Analysis of Limitations and Metrology Weaknesses of Enterprise Architecture (EA) Measurement Solutions & Proposal of a COSMIC-Based Approach to EA Measurement

By

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ANALYSE DES LIMITATIONS ET DES FAIBLESSES EN MÉTROLOGIE DES SOLUTIONS DE MESURE ARCHITECTURE D'ENTREPRISE (AE) ET PROPOSITION D'UNE APPROCHE COSMIC POUR LA MESURE DE L'AE

Ammar ABDALLAH QASAIMEH

RESUME

La littérature sur l'architecture d'entreprise (AE) postule que celle-ci apporte une valeur considérable aux organisations Cependant, bien que cette littérature documente un certain nombre de propositions de solutions de mesure des AE, il existe peu de recherches factuelles soutenant les réalisations et les limites des résultats de la recherche sur ces types de mesures.

Cette thèse vise à aider à comprendre les tendances existantes dans la recherche sur la mesure des AE et à reconnaître les lacunes, les limites et les faiblesses des solutions de mesure proposées dans la litérature. En outre, cette thèse vise à aider la communauté à concevoir des solutions de mesure pour leur évaluation basée sur les meilleures pratiques en matière de mesure et de métrologie.

Les objectifs spécifiques de cette recherche suivants sont:

1. Classer les propositions de solutions de mesure AE dans des catégories spécifiques afin d'identifier les thèmes de recherche et d'expliquer la structure de ce domaine de recherche.
2. Évaluer les propositions de solutions de mesure AE du point de vue de la mesure et de la métrologie.
3. Identifier les problèmes de mesure et de métrologie dans les solutions de mesure AE.
4. Proposer une nouvelle approche de mesure AE basée sur les directives de mesure et de métrologie et les meilleures pratiques.

Pour atteindre le premier objectif, cette thèse mène une étude de cartographie systématique (SMS) : ceci permet de comprendre l'état actuel de la recherche sur les mesures AE et de classer

le domaine de recherche afin d'acquérir une compréhension générale des tendances de la recherche existante.

Pour atteindre les deuxième et troisième objectifs, cette thèse mène une revue systématique de la littérature (SLR) : ceci permet d'évaluer les solutions de mesure de l'AE du point de vue de la métrologie et de la mesure, et donc de révéler les faiblesses des solutions de mesure de l'AE et de proposer des solutions pertinentes à ces faiblesses. Afin de réaliser cette évaluation, nous développons un processus d'évaluation basé sur la combinaison des composants de la théorie de l'évolution et des concepts de meilleures pratiques de mesure et de métrologie telles que ISO 15939.

Pour atteindre le quatrième objectif, nous proposons une correspondance entre deux normes internationales :

- COSMIC - ISO / IEC 19761: une méthode de mesure de la taille fonctionnelle d'un logiciel.
- ArchiMate: un langage de modélisation AE.

Le résultat est une nouvelle approche de mesure AE qui pallie aux faiblesses et limitations rencontrées dans les solutions de mesure AE.

Les résultats de la recherche démontrent que:

1. Les publications actuelles sur la mesure AE tendent de plus en plus à se concentrer sur la pensée « architecture informatique d'entreprise », et n'utilisent pas la terminologie rigoureuse utilisée en science et en ingénierie et montrent une adoption limitée des connaissances d'autres disciplines dans les propositions de solutions de mesure AE.
2. L'attention portée à la formulation de propositions de mesures d'AE appropriées en métrologie est insuffisante : toutes les propositions de mesure AE sont caractérisées par une notation de couverture métrologique insuffisante, théorique et empirique.
3. La nouvelle approche proposée pour la mesure AE montre qu'elle est pratique pour les praticiens AE et facile à adopter par les organisations.

Mots-clés: enterprise architecture, measurement, metrology, ArchiMate, COSMIC

ANALYSIS OF LIMITATIONS AND METROLOGY WEAKNESSES OF ENTERPRISE ARCHITECTURE (EA) MEASUREMENT SOLUTIONS & PROPOSAL OF A COSMIC-BASED APPROACH TO EA MEASUREMENT

Ammar ABDALLAH QASAIMEH

ABSTRACT

The literature on enterprise architecture (EA) posits that EA is of considerable value for organizations. However, while the EA literature documents a number of proposals for EA measurement solutions, there is little evidence-based research supporting their achievements and limitations.

This thesis aims at helping the EA community to understand the existing trends in EA measurement research and to recognize the existing gaps, limitations, and weaknesses in EA measurement solutions. Furthermore, this thesis aims to assist the EA community to design EA measurement solutions based on measurement and metrology best practices. The research goal of this thesis is to contribute to the EA body of knowledge by shaping new perspectives for future research avenues in EA measurement research.

To achieve the research goal, the following research objectives are defined:

1. To classify the EA measurement solutions into specific categories in order to identify research themes and explain the structure of the research area.
2. To evaluate the EA measurement solutions from a measurement and metrology perspective.
3. To identify the measurement and metrology issues in EA measurement solutions.
4. To propose a novel EA measurement approach based on measurement and metrology guidelines and best practices.

To achieve the first objective, this thesis conducts a systematic mapping study (SMS to help understand the state-of-the-art of EA measurement research and classify the research area in order to acquire a general understanding about the existing research trends.

To achieve the second and third objectives, this thesis conducts a systematic literature review (SLR) to evaluate the EA measurement solutions from a measurement and metrology perspective, and hence, to reveal the weaknesses of EA measurement solutions and propose relevant solutions to these weaknesses. To perform this evaluation, we develop an evaluation process based on combining both the components of the evolution theory and the concepts of measurement and metrology best practices, such as ISO 15939.

To achieve the fourth objective, we propose a mapping between two international standards:

- COSMIC - ISO/IEC 19761: a method for measuring the functional size of software.
- ArchiMate: a modelling language for EA.

This mapping results in proposing a novel EA measurement approach that overcomes the weaknesses and limitations found in the existing EA measurement solutions.

The research results demonstrate that:

1. The current publications on EA measurement are trending toward an increased focus on the "enterprise IT architecting" school of thought, lacks the rigorous terminology found in science and engineering and shows limited adoption of knowledge from other disciplines in the proposals of EA measurement solutions.
2. There is a lack of attention to attaining appropriate metrology properties in EA measurement proposals: all EA measurement proposals are characterized with insufficient metrology coverage scoring, theoretical and empirical definitions.
3. The proposed novel EA measurement approach demonstrates that it is handy for EA practitioners, and easy to adopt by organizations.

Keywords: enterprise architecture, measurement, metrology, ArchiMate, COSMIC

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LIST OF ABBREVIATIONS

ADM	Architecture Development Method
AHP	Analytic Hierarchy Process
AIS	Association for Information Systems
BPMN	Business Process Model and Notation
BTEP	Business Transformation Enablement Program
CIO	Chief Information Officer
COBIT	Control Objectives for Information and Related Technologies
COSMIC	Common Software Measurement International Consortium
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DoDAF	Department of Defense Architecture Framework
E	Entry (data movement)
EA	Enterprise Architecture
EAF	EA framework
EAIM	Enterprise Architecture Implementation Methodology
EAM	Enterprise Architecture Management
EAP	Enterprise Architecture Principles
FEA	Federal Enterprise Architecture
FP	Functional Process
FUR	Functional User Requirement
GADA	Geographically Distributed Agile Development
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers

ISO	International Organization for Standardization
IT	Information Technology
ITO	IT Objects
MQ	Mapping Question
PLS	Partial Least Square
R	Read (data movement)
RPN	Risk Priority Number
RQ	Research questions
SLR	Systematic Literature Review
SMS	Systematic Mapping Study
TOGAF	The Open Group Architecture Framework
UML	Unified Modeling Language
USA	United States of America
VIM	International Vocabulary of Basic and General terms in Metrology
W	Write (data movement)
X	Exit (data movement)

LIST OF SYMBOLS

r_s	Spearman's rank order correlation coefficient
SCU	Structural complexity unit
Cm	Centimeters
SD	Standardization degree
ST_{sub}	Number of Information Technology Objects that have the standard lifecycle status
δ_{ITO}	Status of the Information Technology Object
gP_{ITO}	The contribution of the Information Technology Object
$Prod_{sub}$	Number of Information Technology Objects that have the productive lifecycle
u_r	The weight of the r^{th} EA output according to s^{th} expert opinion
${y^s}_{ro}$	The j^{th} output of DMU according to the s^{th} expert opinion
$[\tilde{e}\ (I)]$	The trapezoidal fuzzy number for the impact of a given EA risk
$(w(vp)_k$	The voting power of EA practitioners
CFP	COSMIC function point
T_0	Time at beginning of EA project
T_n	Time at end of EA project
T_{n+m}	Time at any point after EA project
D	Dependency
NPCA	Number of possible client application families
NPV	Net present value
PCAF	Possible client application factor
ROI	Return on investment
I	Weighted impact

%	Percentage
$	Dollar
p	Probability of obtaining a test statistic (*p*-value)

INTRODUCTION

Organizations (industrial and governmental) are functioning in challenging business environments caused by technology innovations, demanding clients, and business competitors. The challenges include difficulties in managing business strategies and technologies in a coherent perspective (Op’t Land, Proper, Waage, Cloo, & Steghuis, 2009).

Clients of industrial organizations are likely to expect full-integrated solutions that deliver integrated services. Relevant example is an online booking service: clients demand access to integrated services such as flights, hotels, and cars bookings, all together from within the same booking service. Clients of governmental organizations are likely to expect high-quality e-government services. In order to accomplish such integrated services, and other kinds of complex high-tech services, organizations are indeed dependent on information technology (IT) to satisfy their clients and meet the business vision.

IT is a double-edged sword: IT is a facilitator and a challenge at the same time. Despite the fact that IT plays a significant role to facilitate accomplishing business visions, the evolving technology innovations have raised challenges, including redundant and costly IT solutions. Furthermore, the cultural differences add another challenge inside organizations: various stakeholders and decision makers involved in organizations who come from diverse backgrounds will cause social complexity in organizations. Social complexity can be realized through the different stakeholder levels such as organization level, business unit level, department level, and project level (Lankhorst, 2017). These stakeholders have different business and IT visions, and strategies. Regardless of the cultural diversity and social complexity, stakeholders shall collaborate within the interrelated departments, communicate, and share the decision-making process. Therefore, the need to perceive and manage the social complexity, IT, and business strategies through a coherent perspective is indeed growing.

Therefore, the concept of Enterprise Architecture (EA) has emerged to provide a holistic focus and performing organizational objectives, rather than departmental objectives.

EA has emerged in the 1980's as a discipline to manage the architectures of organizations and support the transition from a current (as-is) to a future (to-be) state (Gampfer, Jürgens, Müller, & Buchkremer, 2018). EA can be defined as a set of management system components and their structure, interrelationships and interdependencies (Ilin, Levina, Abran, & Iliashenko, 2017). Multiple EA definitions can be found in EA literature, such as (Lankhorst, 2017) who defines EA as "a coherent whole of principles, methods, and models that are used in the design and realisation of an enterprise's organisational structure, business processes, information systems, and infrastructure."

The EA literature currently acknowledges multiple EA definitions and the lack of common understanding in EA (Saint-Louis & Lapalme, 2018), in addition to the lack of theoretical foundations of the EA field (Nurmi, 2018). However, the expected benefits of EA are manifest. The intent of EA is to help organizations achieve their business goals by aligning IT initiatives with business objectives. EA is expected to improve decision-making, reduce IT costs, improve business processes, and enhance the reuse of resources (Bonnet, 2009; Boucharas, *et al*.; Tamm, Seddon, Shanks, and Reynolds, 2011; Hill, 2011; Wan, Johansson, Luo, and Carlsson, 2013; Zhang, Chen, and Luo, 2018).

EA has received an increasing attention by governments worldwide (Dang & Pekkola, 2017). In order to support resources reuse, and align interrelating and overlapping projects, several governments established or plan to establish EA programs: for instance, 93.3% of countries are planning to establish EA programs within a year or two (Liimatainen, Hoffmann, & Heikkila, 2007).

For example, in the United States of America (USA), EA is referred to as the Federal Enterprise Architecture (FEA) (Liimatainen *et al*., 2007). The USA related works on EA are noted in the public administration e-services, the law on public IT acquisitions (the Clinger-Cohen Act), and more.

The Canadian EA initiatives present the government's strategy for renewing the public sector, governance, and in delivering high-quality services to citizens (Liimatainen *et al*., 2007). In order to achieve these goals, the Canadian government established an EA program referred to as the Business Transformation Enablement Program (BTEP). BTEP is accountable for being a common language for modeling federal provincial and municipal programs and processes, and includes governmental standards, and other reference documentations. In addition, the Canadian government established a separate unit (The Enterprise Architecture and Standards Division), responsible for the design, development and implementation of the Government of Canada's enterprise architecture. The Government of Canada IT Security Program is one of the outcomes of the Canadian EA initiatives.

EA has received an increasing attention by practitioners and EA frameworks have been created such as the Zachman framework, the Open Group Architecture Framework and the Department of Defense Architecture Framework. Furthermore, the Open Group Architecture introduced ArchiMate as a standard EA modelling language. In addition, Gartner had estimated that EA practitioners influence organizations' IT budgets by more than $1.1 trillion in organizations' IT spending (Alwadain, 2014).

Recently, the focus on EA has shifted from understanding to managing EA (Gampfer *et al*., 2018). Hence, to properly manage the EA development, implementation, and to gain the most of EA benefits, EA should be measurable (Wan *et al*., 2013). Organizations cannot manage what they cannot measure, and will not be able to identify the strengths, weaknesses and to track the deviations from organization's standards (Cameron and McMillan, 2013). EA come at a price (Kaisler, Armour, & Valivullah, 2005; Syynimaa, 2013) and for organizations to invest in EA they must be able to measure and know the positive effects of EA (Morganwalp & Sage, 2004). EA measurement will enable organizations to justify to what degree EA is being achieved, update their EA according to the measurement results, improve their learning processes, and can allow for precise communication about performance and progress toward strategic goals (Cameron and McMillan, 2013).

EA measurement has received some research attention by academics and researchers. For example (Cameron and McMillan, 2013) proposed an EA measurement solution in an attempt to measure the expected EA value, while (Plessius, Raymond & Leo 2012; Schelp and Matthias 2007) proposed an EA measurement solution based on the balanced scorecard providing a multi-perspective framework (financial, customer, internal, learning perspectives) in an attempt to justify investments in EA. Other researchers proposed EA measurement solutions to quantify EA complexity (González-Rojas, López, & Correal, 2017; Schuetz, Widjaja, & Kaiser, 2013). (Kurek, Johnson, & Mulder, 2017) proposed a solution in an attempt to investigate the factors that influence the EA implementation process, (Bakar, Harihodin, & Kama, 2016), proposed a solution in an attempt to quantify EA value on IT projects. Other attempts include (Morganwalp *et al*., 2004; Simonin, Nurcan, & Gourmelen, 2012; Simonin, Le Traon, & Jezeque, 2007; Nikpay, Ahmad, & Yin Kia, 2017).

Despite the increasing research attention on EA measurement, some researchers report on the immaturity of many enterprise architecture practices and point out a number of EA challenges such as: EA modeling, EA definition, EA adoption and application, managing the enterprise life cycle, assess infrastructure stress (Kaisler *et al*., 2005; Bucher, Fischer, Kurpjuweit, & Winter, 2006; Saint-Louis, Morency, & Lapalme, 2017; Gampfer *et al.,* 2018). (Saint-Louis *et al*., 2017) report that regardless of the increasing interest among academics on EA research, there is a deficiency in defining EA, and this deficiency affects the ability of organizations to measure and to realize the expected benefits, value, and impact of EA.

While some publications propose different EA measurement solutions, researchers report that there is a little guidance on EA measurement (Bonnet, 2009; Kaisler *et al*., 2005; González-Rojas *et al.,* 2017). For example, there are insufficient practices that consider all EA functions and processes for evaluation and measurement (Nikpay *et al.,* 2017), the existence of several drawbacks in EA evaluation (Nikpay *et al.,* 2017) and that organizations are facing a challenge on how to measure the value of EA (Cameron and McMillan, 2013).

In parallel with the publications of EA measurement solutions in EA literature, measurement and metrology guidelines and best practices (e.g, ISO 15939) became available in the software engineering field (Abran, 2010). These best practices describe design criteria of mature measurement methods, and offer guidelines on how to distinguish mature measurement methods from quantification techniques. However, it is unknown yet to the EA community whether the proposed EA measurement solutions satisfy the metrology best practices (referred to in this thesis as the 'metrology coverage').

From 1987 to 2015, the number of peer-reviewed publications on EA research increased by 21% per year (Gampfer *et al.*, 2018). Although there are a number of proposed EA measurement solutions, none of them comprehensively covers the limitations and gaps of EA measurement solutions from a measurement and metrology perspective. In view of the aforementioned, this thesis aims to cover comprehensively the EA measurement research area through conducting evidence-based research (e.g, systematic mapping study and literature review), and content analysis.

Our research motivation is to assist the EA community to explore the unknown and hidden issues in the proposed EA measurement solutions, and propose on a novel approach to assist in measuring EA. We consider our results relevant for both EA researchers, who can leverage our findings to design future studies, and EA practitioners who can consult our analysis to better understand the weaknesses of the state-of-the-art on EA measurement, and gain knowledge of the metrology qualities required in the design of EA measurement solutions.

Research objectives

The research objectives of this thesis are summarized as follows:

1. To classify the EA measurement solutions proposed in the literature into specific categories in order to identify research themes and explain the structure of this research area.

2. To evaluate the proposed EA measurement solutions from a measurement and metrology perspective.
3. To identify the measurement and metrology issues in the proposed EA measurement solutions.
4. To propose a novel EA measurement approach based on measurement and metrology guidelines and best practices.

Research questions

The following questions are developed to guide achieving the research objectives.

"What is the state-of-the-art in EA measurement?
What is the metrology coverage score and metrology issues in the proposed EA measurement solutions?
&
How can the metrology coverage score of EA measurement solutions be increased?"

To tackle these questions, our research strategy is divided into the following three (3) research phases:

Phase 1: A systematic mapping study to answer the question of "what is the state- of- the- art in EA measurement?"

Phase 2: A systematic literature review to answer the question of "what is the metrology coverage score and metrology issues in the proposed EA measurement solutions?"

Phase 3: The proposition of a novel EA measurement approach to answer the question of "how can the metrology coverage score of EA measurement solutions be increased?"

Thesis structure

The remainder of this thesis is organized as follows. The first chapter presents a literature review of relevant existing works on evidence-based research in EA, and EA measurement in particular. Chapter 2 describes theories and models needed to answer these research questions. Chapter 3 presents the description of the research strategy and methodology. Chapter 4 presents answers to the systematic mapping study. Chapters 5 and 6 present answers to the systematic literature review. Chapter 7 presents the proposal of a novel EA measurement approach. Finally, we conclude our thesis and we present some future works.

CHAPTER 1

LITERATURE REVIEW

1.1 Enterprise architecture – An overview

In today's modern world, organizations are operating in fast-paced business environments that entail emerging technologies and changing business needs (Nurmi, 2018): these challenges increase pressure on organizations to survive, adapt and integrate with change (Nurmi, 2018; Banaeianjahromi & Smolander, 2014). To manage and align technology with business needs, enterprise architecture (EA) was introduced by Zachman (known as the father of EA) in 1987 as a mediator to improve enterprise integration with change and reduce the gap between business and information technology (IT) (Banaeianjahromi & Smolander, 2014).

There are a number of EA and architecture definitions in the literature. (Tamm *et al*., 2011) defines EA as "the definition and representation of a high-level view of an enterprise's business processes and IT systems, their interrelationships, and the extent to which these processes and systems are shared by different parts of the enterprise."

(Bernard, 2012) defines EA as "the analysis and documentation of an enterprise in its current and future states from an integrated strategy, business, and technology perspective."

(ISO/IEC/IEEE 42010, 2011) defines the 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 this thesis, we do not adopt any of these definitions: therefore, the conduct of the research methodology (in Chapter 3) and the resulting analysis and conclusions (Chapters 4 to 7) are not biased towards any of these definitions.

Furthermore, regarding the effect of EA in the industry, a quantitative study of the value of EA on IT projects was reported by (Kurek *et al.,* 2017) in an attempt to measure (quantify) the value of EA on IT projects from different perspectives. That study compared IT projects carried out without EA with projects exposed to EA and reported an increase of 14.5% in successful IT projects, and a decrease of 26.2% in failed IT projects in favor of IT projects exposed to EA. Furthermore, the systematic literature review conducted by (Saint-Louis & Lapalme, 2018) reports that EA research has gained interest over the years 1990 and 2017.

Nevertheless, EA literature has created the expectation that EA will help improve decision-making, reduce IT costs, improve business processes and enhance the re-use of resources (Bonnet, 2009; Boucharas *et al*., 2010; Tamm *et al*., 2011; Hill, 2011;Wan *et al*., 2013).

1.2 EA evidence based research – Related work

When there is a growth of publications in a research field, it is useful and necessary to characterize the existing body of knowledge in order to identify the state of the art, including gaps and limitations. For example, medical research has built a solid work in providing such summaries and classification schemes using evidence-based research through systematic mapping studies (SMS) and systematic literature reviews (SLR) (Petersen, Feldt, Mujtaba, & Mattsson, 2008). In EA research, some evidence based research works were conducted with the objective to identify the state of the art, including gaps and limitations:

(Tamm *et al*., 2011) conducted a systematic literature review on EA value. The objective was to analyze the available literature on EA to explain how EA leads to organizational benefits.

(Wan *et al*., 2013) conducted a systematic literature review on EA benefits. The objective was to analyze the available literature on EA benefits realization to identify the challenges to trace realization of EA benefits. That research contributes by reporting the challenges on the subject.

(Andersen & Carugati, 2014) conducted a systematic literature review on EA evaluation. The objective was to analyze the available literature on EA evaluation to get an overview of the topic. Some interesting findings were synthesized by examining different evaluated elements of EA such as architecture, IT projects & initiatives, services & applications, and business elements. One of the main findings was that EA evaluation is a complex task that can be seen from various angles.

(Banaeianjahromi & Smolander, 2014) conducted a systematic mapping study on EA & enterprise integration. The objective was to analyze the available literature on the role of EA in enterprise integration to identify gaps and future research opportunities.

(Rasti, Darajeh, Khayami, & Sanatnama, 2015) conducted a systematic mapping study on EA over the previous 10 years. The objective was to analyze the available literature on EA, classify the research area of EA in general in terms of EA distribution over time, journals of published papers, EA topics, and more.

(Saint-Louis & Lapalme, 2016) conducted a systematic mapping study on the lack of common understanding in EA. The objective was to analyze the available literature on EA in order to organize the EA literature according to three major questions concerning 'who' has been published, 'where' they have been located, and 'what' their publications were about.

(Hussein *et al.,* 2016) conducted a systematic literature review on EA readiness. The objective was to analyze the available literature on EA to identify the available mechanisms in measuring readiness and to identify factors for readiness instruments towards the implementation of an organization's EA. The research identified EA readiness measurement mechanisms and EA readiness measurement factors that can assist government agencies in measuring the readiness of their EA.

(Nikpay, Ahmad, Rouhani, & Shamshirband, 2015) conducted a systematic literature review on EA post-implementation evaluation. The objective was to analyze the available literature on EA to identify gaps and limitations of EA post-implementation evaluation. The main findings were synthesized into three main challenges: lack of structured models, difficulties in EA evaluation, and lack of evaluation method.

(Jugel, Sandkuhl, & Zimmermann, 2017) conducted a systematic literature review on EAM visual analytics. The objective was to analyze the available literature on Enterprise Architecture Management (EAM) to explore to what extent visual analytics techniques were applied in EAM research and what improvement potentials exist.

(Dang & Pekkola, 2017) conducted a systematic literature review on EA in the public sector. The objective was to identify the main research topics and methods in EA studies focusing on the public sector.

(Nkundla-Mgudlwa & C. Mentz, 2017) conducted a systematic literature review on EA effectiveness constructs. The objective was s to develop a comprehensive list of constructs for measuring the effectiveness of EA implementation.

(Saint-Louis & Lapalme, 2018) conducted a systematic mapping study on EA definition. The objective was to highlight the challenges concerning the different definitions and descriptions of the expression 'enterprise architecture'. The research highlighted the challenges and shortages of a common understanding of EA, EA definitions and related factors.

(Nurmi, 2018) conducted a systematic literature review on EA definitions. The objective was to discuss the evolving EA discipline, and to strengthen the theoretical foundations of the EA discipline.

(Roos & Mentz, 2018) conducted a systematic literature review on EA decision making. The objective was to analyze the available literature on decision-making factors. The research reports a list of factors that influence EA decisions.

(Ansyori, Qodarsih, & Soewito, 2018) conducted a systematic literature review on EA success factors. The objective was to synthesize the factors that affect EA implementation. The research reports a list of factors that influence EA implementation.

(Zhang *et al.*, 2018) conducted a systematic literature review on the relationship between EA and business – IT alignment. The objective was to improve the understanding of how business – IT alignment can be achieved using EA.

(Gong & Janssen, 2019) conducted a systematic literature review on EA value. The objective was to gain a clear understanding of EA value by analyzing the EA value claims and comparing them with the empirical evidence to identify myths. The research provided a synthesis of EA values supported by evidence and on five myths, pointing out a number of weaknesses in the EA research.

Table 1.1 presents summary of seventeen (17) EA SLR or SMS studies, including their EA research topic.

Table 1.1 Summary of EA evidence-based research – SLR-SMS

EA topic	**Evidence based research type**	
	Systematic literature review	**Systematic mapping study**
EA definition and common understanding	(Nurmi, 2018) (Saint-Louis & Lapalme, 2018)	(Saint-Louis & Lapalme, 2016)
EA value and benefits	(Tamm *et al.,* 2011) (Gong & Janssen, 2019) (Wan *et al.*, 2013)	
EA evaluation	(Andersen & Carugati, 2014) (Nikpay *et al.,* 2015)	
EA readiness	(Hussein *et al.,* 2016)	
EAM visual analytics	(Jugel *et al.,* 2017)	
EA during past 10 years		(Rasti *et al.,* 2015)
EA measurement	(Nkundla-Mgudlwa & C. Mentz, 2017)	
EA in the public sector	(Dang & Pekkola, 2017)	
EA and enterprise integration		(Banaeianjahromi & Smolander, 2014)
EA decision making	(Roos & Mentz, 2018)	
EA implementation	(Ansyori *et al.*, 2018)	

Table 1.1 Summary of EA evidence-based research – SLR-SMS (continued)

EA topic	Evidence based research type	
	Systematic literature review	**Systematic mapping study**
EA and business – IT alignment	(Zhang *et al.*, 2018)	

Of the seventeen (17) SLR-SMS in Table 1.1, only three (3) tackled explicitly EA measurement and EA evaluation:

- (Nikpay *et al.,* 2015;
- Nkundla-Mgudlwa & C. Mentz, 2017 ; and,
- Andersen & Carugati, 2014).

Furthermore, the existing EA evaluation methods focused on business and IT alignment or on architecture maturity while ignoring all other parts of EA implementation (Nikpay *et al.*, 2015). All other SLR-SMS focused on proposing EA measurement solutions without an analysis of the corresponding limitations and gaps.

Table 1.2 provides a summary of the research contributions of the researchers who conducted evidence based research on EA measurement and evaluation topics.

Next, Table 1.2 provides a summary of the research contributions of the researchers that conducted evidence based research on EA measurement and evaluation topics.

Table 1.2 Summary of the contribution of evidence-based – SLR-SMS

Reference	EA topic	Research contribution
(Nikpay *et al.,* 2015)	EA evaluation	"The paper reports on investigating and identifying the practices and factors which are used in order to make an effective EAIM, collecting the factors which implicate on practices, and identifying open problems and areas for potential improvement of EAIM"

Table 1.2 Summary of the contribution of evidence-based – SLR-SMS (continued)

Reference	EA topic	Research contribution
(Nkundla-Mgudlwa & C. Mentz, 2017)	EA measurement	"The paper reports on the results of a study that explored the development of a comprehensive list of constructs suitable for measuring the effectiveness of EA implementation."
(Andersen & Carugati, 2014)	EA evaluation	"The paper reports on an overview of the topic, which can serve as a foundation for further development of the field. Overall, the study shows that while little research has been done within this area, research is especially lacking regarding empirical studies of how EA evaluation unfolds in practice, while holistic views on EA evaluation is almost non-existing."

1.3 Limitations of existing works

This section summarizes the limitation identified about evidence-based research on EA measurement.

Based on Tables 1.1 and 1.2, we deduce that the following contributions are not made available to the EA community:

1. An evidence based research (SMS) on EA measurement research that conducts thematic analysis and identifies gaps and limitations. For instance, the following contributions are missing:
    - Classification of the research intentions motivating researchers to propose EA measurement solutions,
    - Positioning of proposed EA measurement solutions within the EA project life cycle,
    - Analysis of consistency-inconsistency of terms used by authors in EA measurement research,

- Classification of the research type (e.g., evaluation research) of the proposed EA measurement solutions, and
- Classification of EA measurement techniques used or adopted from other disciplines to support the design of EA measurement solutions.

2. An evidence based research (SLR) on EA measurement research that analyze the proposed EA measurement proposals from a measurement and metrology perspective. For instance, the following contributions are missing:
    - An evaluation of the EA measurement proposals from a measurement and metrology perspective.
    - An identification of measurement and metrology issues in EA measurement proposals.

For this thesis, we conducted an extended version of the SMS from our initial study (Abdallah, Lapalme, and Abran, 2017) that goes beyond the limitations of the related work on EA measurement research (see Chapter 2). Furthermore, we conducted an SLR to synthesize and evaluate the EA measurement proposals from a measurement and metrology perspective (see Chapter 2).

