Journal of the Association for Information Systems (2021) **22**(5), 1334-1375
doi: 10.17705/1jais.00696

RESEARCH ARTICLE

ISSN 1536-9323

The Mechanics of Enterprise Architecture Principles

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Abstract

Inspired by the city planning metaphor, enterprise architecture (EA) has gained considerable attention from academia and industry for systematically planning an IT landscape. Since EA is a relatively young discipline, a great deal of its work focuses on architecture representations (descriptive EA) that conceptualize the different architecture layers, their components, and relationships. Beyond architecture representations, EA should comprise principles that guide architecture design and evolution toward predefined value and outcomes (prescriptive EA). However, research on EA principles is still very limited. Notwithstanding the increasing consensus regarding the role and definition of EA principles, the limited publications neither discuss what can be considered suitable principles nor explain how they can be turned into effective means to achieve expected EA outcomes. This study seeks to strengthen the extant theoretical core of EA by investigating EA principles through a mixed methods research design comprising a literature review, an expert study, and three case studies. The first contribution of this study is that it sheds light on the ambiguous interpretation of EA principles in the extant research by ontologically distinguishing between principles and nonprinciples, as well as deriving a set of suitable EA (meta)principles. The second contribution connects the nascent academic discourse on EA principles to studies on EA value and outcomes. This study conceptualizes the "mechanics" of EA principles as a value-creation process, where EA principles shape architecture design and guide its evolution and thereby realize EA outcomes. Consequently, this study brings the underserved, prescriptive aspect of EA to the fore and helps enrich its theoretical foundations.

Keywords: Enterprise Architecture, Enterprise Architecture Principles, Enterprise Architecture Value, Mixed Methods Research

Jan vom Brocke was the accepting senior editor. This research article was submitted on January 9, 2019 and underwent two revisions.

1 Introduction

Since the 1980s, practitioners and academic scholars have propagated the notion of *architecture* as an approach to systematically planning and developing IT landscapes (Earl, 1993; Lederer & Sethi, 1988; Segars & Grover, 1998; Zachman, 1987; Zachman, 1997). The similarities between city planning and the IT domain, which both deal with complex supersystems and require ongoing management to address various stakeholders' constantly changing interests, have inspired the seminal publications and theoretical concepts that underpin the *enterprise architecture* (EA) discipline. In his pioneering work, Zachman (1987) built on architecture abstraction and proposed a framework to systematically document EA, with different representation types addressing different stakeholder concerns. In another early, seminal EA publication, Richardson et al. (1990) took a different, yet complementary, stance, emphasizing a *principles-based* EA. In their view, principles reflect "the organization's basic philosophies that guide the development of the architecture" and have a "far-reaching and significant impact on an organization because they are the most stable element of an architecture" (Richardson et al., 1990, p. 389).

Today, the architecture concept is acknowledged as playing a fundamental role in the *design* of an organization as a complex adaptive sociotechnical system (Haki et al., 2020; Schmidt & Buxmann, 2011) and in guiding its *transformation* from a current state to a future state (Lange et al., 2016). EA is seen as a coherent unity of principles, methods, and models providing a *blueprint* for organizations (Lankhorst, 2009, p. 3; Ross et al., 2006, p. 9). Many EA studies refer to the ISO/IEC/IEEE 42010:2011 Standard (ISO/IEC/IEEE, 2011) to characterize [enterprise] architecture as "fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution." In both definitions, EA comprises both descriptive and prescriptive aspects,[1] an understanding that other architectural disciplines share and which dates back to the Roman author, architect, and civil engineer Vitruvius and his *De architectura*.

In EA, the *descriptive* aspect builds on Zachman's tradition (Sowa & Zachman, 1992; Zachman, 1987, 1999) and is associated with the artifacts representing an organization in its as-is and to-be states.[2] Descriptive EA focuses on creating *architecture representations* to depict and explain an organization's *design* as a sociotechnical system and in terms of its constituents, properties, and relationships. In turn, the *prescriptive* aspect takes Richardson et al.'s (1990) stance and emphasizes the principles governing the design and evolution of architecture. Prescriptive EA draws attention from architecture representations, in the form of artifacts, toward the architectural shape and the question of "how" organizations should be designed and built. The prescriptive aspect therefore comprises *principles* to guide an organization's design and evolution to achieve predefined outcomes and a desired future state.

EA is a still maturing discipline (Boh & Yellin, 2006; Schmidt & Buxmann, 2011; Tamm et al., 2011) and has long focused on the descriptive aspect. In comparison, the number of publications related to prescriptive EA is very limited—a research gap that other studies have also noted (Greefhorst & Proper, 2011; Stelzer, 2010). By enriching the theoretical foundations of EA, this study seeks to bring the underserved, prescriptive aspect to the forefront of EA research. We posit that in dealing with hyperturbulent and dynamic environments, EA needs to be sufficiently agile to constantly adapt IT landscapes to ever-changing organizational and technological requirements (descriptive, the constantly changing aspect of architecture) (Haki & Legner, 2013a; Nan & Tanriverdi, 2017; Tanriverdi et al., 2010). While such an adaptation process is required to survive and thrive in the environment, it also bears the risk of making the evolution of architecture inherently emergent and its outcomes inevitably unpredictable (Benbya et al., 2020; Nan, 2011). Therefore, beyond architecture requiring a plastic core to evolve dynamically with environmental changes, it requires a set of *principles* as a robust core in order to purposefully guide its evolution (prescriptive, the most stable aspect of architecture). Such principles are crucial to ensure the *guided*, rather than entirely emergent, architecture evolution to obtain the predefined value and outcomes of EA (Haki et al., 2020). Drawing on city planning and architectural concepts, we therefore postulate that, without explicating EA principles, the knowledge inherent in EA's as-is and to-be design cannot be shared and developed further.

Previous studies have been instrumental in creating a basic understanding by delineating the definition and formulation of EA principles, although the nascent discourse on these principles still lacks consolidation and theoretical integration: First, prior work suggests either company-specific principles, which may not be generalizable, or proposes generic principles, which are not explicitly studied in the EA context. At the same time, prior studies remain ambiguous in their interpretation of EA principles in terms of their nature and raison d'être to guide design decisions. Second, the debate on EA principles is fragmented and largely isolated from EA value and outcomes research. We therefore know little about how principles (as carriers of

[1] Besides descriptive and prescriptive aspects, Bean (2010) proposes a programmatic strand of EA, which concerns the design of and migration toward a target architecture. We argue that this strand is inherently descriptive by nature because it proposes describing a target state explicitly in terms of an architecture model and its components. Therefore, in line with ISO/IEC/IEEE 42010:2011, as well as other conceptualizations (e.g., Fischer et al., 2010; Hoogervorst, 2004; Winter & Aier, 2011), we distinguish between the descriptive and prescriptive aspects of EA.

[2] Our understanding of descriptive EA reflects the nature of many architecture artifacts, specifically models and modeling notations that explicate how the architecture should be modeled and represented. While they essentially help represent as-is and to-be designs, they do not entail prescriptive knowledge about a "good" or a "bad" architecture design. Consequently, these artifacts cannot be considered prescriptive in the sense of prescribing *how* the architecture should be built. Our view therefore reflects the general knowledge base of the EA discipline, and should not be confused with the prescriptive function of EA in a specific company's context, where the to-be EA is meant to "guide and constrain the subsequent development of business and IT solution" (c.f. Gong & Janssen, 2019).

knowledge about good design) can be used as an effective means to achieve EA value and outcomes. To address these gaps, we investigate the following research questions:

RQ1: What are suitable EA principles to guide architecture design and evolution? (metaprinciples)

RQ2: How do EA principles contribute to achieving EA outcomes? (the mechanics of EA principles)

In answering RQ1, we ontologically analyze the suggested EA principles in the literature and specifically highlight the phenomenon of nonprinciples, i.e., EA principles from academic and practitioner literature that do not conform with the basic understanding of EA principles as a high-level governance instrument. Thereafter, based on their content similarities, we group principles into metaprinciples that provide architecture design and evolution with specific guidance. The focus on metaprinciples, instead of detailed and overlapping principles, provides us with a thorough understanding of the mechanics of EA principles by uncovering their joint contributions and complementarity. Our study thereby contributes to advancing the design knowledge inherent in EA principles and making it accessible to the EA and IS research communities.

In answering RQ2, this study conceptualizes the *mechanics* of EA principles by employing a value-creation approach (Schryen, 2013). Instead of pursuing an outcome-oriented (i.e., deterministic, means-end relations) approach, our study sheds light on the *ways* that EA principles (as *means*) shape architecture design and guide its evolution to create EA outcomes (as *ends*). This study empirically illustrates instantiations of the implications of metaprinciples in obtaining EA outcomes, and reveals complementary relations between metaprinciples as an integral part of their mechanics.

In this study, we opted for an exploratory research design and employed a mixed methods research process.[3] To reflect the research process and its steps, the remainder of this paper is structured as follows: First, we critically review the current status of the research, and outline four distinct research axes. Thereafter, we motivate and present our research design and process. In response to RQ1, we present our ontological analysis and insights from expert studies to derive a set of metaprinciples. We subsequently answer RQ2 by conceptualizing and empirically illustrating the mechanics of EA principles. We conclude by discussing our results and providing a research outlook.

2 State of the Research

2.1 Evolution of the Enterprise Architecture Discipline

EA is a still maturing discipline, mostly driven by practice and underrepresented in the top academic journals. To illustrate the evolution of the EA discipline, Table 1 provides a synthesis of influential EA publications in research and practice that initiated the main discourses of the EA discipline along with their contributions to EA foundations, value, and outcomes. This synthesis builds on some of the first publications that gave rise to the decisive and influential discourses of the EA discipline (i.e., EA frameworks, principles, maturity models, modeling, governance, success, and organizational benefits), regardless of the publication type and outlet. We consequently also acknowledge the influence of the discipline's practitioners.

Although the twin descriptive-prescriptive aspects have been inherent in the EA concept since the earliest contributions (as two sides of the same coin), the extant literature mostly emphasizes the descriptive side. After the early descriptions of architecture artifacts (Sowa & Zachman, 1992; Zachman, 1987), the isolated representations were later integrated into and/or complemented by EA frameworks, such as the enterprise architecture planning (EAP) framework (Spewak & Hill, 1993) and the Open Group Architecture Framework (TOGAF) (The Open Group, 2011, 2018). The EA frameworks were accompanied by a great deal of research to develop modeling techniques (Johnson et al., 2007; Jonkers et al., 2003; Lankhorst et al., 2004), and to propose EA methods (Peristeras & Tarabanis, 2000; Wegmann, 2002) and maturity models (Ross, 2004; Ross et al., 2006; Venkatesh et al., 2007). The key contributions of descriptive EA research are therefore the conceptualization, description, and modeling of EA layers and components, but also the development of specific EA modeling notations. Nonetheless, during the last decade, research interest has shifted from EA representation and modeling to EA value and the more holistic *EA management (EAM)* concept. The increasing academic discourse on EA has resulted in publications in leading journals examining EA governance (Boh & Yellin, 2006), success (Lange et al., 2016; Schmidt & Buxmann, 2011), and organizational value (Tamm et al., 2011).

[3] By following a cumulative research design, this paper complements two conference publications with preliminary research findings derived from the literature review and the expert study (Haki & Legner, 2013b; Haki & Legner, 2012). The manuscript at hand integrates the preliminary research findings into a comprehensive research model and extends them by analyzing the *mechanics* of EA principles, which are based on three case studies. Since this manuscript builds on two prior publications, their fundamental inputs are also included.

Table 1. Overview of Influential EA Publications

Reference	Focus of research	Contribution to EA foundations		Contributions to EA value and outcomes
		Descriptive EA	Prescriptive EA	
Zachman (1987, 1999)	EA framework (practice-oriented)	An EA framework to systematically represent architecture artifacts and organize architecture models	-	-
Richardson et al. (1990)	EA principles	-	A set of EA principles in an exemplary case company	-
Open Group, (2011) – TOGAF	EA framework (practice-oriented)	An EA framework developed by practitioners to step-by-step design, plan, implement, and govern EA	A tentative catalogue of principles	-
Lankhorst (2004)	EA modeling (practice-oriented)	An EA modeling language	-	-
Ross et al. (2006)	EA maturity model and guidelines (practice-oriented)	Architecture maturity model, core architecture diagrams, operating models	-	-
Boh & Yellin (2006)	EA governance	-	EA standards as unifying principles	Impact of governance mechanisms and EA standards on EA outcomes
Schmidt & Buxmann (2011)	EAM success factors and outcomes	-	-	Success factors to attain architecture outcomes
Tamm et al., (2011)	EA value to organizations	-	-	A set of EA benefit enablers leading to organizational benefits

Although the literature has widely discussed the descriptive aspect, the prescriptive aspect (i.e., EA principles) still remains the crux of the EA concept. After the seminal work by Richardson et al. (1990), the academic literature has remained silent about EA principles, with the exception of Boh and Yellin's (2006) study on EA governance. The latter presents EA standards as unifying principles that influence technical choices and decisions related to the data and the application design across projects and business units. Standards can thus be associated with prescriptive EA, even though, in Section 4.1, we provide a more fine-grained distinction between principles and standards (as a course of action and set of rules for principles). It is also noteworthy that TOGAF, the most popular EA framework, comprises a tentative catalogue of EA principles.

Overall, this synthesis of influential EA publications reflects the priorities of the EA discipline: earlier, mostly practitioner-oriented publications focused on the foundations of the EA discipline, which comprised the descriptive and, to a lesser extent, the prescriptive aspects, whereas the more recent top journal publications investigate EA value and outcomes.

2.2 EA Principles as Normative Principles

Generally speaking, principles denote "comprehensive and fundamental laws, doctrines, or assumptions" (Merriam-Webster, 2003) and provide insights into the causes of certain effects, which are rooted in laws of nature, facts, or beliefs (see Greefhorst & Proper, 2011). Principles are fundamental concepts of any engineering discipline, such as civil, mechanical, or software engineering, that emphasize the design of artifacts. They are important instruments for explicating and sharing design knowledge and the rationale that guides design decisions.

EA principles fall into the normative principle category, as they influence an organization's construction and architectural design. Table 2 illustrates the distinction between scientific and normative principles, which Greefhorst and Proper (2011) have discussed extensively. *Scientific principles* are based on laws of nature (e.g., the law of gravity) and do not change with time or distance. They are, therefore, the same today as they were millions of years ago, although their scope of applicability has changed. While scientific principles underlie the working of human-made artifacts, *normative principles* represent "rules of conduct" related to artifacts' design. These normative principles are thus based on fundamental beliefs and assumptions about how things should or ought to be, and how they should be valued in terms of good or bad. These principles restrict freedom of action normatively in order to achieve expected goals. Normative principles are derived from experience and expert knowledge. They are stable and enduring, but new practices and knowledge can change them. Compared to scientific principles that hold naturally, normative principles need enforcement procedures to be put into place.

An EA principle is "included in architecture" and represents "a declarative statement that normatively prescribes a property of the design of an artifact, which is necessary to ensure that the artifact meets its essential requirements" (Greefhorst & Proper, 2011, p. 44). In other words, each EA principle reflects specific architecting knowledge and is derived inductively from EA practice to synthesize knowledge about designing "satisficing artifacts." Therefore, as the theoretical core of a design inquiry, EA principles are design principles that capture, synthesize, and share essential architectural design knowledge (Chandra et al., 2015; Gregor & Jones, 2007; vom Brocke et al., 2020), and allow for the projection of the design knowledge beyond instantiations that are applicable in a limited use context (Baskerville & Pries-Heje, 2019).

