterprise) at least twice over time to understand the effects of a dynamic environment and their relation to EA.

Therefore, another option to conduct the validation could be long-term case studies, which would also present the opportunity to measure whether the suggested approaches yield the expected benefits over time.

In order to simplify implementation in actual enterprises and also the use within a case study, this thesis presents its results in the form of a reference architecture within the next chapter.

5 REFERENCE ARCHITECTURE FOR EA IN DYNAMIC ENVIRONMENTS

The previous chapter presents the core results of this thesis – a collection of approaches on how to run EA effectively in dynamic environments. The objective of this thesis is not only to provide a theoretical discussion of the approaches but instead to provide guidance for practitioners on how to implement the discipline of EA accordingly. Therefore, the fourth research question (RQ4) addresses the need to summarize the findings in a well-structured and consumable manner. RQ4 asks: "*How can a reference architecture for the discipline EA in a dynamic environment be described?*"

The goal within this chapter is to address RQ4 by formally describing and summarizing the EA approaches previously identified and by putting them in relation to each other. While each one of the approaches delivers its share to practice EA in dynamic environments better, it is also essential to consider the dependencies among the individual ideas. Therefore, the answer for RQ4 is delivered in form of a reference architecture.

Reference architectures present a suitable format to describe how a particular system, domain or enterprise should be set-up under given conditions (Martinez-Fernandez et al. 2015). One example of such a reference architecture is the Open Group IT4IT reference architecture (The Open Group 2017b), which describes how IT organizations in modern organizations can be structured to deliver value to the enterprise.

A critical advantage of the reference architecture format is the fact that it can be consumed easily by practitioners who are looking to implement EA in dynamic environments.

The work on RQ3, which has been presented in the previous chapter, has revealed four relevant dimensions for EA in dynamic environments namely EA competence, EA methodology, EA content and EA tools. For each dimension, multiple approaches have been identified, which improve the effectiveness of EA in dynamic environments.

In summary, the EA competence needs to be *integrated* well into the enterprise so that ideas such as decentralization and architectural thinking can be leveraged. On top of this, the EA methodology should be aligned to *agile* practices allowing quick architectural decisions depending on the changing environment. The resulting EA content needs to be *adaptive,* meaning that the architecture can be easily adjusted in case it is required. The architects and other EA stakeholders should be supported by *modern* EA tools which provide the required functionality for dynamically changing environments. Figure 60 provides a graphical overview of the resulting reference architecture, which is described in more detail subsequently.

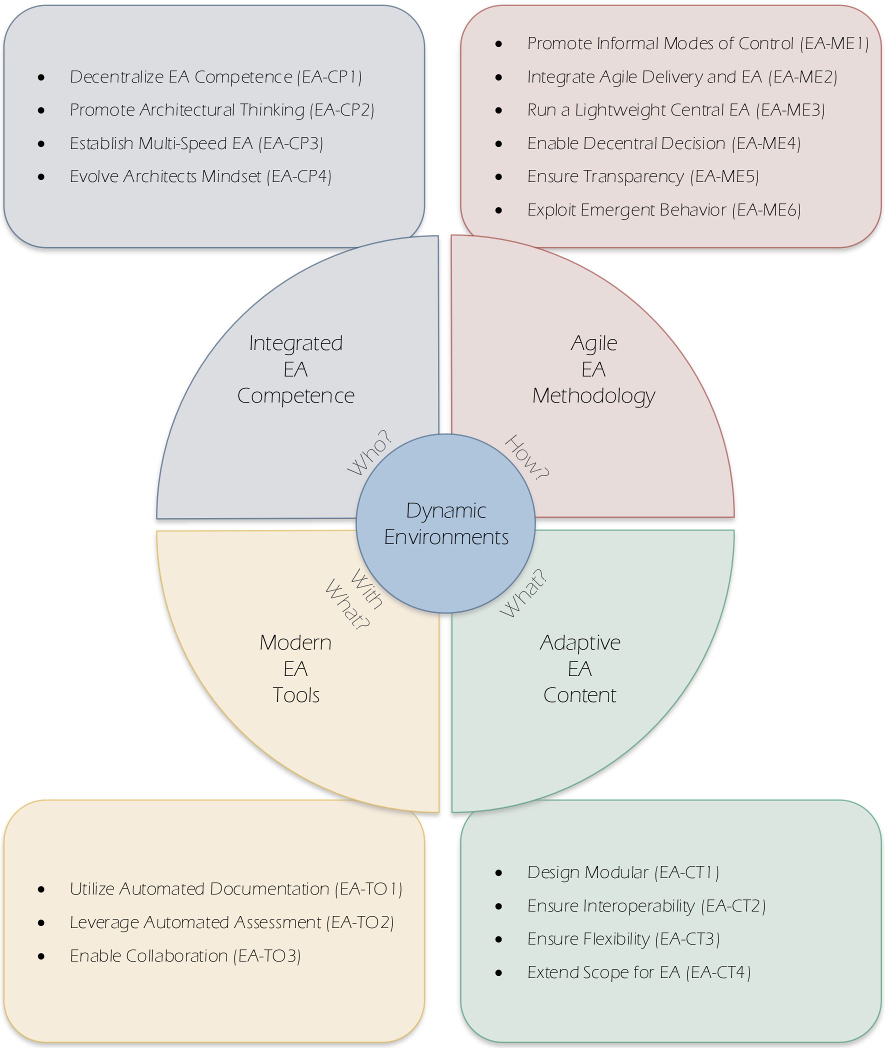

Figure 60: Reference architecture for EA in dynamic environments overview

The following sections are structured according to the dimensions identified, namely EA competence (EA-CP), EA methodology (EA-ME), EA content (EA-CT) and EA tools (EA-TO). Each of the identified EA approaches is mapped to one of the dimensions and assigned a unique identifier accordingly (e.g., EA-CP1, EA-ME2, etc.). For all of the approaches, the following details are described:

- *Principle* statement summarizing the approach
- *Description* providing further details
- *Rationale* behind the principle, including:
  - the link of the approach, to its underlying theoretical background, for example, complexity theory
  - successful practical reference of the approach, for example, in one of the reference organizations
- *Implications* of the approach, e.g. link to other dependent approaches

To better visualize the identified principles, including their implications, an ArchiMate[12] model is created. The EA modelling language ArchiMate contains a 'principle' element and the means to show how principles are linked to drivers, goals and desired outcomes as well as how principles influence each other (The Open Group 2017a). As an example, to explain the format of visualization, Figure 61 shows two principles in ArchiMate where 'Principle 1' influences 'Principle 2'[13].

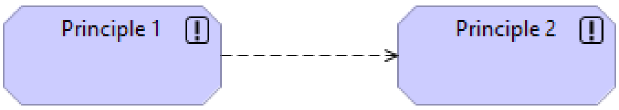

Figure 61: ArchiMate principles example

Figure 62 shows the ArchiMate model for all principles identified, including their dependencies as well as their links to drivers, goals and outcomes. The principles are visually grouped according to the presented dimensions of this thesis. In addition, also the implication for capabilities outside of EA are shown.

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[12] The full ArchiMate documentation is available as a language specification document. For this thesis version 3.0.1 was used (The Open Group 2017a)

[13] The ArchiMate models within this thesis have been created using the open source modelling tool Archi (Beauvoir and Sarrodie 2019)

The ArchiMate model can guide the implementation of these approaches within enterprises. For example, from the model it is quickly evident that EA competence and EA methodology have little incoming but rather outgoing implications and should, therefore, be the starting point for an implementation. EA content and EA tools can follow in a second step.