CHAPTER 2

THEORETICAL FOUNDATIONS

This chapter presents an overview of the best practices of measurement and metrology guidelines. The literature on software engineering measurement indicates that the field has recently established metrology-related guidelines to assist researchers and practitioners in designing mature measurement methods. The Measurement Context Model and the ISO 15939 Measurement Information Model in (Abran, 2010) introduce the design steps and metrology criteria needed to design a mature measurement method. Furthermore, this chapter presents an overview about the evaluation theory and its basic components.

Section 2.1 presents the measurement and metrology guidelines, including the measurement context model, metrology criteria, and ISO 15939 concepts. Section 2.2 presents the evaluation theory, including the basic components of the evaluation process. Section 2.3 presents the development of the evaluation process based on the basic components of the evaluation theory.

2.1 Measurement and metrology guidelines

This section provides a summary of the measurement and metrology guidelines. These guidelines provide general steps and criteria to design mature measurement methods, and will be the basis of the evidence-based research discussed later in Chapter 3.

2.1.1 Measurement Context Model

According to (Abran, 2010), in engineering and technical texts, the “measurement” is used in three (3) different contexts, and means differently according to the usage of the term. The measurement term can be:

1. a measurement method that assigns numerical values to the attribute of an entity,
2. the application of the measurement method, and / or
3. the result of the application of the measurement method,

The three (3) different uses of the term "measurement" are presented in the "measurement context model" in Figure 1. The model illustrates these different meanings in a set of steps (i.e. step1, step 2 and step 3) that guides the design and the application of a measurement method.

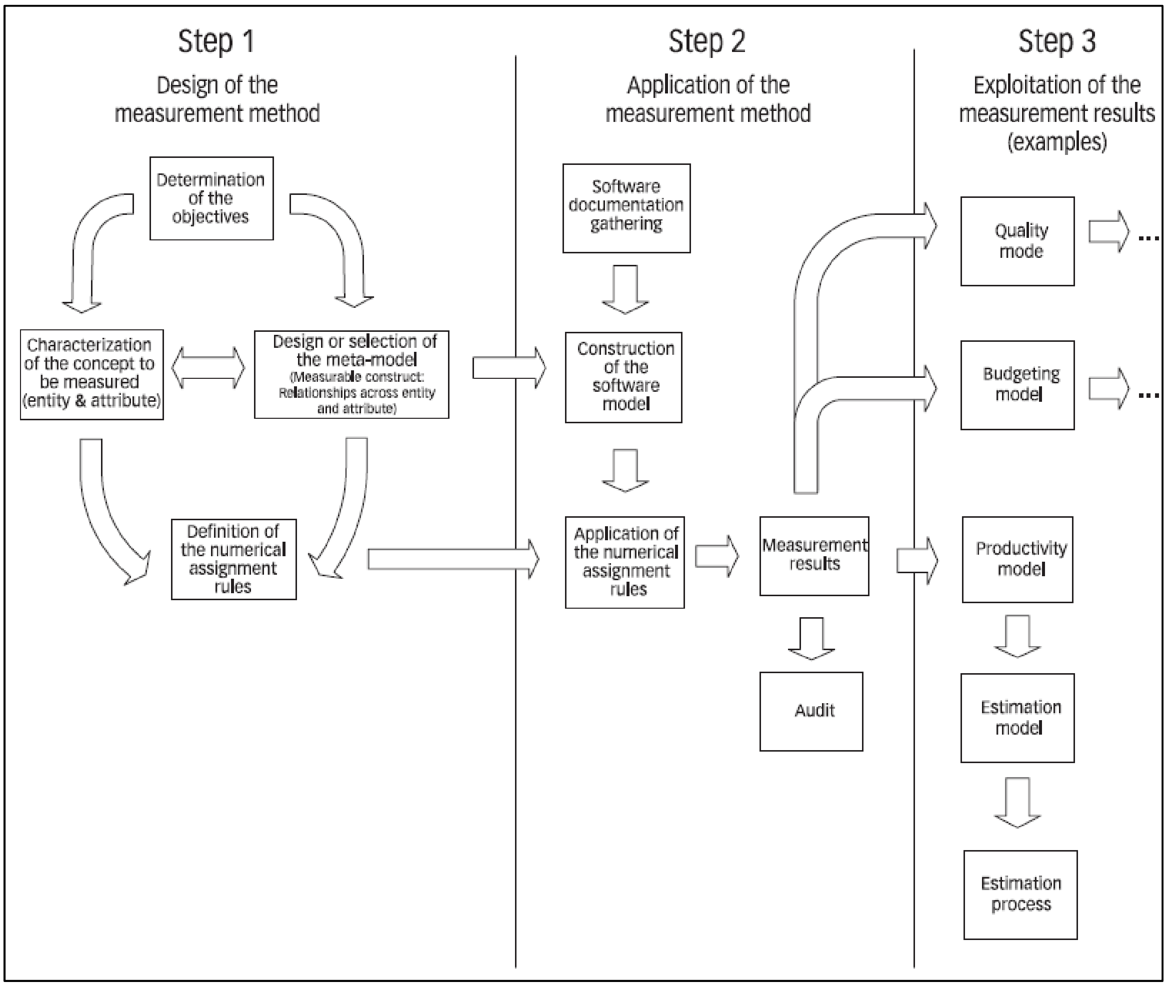

Figure 2.1 Measurement context model
Taken from Abran (2010, p.24) © copyright Wiley & IEEE Press

In this thesis, we focus on the design of the measurement methods (i.e. step1). Next is a description of the suggested theoretical and empirical criteria of step 1 "the design of a measurement method."

Criteria for theoretical definitions: the metrology criteria of the theoretical definitions for a mature measurement method design should satisfy the following:

1. **Determine the measurement objective**. This criterion focuses on identifying what concept is the measurement method intent to measure, and the intended use of measurement results.
2. **Define the concept to be measured**. The measured concept should be clearly defined, or in other words, characterized. The definition of the measured concept includes decomposing the concepts into sub-components. This decomposition is intended to help understand the role of each attribute in forming and creating the main measured concept. Moreover, each concept, with the relevant attributes, represents the measured entity. For example, measuring the size of the code of software: the software code can be an entity, and the size is the attribute of the software code.
3. **Design or use a Meta model**. Define the relationships across the attributes and entities.

Criteria for empirical definitions: the metrology criteria of the empirical definitions for a mature measurement method design should satisfy the following:

1. **Define the numerical assignment rules.** It include the following criteria:
    - identify source of input data: example, the measurer,
    - identify type of input data: example, subjective or objective measurement,
    - identify quantification rules: example, ordinal measurement scale type,
    - identify mathematical operations: example, multiplication operation, and
    - identify measurement units: example, a meter.
2. **Metrology properties for quantities:** from the metrology standpoint (Mari & Giordani, 2012) and according to the ISO International Vocabulary of Basic and General terms in Metrology (VIM) in (JCGM, 2008), measurement units and measurands are quantities. For example, length is a quantity, and the indication of this quantity is called the quantity value (a number). Hence, the input to the measurement exercise is a quantity. According to (Abran, 2010) when an analysis is conducted to investigate the quality of measurement method design, the following properties should be recognized:

- **A measurement unit:** the measurement unit should be a product of (or used in) admissible mathematical operations. It can be a base unit (e.g., meter), or a derived unit (e.g., meter per second)
- **Quantity value:** according to the definition by the VIM, it is a number that gives an expression of the quantity with a measurement unit accompanied.
- **A system of quantities:** according to the definition by the VIM a base quantity (also known as base measure in ISO 15939) is defined as “a simple property defined by convention, with no reference to other attributes, and possibly used in a system of attributes to define other attributes (Buglione & Abran, 2014)”. Examples of a base quantity are “distance and time.”

  The derived quantity (also known as derived measure in ISO 15939) is defined as “a property defined in a system of attributes as a function of base attributes. Derived measure is therefore the product of a set of measurement units properly combined (through a measurement function) (Abran, 2010)”. An example of a derived measure is the “speed.”
- **Kind of quantity:** the context of comparing two quantities with the same kind. For example, comparing the speed of two cars.

2.1.2 ISO 15939 Measurement Information Model

The scope of ISO 15939 sets out the necessary steps that differentiate between numbers obtained from a measurement method with metrological properties, and numbers obtained from an analysis model. The terms of ISO 15939 clarify that numbers are not all equal, and measurement and quantification are not the same. For instance, numbers can be:

- The result of different mathematical operations such as addition or division. The number obtained through mathematical operations is only a number in a mathematical sense, and does not represent a measurement exercise, or any measurement meanings.
- The result of a measurement exercise that satisfies: the metrology criteria and is produced from an admissible mathematical operation.
- The result of quantitative decision-making model, for instance, an estimation.

The terms and definitions in ISO 15939 are adapted from the VIM. The VIM establishes measurement related vocabulary and definitions as a common reference for researchers and practitioners performing measurement. ISO 15939 is decomposed into two sections from the bottom up as follows – see Figure 2.2: the metrology related section, and the non-metrology related section.

1. **Metrology – Related (Measurement of the Attribute of an Entity):**

   - **Data Collection:** in this step, attributes of interest are being identified for each entity, and a measurement method is designed based on the guidelines of the measurement context model. Accordingly, the measurement method measures the attributes and the output of the measurement method is called the base measure.
     - **Attributes**: a property of an entity that can be determined quantitatively (Abran, 2010).
     - **Measurement method**: represents the logical steps to assign numerical values to a measurable attribute. For a measurement method to be metrologically sound, it should comply with relevant quality criteria such as those of (Abran, 2010) for the design and application of measurement methods. An example of a quality criterion for designing a measurement method is a measurement unit. An assigned quantity without a measurement unit does not qualify in metrology as a valid measurement

   - **Data Preparation:** in this phase, based on the data collection section, the base measures are identified and quantified. Afterwards, base measures can be combined in a measurement function to derive the derived measures.
     - **Measurement function** is a mathematical formula used to combine base measures to deliver derived measures.

2. **Non Metrology-Related (quantification of relationships across attributes and entities):**

   This is the top section of the ISO 15959, and is known as Data analysis. This section is not metrology related, and it attempts to quantify the relationship between base and/or derived measures.

   From the bottom up, the inputs to the data analysis section are the results of the metrology section. Therefore, the quality of the data analysis is as good as the measurement method. (Abran, 2010) summarize this by "garbage in, garbage out" referring to the weak metrology qualities that lead to weak data analysis models.

   As illustrated in Figure 2.2, the analysis model attempts to focus on the relationships between attributes so that it quantifies these relationships and produces an indicator (a value). In order to draw conclusions, the indicator is interpreted based on defined decision criteria, and used for decision-making purposes.

   Furthermore, the data analysis section of ISO 15939 contains additional concepts as follows:

   - **A standard reference model**: this refers to an accepted model of relationships from industry, ISO or a known statistical technique (e.g., regression analysis).
   - **An organizational reference context**: this includes specific reference values (thresholds) or evaluation criteria to organizations. These can be used for interpretation purposes.

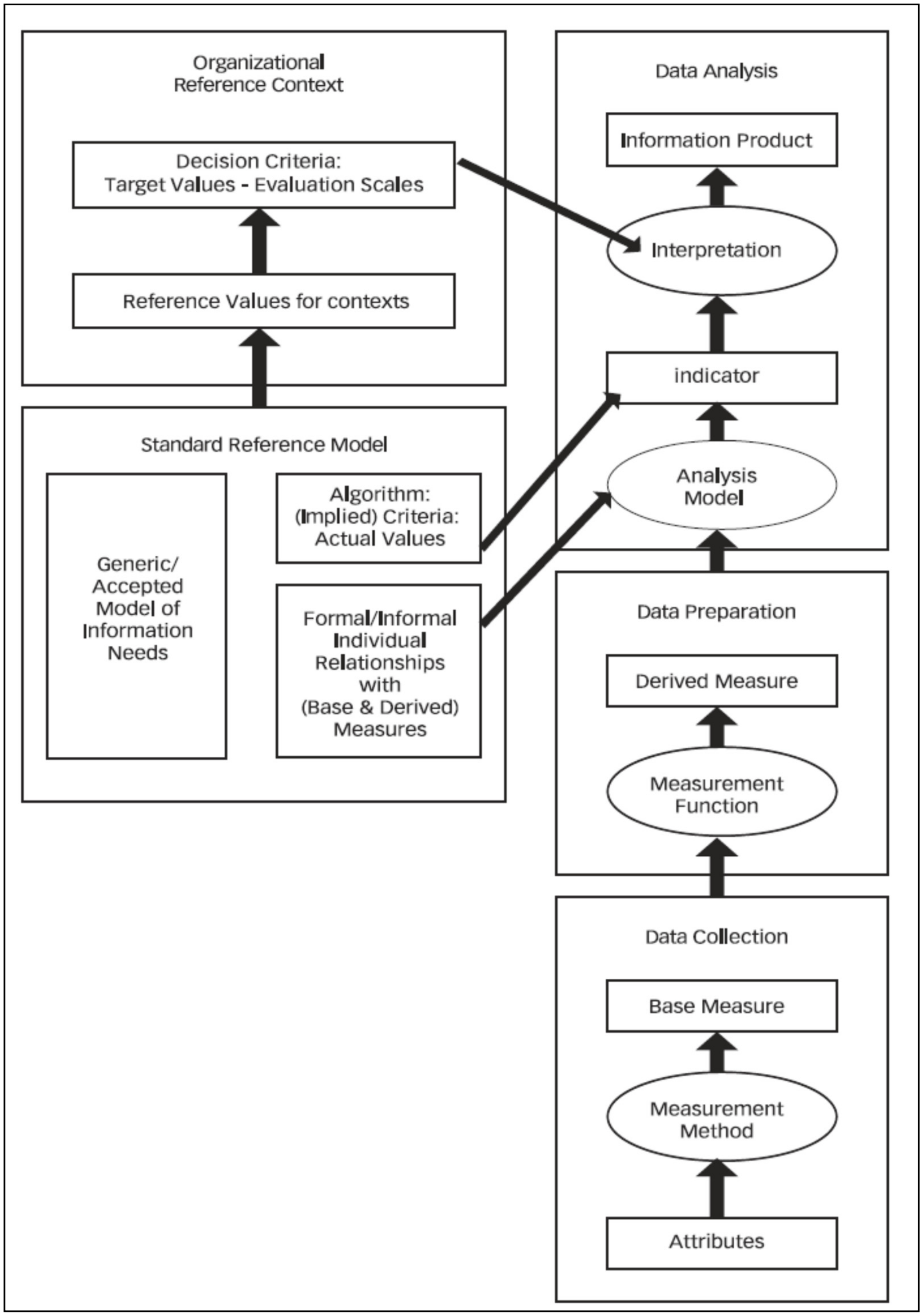

Figure 2.2 ISO 15939 Measurement information model

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2.2 The evaluation theory

This section presents a background about the concepts of evaluation theory needed to develop the proposed evaluation process presented in section 2.3.

According to (López, 2000), the term "evaluation" means the act of determining the worth, merit or significance of a given object. Furthermore, (López, 2000) mentions that there are other common synonyms for the terms in this definition: "quality" is often used instead of "merit," "value" instead of "worth," and "importance" instead of "significance."

Evaluation is not a distinct discipline, instead, it is used as part of other disciplines (López, 2000). Furthermore, in order to conduct an evaluation, there is no one single evaluation method. Several evaluation methods are reported in the literature. For instance, (Fitzpatrick, Worthen, & Sanders, 2004) classifies the evaluation methods as follows:

- Objective-oriented evaluation: "determining the extent to which goals are achieved."
- Management-oriented evaluation: "providing useful information to aid in making decisions."
- Consumer-oriented evaluation: "providing information about products to aid in making decisions about purchases or adoptions."
- Expertise-oriented evaluation: "providing professional judgments of quality."
- Adversary-oriented evaluation: "providing a balanced examination of all sides of controversial issues, highlighting both strengths and weaknesses."
- Participant-oriented evaluation: "understanding and portraying the complexities of a programmatic activity, responding to an audience's requirements for information."

Despite the several evaluation methods, (López, 2000) reports that the evaluation should contain mandatory and basic components. The basic components are summarized as follows:

1. **Target**: This is the object under evaluation.
2. **Criteria**: The characteristics of the target that are to be evaluated. According to (López, 2000) there are different techniques that can assist to determine the characteristics of the target, where the selection of the technique depends on the target. For instance:
   - Functional analysis of the target: “defined as the detailed description of the target’s function.”
   - Needs assessment: “refers to any study of the needs, wants, market preferences, values, standards, or ideals that might be relevant to the target.”
   - Scientific standard: refers to criteria of a known scientific standard or theory.
3. **Yardstick**: This is the ideal target, which against the target is to be compared. The yardstick must contain information such as the specifications, requirements, descriptions, or values for each criterion considered, and related to the target.
4. **Data gathering techniques**: The techniques needed to obtain data to analyze each criterion related to the target. (López, 2000) summaries the main data gathering techniques in software engineering field are as following:
   - Measurement: Refers to collecting data through measurement devices or methods.
   - Assignation: Refers to collecting data through questionnaires, interviews, or documentation reviews.
   - Opinion: Refers to collecting data through subjective observations.
5. **Synthesis techniques**: The techniques used to judge each criterion and, in general, to judge the target, obtaining the results of the evaluation.
6. **Evaluation process:** This step describes the activities of when to apply all the previous basic components in practice. The evaluation process contains three (3) main activities, and are summarized according to (López, 2000) as follows:
   - Planning: Involves identifying the target to be evaluated, goals of the evaluation, and team of evaluators.
   - Examination: Involves applying the data gathering techniques.

- Decision-making: Involves applying the synthesis techniques, and presenting the results to complete the evaluation.

2.3 Development of the evaluation process of EA measurement proposals

The development of the EA measurement evaluation process is presented in Table 2.1. In this thesis, Table 2.1 will be the basis for evaluating the EA measurement proposals later in Chapter 5.

Table 2.1 EA measurement proposals evaluation process

Activity 1: Planning		
Evaluation basic component	**Description**	**Details presented in**
Identifying the target to be evaluated	EA measurement proposals	Chapter 4 Chapter 5
Establish the evaluation goals	To calculate the metrology coverage scoring, and identify the metrology weaknesses in EA measurement proposals	Chapter 4 Chapter 5
Identify the evaluation criteria	Design criteria of measurement methods	Chapter 2
Identify and apply the evaluation yardstick	Metrology coverage (theoretical and empirical definitions). Based on measurement and metrology guidelines, adopted from (Abran, 2010)	Chapter 5
Activity 2: Examination		
Apply the data gathering techniques	Assignation: documentation review (coding primary studies), and SLR	Chapter 3
Activity 3: Decision making		
Apply the synthesis techniques	Present figures and tables of the evaluation results	Chapter 5 Chapter 6

CHAPTER 3

RESEARCH STRATEGY & METHODOLOGY

The research strategy in this thesis – illustrated in Figure 3.1 is decomposed into three phases. The first phase is to conduct a mapping study, the second is a systematic literature review, and the last phase in our research journey is a proposal of a novel EA measurement approach.

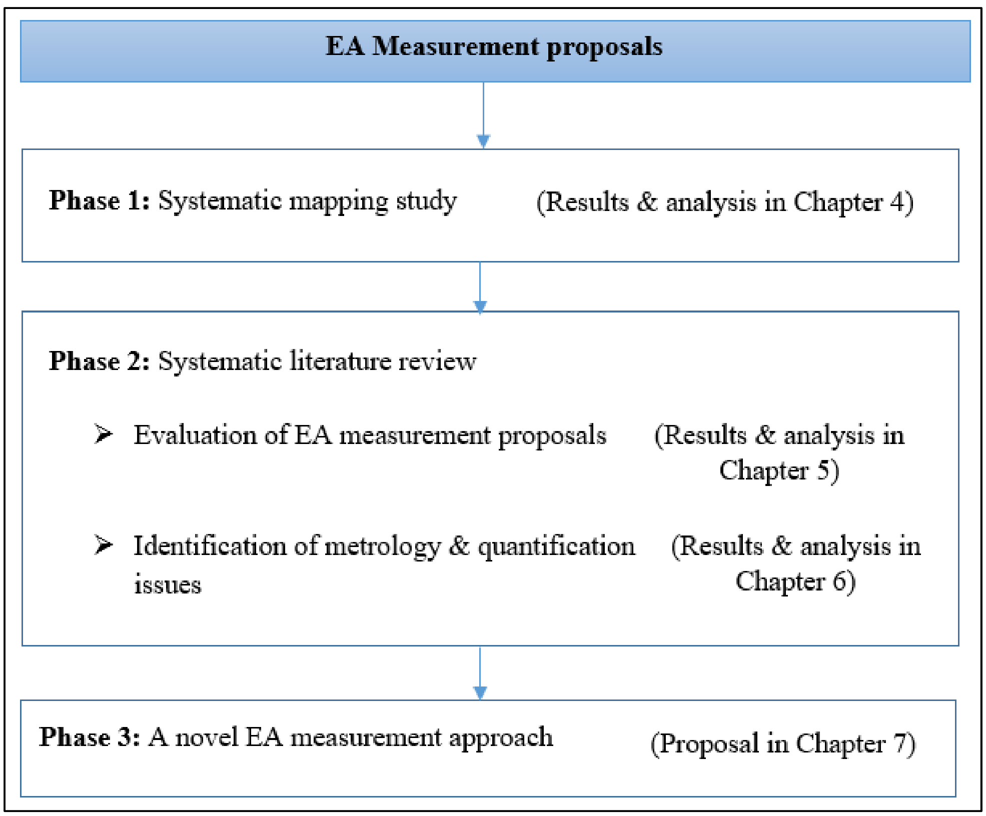

Figure 3.1 Research strategy

Section 3.1 presents an overview about evidence-based research. Section 3.2 presents a detailed description of the systematic mapping study. Section 3.3 presents a detailed description of the systematic literature review.

3.1 Evidence based research

Based on the findings of the literature review in Chapter 1, until recently and to our knowledge, there is little evidence-based research supporting the findings, achievements, and limitations of the EA measurement research.

Therefore, in the first phase of this thesis, we adopt the systematic mapping study (SMS) to EA measurement research area. According to (Petersen *et al.*, 2008), the SMS is a research methodology used to analyze and review the research area from a broad perspective. SMS classifies the primary studies into specific categories, according to selected mapping questions, in order to identify the research themes and explain the structure of the literature. In the SMS of this thesis, the research objective is to provide classification schemes and draw themes and conclusions about EA measurement research.

In the second phase of this thesis, we adopt the systematic literature review (SLR) to EA measurement research. According to (Kitchenham, 2004) "a systematic literature review is a means of identifying, evaluating, and interpreting all available research relevant to a particular research question, or topic area of interest". In the SLR of this thesis, the research objective is to evaluate the EA measurement proposals based on the measurement and metrology guidelines.

The type of the research questions and objectives of SMS and SLR deals with documents (primary studies) rich of textual content. Consequently, there is a need to identify a research approach by which can develop a strategy for data extraction and analysis. Therefore, the content analysis is selected for this purpose.

Content analysis approach is used in the qualitative methodological research. The approach is used by researchers to collect and analyze data through developing codes and themes about primary studies (Krippendorff, 2018). Codes are labels associated to sentences, paragraphs, or phrases in order to capture meanings from large texts. There are two (2) types of codes:

1. Data-driven: based on extracting codes from the raw data.

2. Theoretical- driven (pre-defined list): based on using existing reference, standard, or theory.

Once the coder has identified the codes, he/she can develop a codebook. A codebook is a set of the derived codes and their definitions, examples, and guidelines that represent the framework of the data reduction process (DeCuir-Gunby, Marshall, & McCulloch, 2011). The process of creating the codes and the codebook is iterative, and the coder has to perform two levels of coding. The open coding which is the first step toward labeling the text, and the second is the axial coding by which the coder starts to create relationships between the codes to create themes (DeCuir-Gunby *et al*., 2011). A theme is a coherent integration of codes that captures something important about the data with respect to the research question; therefore, it is an expression of the latent content of the text (Vaismoradi, Turunen, & Bondas, 2013).

The codebooks for the SMS and SLR are presented in Annex 1 and Annex 2 respectively.

The research strategy of this thesis adopts the SMS and SLR methodology guidelines proposed in (Tranfield *et al*., 2003; Kitchenham, 2004; Okoli & Schabram, 2010; Kitchenham & Charters, 2007). The guidelines help to classify and evaluate available research in a particular field and include three main phases:

- Planning of the study by developing a review protocol that includes the research questions, the search strategy, the inclusion/exclusion criteria and the data extraction strategy,
- Executing the study includes the collection of data addressing the research questions, and
- Analyzing and presenting the results of the study.

Next, we detail the three phases for the SMS and SLR as follows:

3.2 Systematic mapping study (SMS)

3.2.1 Planning of the study

In this section, we present the planning used in order to conduct the SMS including the research questions & objectives, search strategy, inclusion/exclusion criteria and data extraction strategy.

1. Mapping questions & objectives: Table 3.1 presents the list of the mapping questions and the corresponding objective.

Table 3.1 Mapping questions and objectives for SMS

ID	Mapping Question	Objective
MQ1	What are the sources of publication on EA measurement?	To discover where EA measurement research is published.
MQ2	How has publication on EA measurement changed over time?	To discover the timeline of EA measurement publications.
MQ3	Which "EA schools of thought" have addressed research in EA measurement?	To help identify which EA schools of thought have addressed research in EA measurement, and which have not, thereby leaving aspects of EA unexamined.
MQ4	Where are EA measurement solutions helpful in the EA project lifecycle?	To discover where the proposed EA measurement solution can be used in the EA project life cycle. This will help researchers design EA measurement solutions capable of assisting organizations to measure EA throughout the EA project life cycle.
MQ5	What were the research intentions of EA measurement research?	To discover the intentions and motivations behind conducting research in EA measurement. This will provide the research community with insights on current research directions.
MQ6	What are the most popular research types in EA measurement literature?	To discover which research types have been most frequently used, and to determine gaps and candidate avenues for future research.
MQ7	What are the most frequently adopted foundations from other fields (disciplines), including the	To provide a classification scheme of the techniques used to date to design or propose EA measurement solutions from other fields, including the EA field. This will provide an

Table 3.1 Mapping questions and objectives for SMS (continued)

ID	Mapping Question	Objective
	EA field, in EA measurement research?	understanding of how EA measurement solutions have been designed and allow determination of gaps and candidate avenues for future research.
MQ8	What are the EA measurement solutions described in the EA literature, and what is the terminology most used?	To identify the EA concepts or attributes targeted for measurement and the terminology most used to describe EA measurement solutions.
MQ9	What measurement terms are most frequently used in EA measurement research? Are measurement, evaluation, assessment and analysis used interchangeably?	To recognize the most frequently used measurement-related semantics in EA measurement literature. In addition, to identify the consistency-inconsistency usage of measurement-related semantics (interchangeability).
MQ10	Is EA measurement research referencing the ISO 15939 standard on software process measurement?	To identify the presence of ISO 15939 within the text and references of the primary studies as an indicator of the awareness of the authors of the measurement terms consensually used in science and engineering.

2. Search strategy: selecting the relevant electronic databases is one of the main steps toward answering the mapping questions. Based on six databases (AIS, Compendex, IEEE, Inspec, Scopus, and SpringLink) our SMS used a combination of keywords to create nine search strings – see Table 3.2. These search strings, customized according to the settings of each database, were then used to search each of the databases.

Table 3.2 Search strings

String ID	Search String
String 1	"Enterprise architecture" AND (measure OR evaluate OR assess)
String 2	"Enterprise architecture" AND scorecard
String 3	"Enterprise architecture" AND (benefit OR value OR impact)
String 4	"Enterprise architecture" AND (success OR effectiveness)
String 5	"Enterprise architecture" AND quality
String 6	"Enterprise architecture" AND maturity
String 7	"Enterprise architecture" AND realization

Table 3.2 Search strings (continued)

String ID	Search String
String 8	"Enterprise architecture" AND "quantitative analysis"
String 9	"Enterprise architecture" AND performance

The search strings were defined and applied with filters limiting the search to explore titles and abstracts of journal papers. The rationale for limiting the search to journal articles derives from the general practice at conferences to present preliminary results and later publish in journals the detailed and complete analysis. After exploring the databases using the search strings in Table 3.2, 774 primary studies were identified and stored in an Excel sheets.

The 774 primary studies may contain duplicates among the six databases for each search string, and among the six databases overall; pivot tables were used to remove duplicates, which reduced the candidate primary studies to 236 unique studies.

3. Inclusion/exclusion criteria (filtering approach): To select the most relevant primary studies out of the 236 candidates, the following inclusion and exclusion criteria were defined:

Inclusion: the primary studies meeting the following criteria were selected:

- Exact keyword "enterprise architecture" is present in the title of the primary study.
- Exact keyword "measurement," or (evaluation, assessment, analysis) is present in the title and/or the entire text of the primary study.
- Only the most recent publication for a study reported more than once.
- Discusses or presents an EA measurement proposal - this can be, but is not limited to, method, theory, framework and tool.

Exclusion: primary studies meeting the following criteria were removed:

- Without the exact keyword "enterprise architecture."

- Without the exact keyword "measurement" or its synonyms.
- Without the combination of "enterprise architecture" and "measurement" or (evaluation, assessment, analysis).