2.3 The Nascent Academic Discourse on EA Principles

Since the 2010s, several authors have begun to acknowledge EA principles as the cornerstone and an integral part of EA but have also pointed out that EA principles remain an underexplored aspect of the EA concept (Aier et al., 2011; Op't Land & Proper, 2007; Proper & Greefhorst, 2011; Stelzer, 2010; Winter & Aier, 2011). This debate has resulted in a number of conference publications but has not yet been incorporated into the existing body of academic knowledge to enrich EA foundations (see Table 1). Consequently, research on EA principles is not easily accessible to the broader IS research community. To assess this nascent discourse on EA principles, we conducted a literature review and classified prior publications based on the primary IS research objectives and theory types that Gregor (2006) suggested. While different types of theory are closely interrelated, Gregor's (2006) taxonomy systematically distinguishes theory types with regard to their distinct goals and attributes. Building our investigation of EA principles on Gregor (2006) thereby allowed us to identify the theoretical contributions that EA principles research should provide and assess how the relevant literature has addressed them. This analysis resulted in the identification of four research axes in EA principles research (see Table 3).

2.3.1 Nature (What Are EA Principles?)

This research axis investigates the *what*, in other words, the definition and characteristics of the phenomena of interest, resulting in theory type I (theory for analyzing) in Gregor's taxonomy, which is the most basic theory type. In this research axis, theoretical contributions lay the groundwork for other theory types by providing basic definitions, classification schema, taxonomies, or typologies. On assessing prior studies (see Table 3), we found that they predominantly focus on this axis by: (1) suggesting an exhaustive and comprehensive definition of EA principles and shedding light on their role, (2) discussing the formulation and statement of EA principles as a set of constraints regarding the syntax and semantics of the documentation of EA principles, and (3) categorizing EA principles into different areas and scopes. The most important contribution of the first research axis is a shared understanding of the role, definition, and documentation of EA principles as follows.

EA principles are used to *govern architecture design and evolution*, and to *limit design space* and *guide architecture design decisions* (Op't Land & Proper, 2007; Stelzer, 2010; Van Bommel et al., 2007; Van Bommel et al., 2006). These principles can be attributed to *different architectural layers*, should be based on *business and IT strategies*, and refer to *an organization's construction.* Since architecture is about the aligned (re)design of an organization's technological (i.e., IT components and their relations) and organizational (e.g., business processes) constituents, EA principles refer to principles that guide such essential design decisions in order to achieve predefined outcomes.[4] For complete and exhaustive documentation, each EA principle should be described in a principle *statement*, along with a *rationale* that explains why that principle is helpful to achieve predetermined outcomes, and the *implications* that describe how to implement this principle. Finally, metrics should be identified for each principle to measure its fulfillment (Aier et al., 2011; Fischer et al., 2010; Lindström, 2006; Richardson et al., 1990; Van Bommel et al., 2006).

[4] The notion of EA principles guiding the design and evolution of *architecture* should not be confused with principles, enablers, or factors for successfully deploying EA as a function (e.g., implementing EA frameworks or modeling techniques in specific companies' context) to achieve a high-quality EA function (Niemi & Pekkola, 2013, 2016).

Table 2. Normative vs. Scientific Principles

	Normative principles	**Scientific principles**
Nature of principles	Declarative statements that define the artifact properties ("what should be")	Scientific rules that govern the working artifact ("what is")
Causes of principles	Facts and fundamental beliefs	Laws of nature
Formulation/derivation of principles	Inductive (based on expert knowledge and experience)	Deductive (derived from laws of nature)

Table 3. Current State of Literature Related to EA Principles

Research axis	**Theory type (Gregor, 2006)**	**Current state and research directions**
Nature: What are EA principles?	Theories for analyzing (type I)	*Consensus on EA principles definition and documentation*: 1. The definition and role of EA principles (Aier et al., 2011; Armour et al., 1999; Chen et al., 2008; Fischer et al., 2010; Greefhorst & Proper, 2011; Hoogervorst, 2004; Proper & Greefhorst, 2010, 2011; Stelzer, 2010; Van Bommel et al., 2007; Winter & Aier, 2011; Sandkuhl et al., 2015; Greefhorst et al., 2013); 2. The formulation and documentation of EA principles (Lindström, 2006; Richardson et al., 1990; Van Bommel et al., 2007; Van Bommel et al., 2006; Greefhorst et al., 2013; Marosin et al., 2016); 3. Categorizing EA principles (Lindström, 2006; Op't Land & Proper, 2007; Richardson et al., 1990; Winter & Fischer, 2007).
Practices: How does one design, implement, and manage EA principles?	Theories for design and action (type V)	*Tentative or implicit processes for principle extraction and management, as well as some sample principles*: 1. The extraction process of EA principles (Aier et al., 2011; Fischer et al., 2010; Greefhorst & Proper, 2011; Winter & Aier, 2011); 2. The life cycle management of EA principles (Greefhorst & Proper, 2011; Op't Land & Proper, 2007; Van Bommel et al., 2007; Winter & Aier, 2011; Uludağ et al., 2019; Sandkuhl et al., 2015); 3. Sample EA principles (Janssen & Kuk, 2006; Lindström, 2006; Nightingale, 2009; Richardson et al., 1990; Wilkinson, 2006).
Adoption: Why, how, and to what extent are EA principles adopted?	Theories for explaining (type II)	*First empirical insights, but no general theories on the adoption of EA principles*: 1. Moderating role of organizational culture (Aier, 2014); 2. Main challenges in establishing EA principles (Uludağ et al., 2019).
Impact: What are the impacts of EA principles?	Theories for explaining and predicting (type IV)	*First attempts to examine EA principles' impact*: 1. The impact of EA principles on EA consistency and EA utility (Aier, 2014); 2. The impact of EA principles on managing IT investments and sustainable business-IT alignment (Pessi et al., 2014; Pessi et al., 2011).

2.3.2 Practices (How Does One Design, Implement, and Manage EA Principles?)

This axis specifies guidelines on how organizations should develop, deploy, and manage EA principles. Gregor (2006) classifies this research axis as theory type V (theory for design and action) and associates it with a constructivist type of research or design science. Prior contributions related to this research axis can be categorized into three different areas: (1) the generic process of determining or extracting principles, (2) managing the lifecycle of principles in order to turn these principles into effective means to guide EA design and evolution, and (3) suggesting either a set of company-specific EA principles or principles that are not explicitly studied in the EA context.

2.3.3 Adoption (Why, How, and to What Extent Are EA Principles Adopted?)

This research axis comprises approaches to analyze the adoption and diffusion of EA principles in different organizational contexts. Studies in this research axis ultimately lead to insights into adoption patterns and the factors that underlie or explain the organizational adoption of EA principles, generating theory type II (theory for explaining) in Gregor's taxonomy. Prior research has not yet adequately embraced this research axis. Exceptions are Aier (2014), who illustrates how organizational culture moderates the organizational adoption of EA principles, as well as Uludağ et al. (2019), who investigate how EA principles are established and discuss the associated challenges.

2.3.4 Impact (What Are the Impacts of EA Principles?)

This research axis considers the theoretical constructs and relationships between them in order to explain and predict their impacts. The research in this axis generally results in theory type IV (theory for explaining and predicting) in Gregor's taxonomy. In EA, the measuring of impacts and organizational outcomes are very important, but we found only a few studies (Aier, 2014; Pessi et al., 2014; Pessi et al., 2011) related to the impacts of EA principles. Aier (2014) suggests that the grounding, management, and guidance of EA principles improve the consistency and utility of EA and suggests that EA principles have an indirect effect on EA outcomes. Pessi et al. (2014, 2011) argue that the choice of EA principles impacts both (1) the ability to achieve and maintain a sustainable business-IT alignment in a dynamic business context, and (2) the responsibility for IT investments and the coordination of such investments with business changes.

2.4 Research Gap

EA principles are normative principles that should be used in the constant examination and reevaluation of a proposed IT target plan (Richardson et al., 1990; Stelzer, 2010) toward the expected value and outcomes. Although there is increasing consensus regarding the nature of EA principles and suggestions for their definition and documentation, knowledge related to the principles governing the design and evolution of architecture is fragmented and not systematically accumulated. Beyond EA design knowledge, we know little about what constitutes a suitable principle in the EA context. Prior work suggests either company-specific principles, which might not be generalizable, or proposes generic principles, which are not explicitly studied in the EA context. In addition, studies on EA principles are largely isolated and not connected to the discourse on EA value and outcomes. The extant literature thereby disregards how EA principles shape the architecture design and evolution, and how they contribute to achieving the expected EA value and outcomes.

To strengthen the theoretical core of the EA discipline, this study consolidates the existing body of knowledge on EA principles and addresses three important research gaps outlined by existing studies:

- Proposing a set of suitable principles with the potential to act as effective means to guide architecture design and evolution (Radeke, 2011; Stelzer, 2010);
- Studying the roles and usefulness of principles in EA endeavors (Greefhorst & Proper, 2011); and
- Investigating the relationship between deploying EA principles and achieving architecture value and outcomes (Fischer et al., 2010; Stelzer, 2010; Winter & Aier, 2011).

3 Research Method and Approach

To synthesize suitable EA principles (RQ1) and investigate their mechanics (RQ2), we opted for a mixed methods *exploratory research* design (Creswell & Clark, 2011; Tashakkori & Teddlie, 2010), and combined a literature review, an expert study, and case studies (see Table 4). Mixing methods can lead to new insights and modes of analysis that are unlikely to occur if only one method is used (Kaplan & Duchon, 1988; Venkatesh, et al., 2013). Following its reference disciplines, the use of mixed methods research is gaining momentum in IS (Venkatesh et al., 2013; Venkatesh et al., 2016) and has already been employed in investigating various IS phenomena (e.g., Ågerfalk & Fitzgerald, 2008; Cyr, et al., 2009; O'Leary et al., 2014; Turel & Bart, 2014). In our study, this approach not only helped us critically assess the current body of research, but also assisted us in matching the current literature with insights from subject matter experts and in-depth empirical investigation.

Our research process is organized into three steps, with each step informing the theory building. Appendix A introduces our study's key terms along with their investigation in each step of the study and findings. In **Step 1**, we reviewed the extant literature to *extract assumptions about the nature and role of EA principles*, *collect and critically assess the proposed EA principles*, and *develop the initial conceptualization on the mechanics of EA principles*. For this purpose, we carried out a systematic literature review of scientific journal and conference publications based on the guidelines provided by Webster and Watson (2002) and vom Brocke et al. (2015). A set of key terms (i.e., "principle" and "architecture principle") was used to identify the related publications. In our search, we included articles in an EA[M] context and excluded articles addressing principles in other fields, such as in modeling (Balabko & Wegmann, 2006; Brown, 2004). Owing to the paucity of publications on EA principles, we did not apply any publication date limitation.

Table 4. Research Process

Steps and contribution	Tasks	Outcomes
Literature review (S1) → *Ontological analysis to distinguish between principles and nonprinciples*	Extract insights from literature (S1.T1)	• A set of assumptions about the definition, roles, and usefulness of EA principles • An initial conceptualization of the mechanics of EA principles
	Collect EA principles from the literature (S1.T2)	152 nonunique principles and their statement, implications, and rationale
	Conduct ontological analysis to critically assess the proposed principles in the literature (S1.T3)	• Ontological analysis of the collected principles (S1.T2) in comparison with their basic definition (S1.T1) • Distinguishing between principles and nonprinciples
	Consolidate the remaining principles into unique principles (S1.T4)	A set of 45 unique principles
	Group principles into metaprinciples based on their shared implications and rationales (S1.T5)	A consolidated list of 45 unique principles, classified into nine EA metaprinciples
Expert study (S2) → *Experts' opinions on EA principles in practice*	Expert sampling (S2.T1)	A list of experts from the Open Group Conference and EA expert communities
	Conduct expert interviews (S2.T2)	• Refined and enhanced assumptions about EA principles based on S1.T1 • Refined and enhanced EA metaprinciples based on S1.T5
	Conduct a semistructured survey (S2.T3)	• Experts' feedback on the assumptions about EA principles (from S1.T1 and S2.T2) and a set of new assumptions resulting from the open-ended questions • A set of metaprinciples based on S1.T5 (experts deemed eight of the nine metaprinciples as practically relevant)
Case studies (S3) → *Conceptualization and empirical illustration of the mechanics of EA principles*	Case sampling (S3.T1)	• Selection of three companies from different industries employing different principles
	Data collection (S3.T2)	Three comprehensive case write-ups
	Within-case analysis (S3.T3)	• Coded case write-ups based on a predefined coding scheme. The latter is developed based on the initial conceptualization of the mechanics of EA principles (S1.T1), concluded metaprinciples (from S2.T3), and EA outcomes • EA principles, their implications, and their impacts on EA outcomes for each case as a stand-alone entity
	Cross-case analysis (S3.T4)	• Commonalities and differences between the employed EA principles, their implications, and their impact on EA outcomes

We identified the related articles by scanning scientific databases, namely AIS electronic library, ACM Digital Library, DBPL, EBSCOhost, IEEE Xplore Digital Library, Science Direct, Web of Science, and SpringerLink to cover a wide range of outlets since EA scholars publish in various communities. The first step of our literature review resulted in 32 articles on EA principles. We then coded and analyzed the identified articles based on Gregor's (2006) taxonomy of theory types (see Section 2.3). In the subsequent step, we analyzed the proposed EA principles in existing research. Our primary source for identifying EA principles was peer-reviewed EA-related publications (Dietz & Hoogervorst, 2012; Janssen & Kuk, 2006; Lindström, 2006; Richardson et al., 1990; Wilkinson, 2006). Since certain practitioner publications provide comprehensive collections of principles, we decided to include the catalog of principles that the Open Group (2011) provides as the most important professional resource for EA experts, and the ones that Greefhorst and Proper (2011) propose in the only published book on EA principles. This effort resulted in 152 nonunique principles from the aforementioned sources. Table 5 provides an overview of sources and their proposed principles.

In the next step, we coded the identified 152 nonunique principles based on their *statements*, *implications*, and *rationales*. The results formed the basis of an ontological analysis to distinguish between principles and nonprinciples; we excluded the latter from further investigation. Thereafter, we consolidated similar principles and classified the remaining 45 unique principles during the course of several rounds and synthesized them into nine *metaprinciples* (i.e., principles that share common implications and rationale).

Table 5. Overview of the Literature on the Proposed Principles

Reference	Methodology	Suggested principles	Documentation
Richardson et al., (1990)	Case study: Texaco and Star Enterprise	*18 principles* in four architectural layers: organization, application, data, and infrastructure	Statement, rationale, and implications per principle
Lindström (2006)	Case study: Vattenfall	*35 principles* classified into governance, outsourcing, risk management and security, system management, environment, standardization, application, and infrastructure categories	Only list of principles
Greefhorst and Proper (2011)	Experience-based	A catalogue containing *59 principles* covering different architectural layers	Type of information, quality attributes, rationale, and implications per principle
Open Group (2011)	Experience-based	*21 principles* in four architectural layers: business, data, application, and technology	Statement, rationale, and implications per principle
Wilkinson (2006)	Conceptual insights	Modularity, simplification, integration, and standardization (*4 principles*) as the main principles for adaptive EA	General description per principle
Janssen and Kuk (2006)	Insights from 11 e-government projects	*8 principles* from a complex adaptive system perspective	General description per principle
Dietz and Hoogervorst (2012)	Conceptual insights	*7 principles* for dealing with enterprise transformation	General description per principle

Step 2 comprised an exploratory study to *collect experts' judgments on the metaprinciples* resulting from Step 1 *and refine the assumptions about the mechanics of EA principles.* The expert study's main objective was to complement the literature review (Step 1) and to inform theory building regarding the mechanics of EA principles (Step 3).