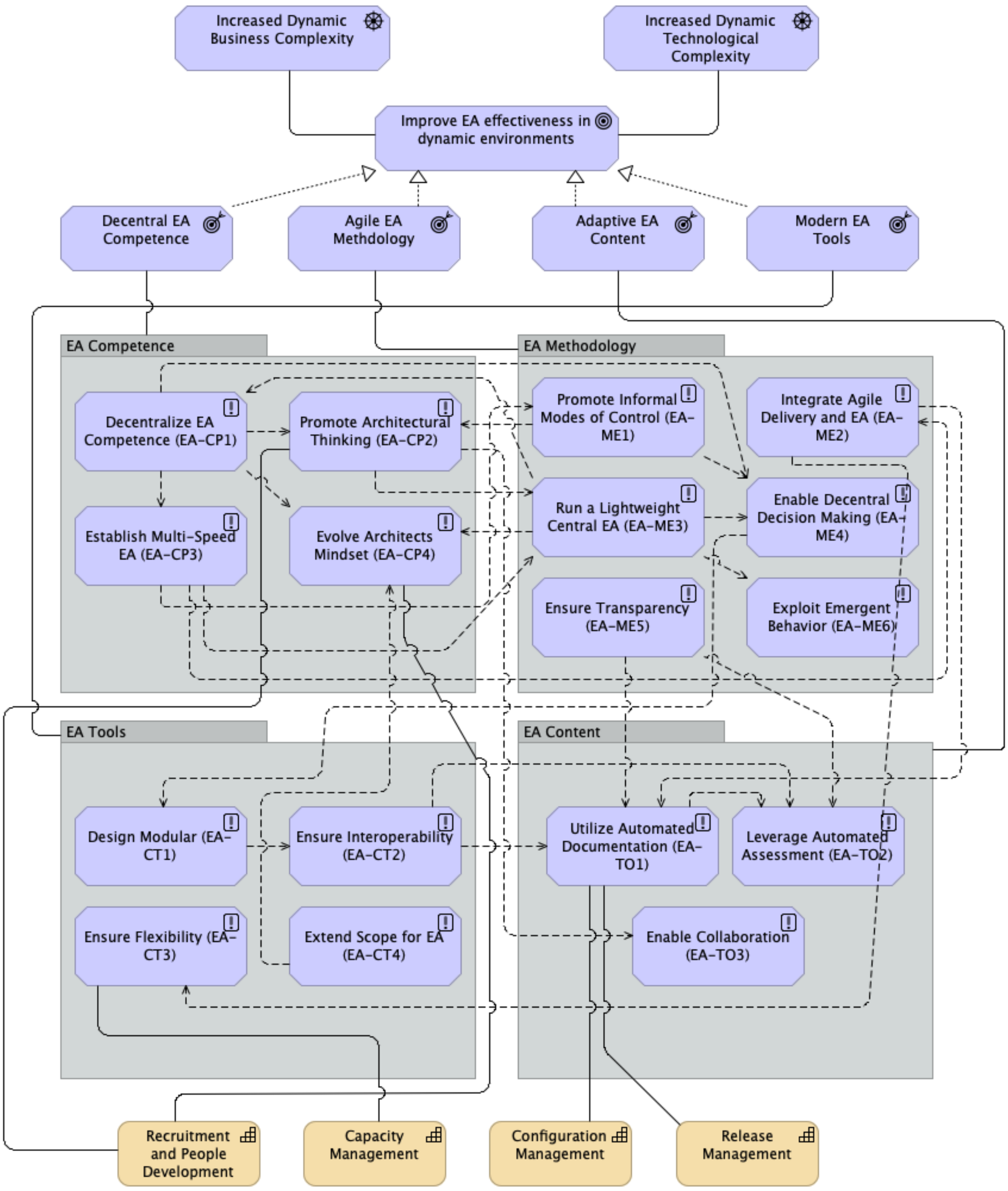

Figure 62: Dependencies of principles – ArchiMate model

5.1 INTEGRATED EA COMPETENCE (EA-CP)

In order to deliver value in dynamic environments, the EA competence needs to be well-integrated into the organization. The goal should be the exact opposite of an *ivory tower architecture*, which is developed by architects in relative isolation from the day-to-day activities in the enterprise (Ambler 2019). As a result, the architecture will likely have little in common with reality and will be challenging to be implemented. This common misconception is already a problem in non-dynamic environments but even more problematic if the pace of change is increasing. Therefore, especially in dynamic environments, architects should actively collaborate with the rest of the organization and motivate stakeholders to take architectural decisions. Consequently, architectural competence will be distributed throughout the organization.

5.1.1 Decentralize EA Competence (EA-CP1)

EA-CP1 Principle: The more dynamic the environment, the more decentral the EA competence should be set up.

EA-CP1 Description: Enterprises must ensure that organizational structures and competencies are in place so that architectural decision can be taken on the lowest possible level. This will make them more responsive and, hence, help to ensure competitive advantage in fast-paced highly dynamic environments.

EA-CP1 Rationale: Janssen and Kuk (Janssen and Kuk 2006) apply CAS theory to the question of whether central or decentral EA is more effective. They conclude that one critical ingredient to a successful EA practice is finding the right balance of central and decentral layers. The characteristics of the environment must be considered when determining this balance. The more responsive an organization needs to be, the more decentral the EA competence should be set up. For dynamic environments, this calls for a light-weight central EA practice and empowered teams which have the required skills, knowledge and mandate to take architectural decisions on their own. This is in line with the approach promoted by the agile framework SAFe, which states: "Centralize strategic decisions and decentralize everything else" (Scaled Agile Inc. 2019).

EA-CP1 Implications:

- *Promote Architectural Thinking (EA-CP2):* Decentralization can be further improved by involving non-architects.
- *Evolve Architects Mindset (EA-CP4)*: Working in a decentralized manner is a significant change for many architects and requires them to think differently.
- *Enable Decentral Decision Making (EA-ME4)*: To leverage the benefits of a decentral competence, also the decision making needs to be decentral. This needs to be considered on the methodological level.

5.1.2 Promote Architectural Thinking (EA-CP2)

EA-CP2 Principle: Promoting and fostering Architectural Thinking throughout the entire organization to ensure this way of thinking is not restricted to architects and systems developers only.

EA-CP2 Description: For the current decade, the concept of Architectural Thinking (AT) has received increased attention (Jeanne W. Ross and Quaadgras 2012). AT is the logical next step from EA-CP1. This implies a decentralization of the architecture competence not only to various architects within the enterprise but to other stakeholders as well. For AT to work, the central EA team needs to assume a leading role which does not only focus on architectural decisions but also includes enablement of the various roles that can apply AT.

EA-CP2 Rationale: The major challenge for EA in dynamic environments is to enable quick architectural decision cycles while, ensuring alignment throughout the enterprise at the same time. AT can help to address this challenge by decentralizing the EA competence further and, thus, enabling decisions on lower levels in the organizations, for example, by the project working on a specific implementation. At the same time, AT can help to foster better decisions and thus alignment by enabling various stakeholders to understand the architectural implications of their decisions better.

EA-CP2 Implications:

- *Run a Lightweight Central EA (EA-ME3):* In order to support AT the central process for EA needs to be as lightweight as possible.