In addition, another filter to select primary studies was added when necessary. Namely, if the title of the primary study did not provide sufficient detail to make the decision, the researcher screened the full article, including abstracts and conclusions. By reading the primary study, the researcher identified whether the content was relevant to answering the mapping questions. A primary study is considered useful if the content is relevant to our research objectives, that is, it contains:

- A definition of EA,
- The word "measurement" and/or (evaluation, assessment, analysis) to be able to identify an answer to MQ9,
- The identification of an EA measurement concept and/or attribute to answer MQ8, and
- A proposal of a measurement solution.

  The outcome was a set of 23 relevant primary studies used to answer the mapping questions in Table 3.1.

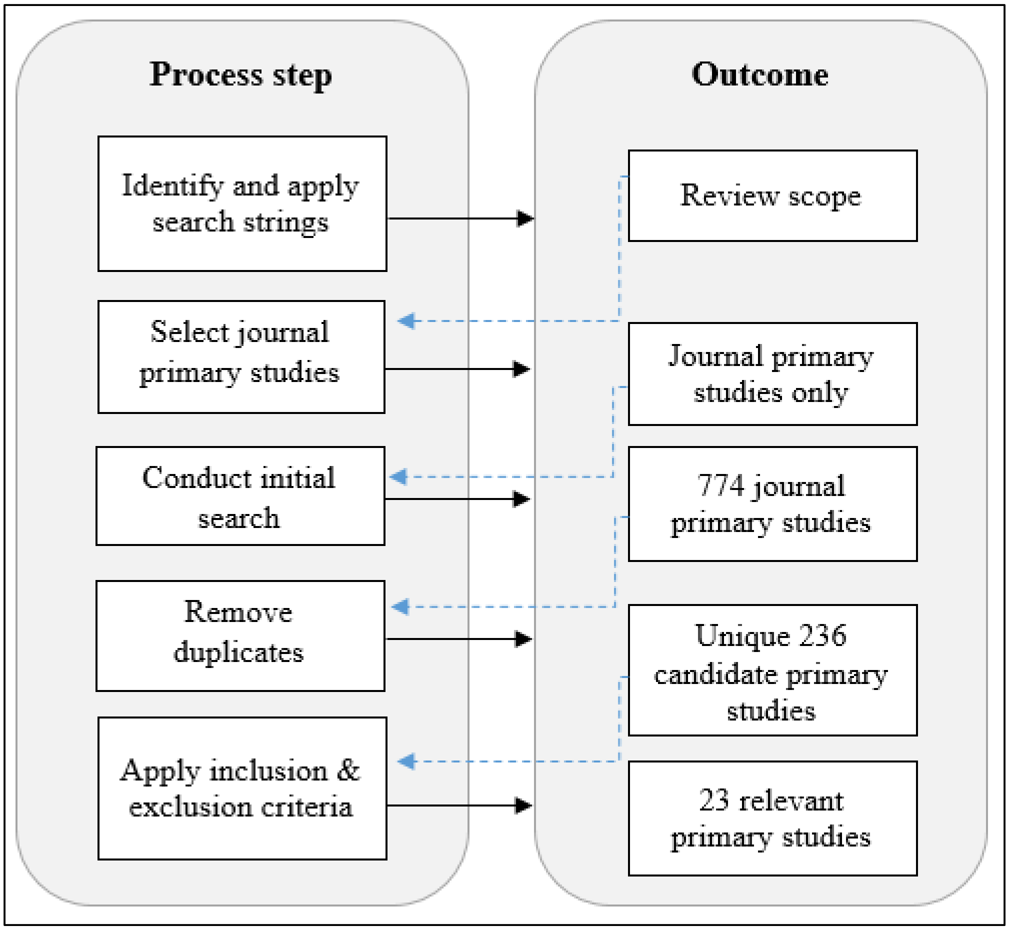

Figure 3.2 Search strategy and filtering approach to select primary studies

4. Data extraction strategy: To address the research questions and conduct the data extraction, we defined the data extraction strategy with the corresponding coding types for each mapping question (see Table 3.3)

Table 3.3 Data extraction strategy for SMS

Mapping question (MQ)	Coding type	Codes
MQ1 & MQ2	Pre-defined list	Title, year of publication, & source of publication
MQ3	Pre-defined list	Enterprise IT architecting, Enterprise integrating, & Enterprise ecological adaption

Table 3.3 Data extraction strategy for SMS (continued)

Mapping question (MQ)	Coding type	Codes
MQ4	Pre-defined list	Development, Realization, & Use
MQ5	Data driven	Unspecified
MQ6	Pre-defined list	Validation research, Evaluation research, Solution proposal, & Philosophical research
MQ7	Data driven	Unspecified
MQ8	Data driven	Unspecified
MQ9	Pre-defined list	Evaluation, Assessment, & Measurement
MQ10	Pre-defined list	Not using ISO 15939, & Likely to use ISO 15939

Data extraction for MQ1 and MQ2 was based on a pre-defined list of codes extracted directly from the databases and included article title, year of publication, and source of publication. No effort was made to read the latent (hidden) meanings behind the text.

Data extraction for MQ3 was based on pre-defined codes to determine the type of EA based on the taxonomy of the three EA schools of thought (Lapalme, 2012):

- Enterprise IT architecting: "EA is about aligning enterprise IT assets (through strategy, design, and management) to effectively execute the business strategy and various operations using proper IT capabilities".
- Enterprise integrating: "EA is about designing all facets of the enterprise. The goal is to execute the enterprise strategy by maximizing overall coherency between all of its facets—including IT."
- Enterprise ecological adaption: "EA is about fostering organizational learning by designing all facets of the enterprise—including its relationship to its environment—to enable innovation and system-in-environment adaption."

Data extraction for MQ4 was based on a pre-defined list of codes to determine where the EA measurement solution can be used within an EA project life cycle. In practice, the value of EA is a result of several changes over time (Plessius *et al.*, 2012). Therefore, we carried out an investigation of EA measurement solutions and EA lifecycle to leverage the knowledge about the useful utilization of EA measurement solutions within an EA lifecycle. For this SMS, we adopted the EA project life cycle of (Plessius *et al.*, 2012) where the phases provide traceability of the EA project and provide information about where in the cycle EA value may be created:

- Development: In the development phase, EA is developed and maintained. "This phase corresponds to the ADM phases: architecture vision, business architecture, information systems architectures and technology architecture".
- Realization (implementation): The realization phase is where projects are defined and carried out to implement the changes defined in the EA. "This phase corresponds to the architecture development method (ADM) phases, opportunities and solutions, migration planning and implementation governance."
- Use: After implementation, changes have been implemented in the organization and the promised benefits should materialize. This corresponds to architecture change management in ADM of TOGAF 9.1.

Therefore, to extract information about the relevant EA lifecycle, the researcher reads the text (e.g., abstract, introduction, and sections where the measurement solution is presented) and maps the findings with the EA project life cycle. For instance, the following statement explains when the proposed measurement solution can be used: "Moreover, because the risk and impact of EA are pervasive across the enterprise, it is critical to perform an architecture assessment before any decision about choosing a scenario." The word "before" explains that the decision to select a candidate EA scenario is not taken before the architecture of the candidate EA scenario is assessed, e.g., before the EA scenario is used and implemented.

Data extraction for MQ5 was based on data driven codes to investigate the research intentions on EA measurement research in order to gain insights into the relevance of the research to stakeholders. This is a valuable piece of information for outlining research directions. Hence, the codes for this question were extracted by identifying phrases in the primary studies that indicate research intentions such as, but not limited to, "the key contribution is...," "this investigation helps organizations to..."

Data extraction for MQ6 was based on a pre-defined list of codes. The objective of MQ6 was to provide the EA community with a classification scheme of the most popular research types in the EA measurement literature. The classification type and criteria in EA measurement research of (Petersen *et al.,* 2008) were adopted:

- Validation research: A primary study where the measurement solution is not yet implemented in practice with an industry partner, but uses statistics, hypothesis, or regression analysis to test a model or to validate a research hypothesis related to the EA measurement solution.
- Evaluation research**:** A primary study that has an industry partner and implements the EA measurement solution in practice with the industry partner.
- Solution proposal**:** A primary study that has no industry partner and explains the potential benefits of the EA measurement solution but has no statistics, hypothesis, or regression analysis, and is not yet implemented in practice.
- Philosophical research**:** A primary study that provides taxonomy on EA measurement research, structures the EA measurement research field, and provides a new way of looking and understanding the EA measurement literature. Technically, it should not match any of the criteria for validation research, evaluation research, and solution proposal.

Data extraction for MQ7 was based on data driven codes to provide a classification for which foundations have been established in other fields (disciplines) of engineering or business, or from the EA field, in order to design the EA measurement solution.

Data extraction for MQ8 was based on data driven codes to identify the most frequently used terminology to describe EA measurement solutions, and to identify the EA concepts or attributes targeted in each EA measurement solution. The steps to extract the data driven codes of MQ8 are as follows:

- The title may contain terminology describing a measurement solution.
- The abstract may contain terminology describing a measurement solution. Example of a sentence found in a given primary study: “The proposed method is used for evaluating twenty EA risk factors.” This sentence indicates that the author(s) used the word “method” to describe their EA measurement, evaluation, and-or assessment solution.
- Other sections of the primary study might contain a description of EA measurement solutions: sections related to the research objectives, the research methodology, and the conclusion.

Two different levels of research were investigated. The first was an abstraction level; the second was a detailed and decomposed level as follows:

- The first level is to find the main concept (EA concept) for the EA measurement solution.
- The second level is a more detailed means of investigating a decomposed EA concept (sub-concept) for the EA measurement solution.

Both levels may be found in the abstract section, the introduction, the section where the measurement solution is presented or the conclusion section. Example: “The proposed method is used for evaluating twenty EA risk factors.” In this example, the word “method” refers to the language used to determine the EA measurement solution, and the word “risk” refers to the measured EA concept.

Data extraction for MQ9 was based on a pre-defined list of codes where the following definitions of measurement, evaluation, assessment, and analysis do not share the same meaning:

- Evaluation (Zarour, 2009): The process of determining merit, value or worth. The six basic components of evaluation are target, criteria, yardstick (the ideal target against which the real target is to be compared), data gathering techniques, synthesis techniques, and the evaluation process.

- Assessment (Loon, 2004): A procedure which includes initiating the assessment, planning the assessment, briefing, data acquisition (normally through interviews and a review of documents), process rating (outcome of the assessment), and reporting results.
- Measurement (Abran, 2010): In the measurement context model and the ISO 15939 measurement information model measurement can be: a method of assigning a numerical value to an object, the action of measuring, the result of measurement, the use of measurement results, or any of these.

We used these terms and definitions as a pre-defined list of codes in MQ9 to conduct thematic analysis to investigate whether these terms are used interchangeably or not in the EA measurement literature.

Data extraction for MQ9 was also based on a pre-defined list of codes. Until recently, the maturity of EA measurement solutions concerning metrology had not been identified as a qualitative issue in EA measurement research. In particular, it was not clear if EA measurement solutions had considered measurement standards in the attempt to propose EA measurement solutions. Consequently, through MQ9 we investigated if the literature on EA measurement referred to the ISO 15939 measurement information model and terminology.

In this SMS, to answer MQ9, we used the metrology section of ISO 15939. More specifically, we refer to the non-metrology related section (analysis of relationships) in the top section of ISO 15939, which presents the quantification steps that lead to numbers based on analysis models and their interpretation. Based on (Zarour, 2009; Loon, 2004; Abran, 2010) evaluation, measurement, analysis, and assessment do not share the same meaning. According to (Krippendorff & Bock, 2009):

- On the one hand, evaluation consists of measurement and analysis as data gathering techniques. In other words, measurement and analysis are both part of the evaluation process.
- On the other hand, assessment aims to discover the strengths and weaknesses of a given process. Furthermore, to conduct an assessment, practitioners deploy questionnaires,

interviews, and document comparisons for data acquisition. Hence, in the assessment process, the results are driven by different semantics and interpretations while the results of measurement processes are related to repeatability and reproducibility as key characteristics of a well-designed measurement process.

To extract data and answers for MQ10, we used the search tool to find the words ISO 15939 and/or the International Vocabulary of Metrology (VIM) from the list of references of each primary study. Ultimately, the primary studies were classified into:

- Primary studies not using ISO 15939 where none of the words (ISO 15939 and/or VIM) was found in the references.
- Primary studies likely to use ISO 15939 where at least one of the words (ISO 15939, and/or VIM) was present in the list of references. The presence of these words in the references list does not assure that the primary study follows ISO 15939. Rather it represents a potential for these primary studies to be aligned with ISO 15939 and requires further investigation and analysis.

3.2.2 Execution of the SMS

The detailed results (e.g., tables) of this step are presented in Appendix I.

3.2.3 Analyzing and presenting the results of the study

The results of this step are presented in Chapter 4.

3.3 Systematic literature review (SLR)

The scope and objective of the SLR and SMS are not identical. As mentioned earlier, the objective of the SMS in this thesis is to draw themes, and classify the research area about EA measurement. In turn, the scope and objective of SLR is more in depth focused on evaluating EA measurement proposals with respect to measurement and metrology guidelines.

Nevertheless, since SLR is the second phase of the evidence-based research of this thesis, the research strategy including the research guidelines (e.g., planning of the study) are used in the conduct of the SLR as follows:

3.3.1 Planning of the study

This section presents the planning used in order to conduct the SLR including the research questions & objectives, search strategy, inclusion/exclusion criteria and data extraction strategy.

1. Research questions (RQ) & objectives: Table 4 presents the list of the research questions and the corresponding objective.
2. Search strategy: the search strategy including the search strings are the same as the strategy and strings used in section 3.3.1 (Figure 3.2 and Table 3.2).
3. Inclusion/exclusion criteria: the search strategy including the search strings are the same as the strategy and strings used in section 3.3.1.
4. Data extraction strategy: since the scope of the SLR and SMS is not identical, the data extraction strategy for the SLR is different from the strategy of the SMS. The data extraction strategy for the SLR is explained as following:
   - EA entity type: Is the measured EA entity type in the primary study?
   - EA attribute: Is the measured EA attribute in the primary study?
   - Source of input data: Is the source of data used to collect data to conduct the EA measurement proposal in the primary study?
   - Type of input data: Is the type of data inputs to the EA measurement proposal in the primary study?
   - Math on input/output data: Is the mathematical operation of the EA measurement proposal in the primary study?
   - Measurement unit: Is the measurement unit of the EA measurement proposal in the primary study?

- Quantification rule: Is the quantification rule of the EA measurement proposal in the primary study?

Table 3.4 Research questions and objectives for SLR

ID	Research Question	Objective
RQ1	What is the extent of the robustness of EA measurement proposals concerning the measurement and metrology guidelines?	The research objective aims to evaluate the EA measurement proposals with respect to the measurement and metrology guidelines. In particular, to determine the metrology coverage scoring of the theoretical and empirical definitions.
RQ2	What are the metrology and quantification issues in EA measurement proposals?	The research objective aims to identify the hidden and unknown metrology and quantification issues and weaknesses related to EA measurement, and identify future research avenues.

The data extraction strategy for RQ1 and RQ2 is based on the measurement and metrology criteria of (Abran, 2010), and is summarized in Table 3.5.

Table 3.5 Data extraction strategy for SLR

Research question (RQ)	Coding type	Codes
RQ1	Pre-defined list	EA entity type EA attribute Source of input data Type of input data Math on input/output data Measurement unit Quantification rule
RQ2	Pre-defined list	

3.3.2 Execution of the SLR

The detailed results (e.g., tables) of this step are presented in Appendix II.

3.3.3 Analyzing and presenting the results of the study

The results of this step are presented in Chapters 5 and 6.

CHAPTER 4

RESULTS OF THE SYSTEMATIC MAPPING STUDY

This chapter presents the results of the systematic mapping study presented earlier in Chapter 3. The answers of the mapping questions (MQ) are presented in sections 4.1 – 4.9, including labels of the primary studies (e.g., S1), followed by a discussion about the results of the SMS in section 4.10.

4.1 Answers to mapping questions (MQ1 & MQ2)

MQ1: The 23 primary studies have been published in 22 distinct publication sources, two in "Information Systems and e-Business Management," and the rest in 21 publication sources – see Annex III.

MQ2: Figure 4.1 shows one to two publications from 2004 to 2010, two to three from 2011 to the end of 2018. The trend line shows a slowly increasing publication pattern, but this is still a fairly low number of publications on EA measurement over a period of almost 15 years.

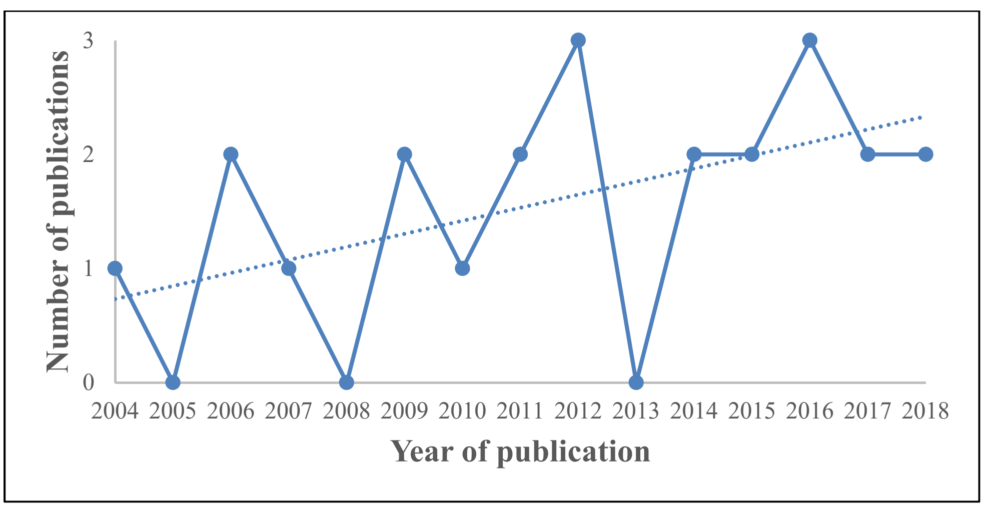

Figure 4.1 Number of publications over time (answers to MQ2)

4.2 Answers to mapping question (MQ3)

The objective of MQ3 was to investigate and discover which EA schools of thought have addressed EA measurement-related issues. Figure 4.2 shows that almost 74% of the EA measurement research is being addressed within the "enterprise IT architecting" school of thought, with much less within the other two EA schools of thought.

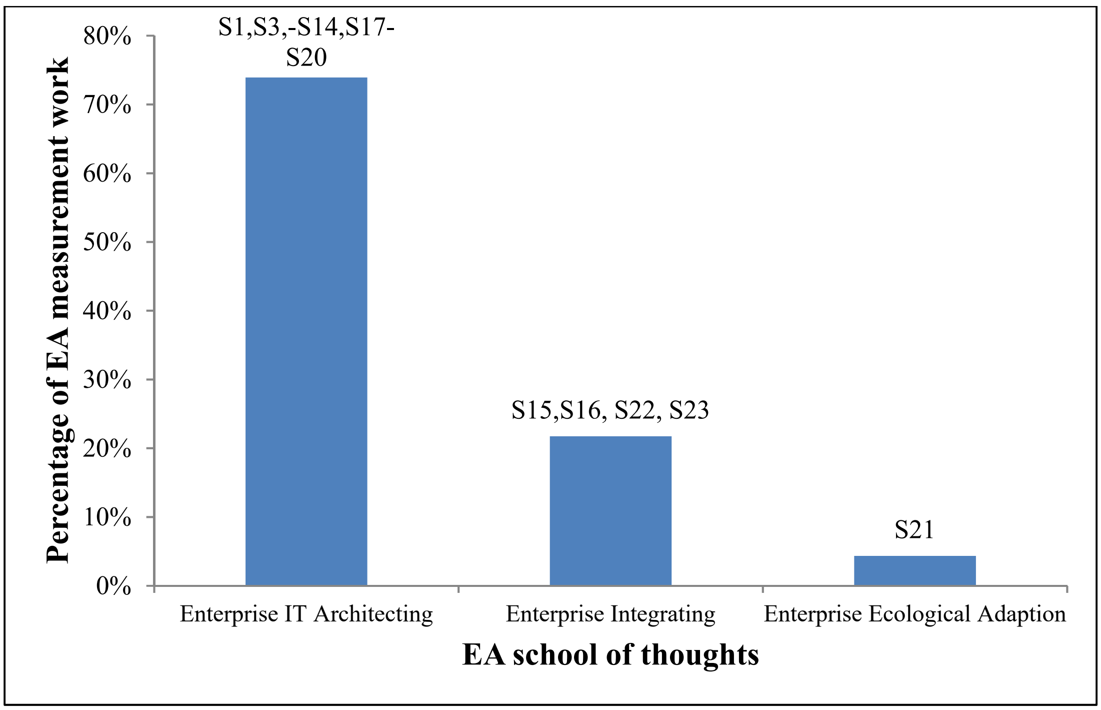

Figure 4.2 EA schools of thought (answers to MQ3)

4.3 Answers to mapping question (MQ4)

The objective of MQ4 was to investigate where within the EA project life cycle a proposed EA measurement solution can be used. Figure 4.3 shows that:

- 30% were used during the development phase, e.g., before spending costs and resources on EA.
- 26% support practitioners after implementing EA, e.g., EA use .

- 4% support EA in two phases: development and use.
- 5% in the implementation phase, and
- 30% of the primary studies did not take into account the EA life cycle when proposing an EA mesurement solution. These primary studies are tagged “NA” in Figure 4.3.

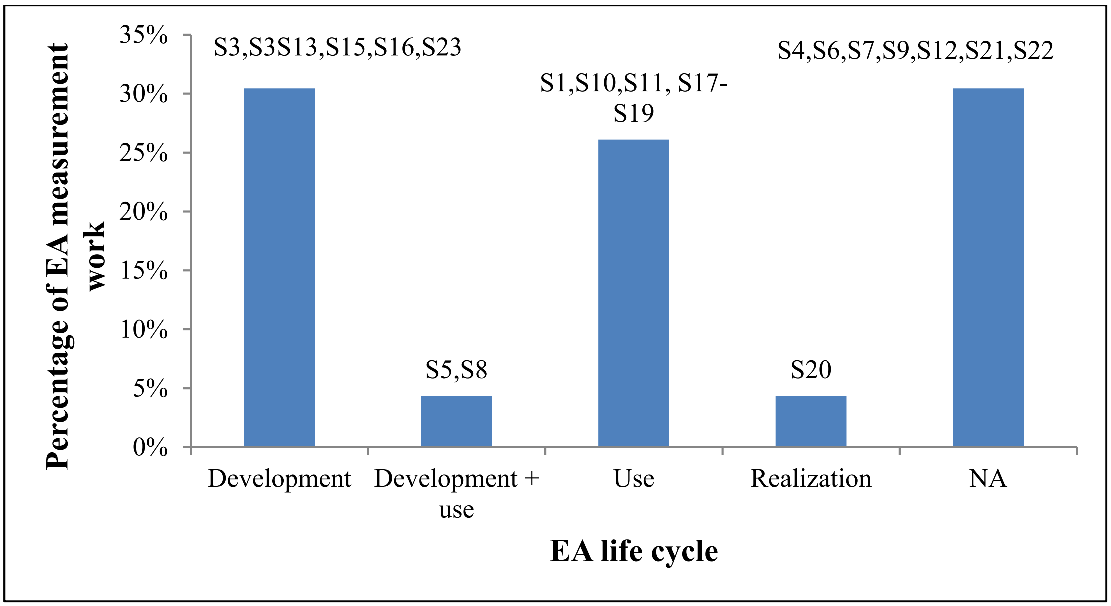

Figure 4.3 Targeted use of EA measurement solutions within EA project life cycle (answers to MQ4)

4.4 Answers to Mapping question (MQ5)

The objective of MQ5 was to investigate the research intentions that motivated researchers to propose EA measurement solutions. Figure 4.4 shows the distribution of the research intentions in the primary studies:

- 26% to facilitate organizational understanding of EA
- 17% to facilitate organizational decision-making ability in selecting EA initiatives
- 13% to assist organization in EA implementation
- 13% to assist organizations to manage EA spending and measure EA financial returns.

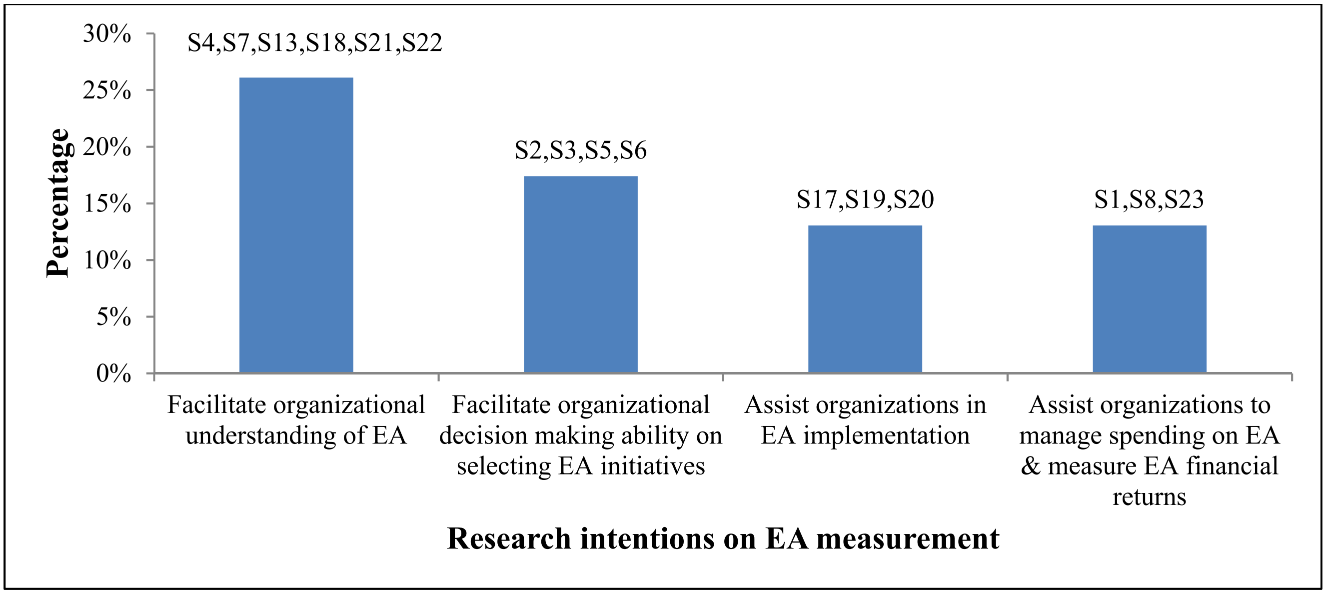

Figure 4.4 Intentions of EA measurement research (answers to MQ5)

4.5 Answers to Mapping question (MQ6)

The objective of MQ6 was to provide a classification scheme of the literature on EA measurement by identifying the research types used in EA measurement research. Figure 4.5 shows the distribution of the research types in these primary studies:

- 39% evaluation research
- 35% validation research
- 22% solution proposal", and
- 4% philosophical research".

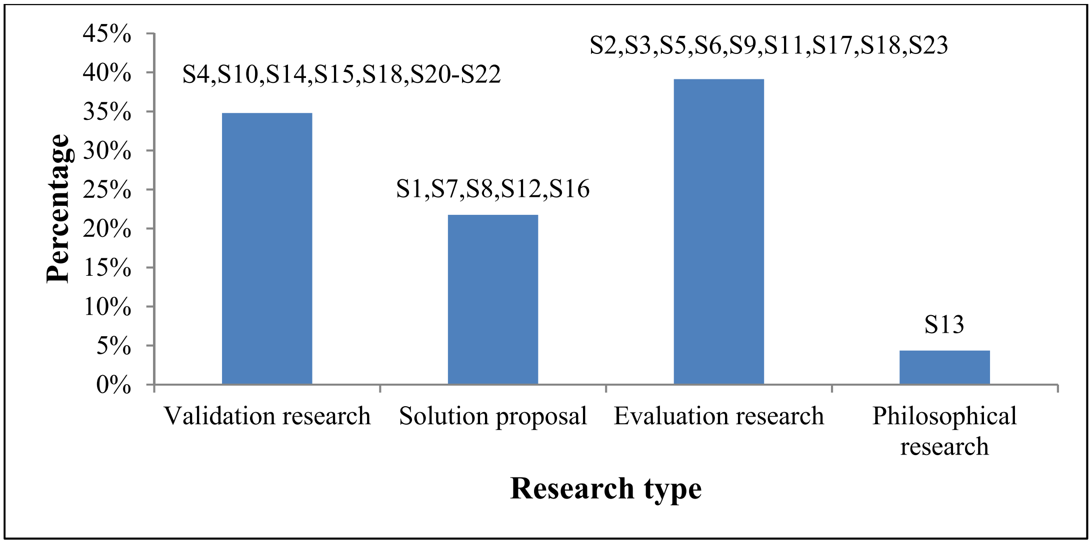

Figure 4.5 Research type distribution in the EA measurement literature (answers to MQ6)

4.6 Answers to Mapping question (MQ7)

The objective of MQ7 was to explore the techniques used to design or propose EA measurement solutions from other fields, including the EA field. Figure 4.6 shows that in these primary studies:

- The majority (e.g., 61%) refers to design and structure of the EA measurement solutions based on the knowledge in EA literature itself, and
- 39% refer to foundations from various fields, including the AHP method, a widely accepted decision-making technique.