First, we organized exploratory interviews with two experienced enterprise architects in the banking and insurance industries. Each interview lasted two hours on average and resulted in complementary assumptions and principles based on the interviewees' experience and observations. Second, we conducted a questionnaire-based exploratory survey because this is the most effective way to rigorously collect opinions and to ask experts to grade a variety of assessment items about a topic (Pinsonneault & Kraemer, 1993).

We prepared a questionnaire (see Appendix C) containing scale-response (on a 5-point Likert scale) and open-ended questions to collect expert feedback on our assumptions and metaprinciples. We identified experienced practitioners with a strong background and with demonstrated field expertise in developing and deploying EA principles from those attending the Open Group Conference, one of the most influential EA conferences, and from EA expert communities (reached through LinkedIn's professional database). The sample covered 26 experts with an average of 10 years' experience in EA as (chief) enterprise/IT architects and representing different sectors and company sizes. All except one used EA principles, either in their affiliated companies or for their clients. The sectors are consultancy (10), banking, insurance, government (3 each), health (2), aerospace, defense, telecommunications, retail, and transportation (1 each). The nonconsultancy companies covered seven large (> 5,000), four medium-sized to large (1,000 to 5,000), four medium-sized (100 to 1,000), and one small (< 100) organization.

There are two noteworthy points about the expert study in Step 2. First, a small sample size is a typical characteristic of expert surveys (Christopoulos, 2009; Hakim, 1987), since the population comprises particular, rarely available individuals with a specific expertise. This is even more decisive in the field of EA principles, which is considered an uncharted EA territory (Greefhorst & Proper, 2011). Second, the expert survey in Step 2 did not follow the purpose of conventional surveys (Hawlitschek et al., 2016; Otjacques et al., 2007; Pinsonneault & Kraemer, 1993) because of its exploratory nature and complementary usage. It was employed as a complementary step to the literature review (Pinsonneault & Kraemer, 1993) for the purpose of systematically collecting experts' judgments and opinions on the types of and reasons for employing EA principles (see Appendix D).

At the end of Step 2, we had EA metaprinciples and derived an initial conceptualization of their mechanics. However, we still lacked insights into how these principles restrict architecture design freedom and how they contribute to achieving the expected EA outcomes. In **Step 3**, we therefore conducted multiple-case studies to *empirically study how the most prominent EA principles impact architecture design and evolution and create value* to eventually *theorize the mechanics of EA principles*. Case studies provide an understanding of the dynamics present within and between single settings (Benbasat et al., 1987;

Eisenhardt, 1989), which serve the purpose of our study on theorizing *how* EA principles contribute to achieving desirable EA outcomes. Specifically, the case studies allowed us to observe how principles shape architecture design, guide architecture evolution, and contribute to achieving EA outcomes.

When conducting the case studies, we followed the guidelines and steps set out by Yin (2003). Since EA is expected to be most useful for large organizations (Boh & Yellin, 2006; Schmidt & Buxmann, 2011; Tamm et al., 2011), we selected three firms with more than 5,000 employees and applied additional selection criteria to follow a replication logic (Yin, 2003) to ensure cross-case diversity and generalizability of findings (Dubé & Paré, 2003): (1) The selected cases had a long history in architecture initiatives and explicitly used principles to guide their business and IT design decisions. This allowed us to observe how the principles shape the design and guide the evolution of architecture over time. (2) The selected cases covered highly ranked metaprinciples identified in our expert study in the previous step. (3) They also exploited some common metaprinciples, which allowed us to identify the commonalities and the differences in the implications of the same metaprinciple across the cases. Table 6 summarizes the main characteristics of the three cases based on the abovementioned criteria and the employed data collection sources.

Primary data were collected by means of semistructured interviews with several key informants (Yin, 2003). We conducted between three and six interviews (12 in total) in each company, ensuring that we interviewed the key informants in the architecture roles with significant expertise in business processes/business domains, applications and technology, as well as with oversight on the enterprise architecture (chief architects or CIO). Each interview was conducted by two researchers and lasted up to 150 minutes. The interview questions focused on the case company's turning points in the architecture design, the underlying principles that guided and led to such architecture designs, and the obtained value and outcomes. We also requested the interviewees to provide us with complementary documents that we could use as secondary data. Each interview was recorded and transcribed. Transcripts and collected documents were used to prepare comprehensive case write-ups (20 to 25 pages each), and to summarize the empirical data into a consistent whole. Consequently, instead of transcribing each interview as a separate document, we reconciled the interview material with the secondary data and undertook one comprehensive case write-up per case company. The reconcilement involved different (internal and external) perspectives and several rounds with regard to each transcript to ensure an intersubjective case description and a high degree of validity. Finally, we provided the interviewees with the comprehensive case write-ups and collected their signatures as a proxy for our full understanding of the relevant case.

Following the steps set out by Eisenhardt (1989), the data analysis was structured into early analysis and coding, within-case analysis, and cross-case analysis. In order to familiarize ourselves with each case as a stand-alone entity, we coded each case and extracted EA principles, their impact on architecture design decisions, and the realized EA outcomes at each stage of the architecture evolution over time. We relied on a coding scheme (Miles & Hubermann, 1994, p. 55) that reflects the metaprinciples, along with their expected implications and rationale resulting from Steps 1 and 2, and the extracted EA value and outcomes provided by the extant EA literature (see Section 5.1 and Appendix E). Consequently, for each case company as a stand-alone entity, our coding endeavor identified several architecture episodes over time. Further, in each episode, we identified architecture turning points, their guiding principles, and the obtained value and outcomes. Once we had the principles, implications, and outcomes of each case at the different stages of their architecture evolution, we undertook cross-case analysis, which involved a detailed search for the commonalities and differences between the cases. The latter aimed to make cross-case inquiries, such as identifying the common implications and outcomes of different metaprinciples in different cases, the diverging implications and outcomes of the same metaprinciples in different cases, and identifying the commonalities of the same metaprinciples in different cases. Finally, we synthesized the insights from expert judgment (Step 2) and case studies (Step 3) to theorize suitable EA principles and their mechanics.

4 EA Principles

4.1 Ontological Analysis

As outlined earlier, the existing knowledge about EA principles is fragmented and has not been systematically accumulated. To consolidate academic and practitioner knowledge and derive a set of suitable EA principles, we collected 152 EA principles from the literature (see Table 5) and coded them based on their statements, implications, and rationales. We found that the EA literature is still ambiguous regarding the interpretation of EA principles and their related terms, even though several researchers (Lindström, 2006; Richardson et al., 1990; Van Bommel et al., 2007; Van Bommel et al., 2006) have sought to clarify the notion of EA principles. We concluded that to resolve this terminological confusion, which Greefhorst and Proper (2011) have also observed and criticized, an ontological analysis is needed at the outset, as this would clarify EA principles and the vocabulary of their related terms.

Table 6. Overview of Cases and Data Collection Sources

Case	Size (at the time of study)	Industry	EA initiatives	EA principles	Interviewees	Secondary data sources
A	More than €150 billion in revenue, more than 500,000 employees	Auto-motive	Several architecture initiatives, earliest in 2000; major extension in 2009	*Standardization* from 2004 onwards; complemented by *reusability* from 2007 onwards	• Chief architect CTO group, leader of technical domain architects • Enterprise architect with a focus on application management and methods • Enterprise architect with a business focus on SOA and modularity	• Basic organizational data and charts • A wide range of external publications (scientific articles, case studies, and magazine articles) • Governance reports • EA overview presentations • Additional information through a parallel long-term study
B	Circa US$100 billion in revenue, more than 300,000 employees	Food	A global program in 2000 imposing significant architecture changes	First attempted *IT standardization* in 1995; relaunch of *standardization* and introduction of *integration* at both business and IT levels from 2000 onwards	• Global CIO • Head of business process management for one of business domains, former CFO • Management role for technical applications • Enterprise architect with a focus on technical perspective • Enterprise architect with a focus on integrating overarching technical platforms • Enterprise architect with a focus on methods	• Basic organizational data • Global IT project progress reports and presentations • A wide range of external publications (scientific articles, case studies, and magazine articles) • A supervised master's thesis in the case company
C	More than €30 billion in revenue, around 100,000 employees	Bank	First architecture initiatives started in early 2000s, relaunch in 2004	*Reusability* from 2005; *integration* from 2010 onwards	• Chief architect, leader of domain architects as head of architecture • Domain architect (business focus) • Technical architect with a focus on SOA	• Basic organizational data • EA overview presentations • Domain architects' presentations • A wide range of external publications (scientific articles, case studies, and magazine articles)

Table 7. Three Nonprinciple Types Derived from Ontological Analysis

Type of nonprinciple	Reasons for being a nonprinciple	Sample
EA outcomes	… are associated with the rationale of principles, but do not limit the design space or guide the design decisions.	• Most effective use of IT as a strategic tool (Richardson et al., 1990) • Develop competencies (Janssen & Kuk, 2006) • Maximize benefits to the organization (The Open Group, 2011)
EA practices	… describe organizational procedures that can be considered as best practices and success factors in adopting EA, but do not provide guidance or contribute to design decisions.	• IS planning as an integral part of business planning (Lindström, 2006; Richardson et al., 1990) • Cost of IT/IS as part of a decision for M&A (Lindström, 2006) • Primacy of principles (Dietz & Hoogervorst, 2012; The Open Group, 2011)
Low-level governance means	… concern specific guidelines for specific usages, while EA principles are pervasive by nature and concern high-level design decision points.	• Access rights must be granted at the lowest level necessary for performing the required operation (Greefhorst & Proper, 2011) • Using formal planning and software engineering methodologies (Richardson et al., 1990)

In our ontological analysis, we assessed the proposed EA principles against (1) the basic definition of EA principles to *govern architecture design and evolution,* as well as to *limit the design space* and *guide architecture design decisions* (Op't Land & Proper, 2007; Stelzer, 2010; Van Bommel et al., 2007; Van Bommel et al., 2006), and (2) the role of EA principles as a *high-level EA governance instrument* (Aziz et al., 2005; Janssen & Kuk, 2006; Lindström, 2006; Wilkinson, 2006). If the proposed EA principle did not conform with (1) and (2), we considered it a nonprinciple and excluded it from our list.

The ontological analysis allowed us to identify *three nonprinciple types*, representing frequent misinterpretations of an EA principle in the literature (see Table 7 for the reasons for classifying them as nonprinciples, and examples). The first category of nonprinciples comprises EA outcomes that are doubtfully formulated as principles—it confuses principles as means to improve EA capabilities (Abraham et al., 2012) with the outcomes expected from the EA. The second nonprinciple type comprises EA practices rather than EA principles. These nonprinciples describe how EA can be managed effectively (Kaisler et al., 2005; Lucke et al., 2010). Since they do not provide guidance for design decisions, they do not qualify as EA principles. The third nonprinciple type is misinterpretations of principles from the EA governance spectrum. In the hierarchy of governance means, EA principles are a high-level EA governance instrument (Aziz et al., 2005; Janssen & Kuk, 2006; Lindström, 2006; Wilkinson, 2006) that guides every design decision toward the overarching architecture. As high-level EA governance means, principles are thus pervasive by nature and should be clearly distinguished from low-level governance means such as standards (a set of rules and course of action for principles) and guidelines (methodologies in implementation) (Korhonen et al., 2009).

4.2 Metaprinciples

The ontological analysis led us to exclude nonprinciples from the initial set of 152 principles, and to combine identical principles that were proposed in different references. This resulted in 45 unique principles. However, these 45 unique principles have different levels of granularity and partly overlap in their implications and rationales. We therefore decided to group them into nine metaprinciples, i.e., groups of principles that share common implications and rationales. This classification of principles into metaprinciples helped us concentrate on their joint implications and rationales, which is in line with the study's goal to explain the mechanics of EA principles. Figure 1 summarizes our step-wise investigation of principles. In addition, Table 8 presents each metaprinciple's constitutive principles in the extant EA literature. Moreover, we realized that the derived metaprinciples are not necessarily new in the IS literature, even though principles are considered an underexplored topic in EA. We therefore took the existing IS literature into account when synthesizing the general characteristics of the metaprinciples.

Integration: Enterprise integration comprises a set of methods, models, and tools to analyze, design, and maintain an enterprise in an integrated state (Panetto & Molina, 2008). Companies can realize integration through, for instance, APIs and enterprise service buses that allow one application to access others' functionalities, or through enterprise portals providing a single point of access for all applications and possibilities of information exchange along a value network (Greefhorst & Proper, 2011; Lindström, 2006).

Data consistency: Data consistency refers to the degree to which shared data definitions and consistency in stored data have been established across an organization. It also expresses the degree to which a dataset satisfies a set of integrity constraints (Akoka et al., 2007) so that an integrated system does not lose significant functionality if the flow of services is interrupted (Panetto & Molina, 2008). By emphasizing a shared vocabulary and shared data definitions, EA principles related to data consistency seek to ensure that data are captured once, are consistent through and across all channels, are provided by the source, and support business continuity in the case of interruptions (Greefhorst & Proper, 2011; The Open Group, 2011). Accordingly, *data consistency* is necessary to support system *integration* and denotes a complementary aspect of integrated systems (Klischewski, 2004; Panetto & Molina, 2008).

Standardization: Standardization refers to the development of company-wide standards to enable interaction between an organization's constituent sociotechnical components (Weitzel et al., 2006). Standardization-related EA principles recommend standardizing architectural components on different architectural layers, i.e., business processes, applications, data, and infrastructure, in order to reduce variations in all the layers and to master organizational complexity (Greefhorst & Proper, 2011; Janssen & Kuk, 2006; Lindström, 2006; The Open Group, 2011). The adoption and realization of this metaprinciple has a higher initial cost for large organizations, owing to their size and the heterogeneity of legacy systems, but may result in considerable cost reductions in the long run (Markus et al., 2006).

Compliance: *Standardization* requires compliance with company-wide standards and with standards in the company's (micro/macro)environment. This emphasizes not only the development of standards, but also their use and actual deployment (Weitzel et al., 2006).