- *Recruitment & People Development*: For AT to work, employees in various roles need to have a suitable skillset. Hence, architectural skills in different degrees should be considered during hiring as well as for people development:

5.1.3 Establish Multi-Speed EA (EA-CP3)

EA-CP3 Principle: Multi-speed EA can help to transform existing organizations in a step-wise manner for dynamic environments and should, therefore, be considered by enterprises with traditional EA who are looking to change their approach.

EA-CP3 Description: Multi-speed EA presents the opportunity to run parts of the organization with a fast-paced approach and others with a slower pace. Depending on the circumstances, two, three or even more levels of speed might be suitable. Multi-speed EA imposes special requirements to the central EA team because of the need to integrate the different speed levels.

EA-CP3 Rationale: Existing large-scale enterprises will likely not be able to instantly transform their entire organizations and systems to a completely decentralized and agile setup. Moreover, some parts of an enterprise might be more suitable for this transformation while others are not. For example, multi-speed provides the possibility to run consumer-facing applications with a faster pace to react to customer demand while core services, which require stability due to regulations, can be managed more traditionally.

EA-CP3 Implications:

- *Promote Informal Modes of Control (EA-ME1):* While fast-paced parts of the organization ask for informal modes of control, the slow-paced ones require more formal approaches. EA teams need to manage these different levels accordingly.
- *Integrate Agile Delivery and EA (EA-ME2):* Integration with agile delivery is likely only relevant for fast-paced parts of the organization and hence needs to be considered differently for the different speed-levels.
- *Run a Lightweight Central EA (EA-ME3)*: Lightweight central EA is only relevant for the fast-paced part of the organization.

5.1.4 Evolve Architects Mindset (EA-CP4)

EA-CP4 Principle: EA in dynamic environments requires new skillsets and a different way of thinking for architects. Organizations need to ensure that architects are developed and hired accordingly.

EA-CP4 Description: In dynamic environments, EA needs to become an enabler rather than a control instance. Consequently, architects are in need of people and education skills in order to collaborate effectively with the rest of the enterprise. Moreover, due to the fast-paced nature of changes in these environments, architects need to feel comfortable in uncertain situations wherein which they might not have all the required information but are still able to make decisions. Also, they should have state-of-the-art knowledge about current business and technology developments to mitigate risks of bad decisions as much as possible.

EA-CP4 Rationale: To evolve the EA practice within an enterprise, also the people running it need to be selected and developed accordingly. While traditionally, EA required predominantly strong analytical skills, dynamic environments ask more for management and people skills.

EA-CP4 Implications:

- *Recruitment & People Development*: To evolve the skillset of architects exiting people need to be developed and new hires need to be selected accordingly.

5.2 AGILE EA METHODOLOGY (EA-ME)

Agile project management practices have been developed to make projects in uncertain situations with quickly changing requirements more effective.

In dynamic environments, EA is faced with similar challenges. Therefore, EA teams should consider and adopt various of the underlying methodological practices of the agile movement for the discipline of EA to become more responsive. The following principles outline how this can be achieved.

5.2.1 Promote Informal Modes of Control (EA-ME1)

EA-ME1 Principle: In dynamic environments, EA should favor informal over formal modes of control to achieve architecture compliance.

EA-ME1 Description: Informal controls such as self-control and clan-control (Wiener et al. 2016) present mechanisms to foster alignment in decentral organizations without putting hard and mandatory regulations into place. Self-control considers the intrinsic motivation of each person. Clan-control is about the shared norms and values of a group, e.g., in a domain or across the entire enterprise. EA can foster self- and clan control, for example, by supplying architecture enablement and by organizing informal events with mixed groups.

EA-ME1 Rationale: Formal modes of control require central steering and are therefore slower and less flexible than informal ones. In dynamic environments, speed and flexibility are of significant advantage and therefore, informal controls should be favored whenever possible.

EA-ME1 Implications:

- *Promote Architectural Thinking* (EA-CP2): Informal modes of control lead to an increased appreciation of EA as shown by a recent study (Schilling, Haki, and Aier 2018). This should be leveraged as an enabler for Architectural Thinking.
- *Enable Decentral Decision Making (EA-ME4)*: Decision making needs to be aligned to the control mechanism in the enterprise.

5.2.2 Integrate Agile Delivery and EA (EA-ME2)

EA-ME2 Principle: EA methodologies need to integrate tightly with agile delivery practices to deliver successful products in dynamic environments.

EA-ME2 Description: Agile projects or products are delivered differently as compared to traditional ones. Most importantly, there is less upfront planning and more flexibility during the implementation. EA needs to align with these principles by following the idea of just enough architecture just in time. A common pitfall for EA in combination with agile delivery is to over-complicate architecture planning in the beginning and therefore lose the support of agile project teams. Thus, it is essential to align the EA approach to the general delivery approach.

EA-ME2 Rationale: Agile delivery addresses many of the challenges in dynamic environments on the project delivery and especially implementation level. EA needs to ensure that it is an enabler for agile delivery and not a hindering factor. Therefore, EA should align with agile delivery approaches in the enterprise and integrate between the two practices whenever possible (Madison 2010).

EA-ME2 Implications:

- *Ensure Flexibility (EA-CT4)*: Agile delivery asks for flexibility during implementation. Therefore, architecture needs to be designed in a flexible manner allowing changes also when the solution is already (partly) built.
- *Utilize Automated Documentation (EA-TO1)*: Due to the flexible and fast-changing nature of agile delivery approaches it is important to leverage state-of-the-art technology to automatically document topologies and their changes. This will provide up to date information on the as-is architecture to support decision making.

5.2.3 Run a Lightweight Central EA (EA-ME3)

EA-ME3 Principle: In a dynamic environment, the central EA capability and its processes should be as lightweight as possible

EA-ME3 Description: In dynamic environments a central EA capability is indispensable as a function to drive enterprise wide alignment. However, following the ideas of decentralization and autonomy, the central EA team needs to leave maximum design freedom to local teams so that decisions can be taken at the lowest level possible. At the same time, EA should act as an enabler and provide architecture training and support to local teams in order to improve architectural decision making in local teams. Central EA teams can achieve this lightweight setup by focusing on a thorough documentation of the as-is architecture and by providing Minimum Viable Architecture (MVA) which serve as templates.

EA-ME3 Rationale: Architectural decisions should be delegated to the lowest organizational level possible in dynamic environments to increase responsiveness. In order to enable this autonomy of local teams, the central EA team needs to interfere as little as possible with local decision making (Crabb 2018; Lemke, Brenner, and Kirchner 2017).

EA-ME3 Implications:

- *Decentralize EA Competence (EA-CP1)*: If the central EA practice is run in a lightweight style, it needs to be ensured that sufficient architectural competence is available in local teams.
- *Evolve Architects Mindset (EA-CP4)*: For central architecture teams it can be a big change to move towards a lightweight process, especially if they have been used to a command and control format. Therefore, it needs to be ensured that architects are developed accordingly.
- *Enable Decentral Decision Making (EA-ME4)*: Since architectural decisions are delegated to lower levels, enterprises need to ensure that lower levels have the skills and competencies to take these decisions.

5.2.4 Enable Decentral Decision Making (EA-ME4)

EA-ME4 Principle: In dynamic environments, architectural decisions should be taken on the lowest possible level

EA-ME4 Description: Rather than enforcing architectural standards top-down throughout the organization, local teams should have the freedom to take decisions on their own. Domain-driven-design (Nadareishvili et al. 2016) can be used to structure organizations suitably and peer-to-peer review (Speckert et al. 2013) can be leveraged to improve alignment.