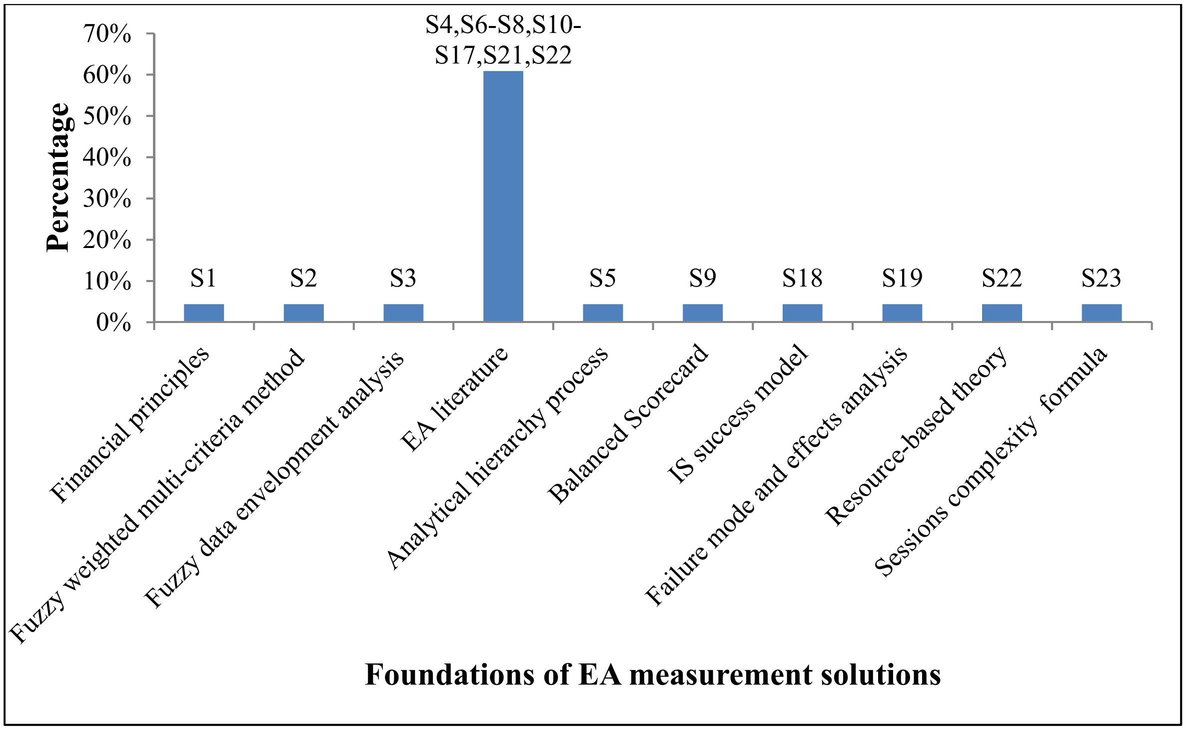

Figure 4.6 Foundations of EA measurement solutions (answers to MQ7)

4.7 Answers to Mapping question (MQ8)

The first objective of MQ8 was to investigate the terminology used to describe EA measurement solutions. Figure 4.7 indicates that:

- 52% of the primary studies used “model” to describe their measurement solution,
- 22% used “method”,
- 9% used “framework”,
- 9% used “approach”, and
- 9% did not use any terminology to describe their measurement solutions.

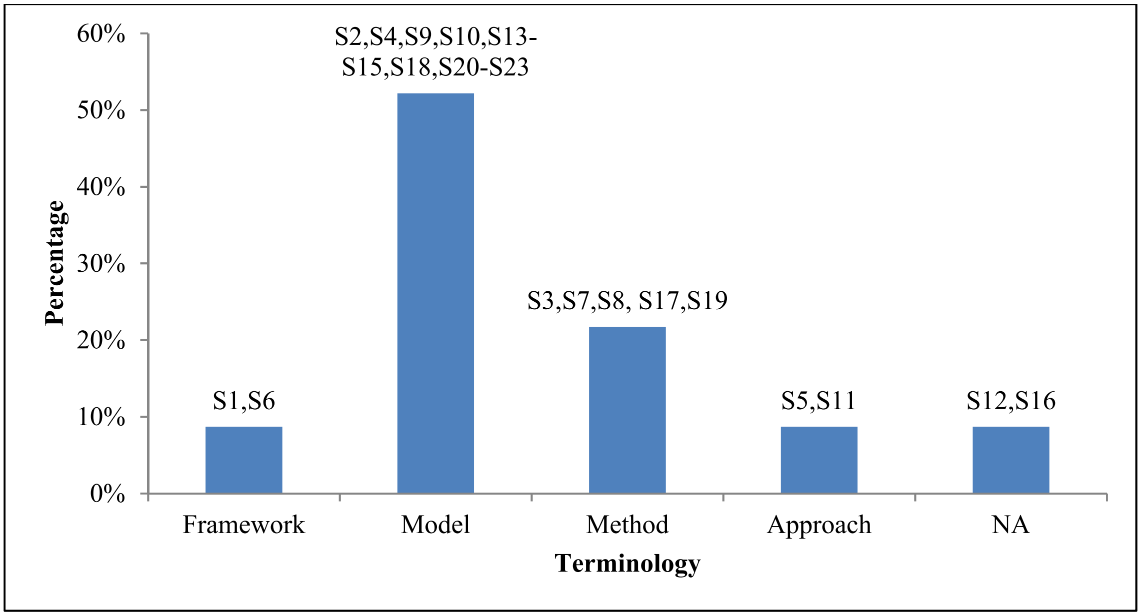

Figure 4.7 Terminology used to describe EA measurement solutions (answers to MQ8)

Having identified the terminology used to describe the EA measurement solutions, the second objective of MQ8 was to identify what measurement concepts were being measured, evaluated, analyzed, or assessed. To measure an attribute, the concept to be measured needs to be defined and characterized (Abran, 2010). Characterization is accomplished by identifying how the sub-concepts contribute to the concept to be measured (e.g., the size of the software code).

In MQ8, the objective was not to evaluate the EA literature with respect to metrology but only to identify, through the coding in the MQ8, which EA concepts and sub-concepts were being utilized in EA measurement research. Therefore, the EA measurement solutions presented in Figure 4.7 were analyzed and coded to find the EA concepts and sub-concepts of each EA measurement solution including the terminology used by the researchers themselves – see Figure 4.8. For example, in the center right-hand side of Figure 4.8, the proposed 'framework' solution attempts to measure the impact of EA, meaning that the concept to be measured was identified as "impact", and its sub-concept was identified as "ROI" – the return on investments.

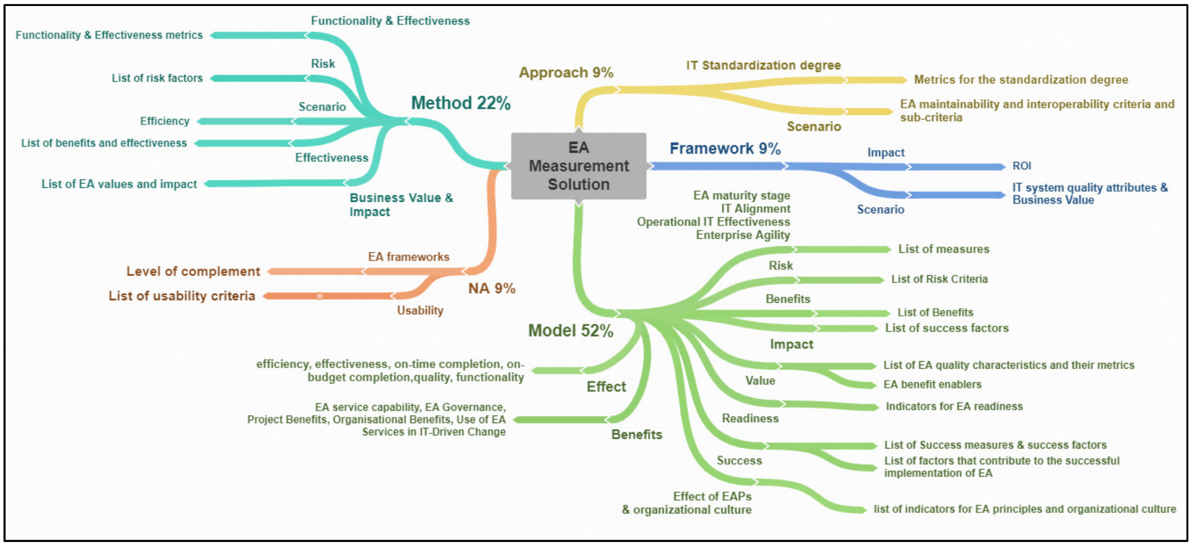

Figure 4.8 Concepts & sub-concepts for each EA measurement solution (answers to MQ8)

4.8 Answers to Mapping question (MQ9)

The objective of MQ9 was to recognize the most frequently used measurement-related semantics in the EA measurement literature. Figure 4.9 shows that in these primary studies:

- 70% fell into the category of measurement + other semantics. This category refers to the primary studies that use the term "measurement", and interchangeably mix it with other terms, such as evaluation, assessment, or analysis.
- 22% fell into the category of evaluation, assessment, or analysis semantics. This category refers to the primary studies that did not use the word "measurement" and instead referred to other terms, such as evaluation, assessment, or analysis.
- 9% fell into the category of measurement semantic. This category refers to the primary studies that did not interchangeably mix "measurement" with other terms, such as evaluation, assessment, or analysis.

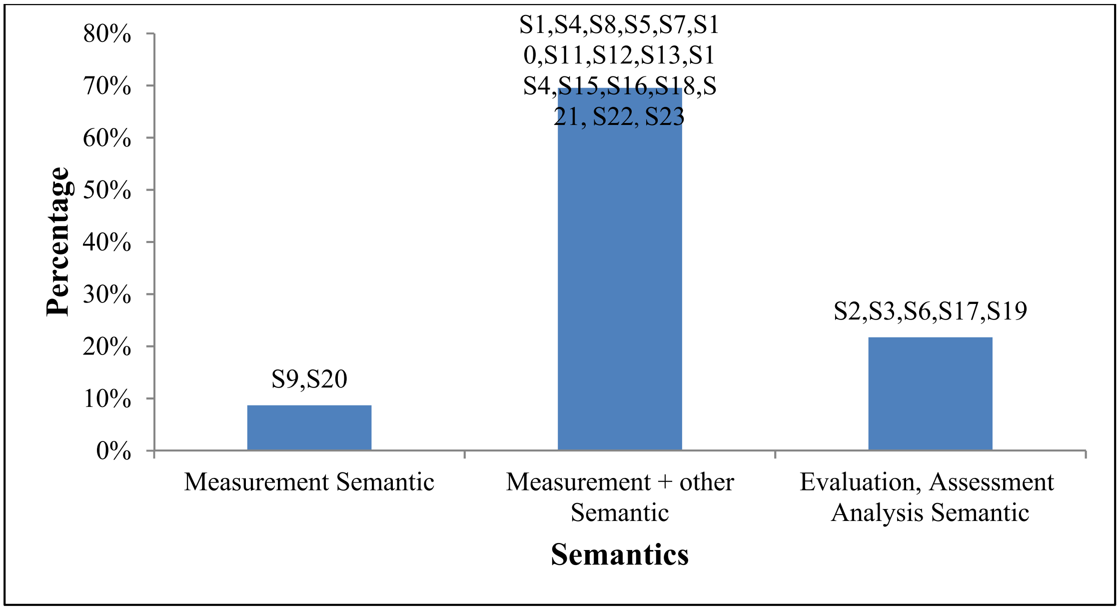

Figure 4.9 Measurement-related semantics and terms (answers to MQ9)

Next, the primary studies that fall under Measurement + using semantics (evaluation, assessment, or analysis) were analyzed to find term combinations. Figure 4.10 presents the distribution of all the possible combinations of terms extracted from this subset of primary studies. Each combination means that the primary studies interchangeably used the combination without a clear definition of each term, nor a differentiation between the distinct terms. For example:

- 28% of the primary studies interchangeably referred to "measurement & analysis."
- 22% of the primary studies interchangeably referred to "measurement & evaluation & assessment."

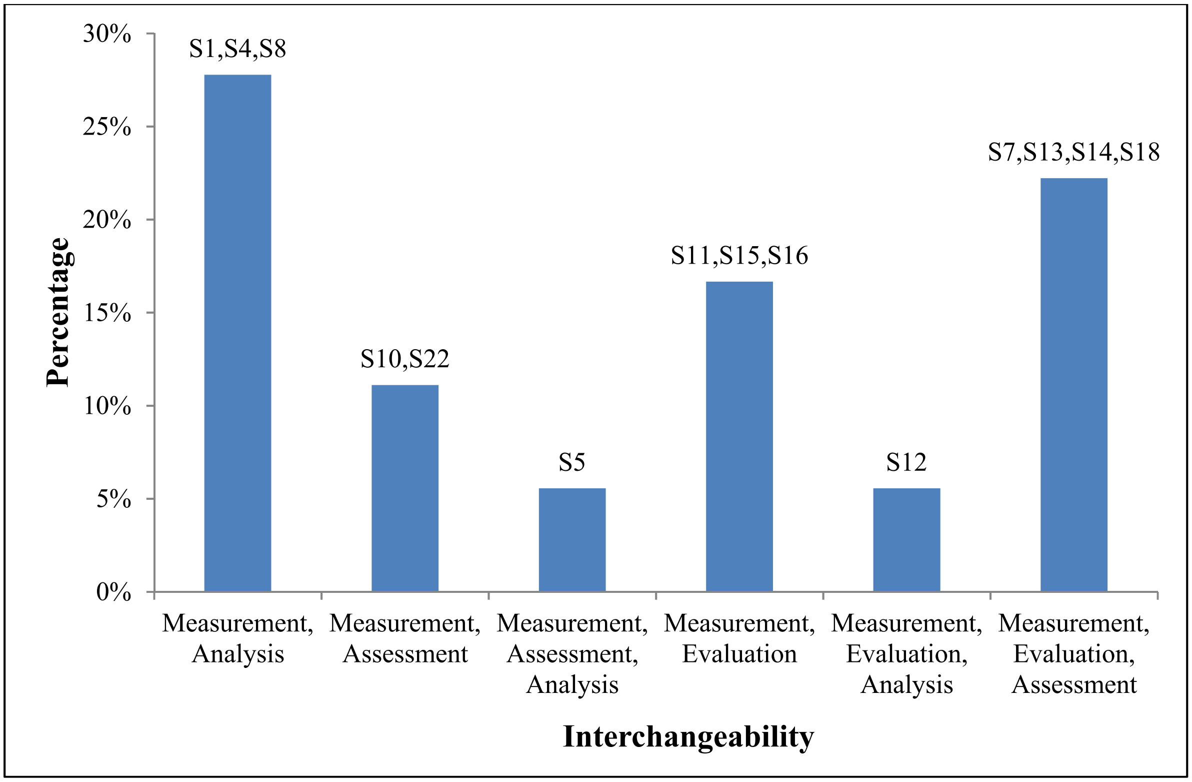

Figure 4.10 Term combinations within the‘measurement & related semantics’ category

4.9 Answers to Mapping question (MQ10)

The objective of MQ10 was to explore the presence of ISO 15939 within the text and references of the primary studies. The findings indicate that:

- ISO 15939 is not present in 95% of the primary studies. Consequently, these primary studies are classified as not utilizing ISO 15939 in their EA measurement design.
- Only one primary study [S7] mentioned ISO 15939 within the text. However, mentioning ISO 15939 in the text or references was not of sufficient detail to classify the primary study as utilizing ISO 15939 in its proposed EA measurement design.

4.10 Discussion on the SMS results

This section discusses the key findings from this SMS that may guide future improvements in EA measurement research.

The limited number of primary studies published in journals, as answers to MQ1 and MQ2, shows evidence that the research on EA measurement is still emerging. This could indicate either a lack of interest or a major research challenge in addressing EA measurement issues.

From the answers to MQ3, the “Enterprise IT Architecting” EA school of thought has by far published the largest majority of EA measurement solutions. According to (Lapalme, 2012), each EA school of thought has a different belief system (i.e. definitions, concerns, and assumptions) and a different vision which impacts on what the EA school of thought can deliver to the organization. Therefore, measuring “Enterprise IT Architecting” implies that measurement solutions were limited to the design of technological solutions, with a focus on assuring high quality models that include planning scenarios. Furthermore, the research on EA measurement has mostly been limited to providing information on how EA can assist aligning enterprise IT assests and business strategy execution. Since EA measurement contributions have mostly been limited to the IT aspects of EA, the state-of-the-art on EA measurement lacks an all inclusive perspective on EA measurement solutions. In fact, there is a scarcity of information on EA-related organizational efficiency and EA-related organizational innovation and sustainability. Thus, researchers need to look to design solutions to answer questions about how to measure enterprise ecological adaption and enterprise integration, the other major schools of thought in EA measurement.

From the answers to MQ4 it is observed that the majority of EA solutions were focused on the development and post implemention phases of EA projects. Given that EA comes at a large cost and requires considerable human and financial resources, EA measurement should support management throughout the EA project life cycle. Therefore, future research is needed to design innovative EA measurement solutions for all the distinct phases of the EA life cycle.

From the answers to MQ5, we observed that research intentions were diverse, each primary study individually proposing an EA measurement solution to support the organization from a distinct perspective and standpoint. For instance, the research intention of some primary studies was to attempt to explain how EA adds value to the organization, while other studies discussed how to facilitate organizational decision making to select the most valuable EA initiative. Furthermore, none of these research intentions were aiming to improve the design of EA measurement solutions, or to design measurement solutions based on recognized measurement theories and best practices.

From the answers to MQ6, the majority of the primary studies fell under evaluation research and validation research. In evaluation research, researchers attempt to evaluate the proposed EA measurement solutions and determine the impact and outcomes of these solutions on organizations. These outcomes can provide readers of these primary studies some insights about whether the research intentions and design of the EA measurement solution meets the intended objectives and benefits, including benefits to the organization. This contrast with the primary studies that fell under validation research. These measurement solutions have not yet been implemented in practice with an industry partner. Readers of these primary studies would not therefore gain insights about the benefits of these EA measurement solutions on the organization. Therefore, researchers are encouraged to design more evaluation research on EA measurement.

From the answers to MQ7, the majority (61% - Figure 4.6) of the primary studies did not adopt knowledge from disciplines other than the emerging EA literature itself to propose an EA measurement solution. In other words, the majority conducted a literature review on EA measurement, and proposed an EA measurement solution based on this limited scope. For instance, primary study [S10] proposed an EA measurement solution (model) on such concepts EA maturity stage, IT alignment, and operational IT effectiveness. On the other hand, (39% - Figure 4.6) of the primary studies adopted concepts and practices from other disciplines in EA measurement. For instance, primary study [S5] proposed an approach to measure EA scenarios based on an AHP (analytical hierarchy process) method – a widely accepted decision-making technique. This being said and given that EA measurement research is still emerging and only slowly increasing (see MQ2 findings of this study), adopting measurement best practices and guidelines from other disciplines, such as science or engineering, to EA measurement research is a key direction to develop not only innovative but also mature EA measurement solutions. In addition, addressing the limitations found in the EA measurement solutions proposed to date is another key priority.

From the answers to MQ8, the majority of the primary studies used the words "model" & "method" as terminologies to describe their measurement solutions. According to Abran (2010), the measurement context model describes three uses of the term "measurement": the design of the measurement method, the application of the measurement method, and the exploitation of the measurement results in quantitative or qualitative models. Furthermore, considering that measurement models and measurement methods are not the same (Abran, 2010), and based on the answers for MQ8, EA measurement models, methods and other EA measurement solutions should be analyzed and evaluated from a measurement and metrology perspective. This evaluation can lead to innovative and sound design of EA measurement solutions that meet measurement and metrology best practices (see Chapters 5-6 on this topic). Furthermore, based on the answers to MQ8, the terminologies used to describe EA measurement solutions were diverse and overlapping. For instance, different primary studies proposed an approach on EA scenario, a method on EA scenario, and a framework on EA scenario. However, it is not clear how these measurement solutions differ, and even whether the meaning of "scenario" among these different solutions is the same. Hence, future research avenues may provide designs of EA measurement solutions that adequately address terminology issues in EA measurement research.

From the findings for MQ9, the research on EA measurement has inconsistently used distinct measurement terms and semantics. For example, approximatly (70% - Figure 4.9) of the primary studies interchangeably used terms such as measurement, evaluation, assessment, and analysis. Since these terms refer to distinct concepts in measurement, this shows that the EA measurement literature lacks the terminology rigor that we find in engineering disciplines and science. EA measurement researchers should therefore adopt the measurement terminology used in mature fields.

From the answers to MQ10, ISO 15939 is present in almost none of the primary studies in the references list. This indicates that the primary studies may not be considering measurement best practices in their design of EA measurement solutions. Hence, another research avenue is improving the design of EA measurement solutions based on the large consensus of metrology terms and best practices.

4.11 Chapter summary

This chapter has reported on a systematic mapping study (SMS) of proposed EA measurement solutions. The study identified 23 relevant primary studies published in journals from 2004 to the end of 2018, which were read and analyzed according to the objectives of ten mapping questions (MQ1-MQ10). The 23 studies were explored from various perspectives including, but not limited to, positioning of the EA measurement solution within an EA project life cycle, analysis of consistency-inconsistency of the terms used by authors in EA measurement research, and an analysis of references to the ISO 15939 measurement information model.

The SMS also undertook a classification of the research area within the primary studies revealing significant gaps and limitations. For instance, the findings indicated a limited adoption of knowledge from other disciplines in proposing an EA measurement solution, and in addition, that current EA research lacks the terminology rigor that found in science and engineering.

CHAPTER 5

EVALUATION OF EA MEASUREMENT SOLUTIONS

The research objective in this chapter aims to evaluate the EA measurement proposals with respect to the measurement and metrology guidelines. The coding results of the SLR in Appendix II are used to perform the evaluation in this chapter. To achieve this objective, the EA measurement proposals are analyzed in detail, and a metrology coverage scoring is assigned to these proposals.

Section 5.1 presents the evaluation guidelines. Section 5.2 presents the evaluation of EA project measurement proposals. Section 5.3 presents next the evaluation of EA architecture measurement proposals. Section 5.4 presents next the evaluation of EA program measurement proposals. Section 5.5 presents next the evaluation of EA framework measurement proposals. Section 5.6 presents next an analysis of EA metrology coverage over time.

5.1 Evaluation guidelines and yardsticks

This section presents the guidelines (theoretical and empirical) to evaluate the EA measurement proposals, including the corresponding guidelines for the metrology coverage scores.

The metrology coverage evaluation guidelines for theoretical definitions are presented in Table 5.1 and the metrology coverage evaluation guidelines for empirical definitions are in Table 5.2.

The SLR coding results in Appendix II show that the EA measurement proposals are classified into different categories such as EA projects, EA frameworks, etc. Next, the EA measurement proposals of these categories are presented, and evaluated from a measurement and metrology perspective.

Table 5.1 Metrology coverage evaluation guidelines for theoretical definitions

Theoretical definition criteria (Yardstick)	**Metrology coverage score**
Define the concept (attribute)	If the concept (attribute) is explicitly defined, score = 1 If the concept is not explicitly defined, score = 0
De-compose the concept (attribute)	If the concept (attribute) is decomposed into sub-concepts, score = 1 If the concept (attribute) is not decomposed into sub-concepts, score = 0
Define the sub-concepts (attribute)	If the sub-concepts (sub-attribute) are explicitly defined, score = 1 If the sub-concepts concepts (sub-attribute) are not explicitly defined, score = 0
Identify intended use of measurement	If the intended use is explicitly defined, score = 1 If the intended use is not explicitly defined, score = 0

Table 5.2 Metrology coverage evaluation guidelines for empirical definitions

Empirical definition criteria (Yardstick)	**Metrology coverage score**
Identify Source of input	If the source of input is explicitly identified, score = 1 If the source of input is not explicitly identified, score = 0
Identify Type of input	If the type of input is explicitly identified, score = 1 If the type of input is not explicitly identified, score= 0
Identify Quantification rule	If the quantification rule is explicitly identified, score = 1 If the quantification rule is not explicitly identified, score = 0
Identify Math operations	If the math operations are explicitly identified, score = 1 If the math operations are not explicitly identified, score = 0
Identify Measurement unit	If the measurement unit is explicitly identified, score = 1 If the measurement unit is not explicitly identified, score = 0

5.2 EA as a project

This section groups some of the EA measurement proposals into the category of 'EA projects' when the authors consider EA as a project, and therefore focus on evaluating or measuring concepts within EA projects. Some of the primary studies under this category refer to EA projects through three stages: EA (As-Is), EA (To-Be), and EA transition to the desired architecture.

Other primary studies define the EA project as a set of stages: initiation, controlling, and sustainability of EA implementation. An EA project is like any project: it has a timeline and outputs to its environment. Therefore, primary studies on EA projects attempt to quantify different concepts related to EA projects, including anticipated benefits of EA projects on organizations.

5.2.1 Analysis of the theoretical definitions for EA project entities

This subsection analyzes the EA project measurement proposals. Figure 5.1 shows the type of entities that are considered in the attempt to quantify concepts in EA projects, such as EA approach, EA services, EA products, etc.

Figure 5.2 shows that close to 60% of the primary studies explicitly identified the EA project entities, and close to 40% did not.

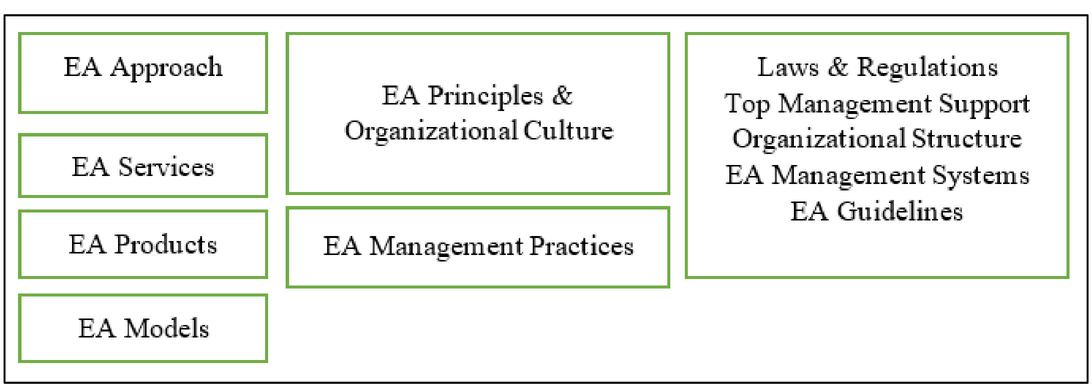

Figure 5.1 EA project entities

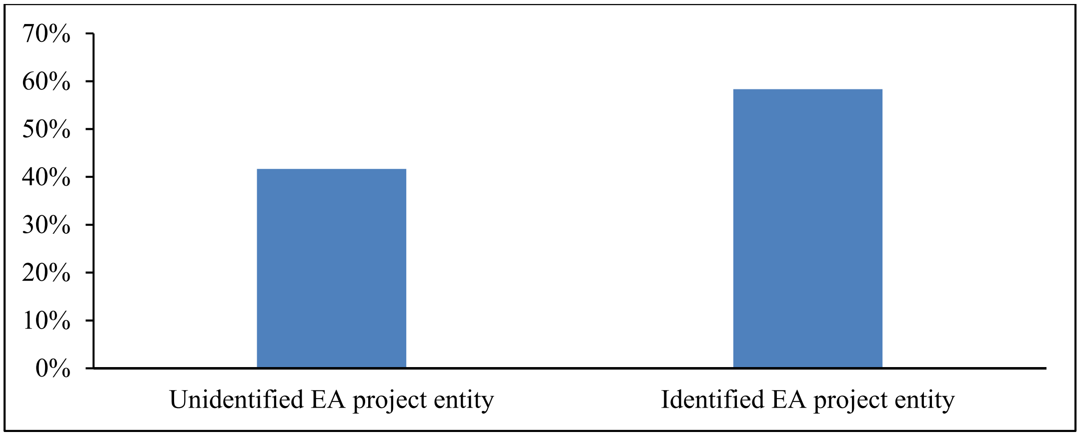

Figure 5.2 Distribution of the identification of EA project entities

These entities are analyzed next from two viewpoints: their theoretical definitions and their empirical definitions.

This sub-section presents an analysis of the primary studies to find out whether or not the primary studies identify and present a theoretical definition of the entities of concern.

For instance in [S4], to understand and investigate the benefits of EA projects, the **EA Approach** is identified as the EA project entity that may affect how EA yields organizational benefits. In [S4] an EA approach is defined as “the set of practices that the organization employs for working with EA and for having projects comply with architectural norms.” Furthermore, in [S4], an EA Approach consists of "practices such as compliance assessments, knowledge exchanges, and formal approval of EA and management support”. As an entity, **EA Approach** was further used to analyze the role of EA approach in organizations towards realising EA benefits (referred as EA Impact on Business Value).

[S22] takes the position that EA, as a collection of artifacts, will not deliver by itself benefits and value to organizations. However, **EA Services** being the high-quality information and advice given to decision makers is what matters. Therefore, the focus in [S22] is to analyze how EA advisory service lead to organizational benefits. This concept of **EA Services** is defined, and decomposed into sub-concepts in [S22].

In [S23], EA deliverables, and in particular the **EA models** (such as Target Architecture, Solution Architecture, Gap Analysis, and Road Map), are considered as the EA project entities in which their complexities are being measured during the design stage of EA. Furthermore, definitions of each EA project entity are provided. For instance:

- Target Architecture is defined as the "description of a future state of the architecture being developed for an organisation",
- Solution Architecture is defined as the "architecture which describes how information systems (IS)/IT support a business, discrete and focused business operation or activity."