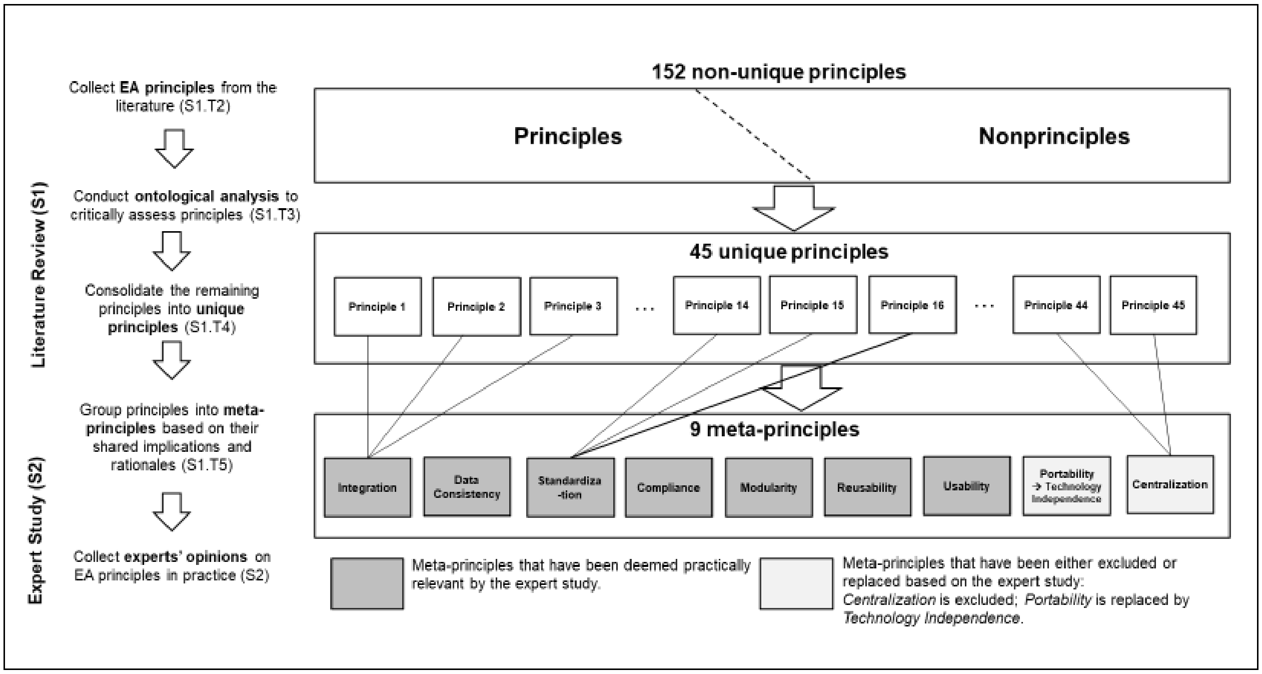

Figure 1. The Investigation of Suitable EA Principles (RQ1)

EA principles propagate adherence to open standards (Greefhorst & Proper, 2011; Janssen & Kuk, 2006; Lindström, 2006; The Open Group, 2011), standards created in international and/or national institutional regulatory contexts (Lindström, 2006; Lyytinen & King, 2006; The Open Group, 2011), and company-level documents—for instance, enterprise IT architecture, and overall corporate security models (Lindström, 2006).

Reusability: Reusability-related EA principles prefer the development of applications used across the organization over the development of redundant applications (Lindström, 2006; The Open Group, 2011). Reusability is an important approach in architecture that leads to the utilization of well-established modules, which in turn improves productivity (reducing the time required to design, develop, and test), maintainability, quality, and portability (Apte et al., 1990).

Modularity: Modularity comprises a set of principles for dealing with organizations and the increased complexity of modern technologies in order to survive in a rapidly changing environment (Langlois, 2002; Wiederhold, 1992). By shaping a system as a complex of loosely coupled components or subsystems (Weick, 1976), modular architecture allows components to be removed, replaced, and reconfigured more dynamically (Benbya & McKelvey, 2006). Proposed EA principles for modularity provide guidance for designing modular business architecture (Greefhorst & Proper, 2011; Wilkinson, 2006), modular application architecture (Greefhorst & Proper, 2011; Janssen & Kuk, 2006; Wilkinson, 2006), as well as multi-tier or independent architectural layers (Greefhorst & Proper, 2011; Lindström, 2006; Richardson et al., 1990; Wilkinson, 2006) to leverage *reusability*.

Usability: Usability (ease-of-use) refers to the degree to which users can associate a system's use requirements with their existing knowledge of other systems and perceive a system's use free of effort (Davis, 1989; Murray & Häubl, 2011). Usability has been frequently proposed as an EA principle (Greefhorst & Proper, 2011; Lindström, 2006; Richardson et al., 1990; The Open Group, 2011) in order to achieve a shared look and feel and to support ergonomic requirements. Nevertheless, a strong emphasis on usability, particularly at the cost of functionality, is not advisable (Adams et al., 1992).

Portability: Portability-related principles foster a system's ability to run in different computing environments (Richardson et al., 1990). This ability leads to flexibility in hardware and vendor selection. It thereby lowers the costs and facilitates migration to new technologies (Richardson et al., 1990). Portability-related principles in EA also emphasize technology independence (Dietz & Hoogervorst, 2012; Richardson et al., 1990).

Centralization: This EA metaprinciple concerns the centralization of application components as well as the centralization of the application development and implementation efforts within an organization (Ein-Dor & Segev, 1982; Greefhorst & Proper, 2011; Lindström, 2006). Some scholars question the feasibility of centralization, pointing out the high associated costs (e.g., Langlois, 2002).

Table 8. Synthesis of Metaprinciples from EA Principles Literature

Metaprinciple	Statements (descriptions) of the constitutive principles*	Implications of the constitutive principles	Rationales of the constitutive principles	Reference	Relationship to other metaprinciples
Modularity (6 principles)	Principles that guide the design of modular (sub)systems to deal with complexity at business and/or IT levels: • The principles guiding the design of modular business architecture (e.g., the autonomy of the business units), modular application architecture (e.g., define the basic component functionality), and modular integration architecture (e.g., interfaces to invoke the components); • Principles prescribing multi-tier architectures with independence and low coupling between architecture layers (e.g., the decomposition of the business and applications, the separation of presentation and business logic, developing and maintaining data independently of applications and storage	The process, data, and application architectures are developed separately; components have a layered structure with minimal dependencies; applications are decoupled with regard to their common functionalities; applications are decomposed and have limited dependencies	Utilization of resources by wider audiences; the portability of applications and their independence from the underlying technology; independent change and the reuse of process, data, and application components; faster and less-disruptive change initiatives	Greefhorst & Proper, (2011); Janssen & Kuk, (2006); Lindström, (2006); Richardson et al. (1990); Wilkinson (2006)	Prerequisite for reusability
Integration (9 principles)	Principles that help maintain an enterprise in an integrated state: • The principles maintaining integration at different EA layers and for different EA components (e.g., process, data, application, and infrastructure integration); • Principles prescribing a specific integration means (e.g., an enterprise portal as a single point of access and single sign-on for users, APIs, and enterprise service buses)	Portal, API, or service bus-enabled access to all applications' functionalities; applications do not send messages directly to other applications (an additional integration layer is introduced); data are accessible to and shared between different users and employee roles; a business process management system is in place to run and integrate business processes	Enterprise-wide integration of business processes, applications, and data; timely access to accurate and relevant data for decision support; automated and integrated execution of business processes	Greefhorst & Proper (2011); Lindström, (2006); Richardson et al. (1990); Wilkinson (2006)	Requires data consistency
Standardization (6 principles)	Principles that recommend standardizing architectural components on different architectural layers: • The principles enforcing the standardization of business processes, specifically of nondifferentiating processes; • Principles pursuing application development standards; • Principles enforcing the development of standard infrastructure components (such as programming languages, development environment, and application server) and standard communication platforms	There is a template (based on best practices) for business processes; standards for applications and infrastructure components are in place; procedures are in place to set up and enforce standards to eventually control technical diversity	Repeatability (cost-cutting) and scalability (flexibility) of standardized processes, applications, and infrastructure components; avoid unnecessary variations in processes, applications, and technologies	Greefhorst & Proper (2011); Janssen & Kuk (2006); Lindström (2006); The Open Group (2011); Wilkinson (2006)	Can be enforced through compliance
Data consistency (11 principles)	Principles that contribute to maintaining and assuring the accuracy and consistency of data over its entire life cycle:	Data are acquired from and provided by the source; data storage is channel-independent	Avoid conflict of collecting similar data from multiple resources; execution of business processes as a consistent whole and	Greefhorst & Proper (2011); The Open Group (2011)	Prerequisite for integration

	• The principles assuring accessibility and shareability of data across business functions; • Principles emphasizing a shared vocabulary and shared data definitions; • Principles seeking to ensure that data are captured once, are consistent through and across all channels, and are maintained in the source application		straight through because of shared data; increased performance and reliability of data		
Compliance (4 principles)	Principles that propagate conformity with internal and external standards: • The principles requiring adherence to enterprise-wide standards, such as enterprise IT/IS architecture, corporate IT/IS security, and project management models; • Principles requiring adherence to guidelines, regulations, laws, and standards issued by industry associations and by national and international institutions	Procedures are in place to ensure conformity with internal and external standards, regulations, and rules; rules and standards are made accessible and a common understanding of rules and standards is ensured	Ensure achievement of the standardization objectives by putting relevant procedures in place for enforcement of standards; compliance with legislations or quality standards	Lindström (2006); The Open Group (2011)	Supports standardiza-tion by enforcing compliance with standards
Reusability (2 principles)	Principles that prescribe the development of components and services used/reused across the organization: • The principles prescribing reusability measures when developing applications; • Principles requiring the effort to identify common requirements and to develop common use applications	Common required functionalities across different units are supported via the same, shared applications; existing applications are evaluated and used when a new functionality is required	Cost-cutting and mastering complexity of IT landscape by using existing applications instead of developing or buying new, redundant ones; avoid data conflict because of the deployment of redundant applications	Greefhorst & Proper (2011); Lindström (2006); The Open Group (2011)	Requires modularity
Portability / technology independence (2 principles)	Principles that advocate operability of applications in different environments: • The principles prescribing portability across various hardware and software platforms; • Principles ensuring technology and vendor independence	Applications can operate on a variety of technology platforms; procedures are in place to avoid development (and investment decisions) in vendors' proprietary technologies	Flexibility in vendor selection (avoid vendor lock-in); facilitate migration to new technologies with lower costs	Dietz & Hoogervorst (2012); Richardson et al. (1990); The Open Group (2011)	-
Usability (2 principles)	Principles that target user front-end design: • The principles ensuring ease-of-use of applications for different types of user groups; • Principles ensuring consistency of appearance and shared look-and-feel of all (or majority of) applications	Common interface standards are developed and utilized throughout the organization	Enhance efficiency of users and maximize utilization of IS resources; reduce the cost of training, design, and support of applications	Greefhorst & Proper (2011); Lindström (2006); Richardson et al. (1990); The Open Group (2011)	-
Centralization (3 principles)	Principles that guide the consolidation and centralization of hardware, software, and communication components: • The principles enforcing centralization of budgets and budget-related decisions; • Principles advocating centralization of applications and infrastructure components	IS resources are placed centrally, unless requirements dictate a decentralized approach; IS investment decisions are made on a global (vs. local) level	Realize synergies through consolidated efforts for enterprise-wide purposes	Lindström (2006); The Open Group (2011)	-
*the original statements of the 45 unique principles appear in Appendix B					

4.3 Expert Perception of EA Metaprinciples

An expert study helped us *refine* and *enhance* the assumptions underlying our research and the set of metaprinciples extracted from the extant literature. While almost all the extracted metaprinciples were strongly supported, the experts assigned the lowest scores to *portability* and *centralization*. Most of the experts questioned the importance and feasibility of centralization, especially in a modular architecture. The only new principles proposed were *technology independence* and *reduce technology variations.* Since technology independence is highly related but more generalizable than portability, we decided to replace *portability* with *technology independence* in our further investigation. Reducing technology variations may be associated with the expected capabilities resulting from standardization, which should be included in this principle.

Besides collecting experts' opinions on the practical relevance of the extracted metaprinciples from our literature review step, we asked the experts about the roles and usefulness of EA principles in general. First and foremost, they acknowledged the important role of EA principles in guiding architecture design and evolution (for the detailed results, see Appendix D). Most of the experts found the principles totally (24%) or very (40%) useful for EA efforts in their affiliated companies or for their clients, while only a minority perceived them as moderately useful (12%) or useful in some cases (24%). They shared the following statements on the nature and role of EA principles: Most of the experts believe that *EA principles should be an integral part of EA* and *regard them as a necessity*. They acknowledge that principles are a means to *impact architectural decisions* at different levels (i.e., *design and implementation decisions*, *project proposals decisions*, and *budgeting decisions*). They believe that *EA principles should be limited in number*, to make them enforceable and traceable throughout the organization. EA principles have also been perceived as a means *to guide the architecture evolution toward an intended architecture design* and *to maintain the overarching architecture's consistency* across various IT projects. EA principles are used to *purposefully limit the design space* and to *manage architecture variations*, particularly in application and technology layers. The experts perceive *principles as an enabler to obtain predefined outcomes from EA* and to *master the architecture's complexity*.

In open questions, the experts commented on the most important reasons for their company to adopt EA principles and on their perceptions of the principles' usefulness: The first reason is using EA principles as a means to achieve internal and external coherence and harmonization (as a part of EA governance), and the second important reason is to emphasize and guide the architecture goals. Principles shape the target architecture on different architectural layers and avoid inconsistent enterprise-level architecture decisions, particularly in respect of nonfunctional requirements. By preventing long debates on architecture decisions, EA principles also support strategic and operational decision-making. Furthermore, the experts believe that EA principles provide a governance model to guide policies and procedures and to develop a shared language.

Concerning the usefulness of principles in EA endeavors, most of the experts strongly emphasized that the key stakeholders should understand EA principles in order to guarantee their intended influence on the architecture, budgeting, and project proposal decisions. Furthermore, the experts also questioned the usefulness of available principles concerning their granularity (i.e., either too generic or too specific), thereby confirming the terminological confusion uncovered in our ontological analysis. According to the experts, the principles should be consistent and adequate (limited) in number. They also articulated the role of EA principles as a lighthouse rather than as mandatory rules.

5 Mechanics of EA Principles

As stated in Section 2, the existing research has not yet linked EA principles to the academic discourse on architecture value and outcomes. After identifying suitable EA principles (RQ1), we therefore sought to provide insights into how EA principles guide architecture design and evolution toward achieving desirable outcomes (RQ2).

5.1 Conceptualizing the Mechanics of EA Principles

To explain how EA principles contribute to achieving architecture outcomes and to integrate the existing research discourses, we take a *value-creation process* approach. This approach is inspired by Schryen's (2013) agenda for IS value research and moves away from existing deterministic means-end relations in predominant outcome-oriented EA research (e.g., Lange et al., 2016; Schmidt & Buxmann, 2011). EA literature has already motivated this approach by identifying reoccurring EA outcomes (Schneider et al., 2013) and annotating EA outcomes in EA information models (Buckl et al., 2010). To capture the value-creation process, we employ the notion of *gradual decomposition* (Saaty, 1980), which is frequently applied in the literature on IS value and outcomes (Mueller et al., 2010; Peppard et al., 2007). The latter suggests separating the different causes of outcomes into *means*, *ways*, and *ends*. Peppard et al. (2007) define *ends* as the desired outcomes, *ways* as the procedures and inductors to achieve the ends, and *means* as the required resources to achieve the ends.