EA-ME4 Rationale: Local decision making improves responsiveness, which is vital in dynamic environments. Allowing decentral decisions is the logical implementation of decentral EA competence on methodological level.

EA-ME4 Implications:

- *Design Modular (EA-CT1):* In order to enable decentral decision making, solutions need to be structured in a modular fashion so that decisions for one part can be taken as independently as possible from the rest.

5.2.5 Ensure Transparency (EA-ME5)

EA-ME5 Principle: Adaptivity of as-is and planned to-be architectures needs to be transparent throughout the enterprise

EA-ME5 Description: An enterprise-wide architecture repository needs to be in place for documentation of as-is and to-be. This repository should not only describe the architecture but also include measures to assess adaptivity of components and domains. Adaptivity describes how a certain part of the architecture can be adjusted easily. For EA in dynamic environments it is important to assess adaptivity and, subsequently, improve it. Automation should be leveraged to document and assess architectures in order to ensure that the information is up-to-date.

EA-ME5 Rationale: Quickly changing environments and distributed decisions impose a strong risk of misalignment within the enterprise. Central EA teams need to mitigate this risk by ensuring architectural transparency so that architectural issues can be identified as soon as possible. Moreover, assessing adaptivity of the architecture helps to understand which areas are likely to run into problems in case of future changes. Transparency allows to take corrective actions in advance.

EA-ME5 Implications:

- *Utilize Automated Documentation (EA-TO1): A*utomated documentation is required so that information on architectures and their adaptivity is as current as possible.
- *Leverage Automated Assessment (EA-TO2)*: Automated assessment can help teams to quickly detect adaptivity problems in large and complex environments.

5.2.6 Exploit Emergent Behavior (EA-ME6)

EA-ME6 Principle: The best architectural ideas emerge from self-organizing teams – these ideas need to be considered not only locally but across the enterprise

EA-ME6 Description: Central EA teams should review architectural decisions and ideas, taken by individual groups to identify opportunities for the larger enterprise.

EA-ME6 Rationale: Due to the proposed decentral EA setup for dynamic environments, architecture development is mostly shifted to individual distributed teams. The central EA team within the enterprise needs to ensure that ideas which are potentially applicable in various areas are made available throughout the organization. Moreover, considering and promoting emerging designs can help improve cross-team collaboration.

EA-ME6 Implications:

- *Run a Lightweight Central EA (EA-ME3)*: During architecture development and decision-making new ideas are being generated. Since these ideas are distributed and decentral, the central EA team needs to ensure that they are picked up and re-used throughout the enterprise.

5.3 ADAPTIVE EA CONTENT (EA-CT)

Dynamic environments can impose quickly changing requirements towards architectures. This can include new use cases as well as new technological developments, which need to be considered. Therefore, solutions should be built with adaptive capabilities so that they can adapt to changing conditions. The following principles summarize how adaptive architectures can be built.

5.3.1 Design Modular (EA-CT1)

EA-CT1 Principle: Modular designs should be favored over tight-coupled monolithic designs in dynamic environments

EA-CT1 Description: For dynamic environments, solutions should be designed modularly since this allows for leveraging the advantages of decentral organizations. Most importantly, each group that is responsible for a particular module can take decisions on their own. Modularity should be fostered both from a service point of view as well as for the different layers of a solution. Services can be split using microservices approaches, which allow teams to decide for themselves how they want to build their service internal. For the collaboration with the broader enterprise, only the interfaces need to be well-defined and aligned. In addition to considering services, also modularity of layers should be pursued. By splitting responsibilities for application, platform and infrastructure layer, well-defined services can be created, which allows the teams running them to optimize internals as they find it suitable, which makes them more responsive. As a practice to achieve modularity, domain-driven-design should be considered because it allows to design and implement modular solutions top-down.

EA-CT1 Rationale: Sturtevant (Sturtevant 2017) shows how the modularity of solutions can be measured and how different degrees of modularity influence productivity. As a significant problem of non-modular solutions, he identifies that once solutions become too big and complicated to comprehend, decision making is slowed down and consequently, teams are less responsive. Moreover, modular designs provide advantages in dynamic environments because they allow distributing responsibilities between various teams more efficiently. As a result, the advantages of the decentral EA competence and decentral EA methodology can be leveraged.

EA-CT1 Implications:

- *Ensure Interoperability (EA-CT2):* Modularity presents major advantages because responsibilities can be distributed. However, especially in a distributed setup, it also needs to be ensured that solutions work end-to-end. Therefore, interoperability is a necessary prerequisite.

5.3.2 Ensure Interoperability (EA-CT2)

EA-CT2 Principle: Interoperability standards need to be defined, measured, and ensured by the central EA team

EA-CT2 Description: While in general, the central EA team should run in a lightweight fashion in dynamic environments, interoperability presents one of the areas which EA actively needs to monitor and control. This can be achieved by defining interoperability standards upfront. These standards should be defined for technical, syntactical and semantical interoperability (Jarwar et al. 2017). Afterwards, monitoring, preferably with automated discovery tools, can help to detect issues as soon as possible.

EA-CT2 Rationale: While distributed and decentral decision making holds many advantages, such as increased responsiveness, there are also risks attached. One of these risks concerns interoperability. Ultimately, local teams might pursue local optimizations of their domains and not consider the end-to-end functionality and experience perceived by the customer. The worst-case scenario would be if two local services relied on each other and stopped working due to incompatibility.

Therefore, EA needs to consider this end-to-end view and ensure interoperability across services.

EA-CT2 Implications:

- *Utilize Automated Documentation (EA-TO1)*: Automated documentation is required, so that information on architectures and their interoperability is as current as possible.
- *Leverage Automated Assessment (EA-TO2)*: Automated assessment can help teams to detect interoperability problems in large and complex environments quickly.

5.3.3 Ensure Flexibility (EA-CT3)

EA-CT3 Principle: Flexible designs should be preferred over static ones in dynamic environments

EA-CT3 Description: In order to adequately react to changing conditions and requirements, designs for dynamic environments should have inherent flexibility. The concept of flexibility is closely linked to modularity (EA-CT1) since modular solutions allow, for example, to exchange or modify a particular module without changing the rest. However, flexibility should be considered on top of modularity. Therefore, individual modules should be designed flexibly to simplify the implementation of changes. One example of a design to foster flexibility is Software Defined Architecture (SDA). SDA decouples application, middleware and network layer entirely from the underlying hardware and therefore allows for flexible reconfigurations without actually changing an infrastructure.

EA-CT3 Rationale: Inherent flexibility helps enterprises to simplify and speed up implementation of changes and should, therefore, be considered as a central principle for designs in dynamic environments. At the same time, flexibility might have negative implications as well, such as increased resource consumption or overhead. However, in dynamic environments, flexibility and the resulting improved responsiveness bring substantial benefits which justify investments in flexibility.

EA-CT3 Implications:

- *Capacity Management*: Flexibility will likely lead to increased capacity demand, which needs to be considered.

5.3.4 Extend Scope for EA (EA-CT4)

EA-CT4 Principle: In dynamic environments, it is essential for EA not only to consider IT but also overarching the business and environment perspective

EA-CT4 Description: In the domain of EA, there are multiple schools of thought which have a different understanding of EA's purpose and scope. While some practitioners heavily focus on IT only, there are others which drive EA from the business architecture point of view instead. For EA in dynamic environments, EA should have a holistic scope considering IT, business and the environment in architectural decisions.