Another kind of EA entities **EA principles & organization culture** are identified in [S15] as the EA project entity. **EA principles (EAPs)** are artifacts part of the EA project proposal. EAP according to [S15] is defined to be rules or restrictions in the design of EA projects guiding an EA design and its evolution from the as-is state to the to-be state. In the attempt to understand the role of EAP in the organizational culture, [S15] is proposing these entities, and identifying related concepts to perform this analysis:

- **EA principles** are decomposed further, and
- **organization culture** is decomposed into sub-concepts such as Group culture, and Development culture

To understand the factors that affect the successful implementation of EA projects, [S20] introduces other kinds of EA entities: **Laws & Regulations, Top Management Support, EA Management Systems, EA Guidelines, and Organizational Structure**. These entities are considered factors that affect EA performance, and therefore, defined and quantified.

Since EA projects produce deliverables to its environment, **EA products** of EA implementation are theoretically defined in [S17], and decomposed into the following sub-concepts: **Architecture vision, Architecture design, Migration plan, Governance plan,**

and Continual improvement plan as the EA project entities when measuring the EA implementation practices for the three (3) EA project stages: design, management (development), and maintenance. **EA products** are later evaluated in terms of functionality and effectiveness.

The **EA Management (EAM) Practices** conducted within EA projects is another kind of EA project-related entities claimed to affect the organizational benefits gained from EA. The outcome of these management practices is theoretically defined and further broken down in [S18] into:

- EAM products,
- EAM infrastructure, and
- EAM services.

Figure 5.3 illustrates these EA project entities, and the decomposition of these concepts to more granular levels. For instance:

- The organizational culture is decomposed into different kinds of cultures such as development and group cultures.
- EA models are also decomposed into different kinds such as the target architecture and the solution architecture

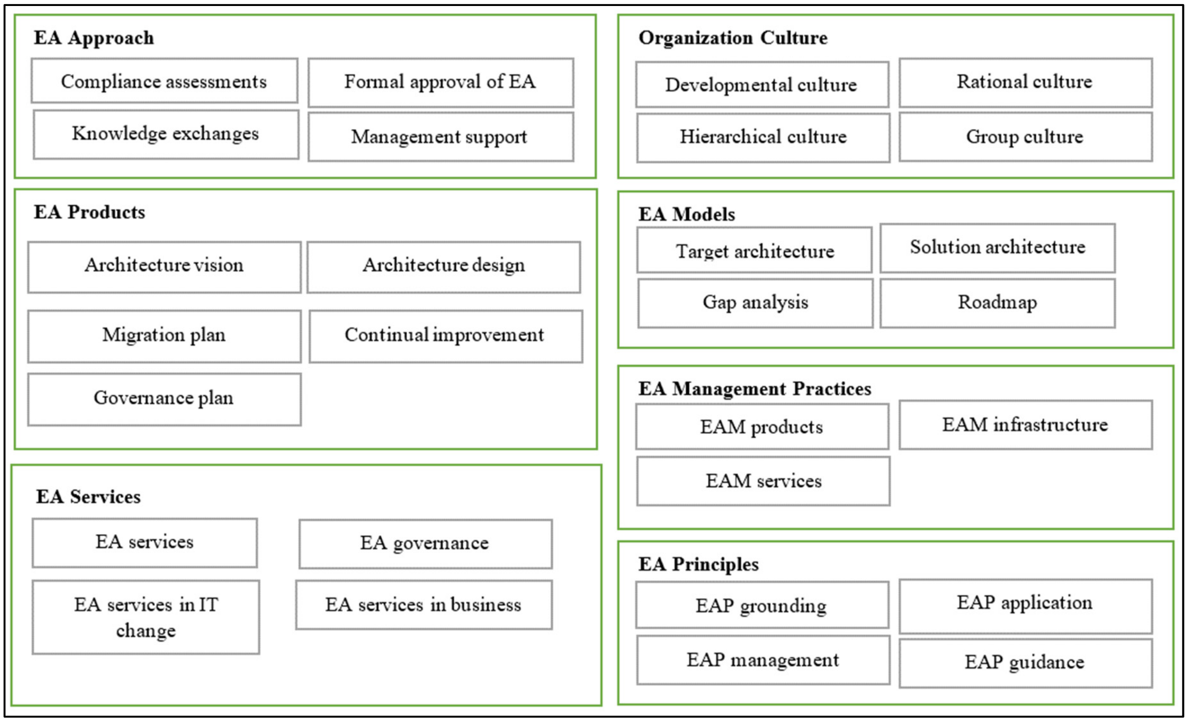

Figure 5.3 Characterization of EA project entities

Next, for an adequate measurement design within the measurement context model, concept characterization is necessary: that is, EA concepts need to be defined, and decomposed so that it is determined what exactly is being measured. Therefore, the EA project entities in Figure 5.3 are analyzed using the following criteria:

1. **Define the concept**: are the measured or quantified concepts defined in the primary study?
2. **De-compose the concept**: are the measured or quantified concepts decomposed to a granular level, which will allow quantification?
3. **Define the sub-concepts**: are the measured or quantified sub-concepts defined within the primary study?
4. **Identify intended use of measurement.**

To evaluate the metrology coverage of the primary studies in terms of the theoretical definition criteria, Table 5.1 presented our selected guidelines for the evaluation and the scoring for each criterion.

The metrology coverage evaluation of the theoretical definitions of EA project entities is divided into the following groups:

1. Overall metrology coverage evaluation to explore an abstract overview of the coverage scoring of EA project entities. The evaluation is presented in Figure 5.4. The results of this evaluation reveal that:
    - 77% of the theoretical definitions criterium is satisfied, indicating a high coverage scoring of theoretical definitions of EA project entities.
    - 23% of the theoretical definitions criterium is not satisfied, indicating that there are weaknesses that require more in-depth research – See Figure 5.5.

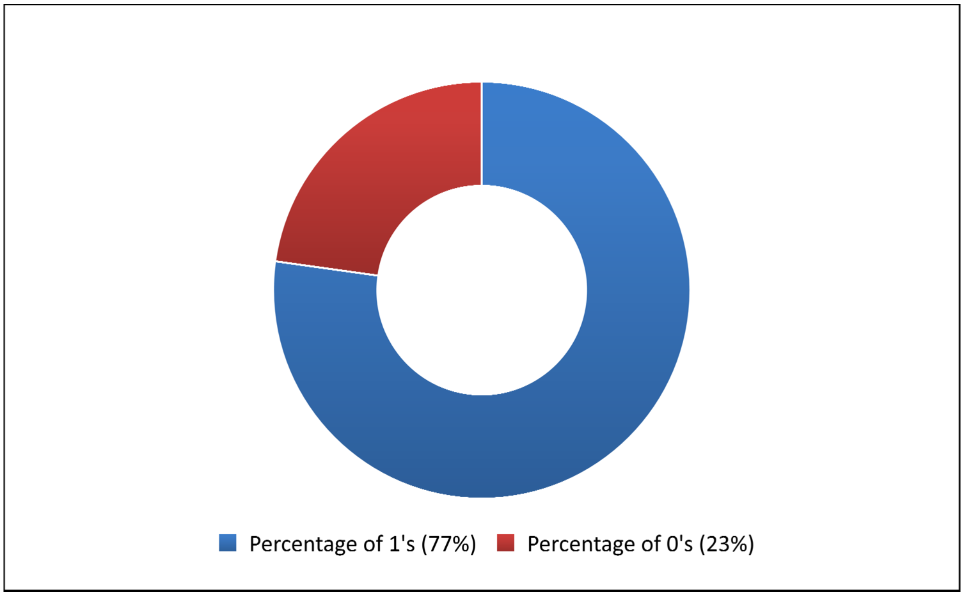

Figure 5.4 Average metrology coverage scoring for the theoretical definition – EA project entities

2. Detailed metrology coverage evaluation of the theoretical definitions for each metrology criteria. Figure 5.5 presents the coverage evaluation of the theoretical definitions of EA project entities:
   - All the EA project entities are theoretically defined,
   - Intended use of measurement results are identified,
   - more than 60% are decomposed into sub-concepts, and
   - Only 40% are theoretically defining the sub-concepts.

   The overall result indicates that the deeper in theoretical definitions, the more theoretical deficiencies. For instance, the absence of definitions of sub-concepts is a major weakness in the design of measurement methods of these EA project related entities.

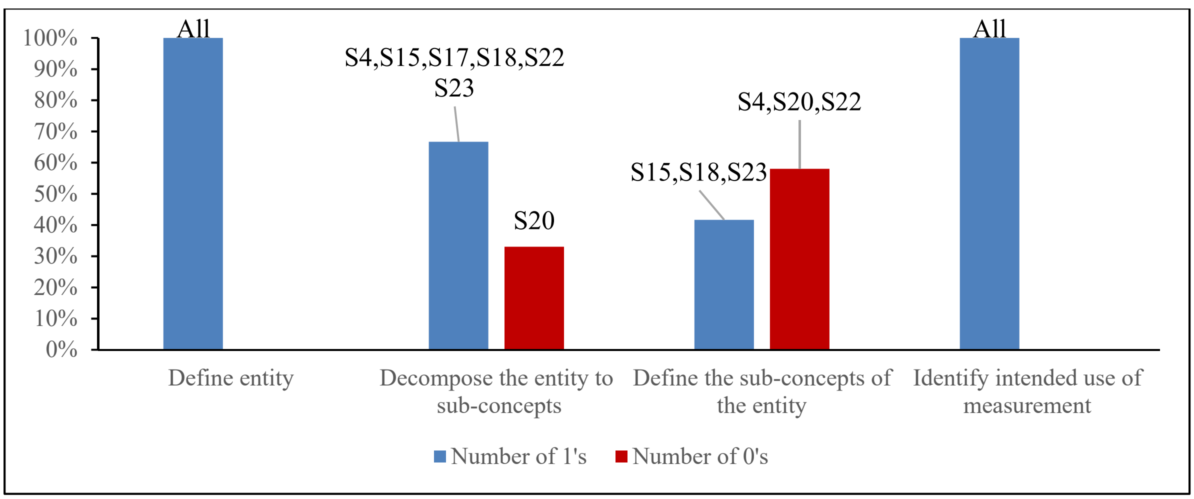

Figure 5.5 Evaluation of EA projects entities per theoretical definition

Furthermore, the results indicate that not all the primary studies are on the same level of metrology coverage scoring. For the primary studies that defined an EA project entity type, the metrology coverage-scoring index in Appendix III illustrates that the coverage scoring varies per primary study. For instance, [S4], [S20], and [S22] primary studies have the lowest number (e.g., 50%) of quality criteria met relating to the theoretical definitions defined earlier.

5.2.2 Analysis of the empirical definitions for EA project entities

This sub-section presents the analysis of the empirical definitions of the EA project entities. According to the measurement context model, empirical definitions include the following criteria:

1. **Source of input**: is the point of view (perspective) of quantification identified? Examples of these criteria can be EA architects who are involved in data collection about a given EA project entity.
2. **Type of input**: is the data input (subjective or objective) determined? For instance, if the EA architects are involved to fill questionnaires about their opinion of the EA project entity, then this is a subjective input to quantification.
3. **Quantification rule:** are the rules on how to quantity the EA project entity and its concepts identified? Example of a quantification rule can be using an ordinal scale, such as Likert scale, to express opinions.
4. **Math operations:** according to the measurement context model, is there any mathematical operation performed on the collected input data prior to its use in analysis models?
5. **Measurement unit:** according to the measurement context model, is there a standard measurement unit used when quantifying the EA project entity?

The metrology coverage evaluation of the empirical definitions of EA project entities presented next, is divided into the following levels:

1. Overall coverage evaluation to explore an abstract overview of coverage scores of EA project entities. The evaluation results are presented in Figure 5.6 and reveals that:

- 57% of the empirical definitions criteria are satisfied, indicating a modest coverage score of empirical definitions of EA project entities;
- 43% of the empirical definitions criteria are not satisfied, indicating the presence of weaknesses in the empirical definitions of EA project entities.

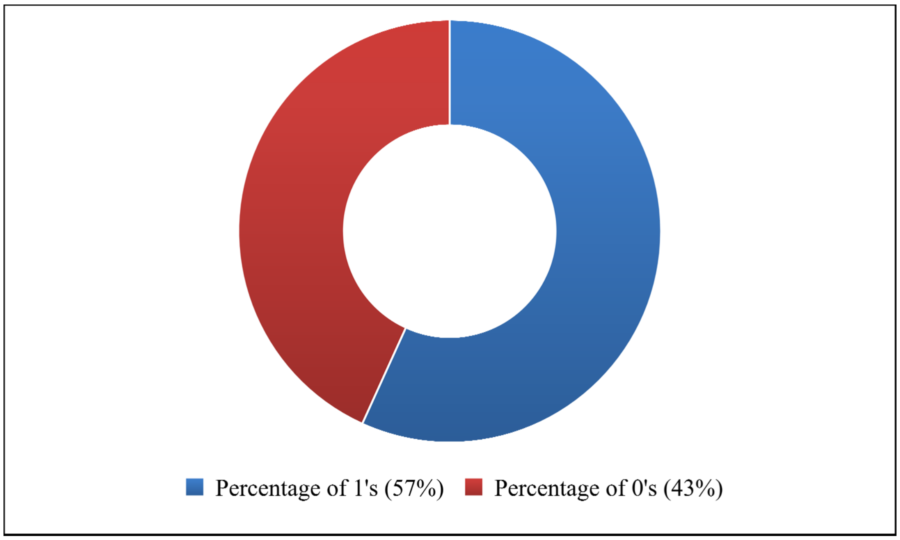

Figure 5.6 Average metrology coverage scoring for the empirical definition – EA project entities

2. Detailed metrology coverage evaluation of the empirical definitions for each metrology criteria. The results of this metrology coverage evaluation are presented in Figure 5.7 where the results show the strength and weaknesses for each metrology criteria. For instance, the metrology coverage scoring of the first three (3) metrology criteria (i.e. identify source of input, etc.) is relatively high. On the rightmost side, weaknesses are presented in the lack of identifying standard measurement units during the quantification process of the concepts, which is a mandatory criterion for a robust measurement activity.

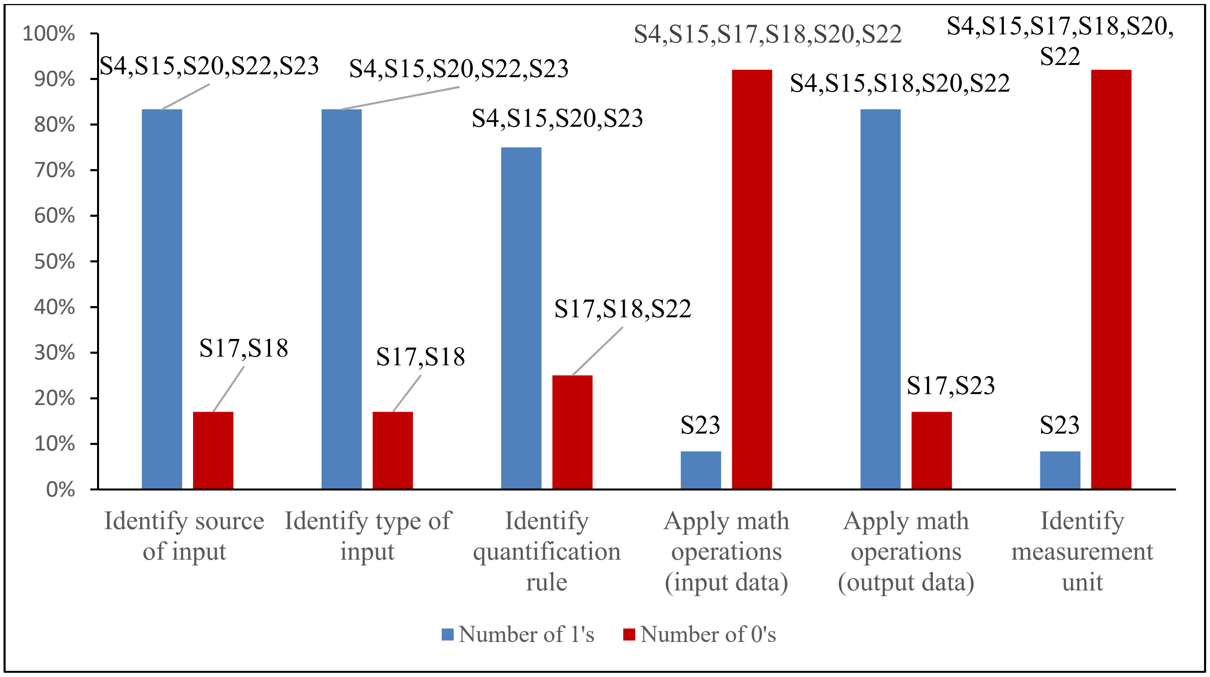

Figure 5.7 Evaluation of EA projects entities per empirical definition

5.2.3 Comparison between the coverage scoring of the theoretical and empirical definitions for EA project entities

Figures 5.5 and 5.7 illustrated the coverage scoring of the theoretical and empirical definitions using metrology criteria, allowing to identify some deficiencies in both theoretical and empirical definitions alike. Figure 5.8 presents next an aggregated view and a comparison between the coverage scoring of both theoretical and empirical definitions for each EA entity. The following results are observed:

- The coverage scoring of the empirical definition of (Laws & relations, Top management support, etc.) is higher than its coverage scoring of their theoretical definition, and
- The coverage scoring of the empirical definition for the rest of the EA project entities is always lower than the coverage scoring of their theoretical definition.

In order to present the overall coverage scoring of EA project entities, Figure 5.9 presents a comparison between the coverage scoring of theoretical and empirical definitions based on the median coverage scoring. The overall result indicates that the coverage scoring of the theoretical definition criteria is higher by 9% than the coverage scoring of the empirical definition criteria. Hence, this highlights that there is more work needed to improve the empirical definition criteria in EA project entities quantification.

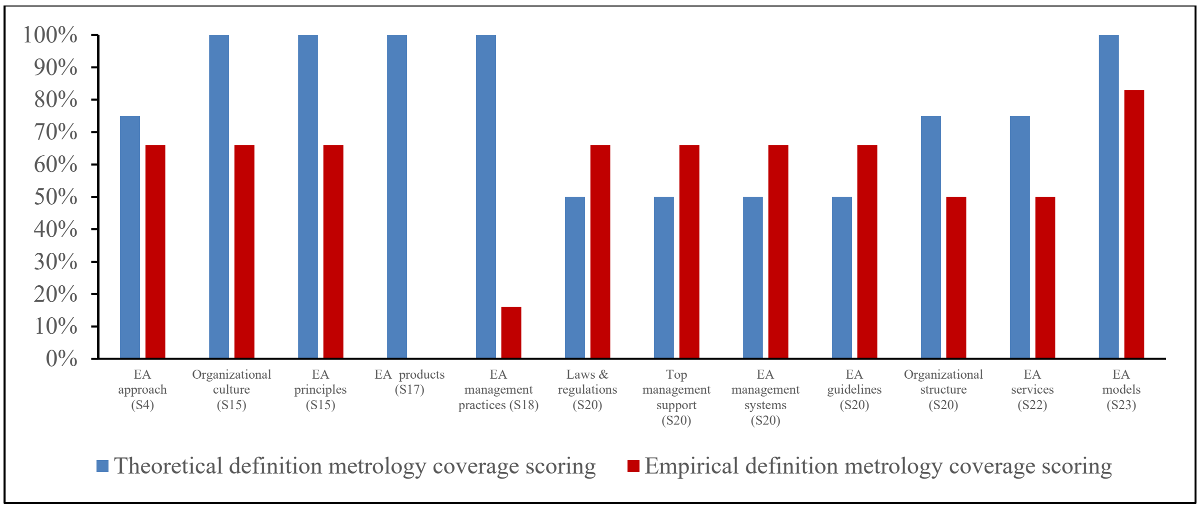

Figure 5.8 Theoretical vs. empirical definitions per EA project entity

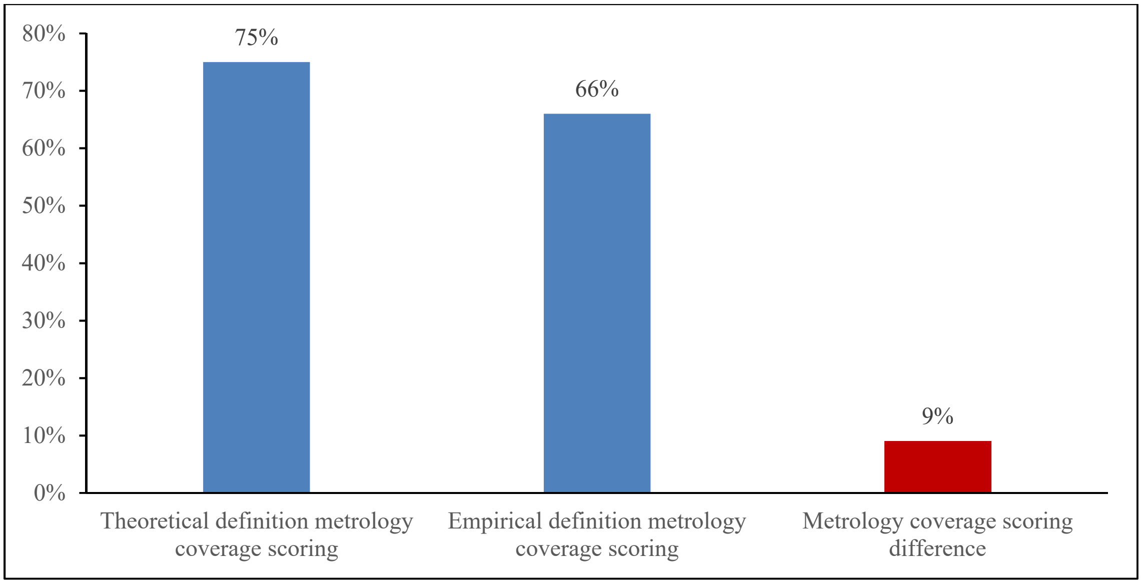

Figure 5.9 Overall comparison between theoretical & empirical definitions – EA project entities

5.2.4 Analysis of the theoretical definitions for EA project attributes

In this section, we analyze the primary studies on EA project entities and identify the EA attributes that are being quantified, or contributed in the quantification process, to quantify the relationships between EA entities and EA attributes. Figure 5.10 shows this classification: the column on the left hand side presents EA project entities and their sub-concepts, and the right hand side presents the corresponding EA attributes and their sub-attributes.

According to the measurement context model, concept characterization is one of the most important steps in designing a measurement method. The concept (e.g., attribute) needs to be theoretically defined and decomposed next into sub-attributes. Widely accepted theoretical definitions will allow measured attributes to be compared. For instance, two vehicles can be compared based on measuring how fast each vehicle is through measuring the speed. Speed, being the distance traveled per unit of time, has its roots, and widely accepted definition in physics.

Furthermore, attribute decomposition will describe the role of each sub-attribute and its role in creating the main attribute. Having said this, and after identifying EA project entities, and the corresponding attributes, this sub-section presents an analysis of the attributes according to the following characterization criteria:

1. **Define the attribute**: are the measured or quantified attributes defined within the primary study?
2. **Decompose the attribute**: are the measured or quantified attributes decomposed to a granular level which will allow it to be quantified?
3. **Define the sub-attributes**: are the measured or quantified sub-attributes defined within the primary study?
4. **Identify intended use of measurement results**.

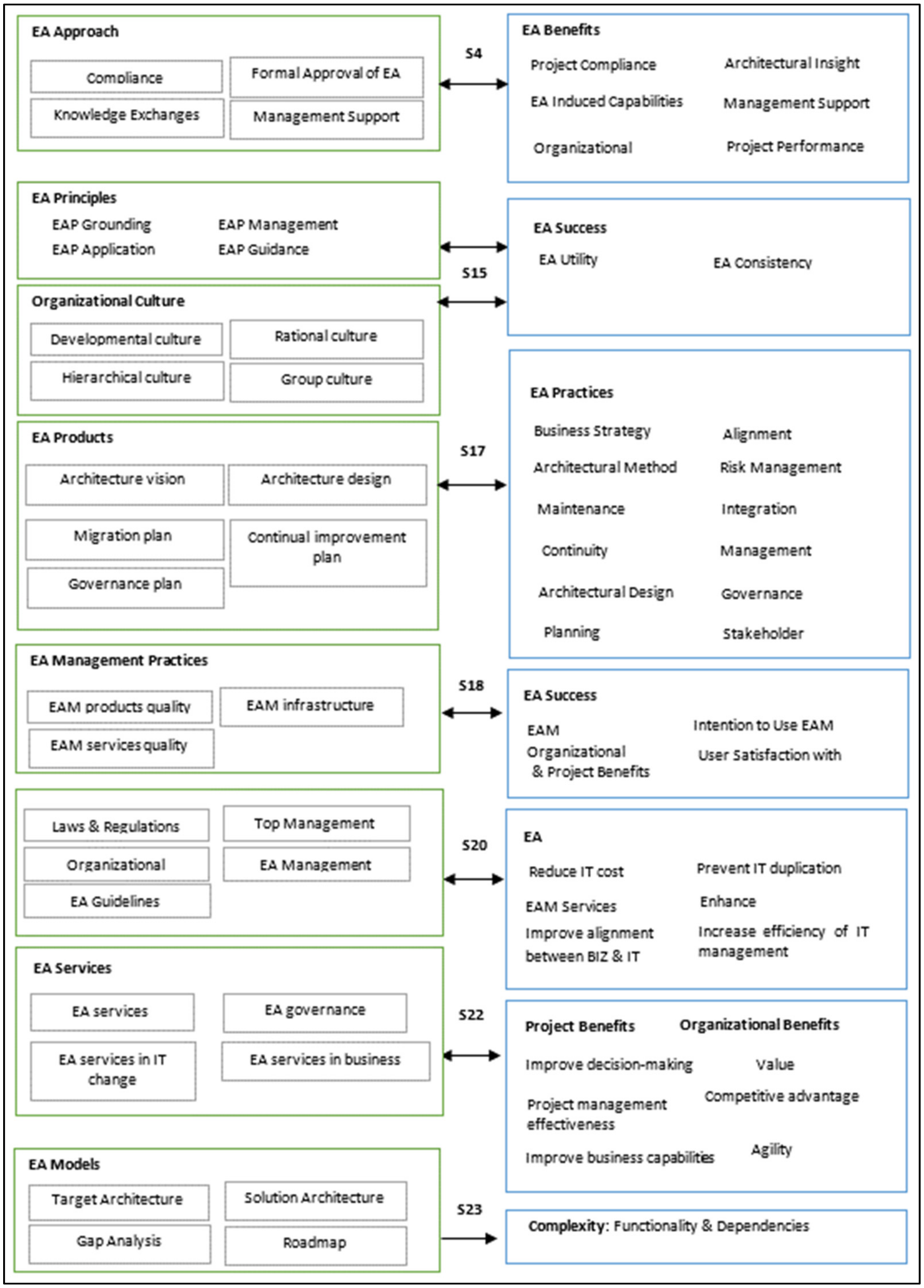

Figure 5.10 Characterization of EA project entities and their corresponding EA attributes

The metrology coverage evaluation of the theoretical definitions of EA project attributes is divided into the following groups:

1. Overall metrology coverage evaluation to explore an abstract overview of the coverage scoring of EA project attributes. The evaluation results are presented in Figure 5.11 and shows that:
    - 88% of the theoretical definitions criteria is satisfied, indicating a high coverage scoring of theoretical definitions of EA project attributes,
    - Only 12% of the theoretical definitions criteria is not satisfied.

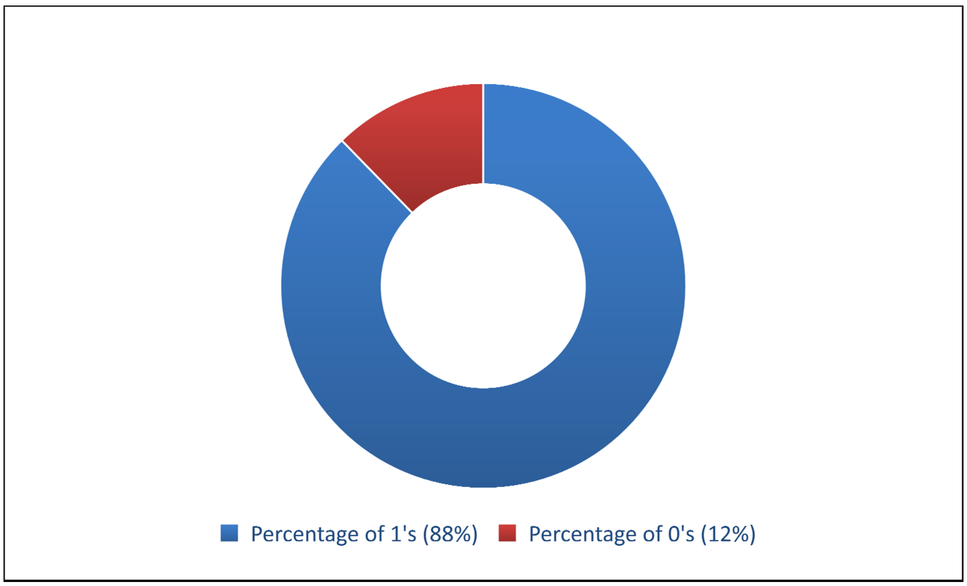

Figure 5.11 Average metrology coverage scoring for the theoretical definition – EA project attributes

2. Detailed metrology coverage evaluation of the theoretical definitions for each metrology criteria.

   The results of the metrology coverage scoring evaluation for the EA attribute theoretical definition are illustrated in Figure 5.12:
    - The majority (more than 80%) of the EA project attributes are defined in the text of the primary studies.
    - All primary studies decompose the main attribute into sub-attributes.

- 60% of the sub-attributes are defined, indicating a 40% deficiency, which is a major issue in metrology.
- All primary studies identify the intended use of measurement results.