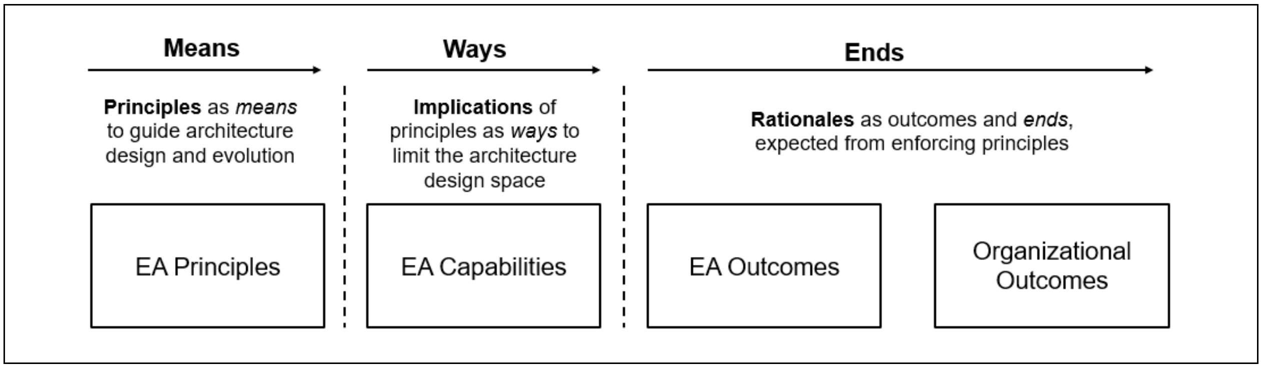

Figure 2. The Mechanics of EA Principles

By applying gradual decomposition, *means*, *ways*, and *ends* can be linked to the definition and formulation of EA principles. This leads to our initial conceptualization of the mechanics of EA principles: The value-creation process (see Figure 2) contains (1) *EA principles*, which are introduced by a principle *statement*, as *means* to guide architecture design and evolution; (2) the *implications* of EA principles, as *ways* to limit the architecture design space and to generate EA capabilities; and (3) the *rationales* of EA principles, as outcomes and *ends* expected from implementing the given principles. In line with Schryen (2013), this conceptualization also accounts for the complementarities of EA principles and their associated EA capabilities in co-creating EA outcomes.

Concerning the "ends" part, the expected EA outcomes are indeed one of the mainstream topics in prior research (e.g., Niemi & Pekkola, 2019; Tamm et al., 2011; Ahlemann et al., 2021). A review of the relevant research (see Appendix E) reveals three prevailing EA outcomes: IT efficiency, IT flexibility, and business-IT alignment and strategic fit (e.g., Allen & Boynton, 1991; Gregor et al., 2007; Lange et al., 2016; Ross & Weill, 2005; Schmidt & Buxmann, 2011; Tamm et al., 2011). *IT efficiency* deals with the relationship between the quality and the cost of the IT functions, whereas *IT flexibility* concerns the speed of application/infrastructure development and improvement projects to adapt to a changing environment. Finally, *business-IT alignment and strategic fit* deal with generating strategic business impact by means of IT.

5.2 Empirical Insights into the Mechanics of EA Principles

Based on three in-depth case studies, we investigate how different EA principles shape the architecture, and how these architectural changes create desirable outcomes. Appendix F provides more details of the cases, including a brief history to illustrate why the companies exploited specific principles, how the employed principles affected the architecture design and evolution concretely, and how different principles worked together to reach the expected EA outcomes. In the following, we synthesize the results of the cross-case analysis to represent the mechanics of principles regarding their complementary relations when supporting common EA outcomes.

In all three case studies, we observed that EA principles were clearly communicated, became actionable through dedicated initiatives, and shaped the architecture's mid- to long-term evolution significantly. Interestingly, we found that companies opted for similar principles—most importantly, standardization, integration, and reusability—but applied them in different ways and in different combinations to fulfill their EA outcomes. Company A started by pushing *standardization* principles to reduce the heterogeneity of the applications and technologies across the different brands and to control the IT costs. At a later stage, *reusability* followed standardization as a key principle. Building on the SOA paradigm, Company A introduced IT module management to develop reusable functional components in order to eliminate application silos and create multipurpose application components. Company B started with *standardization* and continued with *integration* to implement global processes. Standardized business processes and master data implemented in a global ERP system became the motor of business integration; the company's board saw these principles as the main factors for transforming the company and maximizing its global synergies across its different subsidiaries while reducing the IT costs. Company C battled with architectural complexity and a huge number of legacy applications. It thus emphasized the *reusability* of the application components and, at a later stage, the *integration* of applications when modernizing its IT landscape. Its ultimate goal was to connect the application components through SOA-based workflow automation.

Besides the general demonstration of the relevance and role of EA principles, we specifically analyzed the implications of the principles, in order to understand the mechanics of EA principles. We were interested in the "ways" since prior literature does not address them. To this end, we investigated the influence of EA principles on architectural changes and on guiding design decisions to maintain the consistency of the overarching architecture over time. The cross-case analysis allowed us to understand the implications of the same principles in different architecture contexts, as well as the relationships between the different principles.

Standardization: For companies A and B, standardization was a clearly employed metaprinciple for the same reasons. Both companies followed a decentralized IT management approach for a long time, which led to each brand, subsidiary, or local unit building their own applications with heterogeneous technologies and with their own budget. For example, in Company B, approximately 150 local CIOs with 6,000 locally employed employees had decision-making power over the architectural questions, solutions, and budgets. While Company A focused on standardization in the technology and applications, Company B mainly followed business process and data standardization by creating global business process templates. Since conformity with these standards was a major concern, both companies implicitly addressed the **compliance** metaprinciple.

The main implication of the standardization metaprinciple in Company A was to *establish references for standards*. When applying the standardization metaprinciple to guide the design and evolution of EA in Company A, a board was mandated to establish two main references, namely the Book of Standards (standards for IT infrastructure components, such as databases and servers) and the Handbook of System Design (standards for system implementation). In turn, the main implication of the standardization metaprinciple in Company B was the need to *establish a single source of truth for data*. By doing so, and by implementing a global ERP system throughout all of its brands and subsidiaries, Company B opted to standardize the business processes (developing global business process templates) and to standardize the master data as a corporate asset. In Company B, establishing a global template and standards for consistent and enterprise-wide master data was a prerequisite for integrating the business processes in all the subsidiaries and for supporting the global business strategy. In this case, standardization and the *integration* metaprinciples (see Integration metaprinciple below) worked together to create a single source of truth and to establish integrated and enterprise-wide master data.

Besides the abovementioned, distinct implications of the standardization metaprinciple in companies A and B, we found a common implication in both case companies to ensure compliance with standards: *create approval processes*. Our empirical evidence demonstrates that regardless of the type of standards, the standardization metaprinciple can only be effective if relevant procedures are in place to enforce the related standards.

In Company A, a systematic application portfolio management method was established to make consensus-based decisions on the group-wide to-be application landscape and to integrate the central and decentralized units' requirements. In turn, Company B established global business process templates and a global ERP system for which a global organization with three regional teams at the company's headquarters was responsible. In these two cases, the standardization of and compliance with the standards led to considerable cost savings and improved the use of the IT budget. More precisely it resulted in around $3 billion in savings for Company B after several years of using standardized business processes and a global ERP system. The flexible use of business/IT resources and faster application development and implementation projects were the other outcomes. More specifically, the standardization resulted in Company B's instant global deployment of business process best practices and in the decreasing heterogeneity of technologies in Company A's IT landscape. For instance, in Company B, the rapid rollout of applications to 40,000 employees was possible within a few weeks, rather than the previously required two years. Figure 3 illustrates the implications of the standardization metaprinciple and the supporting empirical evidence from Table 9.

Integration: This metaprinciple was applied by Companies B (along with *data consistency* with a focus on a shared core application) and C (with a focus on the integration of existing applications) because of their particular needs and situations. In Company B, the integration between the subsidiaries was initially very limited. On the business side, for instance, while working with the same suppliers, each subsidiary negotiated separately with suppliers, therefore not using the company's size as a negotiation lever for strategic procurement. On the IT side, integration was difficult because of the country-specific configurations and data formats of local ERP systems. As such, in the case of a global requirement or compliance issue, all the local IT teams needed to change their systems. Accordingly, IT spending increased significantly from approximately $575 million per year to $750 million per year. Company C, in turn, made a big effort to develop and implement reusable applications (see Reusability metaprinciple below). Nonetheless, the integration among the developed reusable application functions was missing, which was necessary to keep the company not only in a modular but also in an integrated, state. We conclude that the integration metaprinciple can have two alternative implications for architecture design and evolution, depending on the architecture context: *deploying a shared core application* or *deploying an integration platform*:

Company B sought to establish an enterprise-wide ERP system (an initial $200 million contract with SAP and an additional $80 million for consulting and maintenance) as *a shared core application*. The implementation of this ERP system, along with the standardization of global business processes *established a single source of truth for data* and performed as the motor of Company B's business integration.

Table 9. EA (Meta)Principles, their Implications, and the Resulting outcomes in the Selected Cases

	Company A	Company B	Company C
EA principles (means)	*Standardization* of applications and infrastructure. *Reusability* of application components.	Global *integration* of applications and business processes. *Standardization* in business processes, data, applications, and infrastructure.	*Reusability* of application functions and components. *Integration* of application functions and components.
Implications of EA principles (ways)	A(I-1) *Establish references for standards* to guide investment decisions on application and infrastructure components. A(I-2) *Create approval processes* to enforce standards and to leverage enterprise-wide, consensus-based investment decisions. A(I-3) *Create reusable IT modules* throughout the organization.	B(I-1) *Deploy a shared core application* by means of an ERP system as an enterprise-wide system for integrating business processes. B(I-2) *Establish a single source of truth for data* at the global level by standardizing and integrating master data. B(I-3) *Create approval processes* to enforce standards and the integrated enterprise-wide system through global governance procedures.	C(I-1) *Establish cross-functional application developments* across divisions. C(I-2) *Deploy an integration platform* for application integration.
EA outcomes (ends)	*Efficiency:* A(R-1) Improved use of IT budget. A(R-2) Lower cost of application/ infrastructure development and maintenance. *Flexibility:* A(R-3) Master the complexity of the IT landscape caused by the decreased heterogeneity of the technologies and the increased reusability of the modules. A(R-4) Faster application implementation projects.	*Efficiency:* B(R-1) No business process disruption, owing to globally integrated system and processes. B(R-2) Extensive savings because of global synergies (IT and business). *Flexibility:* B(R-3) Increase in development speeds (e.g., rapid global rollout of applications, instant deployment of business process best practices). *Business-IT alignment and strategic fit:* B(R-4) Driving business transformation through radical reorientation in IS architecture. B(R-5) Global synergies across subsidiaries in different locations. B(R-6) Use the company's size as an asset, for instance, in strategic procurement.	*Efficiency:* C(R-1) Cheaper and more efficient application development and maintenance (lowering project and unit costs). C(R-2) Lower infrastructure costs, owing to a decrease in the number of integration technologies. *Flexibility:* C(R-3) Faster application development, maintenance, and integration because of simplified infrastructure and increased reusability of applications.
Indexing: Company **A**, **B**, or **C** (**I** = implication; **R** = rationale; followed by the **evidence number** for the implication or rationale)			

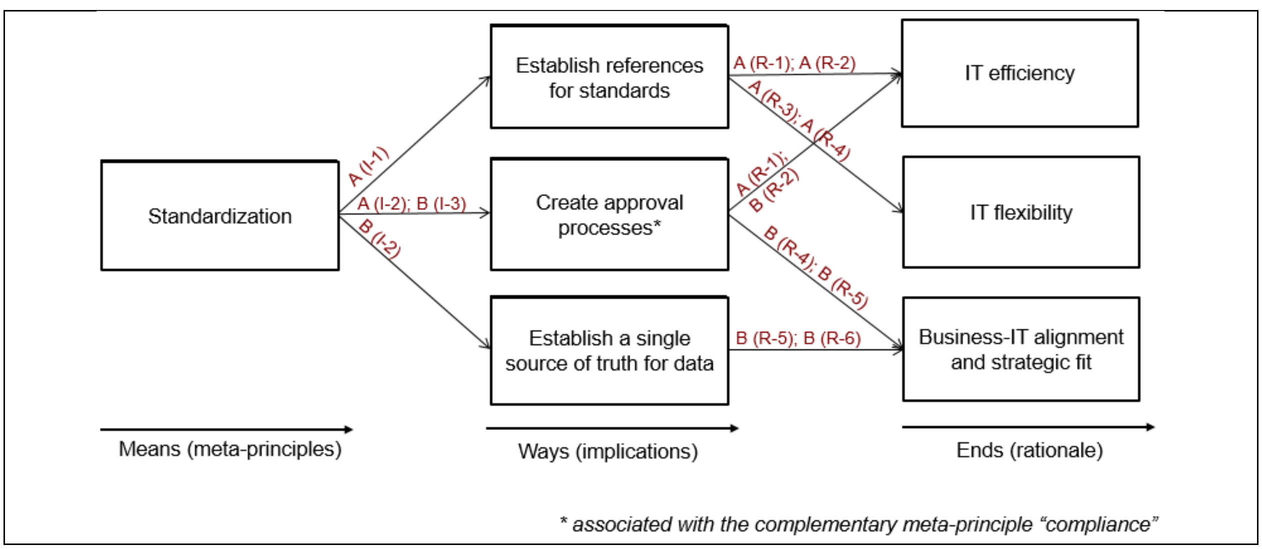

Figure 3. Mechanics of the Standardization Metaprinciple

In this case, **data consistency** was therefore a prerequisite for the integration metaprinciple, because this type of integration (i.e., an ERP system as a shared core application) requires global master data across the local subsidiaries. This helped Company B realize a business transformation and global synergies across subsidiaries at different locations. By deploying this shared core application, Company B could roll out changes to business processes with zero business disruption, owing to the globally integrated system and processes. Currently, 91 markets operate with globally standardized processes, data, and systems. They cover 96% of sales functions, 806 manufacturing sites, 1,109 distribution centers, 594 sales offices, and 169,000 users. The other evident outcome is the extensive cost savings because of the global synergies. For example, local units currently operate with around 50% of the original IT workforce, and the number of data centers has decreased from 150 to four and show a considerable decrease in maintenance costs.

Although Company C was pursuing similar goals, namely enterprise-wide business process integration, the integration metaprinciple had another implication. Given the large number of existing modular applications, Company C did not choose a shared core application but emphasized replacing multiple integration solutions and facilitating interoperability by *deploying an* SOA-based *integration platform*. This integration platform comprises an enterprise service bus and a process engine to leverage integration between modular applications and to implement cross-application workflows. This has resulted in lower infrastructure costs and a simpler (more flexible) IT landscape, owing to the considerable decrease in the number of integration technologies. Figure 4 shows the implications of the integration metaprinciple and the supporting empirical evidence from Table 9.

Reusability: Companies A and C sought to increase reusability by following the SOA paradigm and domain architecture, but also introduced **modularity**. Company A adopted the reusability metaprinciple, because merely focusing on standardization did not eliminate the existing application silos or failed to create the expected synergies between the different brands (see Standardization metaprinciple above). Company C, in turn, introduced a new IT management approach by following the reusability metaprinciple. Company C initially operated in a decentralized, product-based business structure. By following this approach for a long time, the company was confronted with a considerable number of redundant applications across the corporate divisions and, consequently, with constantly increasing IT expenditures.