EA-CT4 Rationale: In dynamic environments, EA with a too narrow and technology-focused only view will likely lead to problems. Many drivers for changes have their origin in the environment – examples are new technology developments or changing market conditions. Therefore, EA needs to have a broad and holistic focus to detect such changing conditions early and derive suitable decisions and actions.

EA-CT4 Implications:

- *Evolve Architects Mindset (EA-CP4)*: For previously technology focused architects, it can be a big change to extend their scope to include business and environments. Therefore, it is important to train and educate architects accordingly.

5.4 MODERN EA TOOLS (EA-TO)

The previously described principles for EA competence, EA methodology and EA content impose requirements towards software tooling.

In summary, architectural stakeholders in dynamic environments need to have access to modern EA tools in order to be successful. The goals are to speed up decision-making and to provide the means for architectural collaboration in a decentral organization. The following principles summarize the critical capabilities for software tools to support these goals.

5.4.1 Utilize Automated Documentation (EA-TO1)

EA-TO1 Principle: Discovery and documentation of the as-is state should be automated to have architectural information in real-time

EA-TO1 Description: State-of-the-art discovery mechanisms can automatically document architectural views from the infrastructure, application and data point of view. Moreover, dependencies among the components and meta information such as version number can be gathered. Architects need to validate the discovered information and complement it with data from the business and strategy layer. This resulting information should be used to support architectural decision making.

EA-TO1 Rationale: Architectures in dynamic environments can quickly change. If documentation is done purely manually, there is a risk of documentation running out of date. At the same time, due to the decentral nature of the EA practice, it can be challenging to ensure the availability of a current and holistic overview of the as-is state. Therefore, automation should be used to overcome this. Ultimately, with this approach, EA receives better and more current information with less manual effort.

EA-TO1 Implications:

- *Leverage Automated Assessment (EA-TO2)*: Automated discovery likely results in a vast amount of data, which can be challenging to analyze manually. Therefore, automation should be used to support assessments
- *Configuration Management*: Discovery and documentation of running services is typically handled by configuration management. EA should not try to discover everything itself but instead re-use the information from configuration management
- *Release Management*: Planning and rollout of new or updated services are typically handled by release management. EA should re-use information from release management in order to have better documentation of planned and executed changes to the as-is state.

5.4.2 Leverage Automated Assessment (EA-TO2)

EA-TO2 Principle: Assessment of architecture should be supported by automation in order to derive information quickly from vast amounts of data

EA-TO2 Description: Analytic tools should be used to assess architectural data automatically. Relevant data sources are in house architecture repositories but also external databases, which can complement internal views in many regards. Automating assessments allows for speeding up analysis, which would take much effort when conducted manually. It can also reveal additional insights.

EA-TO2 Rationale: The amount of data relevant to architectural decision making is growing. At the same time, there is a need in dynamic environments to take a decision quickly. Therefore, it is important to support the decision-making process by tools which can analyze data automatically and summarize information for different stakeholder groups. The evolution of analytics tools throughout the past years simplifies the use of such tools for architectural purposes.

EA-TO2 Implications: Not applicable

5.4.3 Enable Collaboration (EA-TO3)

EA-TO3 Principle: EA tools need to provide collaboration functionalities which allow stakeholders to consume and work on architectural artifacts jointly

EA-TO3 Description: Very likely, not every architectural stakeholder will use the same software tool. For example, business architects and low-level software architects have different requirements towards tooling and therefore have different preferences. However, in this case, it is essential to ensure that relevant information is exchanged by integrating tools when required

EA-TO3 Rationale: Information for architectural decision making should reach all relevant stakeholders. Especially in dynamic environments, it needs to be ensured that architectural tools are not used and consumed by a single architect only. Due to the proposed decentral EA competence and methodology, every architectural stakeholder should be able to access and leverage architecture tools to support their decision making.

EA-TO3 Implications: Not applicable

6 CONCLUSION AND OUTLOOK

6.1 CONCLUSION

Throughout the past decades, the pace of economic and technological change has accelerated. Today, the consequences of this development are vividly visible. The dynamic in corporate environments is still increasing and companies which fail to adapt to changing conditions will be less successful and ultimately go out of business (Bennett and Lemoine 2014; Sinha, Haanaes, and Reeves 2015).

In biology and particular in evolutionary theory, the importance of adaptivity is a well-known fact, which is summarized in a quote often attributed to Charles Darwin[14]: *"It is not the strongest of the species that survives, nor the most intelligent, but the one most adaptable to change."* In today's business world, precisely these adaptive capabilities become more and more critical for companies to be successful.

While building up and improving adaptive capabilities requires the joint work of many parts within the enterprise, EA can deliver a vital share by enabling and guiding various organizational parts to be more effective in dynamic environments. However, in order to do so, EA itself needs to transform.

This thesis delivers results, that describe how EA can become more effective in dynamic environments. The results are structured according to the following four research questions:

- RQ1: What is the current state of EA as a discipline?
- RQ2: How can the interdependency between the increasing pace of change and the discipline EA be described?
- RQ3: What EA approaches need to be applied in order for the discipline to be effective in dynamic environments?
- RQ4: How can a reference architecture for the discipline EA in a dynamic environment be described?

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[14] Even though the quote is often attributed to Darwin, it is not. The quote was derived from Darwin's work by Megginson (Megginson 1963) in 1963 and back then already applied to economics.

The results obtained when addressing these four research questions are summarized below as well as potential next steps, which present opportunities for future research.

The general state-of-the-art review on EA, addressing RQ1 as presented in chapter 2, outlines the development of the discipline throughout the past three decades. From the analysis, it is evident that the focus of EA research has shifted from understanding and defining EA towards effectively managing the discipline in complex enterprise environments. This thesis puts its emphasis on effective management of EA as well by providing EA approaches for specific circumstances, i.e., environments with an increased pace of change.

In addition to the results directly valuable for the subsequent questions addressed within this thesis, chapter 2 provides valuable guidance for EA researches in general. The presented state-of-the-art review analysis outlines areas of increasing interest in the scientific domain of EA such as IoT, sustainability, complexity theory and entrepreneurship. At the same time, a significant discrepancy between scientific EA and practitioner EA is shown. These results can serve as a foundation to design future studies on EA and hence, they present an exciting opportunity for future research.

The subsequent chapter 3 addresses RQ2 and delivers a formalized description of how the effects of the increasing pace of change influence the effectiveness of EA. The primary result within this part of the thesis is a model summarizing the following dependencies:

The increasing pace of change leads to increased dynamic complexity for EA since there is a need to manage parts that are changing more and more quickly. This complexity needs to be considered from a business and technological point of view. To formally describe the value and effectiveness of EA, an existing model developed by Foorthuis et al. (Foorthuis et al. 2016) is considered. Their model describes how the various approaches and activities of EA generate value for individual projects as well as benefits for the overall organization.

In chapter 3 of this thesis, the idea of dynamic complexity arising for EA due to the increasing pace of change is combined with the general theoretical framework for EA practices and benefits. Dynamic business and technological complexity are considered a contextual factor, which influences the correct use of EA. A graphical representation can be found in chapter 3, Figure 31.