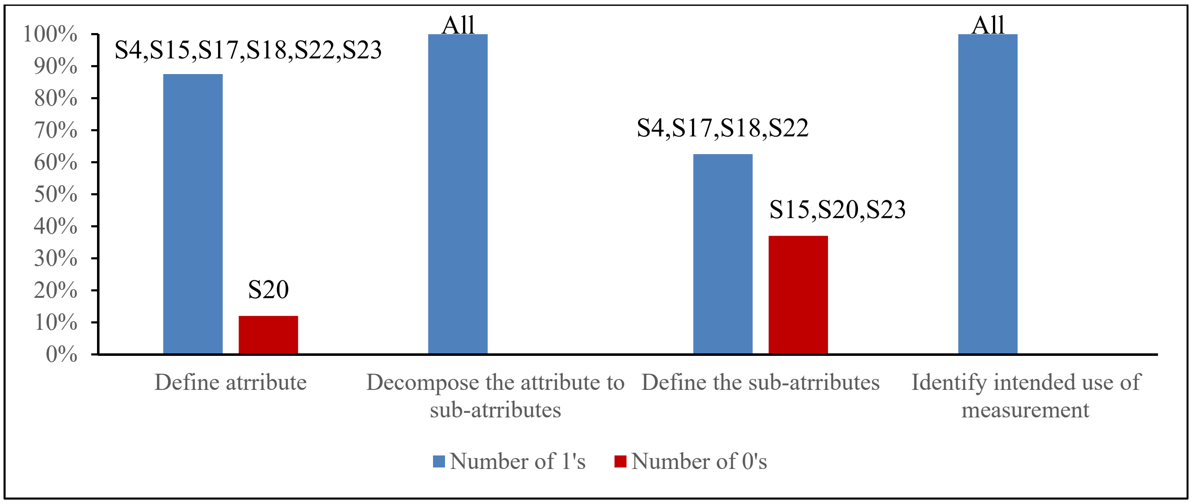

Figure 5.12 Evaluation of EA projects attributes per theoretical definition

Furthermore, these results indicate that not all the primary studies are on the same level of metrology coverage scoring. For instance, Appendix III illustrates that [S15, S20, and S23] lack to define theoretically the EA attributes according to the criteria of the measurement context model.

5.2.5 Analysis of the empirical definitions for EA project attributes

This section seeks to answer the questions of the empirical definitions of the EA project attributes (Source of input, Type of input, Quantification rule, Math operations, and Measurement unit). The metrology coverage evaluation of the empirical definitions of EA project entities is divided into the following levels:

1. Overall metrology coverage evaluation to explore an abstract overview of coverage scoring of EA project entities. The evaluation are presented in Figure 5.13 and reveals that following:

- 50% of the empirical definitions criteria is satisfied, indicating a modest score of empirical definitions of EA project attributes,
- 50% of the empirical definitions criteria are not satisfied, indicating some serious weaknesses in the empirical definitions of EA project attributes.

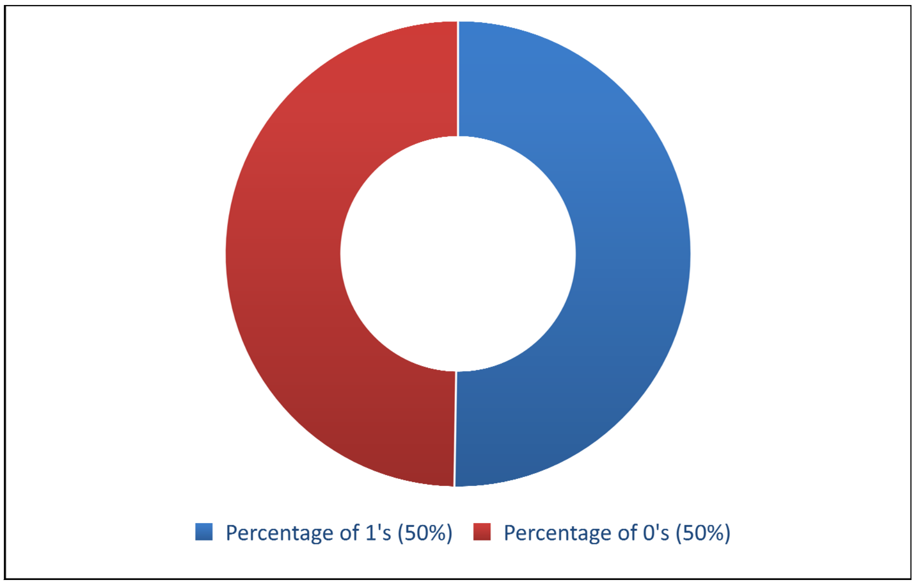

Figure 5.13 Average metrology coverage scoring for the empirical definition of EA project attributes

2. Detailed metrology coverage evaluation of the empirical definitions for each metrology criteria. Figure 5.14 illustrates the results of this coverage evaluation:
    - With respect to the source and type of input, the majority of primary studies meet these criteria.
    - However, there are clear weaknesses related to the identification of measurement units, and applying mathematical operations on the quantified input data.
    - Mathematical operations are more applied on output data.

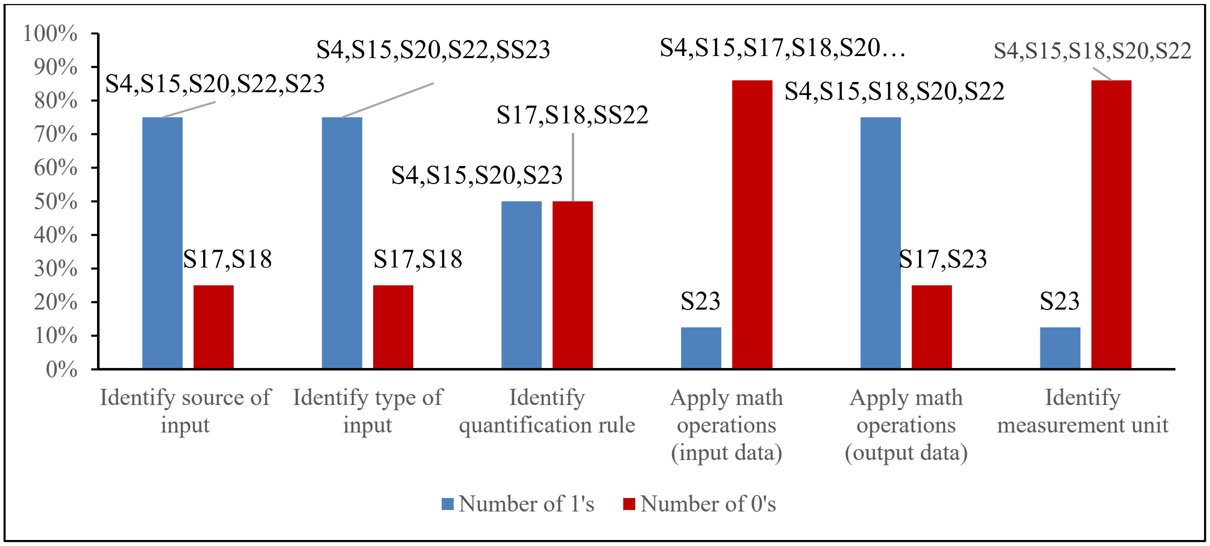

Figure 5.14 Evaluation of EA projects attributes per empirical definition

5.2.6 Comparison between the metrology coverage scoring of the theoretical and empirical definitions of EA project attributes

Figure 5.15 illustrates the aggregated scoring and a comparison of the coverage scoring between both the theoretical and empirical definitions for each EA attribute. For instance:

- The coverage scoring of the empirical definitions of EA performance and complexity is higher than coverage scoring of the theoretical definitions of the same EA project attributes, and
- The rest of the EA project attributes have a higher coverage scoring for the theoretical definitions than the empirical definitions.

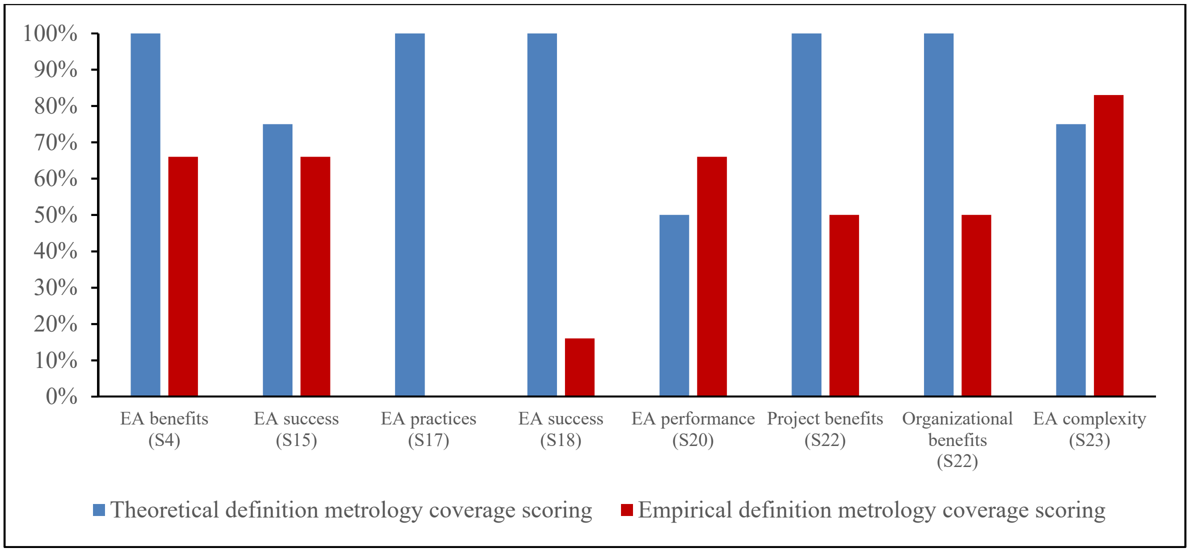

Figure 5.15 Theoretical vs. empirical definitions per EA project attribute

In order to present an overall coverage scoring of EA project attributes, Figure 5.16 shows a comparison between the coverage scoring of theoretical and empirical definitions based on the median coverage scoring. The overall results indicate that the coverage scoring of the theoretical definition criteria overweight the coverage scoring of the empirical definition criteria by 42%. Hence, this shows that there is more work needed to improve the empirical definition criteria in EA project attribute quantification.

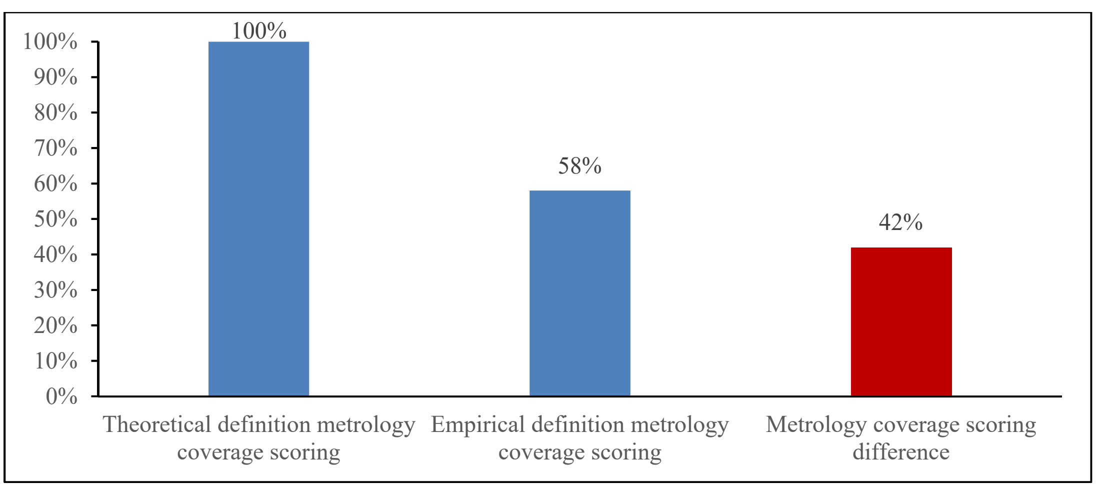

Figure 5.16 Overall comparison between theoretical & empirical definitions – EA project attributes

5.2.7 Primary studies with undefined EA project entities

Not all primary studies on EA projects identify the entity type. Figure 5.2 showed that around 40% of the primary studies on EA projects fail to identify an entity type. Instead, these primary studies discuss EA project attributes and sub-attributes, and attempt to quantify them without any explanation of the related entity type – see Figure 5.17. This sub-section elaborates more on the evaluation of these primary studies in terms of the measurement context model, i.e. based on the criteria of the theoretical and empirical definitions discussed earlier for the EA attributes.

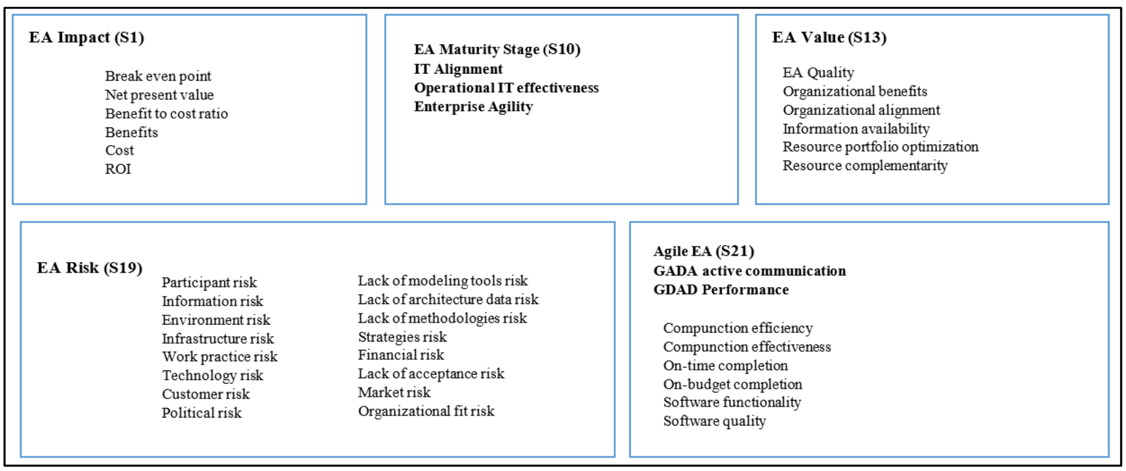

Figure 5.17 Characterization of EA project attributes (undefined EA project entity)

The metrology coverage evaluation of the theoretical definitions of EA project attributes (undefined entity type) is divided into the following levels:

1. Overall metrology coverage evaluation to explore an abstract overview of the coverage scoring of EA project attributes. The evaluation results are presented in Figure 5.18 and reveals that:
   - 75% of the theoretical definitions criteria is satisfied, indicating a high score of theoretical definitions of EA project attributes, and

- 25% of the theoretical definitions criteria are not satisfied, indicating a relatively low coverage scoring characterized with weaknesses.

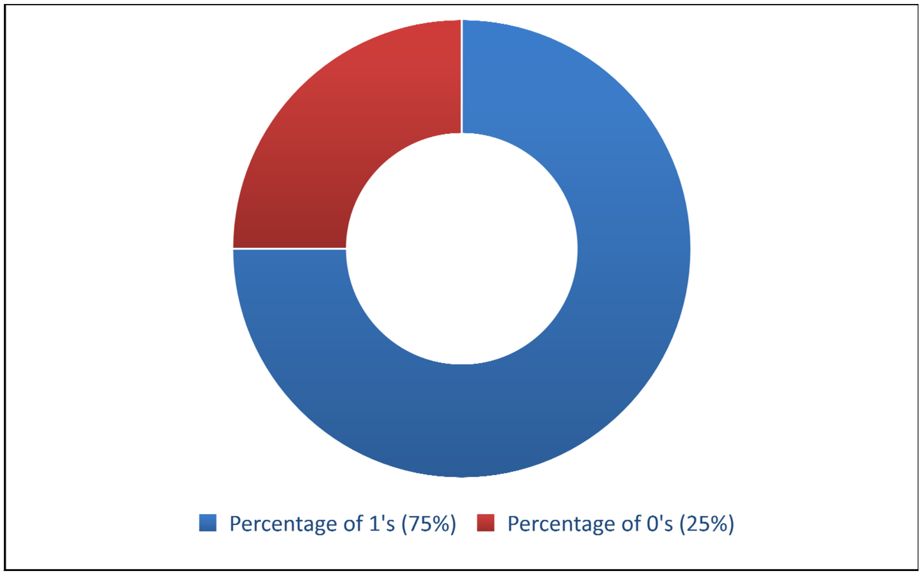

Figure 5.18 Average metrology coverage scoring for the theoretical definition of EA project attributes (undefined EA project entity)

2. Detailed metrology coverage evaluation of the theoretical definitions for each metrology criteria. Figure 5.19 illustrates the results of this metrology coverage evaluation of the theoretical definitions of EA attributes. The results indicate that the number of 1’s (e.g., meeting the criteria) outnumbers the number of 0’s (not meeting the criteria).
   - The majority (90%) of the EA project attributes are defined in the text of the primary studies,
   - The majority (90%) identify the intended use of measurement results, and
   - Overall, less than 40% of the issues are found in dealing with the decomposition and defining the sub-attributes.

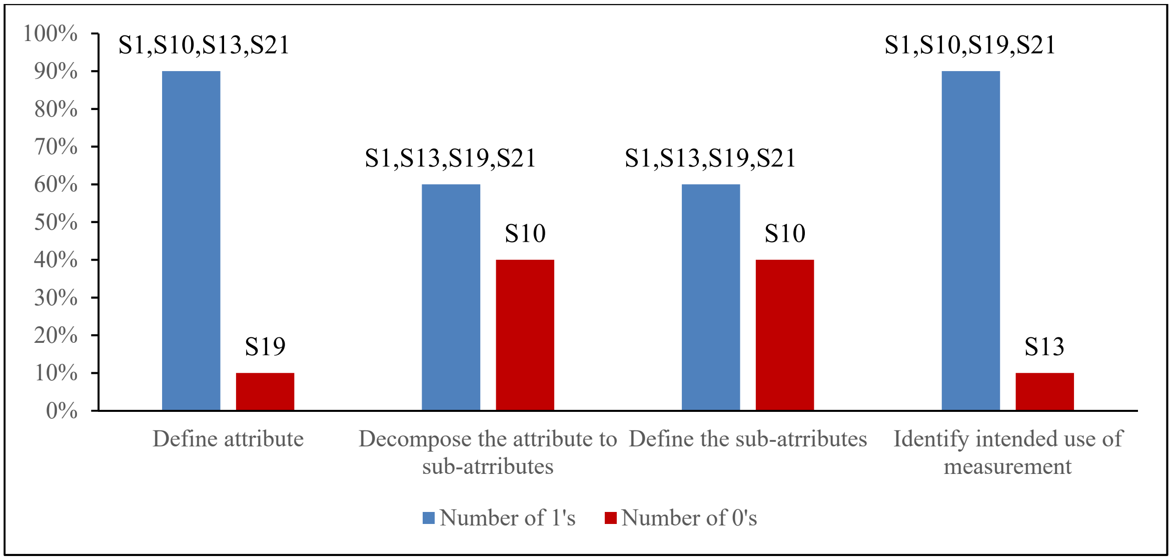

Figure 5.19 Evaluation of EA projects attributes per theoretical definition

The metrology coverage evaluation of the empirical definitions of EA project attributes (no entity type) is divided into the following levels:

1. Overall metrology coverage evaluation to explore an abstract overview of the coverage scoring of EA project attributes. The evaluation results are presented in Figure 5.20 and reveal that:
    - 65% of the empirical definitions criteria is satisfied, indicating a high score of empirical definitions of EA project attributes, and
    - 35% of the empirical definitions criteria are not satisfied, indicating a relatively low metrology coverage scoring characterized with weaknesses.

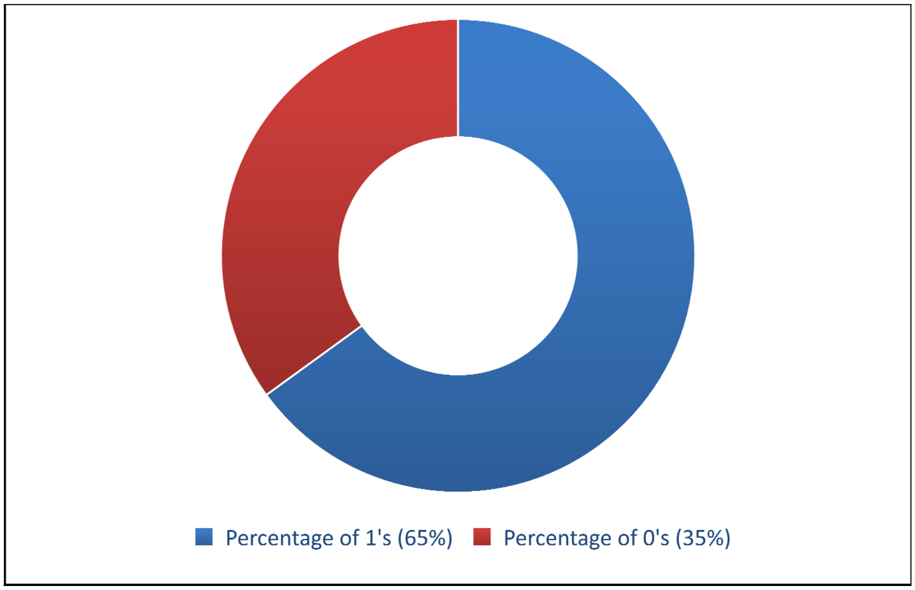

Figure 5.20 Average metrology coverage scoring for the empirical defintions of EA project attributes (undefined EA project entity)

2. Detailed metrology coverage evaluation of the empirical definitions for each metrology criteria. Figure 5.21 illustrates the results of this coverage evaluation: the coverage evaluation results of the empirical definitions of EA attributes. The results indicate the following:
   - Almost a consistent coverage scoring of (90%) among four (4) empirical definitions: identify source of input, identify type of input, identify quantification rules, and apply mathematical operations on output data. This explains that the majority of the empirical definitions are satisfied, and
   - A high deficiency related to measurement units, and applying mathematical operations on input data. The measurement unit is a critical element in the empirical definition metrology criteria. Although the majority of the empirical definition criteria are satisfied, we do highlight the deficiency of missing measurement units.

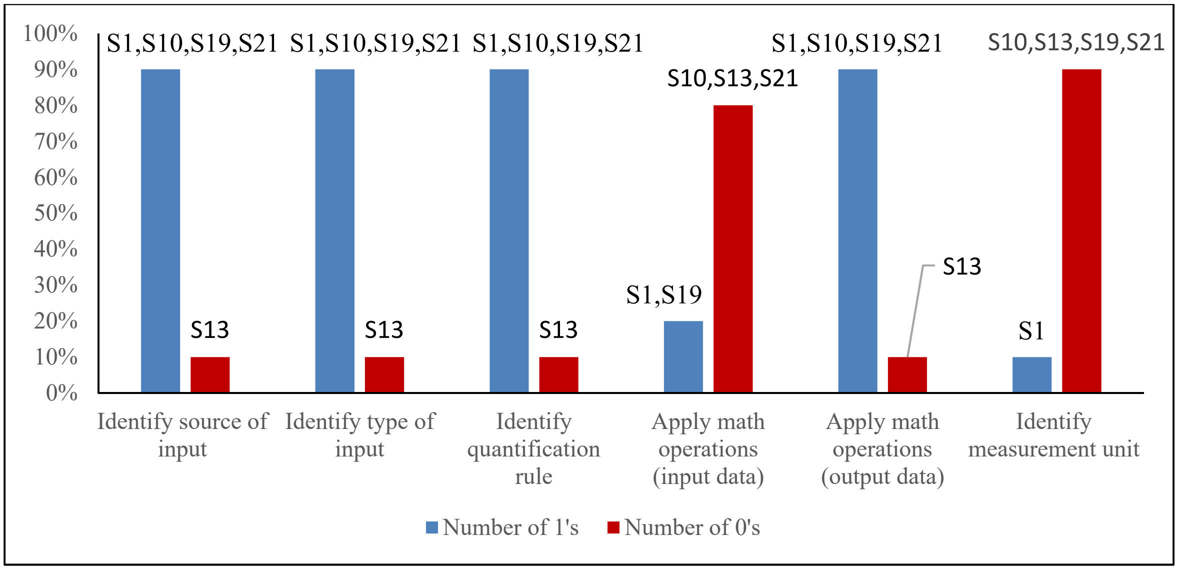

Figure 5.21 Evaluation of EA projects attributes per empirical definition (undefined EA project entity)

5.2.8 Comparison between the metrology coverage scoring of the theoretical and empirical definitions of EA project attributes

Figure 5.22 illustrates an aggregated quality scoring and a comparison of the coverage scores between both the theoretical and empirical definitions for each EA project attribute:

- the coverage scoring of empirical and theoretical definition of EA impact are equal,
- the coverage scoring of empirical definition of (EA maturity, operation IT effectiveness, IT alignment, and enterprise agility) is higher than the coverage scoring of the theoretical definition,
- the coverage scoring of the empirical definition of EA value in [S13] is 0%, and
- the coverage scoring of the theoretical definition of (agile EA, GADA active communication, and GADA performance) is higher than their empirical definition.

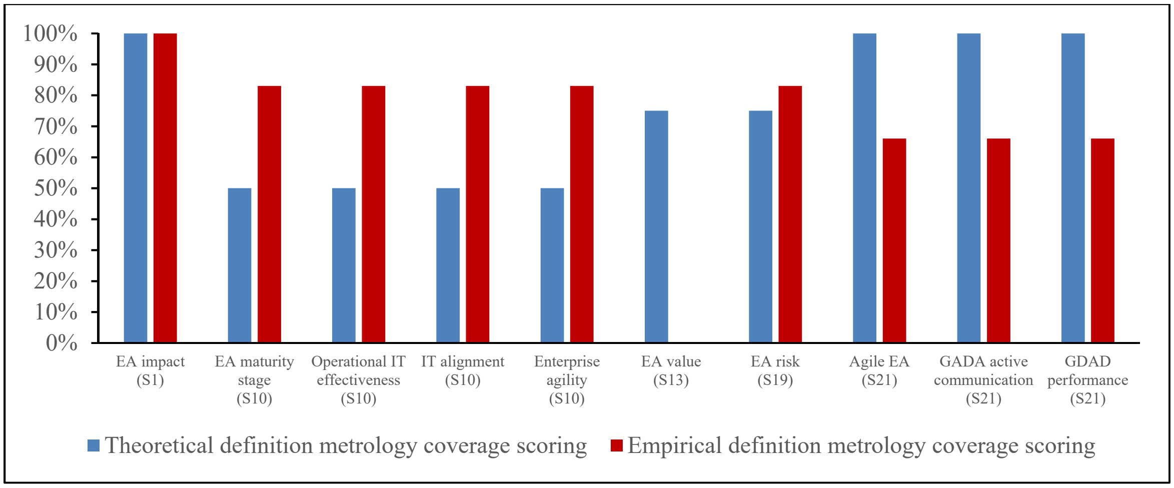

Figure 5.22 Theoretical vs. empirical definitions per EA project attribute (undefined EA project entity)

In order to present an overall coverage scoring of EA project attributes, Figure 5.23 shows a comparison between the coverage scoring of theoretical and empirical definitions based on the median coverage scores. The overall result indicates that the coverage scoring difference is 8%, which is not large.

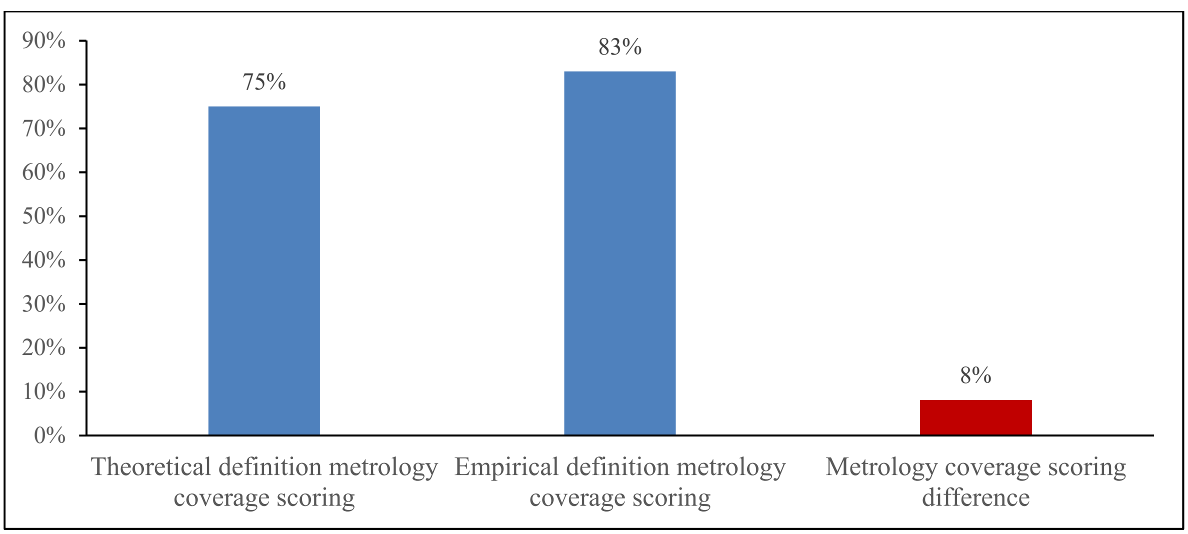

Figure 5.23 Overall comparison between theoretical & empirical definitions for EA project attributes (undefined EA project entities)

5.3 EA as a an architecture

This section groups some of the EA measurement proposals into the category of 'EA architecture' when the related authors consider EA as an architecture, and therefore focus on evaluating or measuring concepts within EA architecture.