In Companies A and C, the reusability metaprinciple affected the architecture design and evolution by *creating reusable IT modules* and *establishing cross-functional application developments*. Company A followed reusability by means of an IT module management initiative, which identified overlapping, similar, and reusable application functionalities across brands and established a catalog of reusable IT modules, i.e., identifying reusable functionalities and developing application components once but for multiple purposes. This resulted in considerably less application development and lower maintenance costs because of the avoidance of redundant application development efforts. More importantly, this resulted in a more flexible IT landscape, owing to increased reusability of the applications and faster application implementation projects. For instance, the IT module management initiative resulted in a 70% increase in the speed of mobile application development projects by using preexisting IT modules and a 550% increase in the reuse of IT applications (294 cross-brand, reusable modules were developed).

Company C, in turn, followed reusability by adopting a domain-driven SOA paradigm, as well as cross-functional domain architecture and application clustering. The company introduced federated responsibilities for application domains, meaning that eight domain architects managed a cluster of approximately 30 applications each. While some domain architects were responsible for function-oriented business domains, others were responsible for cross-functional domains. Following this approach led to the elimination of redundant application developments, which, in turn, decreased application development and maintenance costs, simplified the IT landscape, and increased IT project flexibility. An internal investigation into Company C revealed that following a domain-driven SOA paradigm to deploy cross-functional application components resulted in 40% faster and 50% cheaper application development and maintenance projects. Figure 5 illustrates the implications of the reusability metaprinciple and the supporting empirical evidence from Table 9.

As an important additional insight into conceptualizing the mechanics of EA principles, our cross-case analysis not only illustrates the principles' implications (i.e., their impact on architecture design and evolution over time), but also provides interesting evidence of their complementarity. While the studied cases explicitly approached standardization, integration, and reusability, the deployment of these principles was contingent on the employment of the other, complementary principles. That is, while each metaprinciple can be employed individually, we observed that some metaprinciples build on one another to attain common EA outcomes, resulting in complementary relationships between the metaprinciples.

Companies focusing on *standardization* as the cornerstone of their architecture design also addressed *compliance* implicitly in order to enforce standards (see Figure 3). The same holds for *reusability* and *modularity*, which mostly come together to reinforce the reuse of functional components through modular architecture (see Figure 5). Finally, our case companies demonstrated *integration* with *data consistency* to realize shared data vocabulary and shared data definitions across different applications (see Figure 4).

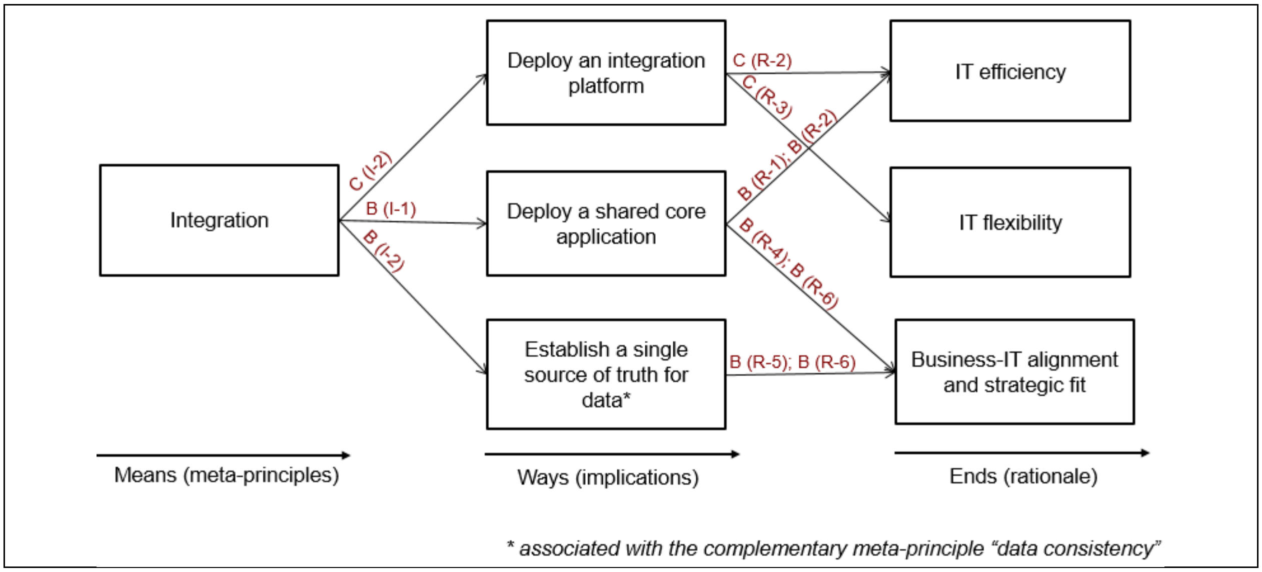

Figure 4. Mechanics of the Integration Metaprinciple

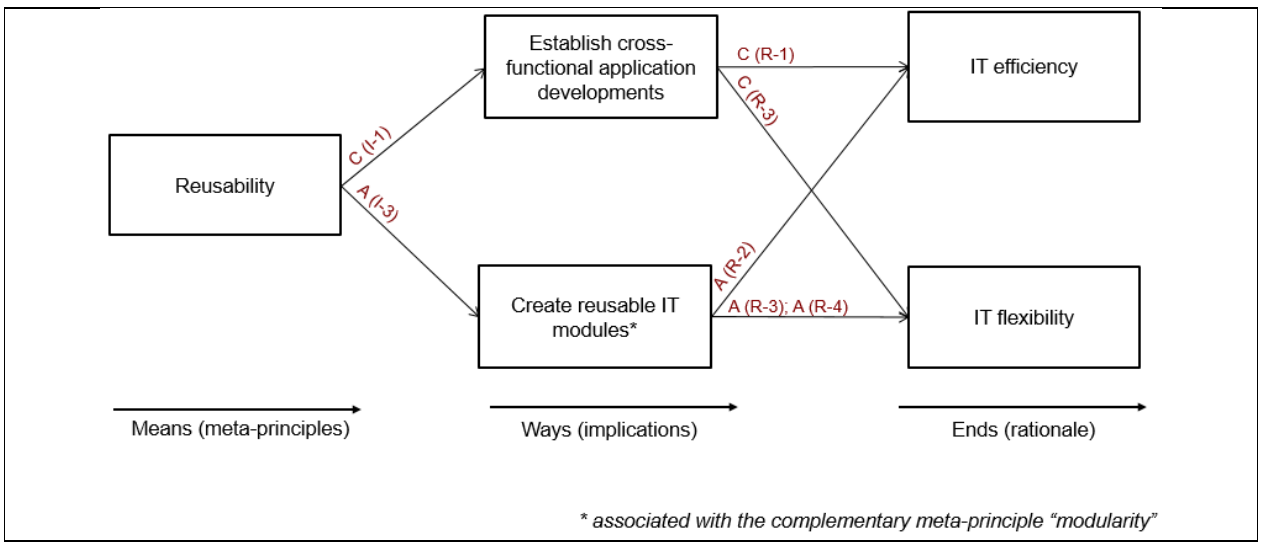

Figure 5. Mechanics of the Reusability Metaprinciples

6 Key Findings and Conclusion

Drawing on the city planning metaphor, the architecture of an enterprise should not only comprise architecture representations in the form of models and documentation (descriptive EA), but also normative principles to guide the design and evolution of architecture (prescriptive EA). While the descriptive foundation of EA has gained considerable attention, this study's elementary contribution is to serve the underexplored, prescriptive foundation. We postulate that, beyond architecture artifacts (e.g., models, documents, landscapes), which need to be constantly adapted and evolved to keep up with changes in the environment, architecture principles, as robust carriers of knowledge about good architecture, are required to give purposeful direction to the evolution of architecture. EA principles act as design principles that capture, synthesize, and share essential architectural design knowledge (Chandra et al., 2015; Gregor & Jones, 2007; vom Brocke et al., 2020) and allow for the projection of the design knowledge beyond instantiations that are applicable in a limited use context (Baskerville & Pries-Heje, 2019).

In advancing the prescriptive theoretical foundation of the EA discipline, our study makes two explicit contributions by providing insights into (1) suitable EA principles to guide architecture design and evolution (metaprinciples), and (2) how EA principles contribute to achieving EA outcomes (*mechanics* of EA principles). We discuss these points in the following two subsections.

6.1 Suitable EA Principles (RQ1)

In enriching the prescriptive aspect of EA, our study elaborates what can be considered to be a suitable principle by ontologically distinguishing between principles and nonprinciples, and offers a set of suitable metaprinciples. It thereby contributes to the research streams on the *nature* and *practices* of EA principles (see Table 3).

Building on the ontological analysis, a considerable part of the suggested principles in prior work is incompatible with the nature and the expected role of principles. As such, these principles do not guide the design and evolution of architecture. Our study identifies three types of nonprinciples, which are misinterpretations of principles caused by terminological confusion: The first nonprinciple type comprises EA goals and outcomes that have been uncertainly formulated as principles. These nonprinciples reflect rationales of deploying principles rather than principles guiding design and evolution. The second nonprinciple type inappropriately synonymizes EA principles with EA practices. These nonprinciples provide guidelines on how to deploy EA as a function rather than guiding architecture design decisions. The third type of nonprinciples comprises low-level governance means that are incompatible with the enduring and robust nature of principles in giving direction to the evolution of architecture.

To turn EA principles into an effective means to guide architecture design and evolution, they need to be pervasive and enduring. Instead of prescribing, for example, specific technologies, methods, or practices, which may change from time to time or vary from one area of implementation to the other, principles should merely provide the basis for purposeful architecture design decisions. These principles should therefore be applied to various design decisions (e.g., in various projects) to guide the evolution of the overarching architecture over time. Building on this understanding, we offer a set of suitable metaprinciples to guide architecture design and evolution. Instead of proposing an extensive catalog of detailed and partly overlapping principles, as has been done in prior research, we put together identical or similar principles and grouped the identified 45 unique principles into eight metaprinciples: *integration*, *data consistency*, *standardization*, *compliance*, *technology independence*, *modularity*, *reusability*, and *usability*.

By proposing metaprinciples that can be used in different organizational contexts, this study extends prior work on detailed and company-specific principles, such as the seminal work by Richardson et al. (1990). Moreover, our ontological analysis challenges the quality of the existing catalogs of EA principles (Greefhorst & Proper, 2011; The Open Group, 2011) and makes scholars aware of common flaws in the formulation and development of EA principles.

6.2 Mechanics of EA Principles (RQ2)

In advancing the prescriptive aspect of EA, our study theorizes the mechanics of EA principles. First, we contribute to the scientific body of knowledge in EA by providing a coherent and empirically demonstrated conceptualization of how principles (means) purposefully limit the design space and guide architecture design and evolution (ways) toward expected outcomes (ends). By spotlighting the underlying value-creation process, we demonstrate that *EA principles contribute to achieving EA outcomes by generating EA capabilities that underlie the intended outcomes.* Therefore, if organizations intend to achieve specific architecture outcomes, they need to have relevant principles in place to purposefully guide design decisions toward generating capabilities that accommodate these specific outcomes. In our empirical analysis, we relate the selected metaprinciples to concrete architectural changes that generate corresponding EA capabilities and support the realization of architecture outcomes. Consequently, this study not only contributes to the research stream on the *impact* of EA principles (see Table 3), but also clarifies how EA principles can be leveraged as high-level governance means to achieve predefined EA outcomes.

Second, our study demonstrates that EA principles do not work in isolation and uncovers the *complementarity of principles to generate common EA capabilities and outcomes.* Even though different (meta)principles have different implications, our case studies illustrate how complementary (meta)principles supplement one another to realize common outcomes and rationales. For instance, there are complementary relationships between integration and data consistency metaprinciples because they complement one another by maintaining an enterprise in an integrated state. Standardization and compliance metaprinciples also complement one another by enforcing internal and external standards. Moreover, reusability and modularity metaprinciples work together to achieve modular business and IT architectures. Our study thereby highlights the *complementary relationship between principles as an integral part of their mechanics*. As such, achieving desirable architecture outcomes entails the need to account for the complementarity of principles; i.e., to concurrently introduce principles that require one another to leverage the achievement of expected outcomes.

In theorizing the mechanics of EA principles, this study extends prior work by employing a *value-creation process* approach instead of following the predominant outcome-oriented approach in EA literature (e.g., Lange et al., 2016; Schmidt & Buxmann, 2011). Therefore, by moving away from deterministic means-end relations, one of our main contributions is in connecting the academic discourse on EA principles with the previously unrelated research stream of EA value and outcomes.

As further advances, our findings extend the existing body of research by taking a broader perspective than the few existing publications that focus on one or two selected principles (Pessi et al., 2014; Pessi et al., 2011; Radeke, 2011). Our findings also complement those of Tamm et al.'s (2011) enterprise architecture benefits model. While Tamm et al. (2011) shed light on four enablers that lead to the organizational benefits of EA, our study highlights the principles that carry the design knowledge about good architecture and that form and guide the architecture evolution.

6.3 Limitations and Implications

Our study provides a structured investigation of how principles guide architecture design toward obtaining EA outcomes. Nonetheless, we cannot claim that the derived set of metaprinciples in this study is complete or exhaustive. The principles were derived from a review of EA literature, without investigating more general principles or standards in IS research and practice (e.g., ISO/IEC 9126 and its latest version, ISO/IEC 25010). It would therefore be interesting to systematically compare principles from the EA literature with general principles discussed in the IS literature, and to elaborate their specificities. Further, we restricted our empirical exploration to a subset of metaprinciples, i.e., highly ranked metaprinciples by experts. While the case studies explicitly covered standardization, integration, and reusability metaprinciples, they implicitly addressed compliance (as a complement to standardization), data consistency (as a complement to integration), and modularity (as a complement to reusability). Further, selection of the experts was driven by their experience applying EA principles and therefore is not a representative of all industry sectors (almost one third of our sample was from the consultancy sector). Thus, because of the advances in adopting EA principles in recent years, prospective research is encouraged to approach a broader and more representative sample.

As implications for research, our study encourages the EA research community to be more aware of the significance of principles as means to accumulate architecture design knowledge beyond specific instantiations (vom Brocke et al., 2020). Since principles are an important foundation of any architecture discipline, we encourage future research to extend our set of investigated principles and to elaborate the link between metaprinciples and their application onto different architecture layers. In addition, researchers should invest more effort into their further theorization, especially with regard to the *adoption* and *impact* axes (see Table 3). Given the limitations of our study, we encourage quantitative-empirical research to further validate the set of metaprinciples, the implications (ways) of the proposed metaprinciples, and the illustrated relationships. Our findings could serve as a basis but require further extension. Specifically, as suggested by Schuetz et al. (2013), EA metrics are relevant to quantify the impacts and outcomes of EA principles. This endeavor could ultimately result in a measurement model with which to assess and compare different EA principles and their impacts on architecture configuration and, in turn, on EA outcomes.

With regard to our study's implications for practice, practitioners could benefit from the suggested set of metaprinciples by using them as a basis for developing company-specific and context-specific principles. The developed EA metaprinciples and their outlined implications could help companies systematically guide and maintain their architectures, as well as evaluate the success of their architectures in terms of the predefined outcomes. Our findings also draw practitioners' attention to the fact that EA principles should be selected carefully and purposefully, in view of their complementary relationships, and should be limited in number, in view of the feasibility of continuously tracking their impacts. Further, relying on the identified nonprinciples, this study questions the suitability of the existing catalogs of EA principles that practitioners use as their primary source of inspiration.