The results derived to answer RQ2 also provide an opportunity for future research. The model presented within this part of the thesis is theoretically underpinned by complexity theory. However, during the subsequent research, it became evident that there might be other theoretical lenses, such as institutional theory or actor-network theory, which might be suitable to be applied to the research question. Schilling (Schilling 2018) provides a summary of some relevant theories. Moreover, Table 11 in section 4.1 shows relevant theoretical lenses identified within the qualitative analysis performed as part of this work. Applying new theories to RQ2 could help to gain further understanding of the underlying development and the related challenge for EA.

The results concerning RQ3 presented in chapter 4 are a collection of approaches to improve the effectiveness of EA in dynamic environments. The presented approaches are structured into four dimensions:

1. *EA Competence*: This dimension addresses the question of who in the organization is working on EA.
2. *EA Methodology*: This dimension addresses the question of how EA is run in the organization.
3. *EA Content*: This dimension addresses the question of what is the output of EA.
4. *EA Tools*: This dimension addresses the question of with what EA is being created and maintained.

Chapter 4 of this thesis includes an initial qualitative validation of the presented approaches based on expert interviews conducted with senior EA practitioners from multiple verticals and geographies. However, there is still potential for an extended validation in future research. Suitable methods to perform this could be, for example, a quantitative survey study or long-term case studies, see section 4.3 for further details.

The goal of the last research question, namely RQ4, is to summarize the findings of this thesis in a consumable manner, which can also be applied in practice. Therefore, chapter 5 presents the results in the form of a reference architecture for EA in dynamic environments. Figure 63 provides a graphical summary of this reference architecture. The EA approaches are structured according to the previously described dimensions. The reference architecture is described on the level of individual approaches as well as on the dimension level.

In summary, the EA competence needs to be *integrated* well into the enterprise. On top of this, the EA methodology should be aligned to *agile* practices allowing quick architectural decisions. The resulting EA content needs to be *adaptive* meaning that the architecture can be adjusted easily in case required. The architects and other EA stakeholders should be supported by *modern* EA tools.

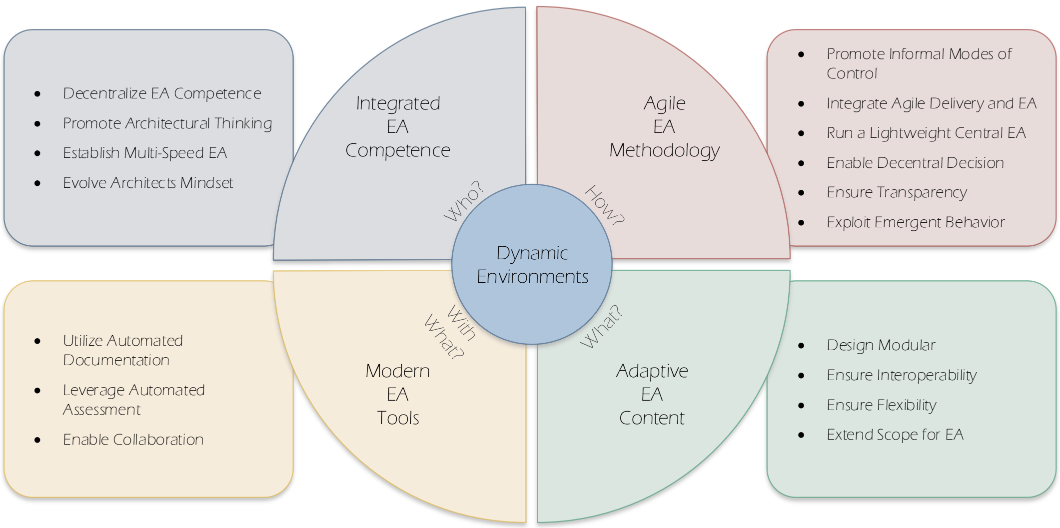

Figure 63: Summary of the proposed reference architecture for dynamic environments

The results provided for RQ4 also hold potential for future research: So far, the reference architecture only describes a final to-be state. For implementation in practice, this might be challenging since likely enterprises will not completely start from the beginning and they also will not implement the entire reference architecture at once. Therefore, a model is required, which shows how organizations can develop their EA competency from a certain level to the next one. Maturity models are a well-established tool to measure and accomplish this kind of discipline development (Ahern, Clouse, and Turner 2008; Gibson and Nolan 1974; Paulk et al. 1993), also in the area of EA (van Steenbergen 2011). A maturity model for EA in dynamic environments should describe different levels of maturity suggestions on how to develop from one level to the next. Such a model could be a valuable addition to the developed reference architecture.

6.2 OPPORTUNITY FOR FUTURE RESEARCH

In summary, after completing the work on this thesis, the following opportunities for future research have been identified.

Upcoming scientific EA trends are identified in chapter 2. According to the forecast provided in this thesis, topics concerning EA in combination with sustainability, IoT, complexity theory and entrepreneurship will likely remain popular throughout the next years and therefore present exciting areas for future research, see section 2.6 for further details.

Discrepancies between developments in the academic and practitioner EA space are identified in chapter 2. However, since this question was not the focus of this thesis, so far only one source was considered for the practitioner space. Further investigating the discrepancy presents an interesting opportunity for future research. To better understand the development within the practitioner space, the content of blogs and news portals could be interesting. Again, text mining is likely a helpful tool to analyze large amounts of text data. See also section 2.6 for further details.

The link between practitioner and academic EA trends seems to be not consistent, as shown in chapter 2. Therefore, it might be worthwhile to have a closer scientific look at those subjects which are prevalent in the practitioner space but have not yet received academic attention. However, also vice versa, EA practitioners should consider those topics with increased attention in the academic world. There is most likely potential for both sides. See also section 2.6 for further details.

Additional theoretical lenses to understand the impact of the increasing pace of change on EA are identified in chapter 2 and 3. While this thesis primarily applies complexity theory to underpin its work, other theoretical lenses might provide additional insights and are therefore worth investigating. Further details can be found in sections 3.3 and 4.1 of this thesis.

Validation of EA approaches for dynamic environments has been done only in an initial form within this thesis by conducting expert interviews. A formal validation could be performed in the next step by using a long-term case study or a quantitative survey study, see section 4.3 for an extended discussion on the validation options.

A maturity model for EA in dynamic environments could present a valuable addition to the results of this thesis. The developed reference architecture only describes a final to-be state. A maturity model could guide practitioners to assess their current state and derive the next steps of transformation.

6.3 OUTLOOK

Since its early days, EA has evolved significantly both from theoretical as well as from a practitioner point of view. While 30 years ago, EA was a niche phenomenon only, by today most large companies have an EA practice with dedicated role descriptions. Still, even in 2019, EA remains a rather young discipline, with much potential. This can be confirmed by the growing research interests in the subject (Gampfer et al. 2018). While overall the maturity of EA has increased, there is still much room for further development. Changing conditions such as the increasing pace of change, which has been considered in this thesis, will be major drivers for this evolution.

This thesis has shown that the underlying goal of EA, namely to ensure alignment of different facets within the enterprise is still required – even given today's changing conditions. However, architects working in dynamic environments will need to review the described dimensions (who? – how? – what? – with what?) of their EA practice in order to remain effective. The presented reference architecture can provide them with guidance to take suitable decisions.