Some of the primary studies under this category consider that architecting in an organization requires an in-depth consideration of the different elements that affect the EA architecture of an organization, be it the technology, business, culture, strategy, and the interconnections and interrelationships between them. Furthermore, other primary studies under this category posit that the fundamental impact of EA on organizations relies on selecting or designing the optimal architecture for the organization. However, since EA entails financial investments, authors in this category of primary studies posit that the right architecture should be designed or selected with care. Therefore, primary studies on EA architecture attempt to quantify and analyze the quality of the EA architecture, EA architecture risk, and the expected generated business value from EA architecture on IT management, and on the organization as a whole.

Moreover, another interest in this category is found to focus on how can EA, through its strategic IT goals, add value (be rewarded for IT governance toward a better alignment between business and IT). In this context, EA value is expected to be exchanged within the various EA architecture layers (e.g., application layer) which provide services to the higher layers (e.g., business layer).

Furthermore, EA architecting in these primary studies is considered as a complex exercise, since it enriches interactions from different stakeholders and architects, and it spans across the entire organization. Therefore, stakeholders and architects face complex decision-making problems in order to design or select the optimal EA architecture. Another EA architecture interest is found to focus on the IT heterogeneity in organizations, and how can the EA IT architecture be consolidated. From this perspective, IT consolidation is considered a trade-off:

IT consolidation may influence the business operations and therefore, too much focus on IT consolidation might affect the business value. On the other hand, IT consolidation is expected to be beneficial, such as in cutting maintenance costs, and improve development time.

Therefore, the attention of the primary studies on EA architecture attempts to quantify different concepts related to EA architecture, and focus on dealing with the underlying decisions and factors that influence the new architecture of the organization by proposing EA measurement proposals that can help decision makers in achieving the optimal EA architecture.

5.3.1 Analysis of the theoretical definitions for EA architecture entities

This subsection presents an analysis to find out whether or not the primary studies identify and present a theoretical definition of the entities under concern. Figure 5.24 shows the type of entities that are considered in the attempt to quantify concepts in EA architectures, such as EA scenario, IT object, and IT strategic goal.

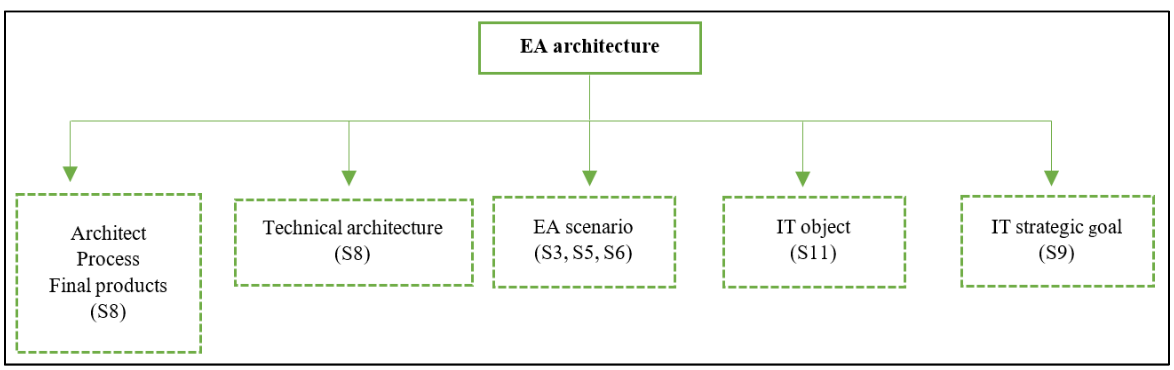

Figure 5.24 EA architecture entities

From Figure 5.25, the majority of the primary studies on EA architecture identify an entity type. An exception is in primary study [S8]: it is presented in the two (2) categories (identified and unidentified EA entity): primary study [S8] introduces various EA architecture-related concepts where some are characterized with an entity, and other concepts are not characterized with an entity.

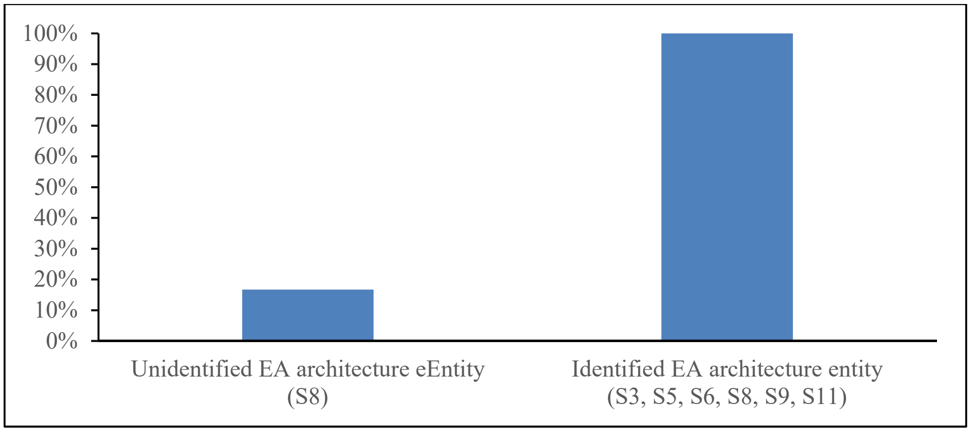

Figure 5.25 Distribution of the identification of EA architecture entities

Different terminologies are used to refer to EA architecture. For instance, it is referred to as **EA scenario** in three (3) primary studies [S3, S5 and S6], and the term is defined in [S5] and [S6]. EA scenario in [S5] denotes an architecture, an architecture proposal, or a solution architecture for an organization, which is not implemented yet in practice. EA scenarios in [S5] are decomposed into different EA views: business, data, software, and technology architectures. In [S6], EA scenario is defined as a model with a configuration of systems, applications, and processes that describes the current and future state of the architecture of the organization.

Overall, an EA scenario across the primary studies is considered as a hypothetical architecture solution, a sub-architecture, an EA artifact (model) that can be presented in documentations to propose a solution architecture. EA practitioners use EA scenario to suggest different solutions without implementing all the solutions, thus without investing on the wrong EA architecture.

Another terminology is used to refer to the EA architecture in [S11]. **IT objects** (ITO) are defined as the hardware platforms, database products, operating systems, application servers, development tools, and programming languages of the IT architecture in an organization.

Furthermore, the **IT Strategic Goal** of an EA architecture as in [S11] is not defined nor decomposed.

Figure 5.26 shows these EA architecture entities and the decomposition of these concepts to more granular levels. Furthermore, based on Figure 5.26, despite that EA scenario is found in three (3) primary studies, it is observed that the characterization of the concept (i.e. EA scenario) is not the same among the primary studies that define it (i.e. S5 and S6). Hence, EA scenario does not mean the same thing in [S5] and [S6]. Therefore, there is a lack of common understanding about EA architecture entities. This deficiency in EA architecture definitions is critical since the context of EA architecture entity is unclear: in other words, distinguishing the EA architecture entities from others is challenging. Therefore, EA practitioners will find difficulties in selecting the right EA measurement proposal for the right EA architecture entity.

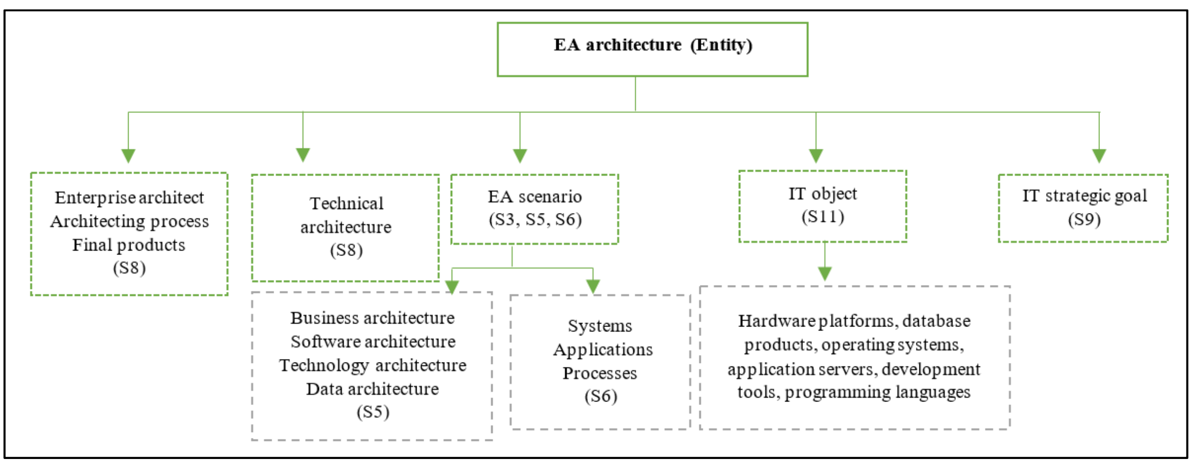

Figure 5.26 Characterization of EA architecture entities

Next, for an adequate measurement design within the measurement context model, concept characterization is necessary. Therefore, the EA architecture entities in Figure 5.26 are analyzed using the following criteria:

1. **Define the concept**: are the measured or quantified concepts defined in the primary study?

2. **De-compose the concept**: are the measured or quantified concepts decomposed to a granular level which will allow it to be quantified?
3. **Define the sub-concepts**: are the measured or quantified sub-concepts defined within the primary study?
4. **Identify intended use of measurement.**

To evaluate the metrology coverage scoring of the primary studies in terms of the theoretical definition criteria, we refer to the evaluation guidelines and yardstick in Table 5.1 introduced earlier in section 5.1 of this chapter. The metrology coverage evaluation of the theoretical definitions of EA architecture entities is divided into the following groups:

1. Overall metrology coverage evaluation to explore an abstract overview of the coverage scoring of EA architecture entities. The evaluation is presented in Figure 5.27. The results of this evaluation reveal that the average metrology coverage scoring for the theoretical definition of EA architecture entities: it reveals that the percentage of satisfying and not satisfying the metrology criteria is almost equal; however, the percentage of (1's being the indicator to satisfy the criteria) is considered low. The figure classifies the entities into two groups:
    - 53% of the theoretical definition criteria are satisfied, and
    - 47% of the theoretical definition criteria are not satisfied.
2. Detailed metrology coverage evaluation of the theoretical definitions for each metrology criteria. Figure 5.28 presents the metrology coverage evaluation of the theoretical definitions of EA architecture entities:
    - Only 56% of the EA architecture entities is theoretically defined,
    - Intended use of measurement results are identified,
    - Only 44% of the EA architecture entities are decomposed into sub-concepts, and
    - Only 11% are theoretically defining the sub-concepts.

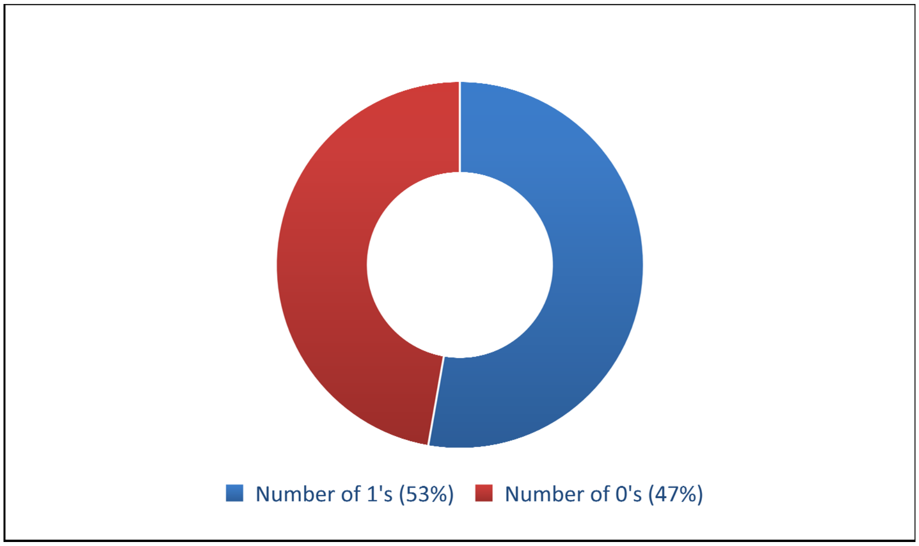

Figure 5.27 Average metrology coverage scoring for the theoretical defintion of EA architecture entities

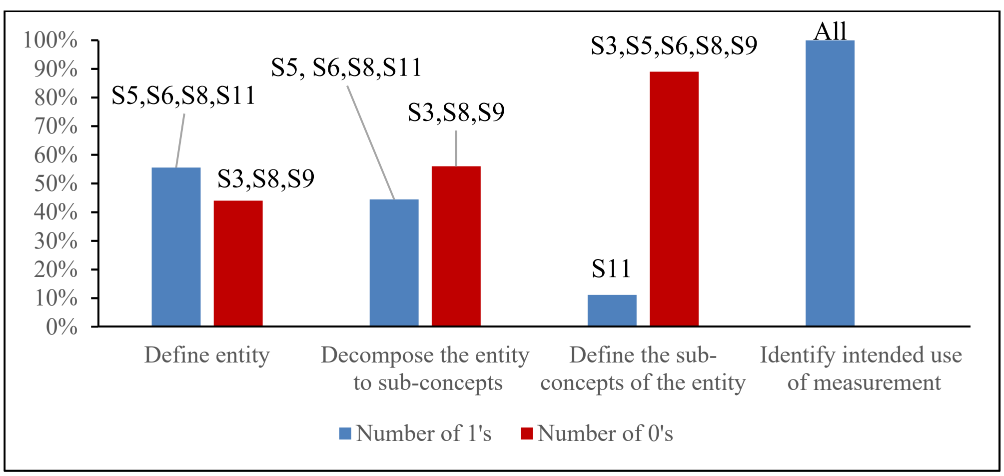

Figure 5.28 Evaluation of EA architecture entities per theoretical definition

The overall results indicate that the deeper in theoretical definitions, the more theoretical weaknesses. Such absence of definitions of sub-concepts is a major weakness in the design of measurement methods of these entities.

The results indicate that not all the primary studies are on the same level of metrology coverage. For the primary studies that defined an EA architecture entity type, the metrology coverage illustrates that the quality varies per primary study. For instance, [S3] and [S9] primary studies have the lowest number (e.g., 25%) of quality criteria met relating to the theoretical definitions defined earlier.

5.3.2 Analysis of the theoretical definitions for EA architecture attributes

Unlike EA project entities, EA architecture entities are not empirically defined through their theoretical definitions (i.e. not through the entity sub-concepts) discussed and presented earlier in Figure 5.26. Instead, the EA architecture entities are empirically defined through another set of EA attributes that are expected to represent the EA architecture entities – see Figure 5.29.

The metrology coverage evaluation of the theoretical definitions of EA architecture attributes is divided into the following groups:

1. The overall evaluation of the theoretical definition of EA architecture attributes is presented in Figure 5.30 and reveals that:
   - 55% of the theoretical definition criteria is satisfied, and
   - 45% of the theoretical definition criteria is not satisfied

Based on the overall metrology coverage evaluation of the theoretical definition of EA architecture attributes, the percentage of satisfying and not satisfying the metrology criteria is not significant. However, while there are definitions, a granular overview is needed.

2. Detailed metrology coverage evaluation of the theoretical definitions for each metrology criteria. Figure 5.31 shows the evaluation of the theoretical definitions of EA architecture attributes. Based on Figure 5.31, primary studies on the EA architecture attributes are not focusing on the definition of the EA attributes and sub-attributes. Instead, it is clear that the primary studies intend to decompose the EA

attributes to sub-attributes without a clear definition of these attributes and sub-attributes.

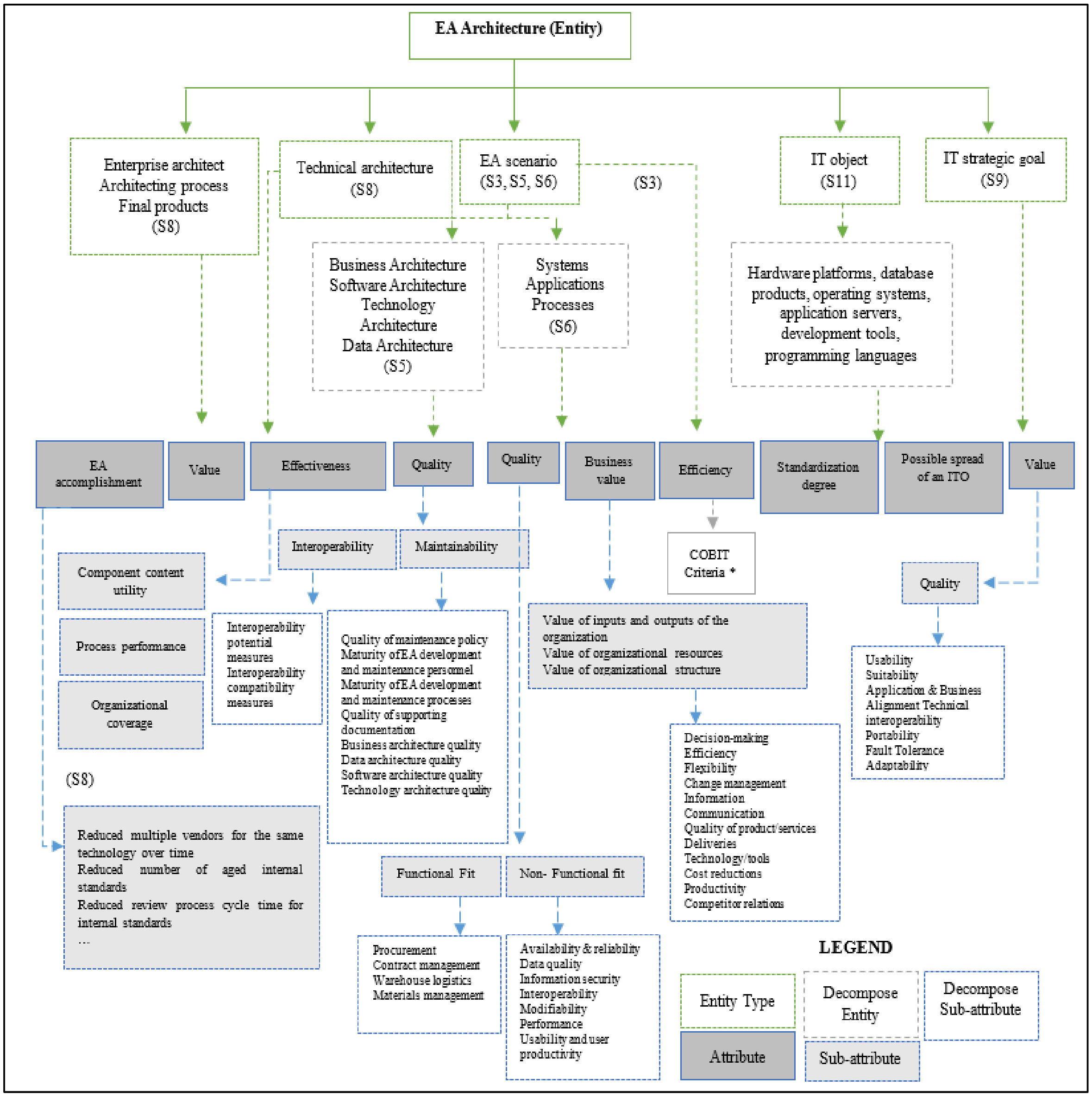

Figure 5.29 Characterization of EA architecture entities and the corresponding EA attributes

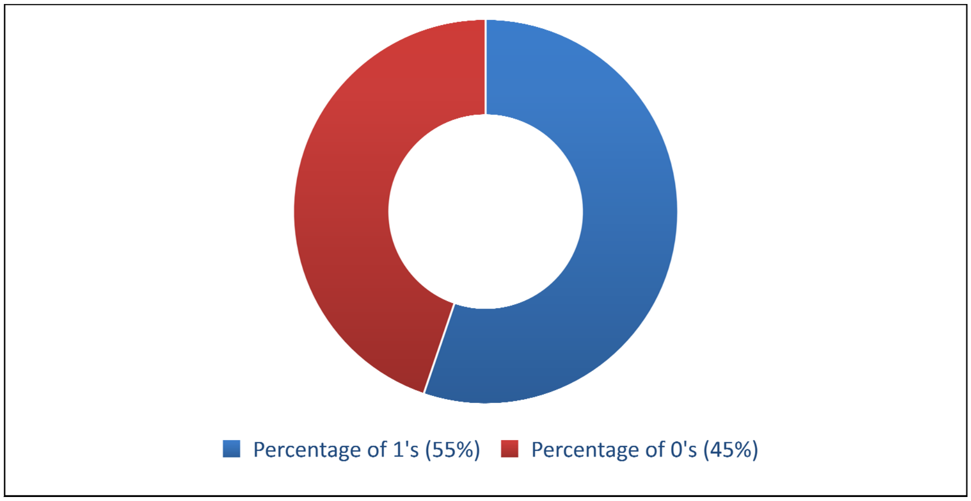

Figure 5.30 Average metrology coverage scoring for the theoretical defintions of EA architecture attributes

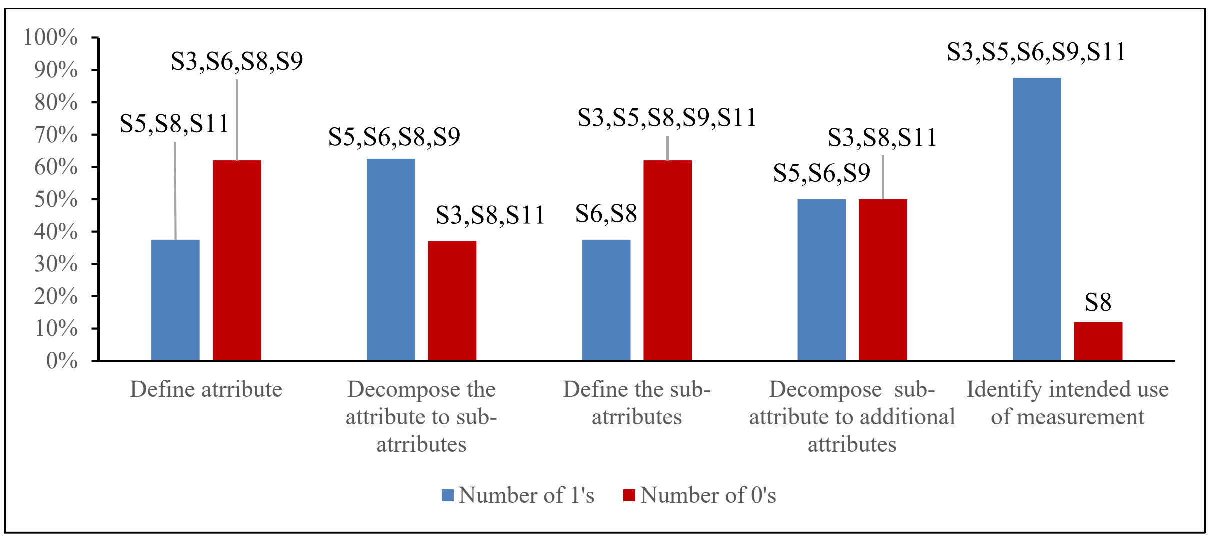

Figure 5.31 Evaluation of EA architecture attributes per theoretical definition

5.3.3 Analysis of the empirical definitions for EA architecture attributes

The metrology coverage evaluation of the empirical definitions of EA architecture attributes is divided into the following levels:

1. Overall metrology coverage evaluation to explore an abstract overview of coverage scoring of EA project entities. The overall evaluation of the metrology coverage of the empirical definitions is presented in Figure 5.32: 53% of the empirical criteria are satisfied, and 47% are not.

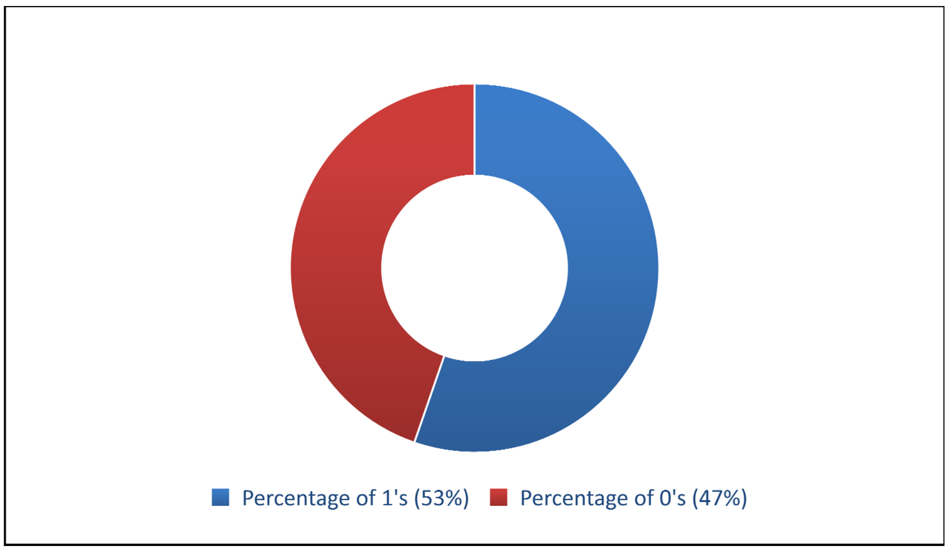

Figure 5.32 Average metrology coverage scoring for the empirical defintion of EA artchitecture attributes

2. Detailed metrology coverage evaluation of the empirical definitions for each metrology criteria. The results of this metrology coverage evaluation are presented in Figure 5.33 where the results show the strength and weaknesses for each metrology criteria.
   - 83% identify the source of input in order to quantify the EA architecture attributes,
   - 67% identify the type of input in order to quantify the EA architecture attributes,
   - No primary studies are identifying a measurement unit.

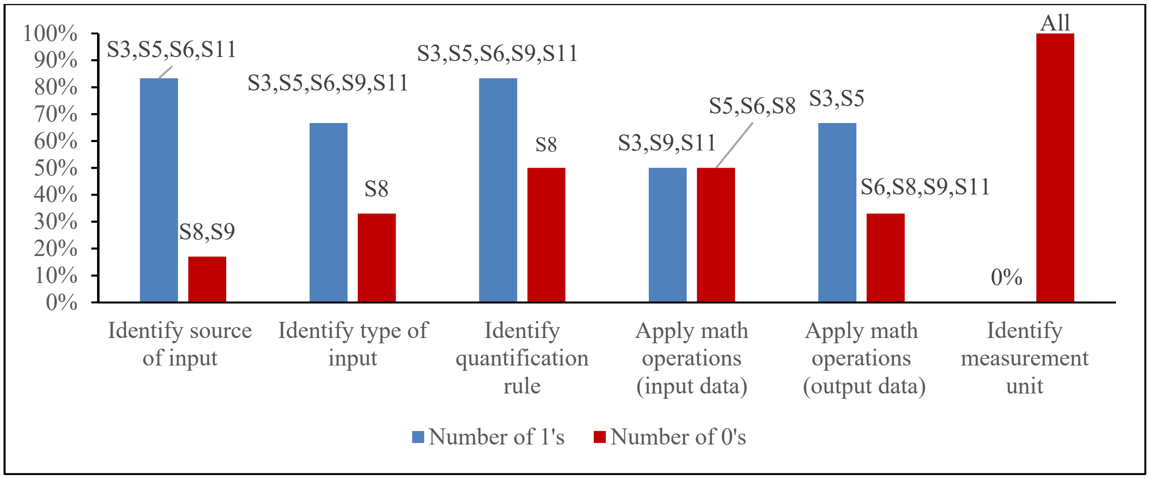

Figure 5.33 Evaluation of EA architecture attributes per empirical definition

5.3.4 Comparison between the metrology coverage scoring of the theoretical and empirical definitions of EA architecture

On a more granular level, Figure 5.34 shows the metrology coverage scoring of each EA architecture attribute according to the criteria of the empirical definitions.

- The coverage scoring of the theoretical definition of "efficiency" is less than its empirical definition by 63%.
- The coverage scoring of the theoretical definition of "quality" & "business value" is less than its empirical definition by 30%.
- The coverage scoring of the theoretical definition of the "standardization degree" attributes is less than its empirical definition by 26%.

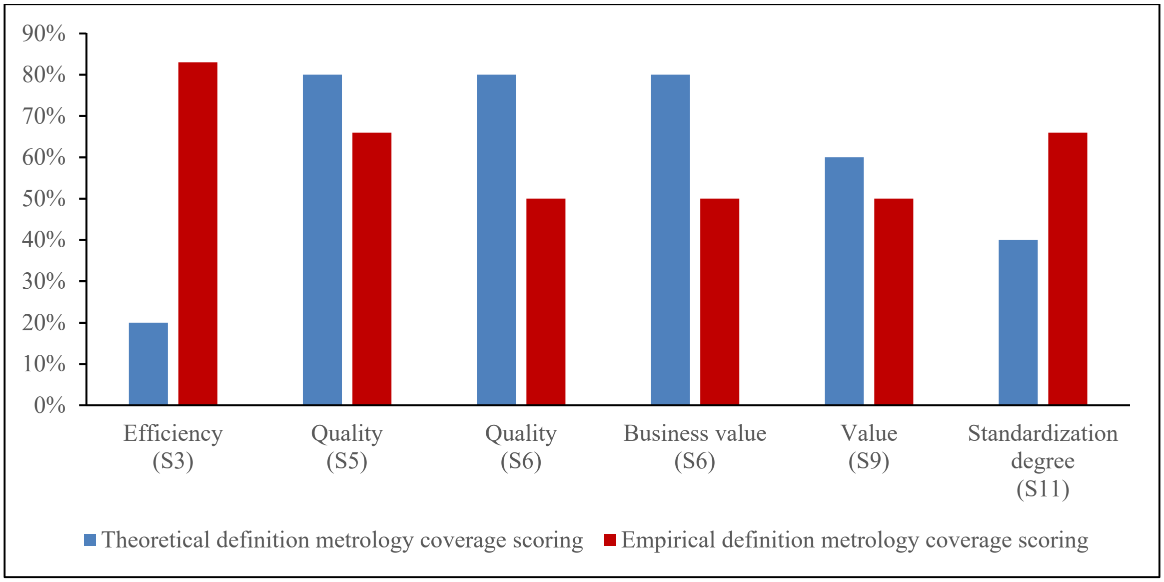

Figure 5.34 Theoretical vs. empirical definitions per EA architecture attribute

In order to present an overall coverage scoring of EA architecture attributes, Figure 5.35 quantifies the coverage score difference between the theoretical and empirical definitions. The coverage score of the theoretical definition is 12% higher than the empirical definition. Therefore, based on the findings above, it can be deduced that the metrology coverage scoring of the theoretical definitions of EA architecture attributes are more defined and explained than the empirical definitions.