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Appendix A: Key Terms

Table A1. Key Terms

Term	Definition	Research process (see Table 4)	Findings
Principle	Targeting architecture design decision points, principles are used to limit the design space and to guide design decisions. Each principle should comprise a statement, implications, and a rationale: • The statement describes and introduces a principle; • The implications concern the ways a principle limits the design space in architecture decisions so as to guide architecture design and evolution; • The rationale concerns the expected benefits from a principle. The notion of EA principles guiding the design and evolution of the architecture should not be confused with principles, enablers, or factors for successfully deploying EA as a function (e.g., implementing EA frameworks or modeling techniques in the context of specific companies) to achieve a high-quality EA function.	In the literature review step (S1), we extracted insights related to the definition and roles of EA principles (S1.T1) and collected EA principles from literature (S1.T2).	152 nonunique principles and 45 unique principles.
Nonprinciple	A nonprinciple is a misinterpretation of a principle in the literature caused by terminological confusion.	In the literature review step (S1), we conducted an ontological analysis to distinguish between principles and nonprinciples (S1.T3).	Criteria for distinguishing between principles and nonprinciples along with identifying three types of nonprinciples: EA outcomes, EA practices, and low-level governance means.
Metaprinciple	A metaprinciple is a group of principles that share common implications and rationales.	In the literature review step (S1), we aggregated principles with commonalities in implications and rationales into metaprinciples (S1.T5). Later in the expert study, we asked experts' opinions on the extracted metaprinciples (S2).	Nine metaprinciples (thereof eight deemed practically relevant by subject matter experts): integration, data consistency, standardization, compliance, technology independence, modularity, reusability, usability, and centralization.
Complementary metaprinciples	Complementary metaprinciples are a set of metaprinciples that work together and complement one another to obtain a set of common EA outcomes.	In the literature review, this study initially identifies the complementary relation between metaprinciples. The resulted insights from case studies (S3) further prove the complementarity of metaprinciples.	Three groups of complementary metaprinciples: 1. Standardization and compliance, 2. Integration and data consistency, 3. Reusability and modularity.
Means	In this study, means are (meta)principles to guide architecture design and evolution.	The means were identified in the literature review (S1) and evaluated by the expert study (S2).	See principles and metaprinciples.

Ways	In this study, ways are the implications of (meta)principles to limit the architecture design space and to generate EA capabilities.	Case studies were used to explore the ways (or implications) for metaprinciples (S3).	Seven ways (or implications) for metaprinciples: establish references for standards, establish a single source of truth for data, create approval processes, deploy a shared core application, deploy an integration platform, create reusable IT modules, establish cross-functional application developments.
Ends	In this study, ends are the rationales of implementing (meta)principles and reflect the expected EA outcomes.	The existing findings in the extant EA literature (see Appendix E) are used to identify the ends (rationales or EA outcomes).	Three main ends: IT flexibility, IT efficiency, business-IT alignment, and strategic fit.

Appendix B: Metaprinciples and Their Associated Principles

Table B1. Metaprinciples and Their Associated Principles from EA Literature

Metaprinciple	Statements[5] of the constitutive principles	
Modularity (6 principles)[6]	MO1	• Develop modular architectures (Janssen & Kuk, 2006).
	MO2	• Presentation logic, process logic, and business logic are separated (Greefhorst & Proper, 2011). • Applications shall have a multi-tier architecture. Presentation, application logic, data logic, and data storage shall be separated from each other (Lindström, 2006).
	MO3	• Business units are autonomous (Greefhorst & Proper, 2011).
	MO4	• Enterprise data plans need to be developed and maintained independently of applications and storage technology (Richardson et al., 1990). • [Data] Content and presentation are separated (Greefhorst & Proper, 2011).
	MO5	• Applications are modular (Greefhorst & Proper, 2011).
	MO6	• Applications do not cross business function boundaries (Greefhorst & Proper, 2011).
Integration (9 principles)	IN1	• Processes are supported by a business process management system (Greefhorst & Proper, 2011).
	IN2	• Applications (bought and build) shall utilize Application Programming Interface (API) that allows other applications to access its functions (Lindström, 2006).
	IN3	• Application interfaces are explicitly defined (Greefhorst & Proper, 2011)
	IN4	• Vattenfall [the studied case] shall have a platform for corporate Internet, extranet, and intranet applications, which provide information exchange possibilities for customers, partners, and employees and the business units' subsidiaries (Lindström, 2006).
	IN5	• Application functionality is available through an enterprise portal (Greefhorst & Proper, 2011).
	IN6	• All messages are exchanged through enterprise service bus (Greefhorst & Proper, 2011).
	IN7	• Customers have a single point of contact (Greefhorst & Proper, 2011).
	IN8	• The status of customer requests is readily available inside and outside the organization (Greefhorst & Proper, 2011).
	IN9	• High level of connectivity and compatibility among all hardware, software, and communications components (Richardson et al., 1990).
Standardization (6 principles)	ST1	• Processes are standardized (Greefhorst & Proper, 2011). • Nondifferentiating processes should be standardized across the group, national standards and different types of markets needs to be considered (Lindström, 2006).
	ST2	• Application development is standardized (Greefhorst & Proper, 2011).
	ST3	• Develop standard infrastructure components (Janssen & Kuk, 2006).
	ST4	• Control technical diversity: technological diversity is controlled to minimize the nontrivial cost of maintaining expertise in and connectivity between multiple processing environments (The Open Group, 2011).
	ST5	• Vattenfall [the studied case] shall have a common standardized platform based on international standards for the exchange of data, messages and documents between users internal and external to Vattenfall (employees, customers, partners, and vendors) (Lindström, 2006).
	ST6	• IT systems adhere to open standards (Greefhorst & Proper, 2011).
Data consistency (11 principles)	DC1	• Data is shared: users have access to the data necessary to perform their duties; therefore, data is shared across enterprise functions and organizations (The Open Group, 2011).
	DC2	• Data is accessible: data is accessible for users to perform their functions (The Open Group, 2011).

[5] Statements are presented exactly as they are formulated in their sources.
[6] This represents the number of *unique* principles that constitute the corresponding metaprinciple. Therefore, sometimes several principles are categorized as one unique principle because of the similarity of their content, even though they may be formulated differently in different sources.

	DC3	• Common vocabulary and data definitions: data is defined consistently throughout the enterprise, and the definitions are understandable and available to all users (The Open Group, 2011).
	DC4	• Data that are exchanged adhere to a canonical data model (Greefhorst & Proper, 2011).
	DC5	• Data are consistent through all channels (Greefhorst & Proper, 2011).
	DC6	• Data are provided by the source (Greefhorst & Proper, 2011).
	DC7	• Data are maintained in the source application (Greefhorst & Proper, 2011).
	DC8	• Data are captured once (Greefhorst & Proper, 2011).
	DC9	• Reporting and analytical applications do not use the operational environment (Greefhorst & Proper, 2011).
	DC10	• Business continuity: enterprise operations are maintained in spite of system interruptions (The Open Group, 2011).
	DC11	• Applications respect logical units of work (Greefhorst & Proper, 2011).
Compliance (4 principles)	CO1	• All design, development and deployment of IS/IT components and processes must conform to the Enterprise IS/IT architecture (Lindström, 2006).
	CO2	• Control of development and implementation of IS/IT projects must comply with a corporate common project management model (Lindström, 2006).
	CO3	• Projects for development or deployment of IT solutions must take current security rules in consideration and perform security review before the implementation is decided. The responsibility for ensuring that security rules are compiled rests with the line management (Lindström, 2006).
	CO4	• We comply with existing laws, regulations, permits, and Vattenfall's [the studied case] environmental policy and take preventive action in order to reduce our environmental impact. This is accomplished by adopting sound methods for the collection and recycling of retired equipment and by using energy efficient products (Lindström, 2006). • Compliance with law: enterprise information management processing comply with all relevant laws, policies, and regulations (The Open Group, 2011).
Reusability (2 principles)	RE1	• IT systems are standardized and reused throughout the organization (Greefhorst & Proper, 2011). • Application development shall focus on reuse with integrated development environment (Lindström, 2006).
	RE2	• Common use applications: development of applications used across the enterprise is preferred over the development of similar or duplicative applications which are only provided to a particular organization (The Open Group, 2011). • Reuse is preferred to buy, which is preferred to make (Greefhorst & Proper, 2011).
Portability (2 principles)	PO1	• Information systems need to be developed to facilitate their portability across various hardware and software systems (Richardson et al., 1990).
	PO2	• Technology independence essence (Dietz & Hoogervorst, 2012). • Technology independence: applications are independent of specific technology choices and therefore can operate on a variety of technology platforms (The Open Group, 2011).
Usability (2 principles)	US1	• Usability of the systems should always be considered (Lindström, 2006). • Ease-of-use: applications are easy to use. The underlying technology is transparent to users, so they can concentrate on tasks at hand (The Open Group, 2011).
	US2	• Ease of use will be enhanced through information systems that present a consistent appearance to the systems users (Richardson et al., 1990) • Applications have a common look-and-feel (Greefhorst & Proper, 2011).
Centralization (3 principles)	CE1	• A partly centralized funding model is needed to realize synergies through consolidated efforts. A centralized funding model bases funding on two factors: 1) project classification – corporate, common, and unique, 2) projects under development and initial implementation (Lindström, 2006).
	CE2	• When performing IT related activities, potential for consolidation/centralization should always be considered (Lindström, 2006).
	CE3	• Components are centralized (The Open Group, 2011).

Appendix C: Survey Questionnaire

This survey seeks to collect expert insights and practical experience about enterprise architecture (EA) principles and their impacts.

According to our understanding, EA principles should guide the design and evolution of architecture (as a part of EA governance). For instance, principles such as standardization and modularization provide a set of guidelines to guide business, data, application, and technology architecture.

This study is part of a larger study to investigate EA design and its design principles at the University of XXX under supervision of Prof. XXX. The target respondents at this stage are selected experts in EA in order to provide a basis for a larger survey.

This questionnaire, which will take roughly only 15 minutes to complete, is made up of three short sections:

- Section 1: General information (10 very short questions)
- Section 2: The nature and importance of EA principles (4 questions)
- Section 3: EA principles (2 questions)

If you are interested in the findings of this survey, please provide your name and email address in the first section of the survey. The mandatory questions are marked with *.

Thank you in advance for sharing your valuable knowledge.

Best regards,

[Researcher details and contact information]

Section 1: General information

Please answer the following questions about you and your company:

Q1: Your name

Q2: Your email address

Q3: Company activity / industry *

Q4: Your position *

Q5: Number of employees *

Q6: How long have you have you been involved in EA (in years)? *

Q7: How long has your company utilized EA (in years)? *

Q8: Have you defined any EA principles for your affiliated company (or clients)? *

Yes ○ No ○

Q9: If *yes*, how beneficial are they for your company (or clients)?

Not useful ○ Helpful in some case ○ Moderately useful ○ Strongly useful ○ Totally useful ○

Q10: Which are the most important reasons that pushed your company to define a set of EA principles?

Section 2: The nature and importance of EA principles

Q11: What is your opinion about the nature of EA principles?

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
EA principles should be an integral part and essential element of EA	○	○	○	○	○
EA principles are useful but not a necessity in EA	○	○	○	○	○
EA principles should impact budgeting and investment decisions (company level)	○	○	○	○	○
EA principles should impact project proposal decisions (project portfolio level)	○	○	○	○	○
EA principles should impact design and implementation decisions (project level)	○	○	○	○	○
EA principles should be limited in number, to be able to enforce and trace them	○	○	○	○	○

Q12: Do you wish to add other statements about the nature of EA principles, based on your experience and observations?

Q13: What is the role of EA principles in the success of EA endeavor?

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
To guide the evolution of architecture toward the intended design	○	○	○	○	○
To purposefully limit design space and architecture variations for a suggested IT solution	○	○	○	○	○
To keep consistency of the overarching architecture across various IT projects	○	○	○	○	○

To master the complexity of architecture	○	○	○	○	○
As enablers to obtain predefined benefits from EA	○	○	○	○	○

Q14: Do you wish to add other roles of EA principles in the success of EA endeavors, based on your experience and observations?

Section 3: Enterprise architecture principles

Q15: How appropriate do you rate each of the following EA principles?

	Not important	Somewhat unimportant	Somewhat important	Very important	Extremely important
Modularity	○	○	○	○	○
Standardization	○	○	○	○	○
Compliance	○	○	○	○	○
Integration	○	○	○	○	○
Centralization	○	○	○	○	○
Reusability	○	○	○	○	○
Data consistency	○	○	○	○	○
Portability	○	○	○	○	○
Ease of use (usability) of applications	○	○	○	○	○

Q16: What are the top EA principles in your EA efforts? If you are EA consultant, please list those common principles you find useful for your different clients.

Principle #1	
Principle #2	
Principle #3	
Principle #4	
Principle #5	

Appendix D: Expert Study Results

Table D1. Experts' Perceptions of the Roles, Application, and Usefulness of EA Principles

Agreement with the following statements (from 1 – *strongly disagree* to 5 – *strongly agree*)		Mean	Median	Standard deviation
Application	Should impact design and implementation decisions (project level)	4.38	5	0.88
	Should impact project proposal decisions (project portfolio level)	4.31	4	0.81
	Should impact budgeting and investment decisions (company level)	4.08	4	1.01
	Should be limited in number, to be able to enforce and trace them	4.00	4	0.77
Roles	To guide architecture evolution toward the intended design	4.31	4	0.85
	To keep consistency of the overarching architecture across IT projects	4.31	5	0.95
	To purposefully limit design space and architecture variations for suggested IT solutions	4.12	4	0.87
	As an enabler to obtain predefined benefits from EA	3.65	4	1.09
	To master architecture complexity	3.62	4	0.98
Usefulness	EA principles should be an integral part and essential element of EA	4.62	5	0.83
	How beneficial or useful are EA principles in EA efforts?	3.8	4	1.06
	EA principles are useful, but not a necessity in EA (*control question*)	2.27	2	1.29
Note: Number of respondents = 26				

Table D2. Experts' Perceptions of the Importance of EA Principles

Importance of principles (from 1 – *strongly disagree* to 5 – *strongly agree*)	Mean	Median	Standard deviation
Standardization	4.38	4.5	0.77
Compliance	4.26	4	0.67
Data consistency	4.25	4	0.67
Modularity	4.13	4	0.74
Reusability	4.08	4	0.71
Integration	3.80	4	0.83
Ease-of-use (usability) of applications	3.80	4	0.85
Portability	3.33	3	0.70
Centralization	3.17	3	0.95
Note: Number of respondents = 26			

According to the results of the expert study, portability and centralization metaprinciples have been excluded from further investigation. Experts frequently questioned the importance and feasibility of centralization metaprinciple. We also replaced portability with technology independence, since (1) experts frequently suggested technology independence metaprinciple, and (2) technology independence metaprinciple is highly related but is more generalizable than the portability metaprinciple.

Appendix E: EA Outcomes

IT efficiency: IT efficiency concerns the relationship between the outputs of IT functions (i.e., the extent and quality of business process support) and the total costs of IT functions (Schmidt & Buxmann, 2011). IT efficiency has been frequently considered as the basic outcome of EA, thanks to the more effective use of IT resources and artifacts, the avoidance of redundancies, and the reduction of overall complexity. The systematic EA development contributes to reducing the development, operation, maintenance, and training costs of IT systems (Boucharas et al., 2010; Espinosa et al., 2011; Ross & Weill, 2005; Tamm et al., 2011).