In general, for the global development of the EA practice, further development of public frameworks, such as TOGAF or Zachman, will play a crucial role as they present the reference for practitioners as well as the foundation for the education of new architects. Just before this thesis was finalized submitted, the Open Group released the first full draft version of the Agile Architecture Framework, which is now called the O-AAF standard (The Open Group 2019). It will be interesting to observe the development of this standard and whether it will be combined with the existing TOGAF content.

The most important next step for the results presented within this work is a real-world validation of the proposed approaches and structures, e.g., as proposed through case studies, which will help to observe their effectiveness and evolve the presented reference architecture. According to the analysis within this thesis, the suggested practices will have a positive impact on the EA capability within individual organizations. Proving the value will present an intermediate step to promote the broader adoption of the suggested EA approaches and thus further develop the practiced discipline in general.

Moreover, the additional previously suggested ideas for future research will hopefully inspire researchers to drive the evolution of EA from an academic point of view.

At the same time, it will be interesting to observe the further development of the pace of change in business and technology. While many factors indicate an increasing acceleration in the future, today nobody can confirm this for certain. In any case, EA holds the potential to play a crucial role in making enterprises successful in dynamic environments.

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A APPENDIX

The content within the following appendix sections has been partly published within the following contributions of the author of this thesis: (Gampfer et al. 2018)

A.1 TEXT-MINING METHODS AND TECHNIQUES

Text mining or text analytics is regarded as a subcategory of natural language programming (NLP), which is one of the founding branches of artificial intelligence (Moreno and Redondo 2016). Text mining methods offer a wide range of possibilities when 'big data' sources need to be analyzed (Rüdiger Buchkremer 2016). Various publications demonstrate the advantages of using statistical methods to derive models and analyze large quantities of data in short periods of time (Erskine et al. 2010; Fan et al. 2006; Hirji and K. 2001). For the review that is described in this thesis, there were several thousand scientific papers to be analyzed and it would have required an immense effort to read and classify these documents manually (Andronis et al. 2011).

There are several papers that deal with a generic approach for analyzing data in which the text is not semantically decoded (Fan et al. 2006; Hirji and K. 2001). Sebastiani (Sebastiani 2002) explains that automated text categorization can be used to work more efficiently in a similar example of analyzing scientific literature. He also describes the information retrieval process, where data are collected and the set of documents – the so-called corpus – is derived. In general, two different approaches are described in the literature (Erskine et al. 2010; Gersten, Wirth, and Arndt 2000):

1. Supervised Learning
2. Unsupervised Learning

In the supervised learning approach, the human teaches the model to the computer. Supervised learning hereby means learning with strong guidance and moderation by the researcher. The computer is used to accomplish several tasks "on its own", but the interaction with humans is quite intensive. The supervised learning method requires human interaction and is highly repetitive.

Due to grammar and spelling rules, proximity and truncation operators need to be used to extract terms in specified distances or patterns. The terms *cloud* and *computing* might appear in a document, for example. However, it seems to be essential to find both terms adjacent to each other to interpret them as *cloud computing*. Since *computing in the cloud* has the same meaning, a proximity rule may interpret *cloud* and *computing* within a distance of four words as the term *cloud computing* (e.g., cloud NEAR/4 computing). The correct distance needs to be refined by further testing and by checking the precision/recall ratio within the test set. The syntax depends on the tool and the required programming language. In most search engines, these proximity operators can be used to search for relevant information to build up the corpus precisely (Rüdiger Buchkremer 2016).

Usually, the proximity functions are defined as simple rulesets, e.g., the distance between 'Term 1' and 'Term 2' in a document (Tao and Zhai 2007). Such search queries can be made more flexible by combining distance operators with wildcards or truncation operations. For example, *word**, with the right-side truncation, represents both *word* and *words* because * can be replaced by zero, one or a variable number of characters (Wallgrün, Klippel, and Baldwin 2014). Truncation operators can be set on the right or left side of a word or in between characters. Supervised clustering is a classification method that is based on a given taxonomy. A taxonomy is hereby defined as a hierarchical description of terms and their relations, such that documents can be scored if they satisfy the specified rules (Yao, Huang, and Cui 2009). A hierarchical taxonomy is derived manually from a sample set of documents and often based on a defined target label. Therefore, the target label must be defined first. The human supervisor suggests clusters or topics and annotates these by identifying descriptive terms for scoring the documents. Once hierarchical clustering has been completed, it can be applied to the corpus to score the documents. The highest-scoring topic may be classified as a category.

The unique characteristic of the unsupervised learning approach is that no human interaction is required, and the computer derives rules "on its own". Pattern recognition and cluster detection, for example, suggest semantic relationships that may not have been known to the researcher upfront. Therefore, an unsupervised learning approach is likely to be effective when applied to large data sources

(Grossman 2004). In general, unstructured or semi-structured big data sources may be analyzed efficiently by text mining procedures (Fan et al. 2006).

To detect patterns and structures, statistical methods may be used. Unsupervised learning means that the text mining algorithm detects patterns in the document pool – the corpus. All documents are processed separately to detect patterns. To identify terms that are present in all documents with equal frequency, the entropy function can be applied to derive the term weight. If term i is given, entropy is calculated in document j. d_i is the number of documents that contain term i and n is the total number of documents in the corpus.

$$entropy_i = 1 + \sum_{j=1}^{d_i} \frac{p_{ij} log_2(p_{ij})}{log_x(n)}$$

This function demonstrates the occurrence of a specific term within a defined set of documents. It is used to identify terms that are important in all documents because they are evenly spread (Guyon and Elisseeff 2003). To identify terms that describe document groups, a different function must be used. For example, the inverse document frequency can be used, which equals the number of documents in corpus n divided by the number of documents d_i where the term occurs. The more frequently a term appears in a group of documents, the more important it is (Miao, Kešelj, and Milios 2005).

$$IDF_i = 1 + log_2(\frac{n}{d_i})$$

Clusters can be identified by using clustering algorithms such as k-means or guessing the number of clusters and centers. The clusters can be identified by their most descriptive terms, which can be interpreted to derive a "friendly" name for each cluster (Jain, Murty, and Flynn 1999). To identify the optimal value of k, the best splitting criteria can be calculated. The Davies-Bouldin Index is used to quantify the quality of a clustering algorithm.

$$DB = \frac{1}{N} \sum_{i=1}^{N} D_i$$

This method allows k, which is the number of cluster centers, to be optimized. It is often used to automatically detect clusters, which are interpreted as topics. There are several steps in determining the sharpness of clusters, which refers to the tightness inside clusters (Davies and Bouldin 1979). These unsupervised learning methods are widely used to discover new patterns and are applied throughout the analysis that is presented in the subsequent sections.

A.2 RESULTS FROM UNSUPERVISED CLUSTER ANALYSIS

Cluster Name	Publication Year-Group	Terms	Count of Documents
A1	2002-2006	alignment, zachman, knowledge, supply, chain, strategic, life, strategy, component, diagrams	85
A2	2002-2006	security, government, access, agencies, federal, adaptive, sharing, local, risk, records	57
A3	2002-2006	manufacturing, virtual, agent, backslash, control, coordination, automation, interoperability, product, distributed	82
A4	2002-2006	object, governance, domain, oriented, principles, distributed, driven, workflow, middleware, core	37
A5	2002-2006	implementation, papers, factors, companies, success, planning, agility, survey, review, directions	55
A6	2002-2006	architectures, software, architectural, languages, language, description, integration, evaluation, change, computer	88
A7	2002-2006	health, care, medical, informatics, clinical, mobile, patient, record, hospital, services	60
B1	2007-2011	oriented, software, services, engineering, driven, patterns, requirements, zachman, architectures, integration	245
B2	2007-2011	ontology, semantic, knowledge, supply, chain, ontologies, mining, domain, manufacturing, artificial	123
B3	2007-2011	method, quality, assessment, algorithm, measurement, force, phase, accuracy, evaluation, metrics	123

Cluster Name	Publication Year-Group	Terms	Count of Documents
B4	2007-2011	decision, change, metamodel, learning, making, archimate, influence, project, performance, portfolio	287
B5	2007-2011	security, health, computing, healthcare, cloud, network, access, grid, care, medical	215
B6	2007-2011	alignment, maturity, strategic, strategy, principles, strategies, governance, aligning, organization, organizations	129
B7	2007-2011	government, interoperability, digital, agencies, local, governance, governments, administration, national, electronic	82
C1	2012-2016	cloud, computing, services, outsourcing, architectures, oriented, providers, privacy, resources, applications	99
C2	2012-2016	manufacturing, smart, networks, network, interoperability, supply, energy, chain, product, sustainable	207
C3	2012-2016	government, factors, governance, innovation, decision, sector, success, making, literature, studies	387
C4	2012-2016	software, engineering, requirements, quality, pattern, project, method, methodology, architectural, agile	516
C5	2012-2016	security, cyber, secure, physical, risk, access, control, privacy, scheme, risks	85
C6	2012-2016	alignment, maturity, strategic, strategy, organizations, organization, aligning, aligned, method, evaluation	192
C7	2012-2016	ontology, social, health, semantic, knowledge, archimate, healthcare, ontologies, semantics, medical	254

A.3 SUMMARY OF INTERVIEW QUESTIONS PROVIDED IN ADVANCE

The following questions have been provided to the interview candidates in advance to the actual interviews described in chapter 4:

1. How have the conditions for EA changed in the past 20 years…
   … in general?
   … considering the pace of change in enterprises?
2. Which requirements result from these changing conditions towards…
   … EA competence?
   … EA methodology?
   … EA content / results?
   … EA tools?
3. How do you see the implementation of these requirements in today's enterprises?

A.4 SUMMARY OF CODINGS FROM QUALITATIVE CONTENT ANALYSIS

Node	**Count of Coding References**	**Aggregated Count of Coding References**	**Count of Coded Objects**	**Aggregated Count of Coded Objects**
EA Competence	0	74	0	30
EA Competence\Architect's mindset	5	5	5	5
EA Competence\Architectural Thinking	11	22	8	11
EA Competence\Architectural Thinking\Bottom-up consolidation	1	1	1	1
EA Competence\Architectural Thinking\Co-creation	1	1	1	1
EA Competence\Architectural Thinking\Demonstrate EAM value	1	1	1	1
EA Competence\Architectural Thinking\Setup architecture community	1	8	1	4
EA Competence\Architectural Thinking\Setup architecture community\Learning	4	4	3	3
EA Competence\Architectural Thinking\Setup architecture community\Participative	3	3	3	3
EA Competence\Decentralization of the EA Competence	15	34	14	22
EA Competence\Decentralization of the EA Competence\Ensure autonomy of decentralized teams	3	3	3	3

Node	Count of Coding References	Aggregated Count of Coding References	Count of Coded Objects	Aggregated Count of Coded Objects
EA Competence\Decentralization of the EA Competence\Ensure cultural requirements are met	5	7	4	5
EA Competence\Decentralization of the EA Competence\Ensure cultural requirements are met\positive perception of EAM	1	1	1	1
EA Competence\Decentralization of the EA Competence\Ensure cultural requirements are met\social acceptance of EA throughout the enterprise	1	1	1	1
EA Competence\Decentralization of the EA Competence\Establish centralized EA practice	5	9	4	7
EA Competence\Decentralization of the EA Competence\Establish centralized EA practice\hands on architects	3	3	3	3
EA Competence\Decentralization of the EA Competence\Establish centralized EA practice\position EAM high in the org	1	1	1	1
EA Competence\Multi-speed EA	12	13	8	8
EA Competence\Multi-speed EA\Pace Layered Architecture	1	1	1	1
EA Content	0	37	0	24
EA Content\Flexibility	3	3	3	3
EA Content\Interoperability	5	5	4	4
EA Content\Modularity	13	18	11	14
EA Content\Modularity\Decompose	1	1	1	1
EA Content\Modularity\Microservices	4	4	4	4
EA Content\Scope of EA	11	11	10	10
EA Methodology	0	86	0	43
EA Methodology\Decentral decision making	4	10	4	9
EA Methodology\Decentral decision making\Domain-driven design	3	3	3	3
EA Methodology\Decentral decision making\Parallelization	1	1	1	1
EA Methodology\Decentral decision making\Peer-to-peer concepts	2	2	2	2
EA Methodology\EA and agile development - operations	9	20	7	15
EA Methodology\EA and agile development - operations\Iterative implementation	5	6	4	5
EA Methodology\EA and agile development - operations\Iterative implementation\Recursion	1	1	1	1

Node	Count of Coding References	Aggregated Count of Coding References	Count of Coded Objects	Aggregated Count of Coded Objects
EA Methodology\EA and agile development - operations\Leverage SAFe	2	2	1	1
EA Methodology\EA and agile development - operations\Scrum	1	1	1	1
EA Methodology\EA and agile development - operations\Think in products not projects	2	2	2	2
EA Methodology\Emergent behavior	3	7	3	6
EA Methodology\Emergent behavior\Effective exploitation of emergence	1	1	1	1
EA Methodology\Emergent behavior\Nudging	1	2	1	2
EA Methodology\Emergent behavior\Nudging\measure compliance in an open fashion - energy labels	1	1	1	1
EA Methodology\Emergent behavior\Organic growth	1	1	1	1
EA Methodology\Measure adaptivity	3	8	3	7
EA Methodology\Measure adaptivity\Feedback loop on validity of standards and principles	2	2	2	2
EA Methodology\Measure adaptivity\Real-time information and communication	3	3	3	3
EA Methodology\Self-organization and self-control	4	25	2	15
EA Methodology\Self-organization and self-control\Active involvement of enterprise architects in projects	8	8	7	7
EA Methodology\Self-organization and self-control\Recommendations instead of guidelines	5	5	5	5
EA Methodology\Self-organization and self-control\Run EA as an enabler rather than a control instance	8	8	7	7
EA Methodology\The focus of the central EA process	6	16	5	11
EA Methodology\The focus of the central EA process\Focus on as-is rather than to-be architecture	1	1	1	1
EA Methodology\The focus of the central EA process\Just enough architecture	6	7	4	5
EA Methodology\The focus of the central EA process\Just enough architecture\Just enough - just in time	1	1	1	1
EA Methodology\The focus of the central EA process\Keep architecture as simple as possible	2	2	2	2
EA Tools	0	47	0	23

Node	Count of Coding References	Aggregated Count of Coding References	Count of Coded Objects	Aggregated Count of Coded Objects
EA Tools\Automated assessment	19	20	15	15
EA Tools\Automated assessment\Design structure matrices	1	1	1	1
EA Tools\Automated documentation	18	22	13	14
EA Tools\Automated documentation\Model-driven engineering	4	4	4	4
EA Tools\Collaboration	4	5	4	4
EA Tools\Collaboration\Architects should use tools of others	1	1	1	1