IT flexibility: IT flexibility, in general, and IT infrastructure flexibility, in particular, refer to the extent to which IT resources can quickly and without major changes be adapted to changing business requirements (Byrd & Turner, 2000; Duncan, 1995). IT flexibility is a prerequisite to realize the strategic value of IT (Byrd & Turner, 2000; Chung et al., 2003; Duncan, 1995) and to enhance business-IT alignment (Chung et al., 2003). IT flexibility has frequently been cited as one of the major outcomes of EA. According to the extant literature, EA is expected to plan flexible use of data assets, leverage swifter application development/improvement, and ensure the agility of IT infrastructure in responding to changing business needs (Espinosa et al., 2011; Lange et al., 2016; Schmidt & Buxmann, 2011).

Business-IT alignment and strategic fit: Previous EA literature considers business-IT alignment as a primary reason that organizations invest in EA (e.g., Bucher et al., 2006; Gregor et al., 2007; Radeke, 2011; Tamm et al., 2011). Some researchers even argue that strategic alignment can be only ensured through EA (Niemann, 2006; Schmidt & Buxmann, 2011), since it is the only approach to systematically translate strategic and operational business requirements to application and infrastructure components. By the same token, strategic fit is often viewed as a prerequisite to ensure the effective use of IT and to be responsive to growing, fast-changing business demands (Henderson & Venkatraman, 1990). The inclusion of strategic fit as an EA outcome has been investigated in terms of better situational awareness (Kappelman et al., 2008), creating a close fit between an organization's competitive advantage and its internal business/IT resources (Radeke, 2011; Ross & Weill, 2005), and driving transformation (Lange & Mendling, 2011).

Table E1. EA Outcomes in Existing Studies

Reference	Focus of research	Investigated outcomes	Relation to prevailing outcomes
Schmidt & Buxmann (2011)	EAM success factors and outcomes	Two main architecture outcomes: IT efficiency and IT flexibility	• IT efficiency • IT flexibility
Lange et al. (2016)	EAM success factors and measures	Organizational/project efficiency, effectiveness, and flexibility	• IT efficiency • IT flexibility
Boh & Yellin (2006)	EA standards in IT management	Reduce heterogeneity and replication of IT infrastructure, business application, and data integration	• IT efficiency *IT flexibility as well as business-IT alignment and strategic fit have been implicitly discussed (p. 194)*
Tamm et al. (2011)	EA value to organizations	A set of *benefit enablers:* organizational alignment, information availability, resource portfolio optimization, and resource complementarity	• Business-IT alignment and strategic fit (organizational alignment) *The other benefit enablers are rather related to "ways" (principles' implications)*
Gregor et al. (2007)	EA as enabler of business strategy and IT alignment	Business-IT strategic alignment	• Business-IT alignment and strategic fit
Ross & Weill (2005)	EA benefits	• Technology-related benefits: IT cost reduction, IT responsiveness, risk management • Business-related benefits: shared business platforms, managerial satisfaction, strategic business impact	• IT efficiency (IT cost reduction, IT responsiveness, shared business platforms) • IT flexibility (IT responsiveness, risk management) • Business-IT alignment and strategic fit (managerial satisfaction, strategic business impact)
Boucharas et al. (2010)	EA contribution to the achievement of organizational goals	Enterprise architecture benefit maps with financial, customer, internal, as well as learning and growth dimensions	• IT efficiency (financial, internal) • IT flexibility (internal) • Business-IT alignment and strategic fit (learning and growth)
Espinosa et al. (2011)	Organizational impact of EA	Data management, application development, IT infrastructure, and business process benefits	• IT efficiency • IT flexibility *All the discussed benefits concern cost, agility, integration, and redundancy*
Radeke (2011)	EA's role in strategic change	Strategic fit, business-IT alignment	• Business-IT alignment and strategic fit

Appendix F: Case Descriptions

Company A

Company A is one of the world's largest automobile manufacturers. It is a group of more than ten different automotive brands that target different customer segments and geographical markets and is active in more than 100 countries. The company originally followed a fully decentralized IT management approach, so that brands and local units built their own applications, with their own budgets. This approach brought about inconsistent decisions, redundant applications, and heterogeneous technologies in different brands and, as a result, increased IT costs. In the words of an enterprise architect with a focus on application management and methods: "It can happen that one application is classified as a tool for further investments within one group, while it is classified as having 'no future' in another."

Phase 1: *Standardization* at the Group Level

Since the early 2000s, Company A took a number of initiatives to drastically reduce IT expenditure and leverage synergies at the group level. It sought to apply well-established principles from the car manufacturing industry to its IT infrastructure and put a lot of emphasis on standardization. As a turning point, a board was mandated in 2004/5 to develop and establish two main references for enforcing technological standardization principles, namely: (1) the *Book of Standards*, which defines standards for IT infrastructure components, such as databases, firewalls, or application servers, and was used to guide technology investments across the group, (2) the *Handbook for Systems Design*, which defines implementation guidelines. According to an enterprise architect with a focus on application management and methods "people feel that the company has standards and that there is a strategy behind decisions; they are not just ad hoc."

By means of strict approval processes, IT investments and projects were subsequently forced to adhere to corporate standards. Applying the standardization principles became a major priority for the CIO and, over time, brought about decreasing the heterogeneity of technologies implemented across the firm. Besides the infrastructure and technological standardization, the company sought to extend standardization principles to the business applications used by the group's hundreds of firms and plants to support their core business processes. For this purpose, it introduced a systematic *application portfolio management method* to make consensus-based decisions on the group-wide to-be application landscape and to integrate the concerns of the central and decentralized units.

> *During the automotive crisis, at a time that the budgets were low, we spent relatively much money on the appearance of final documents [resulting from our application portfolio management method]. We wanted to show people in the organization how serious we were, and that we had strong management support.* (enterprise architect with a focus on application management and methods)

> *The [application portfolio management] method helps to address a content-oriented strategy. In contrast to the project-driven way of thinking at [Company A], the [application portfolio management] method forces many people to think in a larger context than one project or application. It forces them to think for the [Company A] Group.* (enterprise architect with a focus on application management and methods)

By motivating group-wide planning and investments with foresight, Company A reduced application redundancies across brands and improved the use of budgets. In the mid-2000s, IT benchmarking studies in the automotive industry repeatedly revealed Company A's significantly lower IT expenditure (i.e., *higher IT efficiency*) compared to its competitors, which was attributed to the strong emphasis on standardization principles.

Phase 2: *Reusability* through IT Module Management

Despite these efforts, the CIO realized that merely focusing on standardization did not eliminate existing application silos or create greater synergies among different brands. From 2007, the company hence started promoting reusability to complement the standardization principle. According to an enterprise architect with a focus on SOA, "projects often create point-to-point interfaces, sometimes the same interface might reappear two or three times. So, we evaluate whether we can replace it with a reusable service interface."

To realize these principles, the CIO started an SOA initiative to foster a service-oriented design of its IT landscape. This initiative encountered challenges since it turned out that defining fine-grained services for a complex system landscape was difficult and did not fit the project-oriented way of working. One enterprise architect with a focus on SOA stated: "Some project managers question the benefits of our work, especially for their specific project. They wonder whether a topic like SOA is just a hype." Another SOA architect commented: "The questions we currently ask ourselves are: How do we need to change our strategy to implement SOA on a broader scale at [Company A]? How do we incorporate the domain models in managing the IT landscape, and who are the owners and stewards of those models?"

Consequently, the company shifted the SOA endeavor toward the development of reusable IT application components, called IT modules. In 2009, it thus introduced an IT module management initiative, which identified overlapping, similar, and reusable application functionalities across brands and established a catalog of reusable IT modules. As of 2013, 294 reusable modules have been developed—a 550% increase compared to its initiation in 2009. The main effect of applying the reusability principle through IT module management was avoiding redundant application development efforts, thereby lowering IT development costs. However, reusing the developed IT modules allowed projects to reduce implementation times and thereby increase *IT flexibility*. For instance, mobile application development can be sped up by 70% by using preexisting IT modules.

Company B

As one of the world's largest nutrition, health, and wellness manufacturing companies, Company B is represented in close to 200 countries and owns hundreds of factories in dozens of countries. Producing more than 6,000 brands, this company is divided into three geographical zones and several regions and market organizations (also called markets) that distribute the company's products with adaptations to local demands. It traditionally operated on a decentralized business structure, which allowed each local organization to offer customized products, respond to local needs, and conduct business and run IT autonomously. On the IT side, approximately 150 local CIOs with 6,000 locally employed employees had decision-making power over architectural questions, solutions, and budgets.

Phase 1: First Attempt at *IT Standardization*

To control constantly increasing IT costs and to harmonize IT systems, the group-level IT managers in 1995 decided to standardize IT systems by following a single vendor strategy. As a cornerstone of the standardization principle, 14 countries implemented SAP R/2 ERP systems. However, the expected positive effects from standardization were not met since each local ERP system differed because of country-specific configurations and data formats. Synergies were limited and in the case of a global requirement or compliance issue, all local IT teams needed to change their systems. Accordingly, IT spending went significantly up from 1994 to 1999 from approximately $575 million per year to $750 million per year.

Phase 2: Global *Standardization* and *Integration* at Business and IT Sides

In an attempt to capture synergies and significantly increase business efficiencies at the group level, the company's executive board launched a global business excellence initiative in 2000, a $2.4 billion project, with the direct engagement of the global CIO. With this initiative, the company aimed at complementing its focus on IT standardization, by promoting integration and standardization principles at both business and IT sides. It sought to achieve global business integration by (1) establishing a shared business process architecture; (2) standardizing master data as a corporate asset; and (3) standardizing IT worldwide to support the first two goals.

On the IT side, the aforementioned initiative implied standardizing group-wide applications, and promoting common-use applications rather than running local ones. It included the largest ERP implementation project worldwide, which involved an initial $200 million contract with SAP (for the SAP R/3 ERP system) and an additional $80 million for consulting and maintenance. The establishment of a global ERP system, along with standardization of global business processes and master data, was considered as the motor of business integration. To enforce standardization and integration principles, a global organization with three regional teams was created at the company's headquarters to define and maintain the global business process templates and the global ERP system.

Notwithstanding the obvious advantages of global standardization and integration, local managers complain that such initiatives caused an increase in the time needed to implement local requirements, rather than a decrease because: (1) a market-specific requirement causes a modification in the global system, and (2) the global approval and development workflow increases the complexity. Although, since the start of the global business excellence initiative, most of the projects have been approached top-down, the company then sought to solve these issues by running a bottom-up approach to encourage locally initiated technology and process innovations. By defining an architecture framework, the company tried to ensure that the locally developed solutions were compatible or could be extended to become global solutions. According to the global CIO, "[Company B]'s goal is not to centralize, but to globalize. [Company B] sells local products and has to adjust to the customer at a local level. The IT people have to acknowledge and support this." The head of business process management stated: "[The global business excellence initiative] is a fantastic program, because [Company B] is a very decentralized company. And [the global business excellence initiative] allows us to stay decentralized."

As of 2013, this initiative has run for more than one decade, with tremendous effects on the business and IT architecture evolution. On the business side, 91 markets are operating with globally standardized processes, data, and systems. They cover 96% of sales functions, 806 manufacturing sites, 1,109 distribution centers, 594 sales offices, and 169,000 users. This is not only a major *strategic* achievement but has also brought about significant global synergies and *efficiency gains*. On the

IT side, the global ERP system enables group-wide process and data integration. *Flexibility* and *business-IT alignment* have improved because of significantly increased implementation and development speeds for global requirements. The rollout of applications to 40,000 employees is possible in a few weeks, rather than two years, as had previously been the case. The head of business process management commented that “there are no longer discussions about how to integrate the new firm [in cases that Company B acquires a new firm e.g., a supplier], you just do it.”

In 2010, the initiative achieved a worldwide upgrade with zero business disruption. Today, approximately 1,000 IT people work at headquarters, and an additional 500 in the zone regional offices, while the local units only employ around 50% of the original workforce. The number of data centers decreased from 150 to four (one for each zone and one at headquarters), with 40,000 to 70,000 managed users per data center. The initiative has exceeded its overall business case goal which was around $3 billion in savings. According to an IT group lead, “in the end, the common processes, common data, and common systems were giving [Company B] the ability of using its size as an asset.”

Company C

Company C is a global financial services company. It is organized into three group divisions, which are further subdivided into corporate divisions: Corporate and Investment Bank, Private Clients and Asset Management, and Corporate Investments. Company C initially operated in a decentralized and product-based business structure. Likewise, the IT organizations were product based (private and investment banking). While this approach seemed reasonable at the time, the IT landscape’s growing complexity was not managed properly. Consequently, the company was confronted with a huge amount of redundant applications across corporate divisions and, therewith, constantly increasing IT expenditures.

Phase 1: *Reusability* through Service-Oriented Architecture

As of 2005, to modernize its IT architecture like other banks, and to lay aside a large number of legacy applications, the company has opted for reusability principles through adopting the (domain-driven) service-oriented architecture paradigm. The CIO thus announced an SOA initiative, and the first project started in 2006. A domain architect stated that “SOA is the key paradigm to use the same execution for different incoming channels with little adjustment and shaping business processes toward a standardized form.”

Although the first project with SOA took longer than expected, reuse was applied in the second project, which sped up the process considerably. Thanks to the SOA paradigm, projects are estimated to be 40% faster and 50% cheaper than performing projects in the conventional way. Moreover, the company introduced federated responsibilities for application domains. The EA team currently comprises eight domain architects who no longer manage only single applications and project solutions, but a cluster of approximately 30 applications each. While some domain architects are responsible for the functional-oriented business domains, others are responsible for cross-functional domains. Domain architects associated with different business units and responsible for specific application clusters were integral to *strategic IT decision*-making. The head of architecture clarified that “the domain architects are the aligning factor between business analysts and IT architecture, that is why they ensure business IT alignment.” According to the head of architecture, “the role of EAM changed from improvement by escalation toward a proactive influence in projects; earlier, the role was not existent because there was no one who could do it. The domain architects directly influence the business units and so the EAM has an impact on aligning IT and business.”

The domain architecture approach helped to create an overall picture of application clusters and to foster strategic IT decision-making, when replacing legacy applications. It increased reusable application functions across divisions and ultimately resulted in *efficiency* and *flexibility* gains through reduced unit costs, minimized project lifespan, and lowered project costs.

Phase 2: *Integration* to Enable SOA-Based Cross-Application Workflows

Company C soon came to realize that integration principles are required to enable interoperability among the developed reusable application functions. It is now on its way to an SOA-driven, modular application portfolio communicating over well-defined interfaces, but ultimately seeks to leverage SOA-based integration to automate enterprise-wide business processes. The CIO emphasized: “We don’t want to have SOA only to have thousands of services but we want to automate processes, that fact is the core focus and the leverage!”

To this end, in 2010, Company C initiated a project to replace multiple integration solutions and to implement a modular core-banking platform for payment, account management, and saving applications. A process engine and an enterprise service bus were introduced to facilitate integration between modular applications and to implement cross-application workflows. The exploited integration platform has simplified the infrastructure, reduced the number of integration technologies, and contributes to additional *efficiency* and *flexibility* improvements. In the words of one technical architect, “there is a massive difference between having two operational infrastructures and having 20.”

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