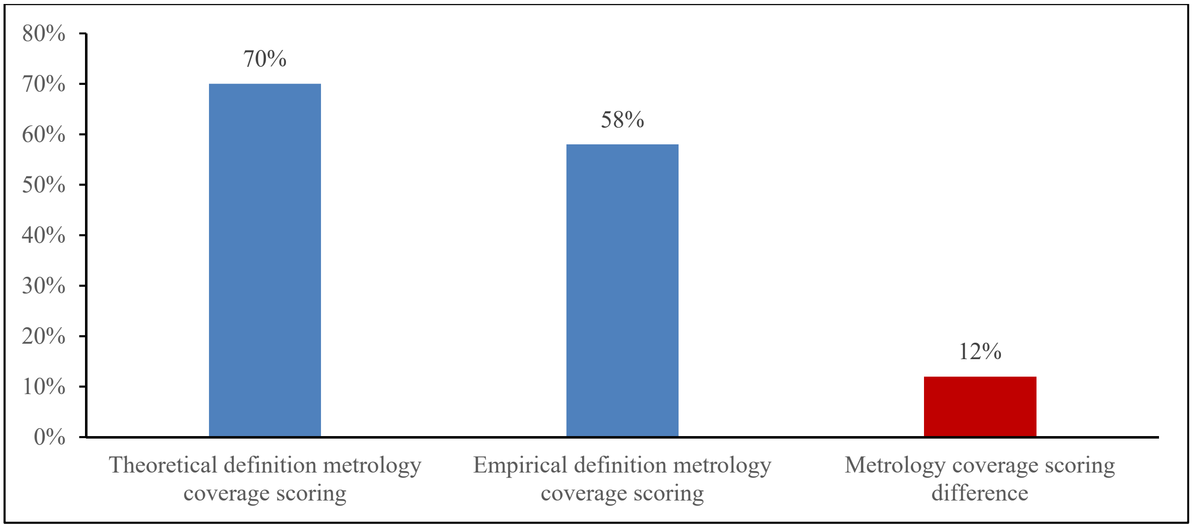

Figure 5.35 Overall comparison between theoretical & empirical definitions for EA architecture attributes

5.4 EA as a program

This section groups some of the EA measurement proposals into the category of "EA program" when the authors consider EA as a program, and therefore focus on evaluating or measuring concepts within EA programs.

Primary study [S14] is the only study positing that performing EA should not be mistaken with a project that has a start and an end: in [S14], performing EA is an ongoing program, which is deployed regularly in the organization. Furthermore, since performing EA is a program, it is executed in stages, and organizations are expected to plan for this execution process. EA program planning involves different factors that affect the success of the EA program, including securing a budget for the program, and insuring that the organizations have the human capital to execute the program. Therefore, this primary study [S14] attempts to quantify the EA readiness of EA program before being executed (i.e. during the preparation stage of EA program).

5.4.1 Analysis of the theoretical definitions for EA program attributes

This subsection analyzes the EA program measurement proposals with respect to the measurement context model.

EA program as a concept is not theoretically defined in [S14]. However, we can implicitly interpret that an EA program is an ongoing EA project: characterized as a permanent program for the organization that should be always revised and improved if need be. However, the implicit interpretation of the meaning of EA program is not considered in evaluating the primary study with respect to the measurement context model. Furthermore, the act of performing EA as a program in [S14] is decomposed into two (2) stages: the preparation and the execution stages as presented in Figure 5.36, which, in theory, is not very different from the stages of a project.

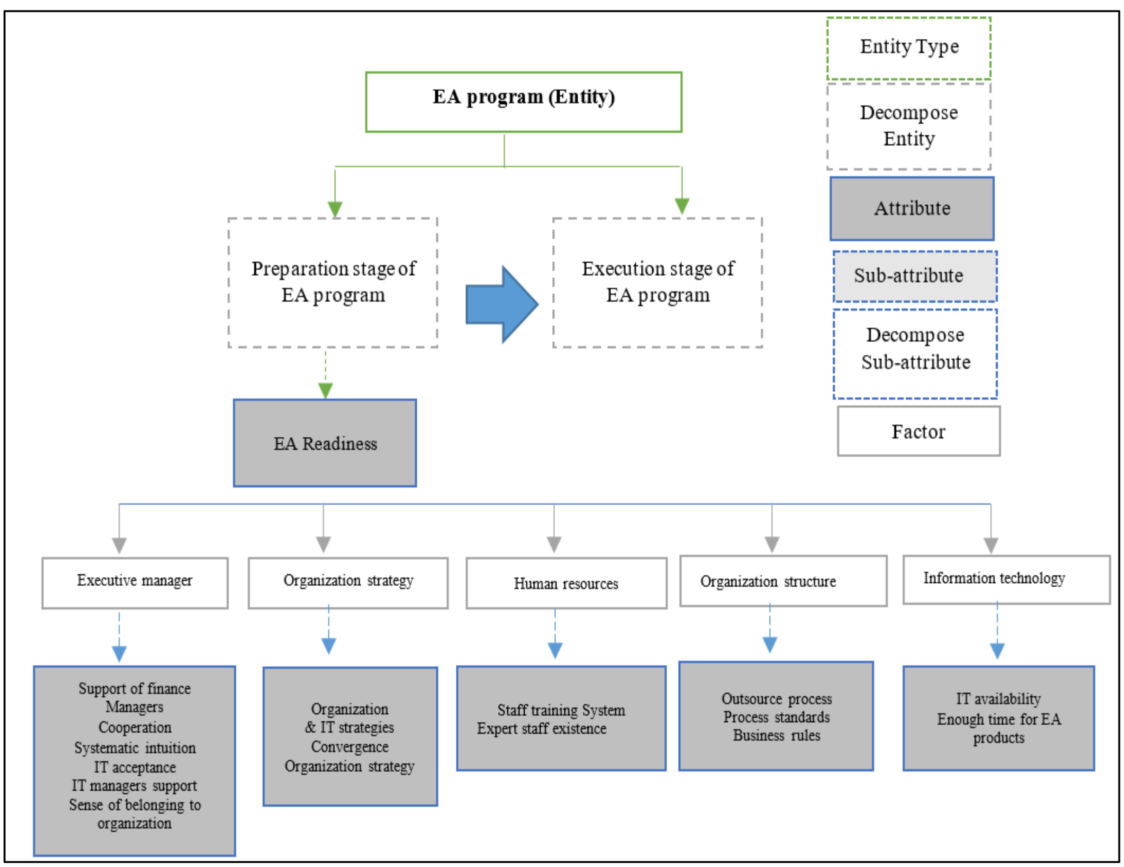

Figure 5.36 Characterization of EA program and the corresponding EA attributes

The EA program in [S14] is only characterized with one EA program attribute (i.e. EA readiness). EA readiness is not explicitly defined in S14; rather, the primary study presents some factors that affect the readiness of the EA in the context of the primary study for an organization. Figure 5.36 shows that senior manager and other factors in the gray boxes are only factors that may influence EA readiness; however, these factors do not define or explain what EA readiness is. Furthermore, Figure 5.36 shows that the factors are assigned a group of attributes that will be assigned numbers to quantify the amount of EA readiness. However, it is not clearly defined nor explained how these attributes represent EA readiness, nor are there definitions for these attributes, and whether EA readiness is limited only to these attributes.

The metrology coverage score of the theoritical definitions for EA readiness is only 25%. Detailed description of metrology coverage evaluation of the theoretical definitions for the EA program attribute is presented in Appendix III.

5.4.2 Analysis of the empirical definitions for EA program attributes

The EA program in [S14] is empirically defined through the attempt of quantifying the EA readiness (EA attribute). Therefore, this section presents the evaluation of the quality of the empirical definitions of EA readiness.

The metrology coverage score of the empirical definitions for EA readiness is 66%. Detailed description of metrology coverage evaluation of the empirical definitions for the EA program attribute is presented in Appendix III.

5.4.3 Comparison between the metrology coverage scoring of the theoretical and empirical definitions of EA program

The evaluation results of EA program reveals that the theoretical and empirical quality of EA program is not of a better metrology coverage scoring from the other group of primary studies on EA architecture or EA project. There are deficiencies in the theoretical definitions of EA readiness: the attribute is not explicitly defined within the context of the primary study. Furthermore, EA readiness is realized (not decomposed) through the means of factors and other attributes. These attributes are afterwards quantified in order to realize EA readiness of an organization. Therefore, from a metrology perspective, measuring the attributes of the factors does not mean measuring EA readiness. For example, the measurement of “IT availability” is not the same as (e.g., does not reflect) the measurement of “EA readiness”, unless EA readiness is characterized and mathematically defined in the form that the sum of these attributes equal the overall EA readiness, which is absent in this primary study.

Figure 5.37 shows next the overall comparison between the metrology coverage scoring of the theoretical and empirical definitions. The metrology coverage of the empirical definitions is 41% higher than the metrology coverage of the theoretical definitions. The comparison reveals that theoretical definitions are weak in EA program quantification, and that the authors attempt to quantify attributes and produce numbers through for attributes that are not well characterized.

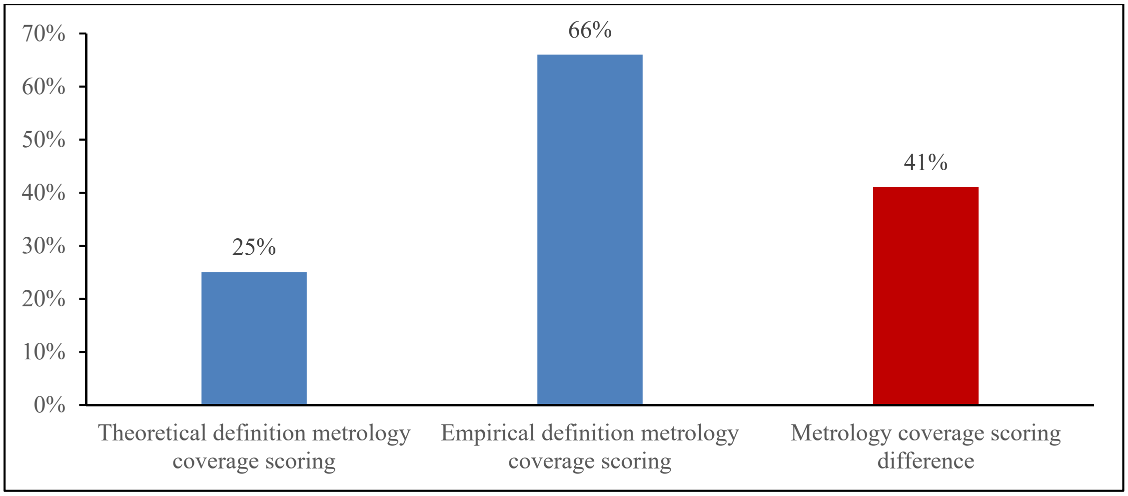

Figure 5.37 Overall comparison between theoretical & empirical definitions for EA program

5.5 EA as a framework

This section groups some of the EA measurement proposals into the category of "EA frameworks" when the authors consider EA as a framework, and therefore focus on evaluating or measuring concepts within EA frameworks.

With the increasing complexity between information technology (IT) and business environment, EA frameworks are expected to provide benefits to organizations through guidance on how to create and use EA. EA frameworks propose best practices and principles to enhance systems thinking in organizations. EA frameworks help manage EA through an integral perspective of the organization by decomposing EA into different domains and layers. Therefore, EA architects use EA frameworks to implement EA in organizations in order to manage the interdependencies between the various elements (e.g, people, and technology) in organizations.

In the EA literature, there are different EA frameworks that provide such guidance; therefore, the more EA framework alternatives, with possible contradictory criteria, the more complex is the decision to select an EA framework. In addition, EA literature indicates that there is no consensus about which EA framework should be used, or should be considered as the best alternative for the organization. Different EA frameworks are characterized with some weakness and strength, and no EA framework is complete. For instance, Zachman framework aligns roles and ideas in a structured way in the organization, while TOGAF offers steps that support the architecture development process in the organization.

Therefore, primary studies on EA frameworks suggest that before an organization selects a particular EA framework, all relevant EA frameworks should be evaluated in terms of defined criteria (attributes), and the appropriate EA framework should be selected accordingly.

5.5.1 Analysis of the theoretical definitions for EA framework attributes

This subsection analyzes the EA framework measurement proposals with respect to the measurement context model.

EA framework characterization is different from the other EA entities discussed earlier (e.g., EA Architecture). Figure 5.38 shows that the EA framework is itself the entity, without no further decomposition of entities. Instead, EA frameworks are being investigated from different perspectives through different attributes.

For example, Figure 5.38 shows that [S2] attempts to quantify the risk of EA framework through decomposing the EA risk into different kinds of EA risks. Similarly, for the EA framework usability in [S16]: the author investigates the usability of different kinds of EA frameworks taking into account the EA architecture layer at the same time. Therefore, an analysis of the theoretical empirical quality scores of the EA attributes is introduced next to study EA frameworks.

Based on Figure 5.38, it is observed that EA frameworks are being investigated from different perspectives. The decomposition of EA attributes are detailed and widespread. This section analyzes the quality score of the theoretical definition of EA framework attributes.

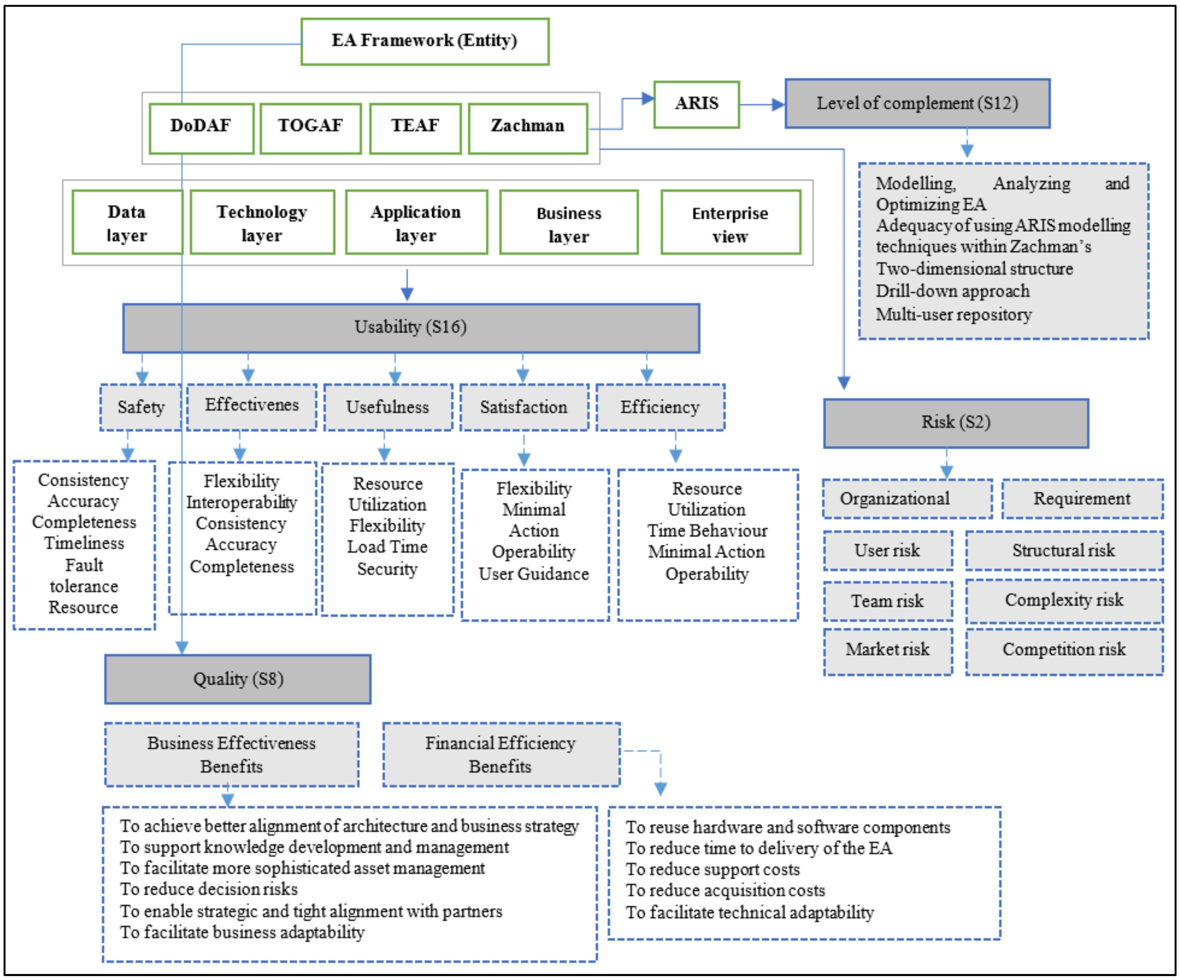

Figure 5.38 Characterization of EA frameworks

EA framework attributes definitions should be adequate by following the criteria of the measurement context model. Figure 5.39 shows the average quality scores for the theoretical definitions of EA framework attributes and classifies the attributes into two groups:

- 70% of the theoretical definition criteria is satisfied, and
- 30% of the theoretical definition criteria is not satisfied.

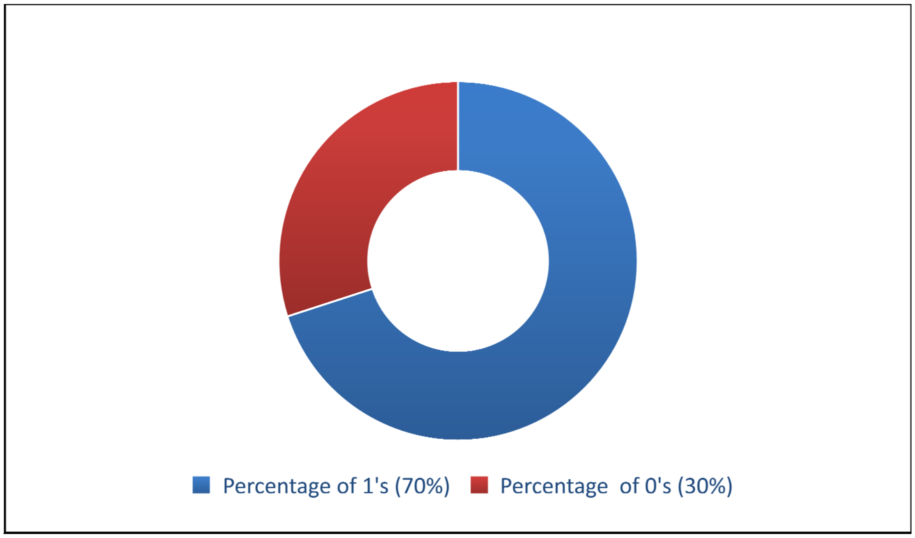

Figure 5.39 Average metrology coverage scoring for the theoretical definintion of EA framework attributes

Figure 5.39 shows that the percentage of satisfying the metrology criteria is greater than the percentage of not satisfying the criteria. However, it is not clear what criteria are satisfied versus the ones that have weaknesses. Answers to this question ae presented in Figure 5.40. The major weakness is in the lack of defining the attribute. For instance, in Figure 5.38, usability is not defined, but is decomposed; level of complement (EA attribute in S12) between EA frameworks is not defined but is also decomposed.

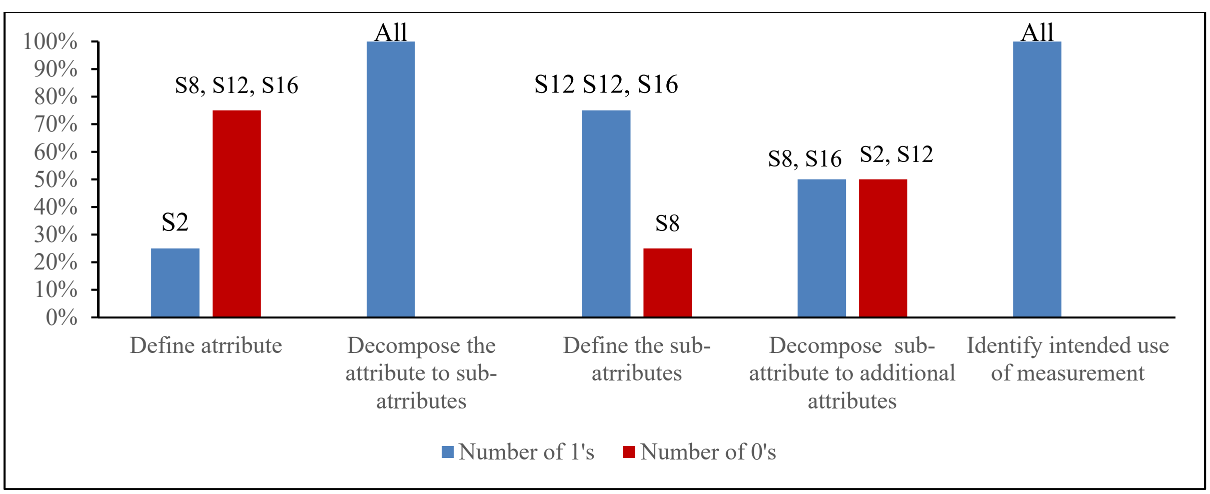

Figure 5.40 Evaluation of EA framework attributes per theoretical definition

Detailed description of metrology coverage evaluation of the theoritical definitions for the EA framework attribute is presented in Appendix III.

5.5.2 Analysis of the empirical definitions for EA framework attributes

Primary studies on EA frameworks attempt to develop measurement proposals to assist decision makers in selecting the optimal EA framework based on numbers. Therefore, the authors attempt to quantify the EA attributes presented earlier in Figure 5.38. This section analyzes the metrology coverage of the empirical definitions of these attributes. Figure 5.41 shows the metrology coverage scoring for the empirical definition of EA framework attributes; the figure classifies the attributes into two groups:

- 63% of the empirical definition criteria are not satisfied, and
- 37% of the empirical definition criteria are satisfied

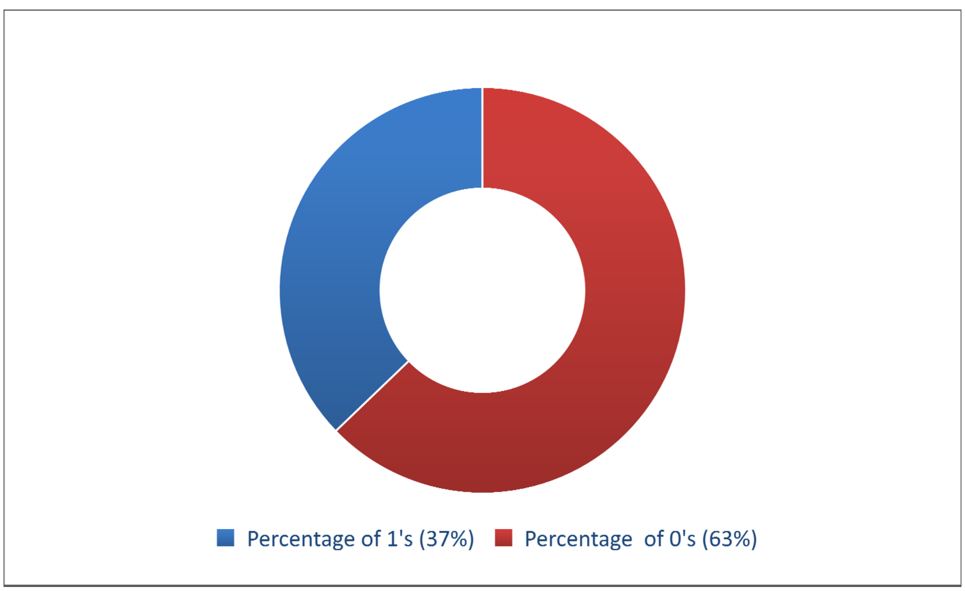

Figure 5.41 Average metrology coverage scoring for the empirical definition of EA framework attributes

Figure 5.41 shows that the majority (63%) of the empirical definitions of EA frameworks attributes have weaknesses.

To find out the type of these deficiencies, a content analysis is performed to analyze the primary studies and produce a more granular analysis. The results of this analysis are presented in Figure 5.42: the metrology coverage scoring shows that there are weaknesses. The absence of measurement units and mathematical operations (e.g., statistical models) are the main missing criteria. This indicates a lack of metrology rigor, a lack of analytical tools for making decisions, such as selecting the optimal EA framework based on adequate analysis methods. Additional deficiencies were identified:

- 50% are not identifying the source of inputs to quantify the EA framework attributes: this leaves questions open on who is quantifying or measuring the attributes.
- 50% are not identifying the type of input data: this means that it is not clear whether the data is actual, historical, forecasting the future or no data at all.
- 50% are not identifying the quantification rules. This indicates that these primary studies talk about it, but do not explicitly quantify the attributes.

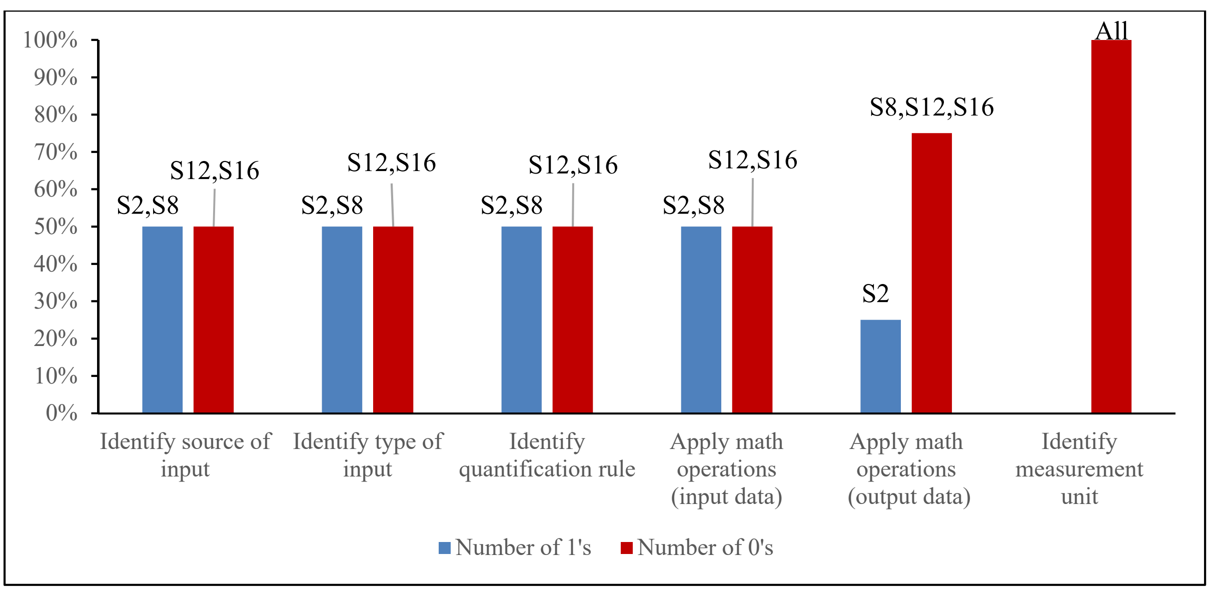

Figure 5.42 Evaluation of EA framework attributes per empirical definition

Detailed description of metrology coverage evaluation of the empirical definitions for the EA framework attribute is presented in Appendix III.

5.5.3 Comparison between the metrology coverage scoring of the theoretical and empirical definitions of EA frameworks

The previous sections presented the EA framework attributes and discussed the quality of theoretical and empirical definitions of EA framework attributes. The results of this analysis indicate that there are weaknesses in both types of criteria (i.e. theoretical and empirical), and the analysis presented a more granular level of details. This section presents now an overview of the metrology coverage evaluation through comparing the metrology coverage scoring of theoretical and empirical definitions as follows:

- Figure 5.43 presents an overview comparison analysis between the median metrology coverage scoring of theoretical and empirical definitions, and produce the coverage scoring difference (difference between the average of theoretical and empirical coverage scoring). The coverage scoring difference shows that the coverage scoring of the empirical definition is 30% less than the coverage scoring of the theoretical definition.
- Figure 5.44 presents an overview comparison analysis, for each EA framework (EAF) attribute, between the empirical and theoretical definitions quality scores. The results show that:
    - [S12] and [S16] lack empirical definitions (metrology coverage scoring = 0%).
    - These EAF attributes are not quantified and are limited to theoretical definitions only.
    - EAF quality relatively lacks theoretical definitions compared to its empirical coverage scoring.

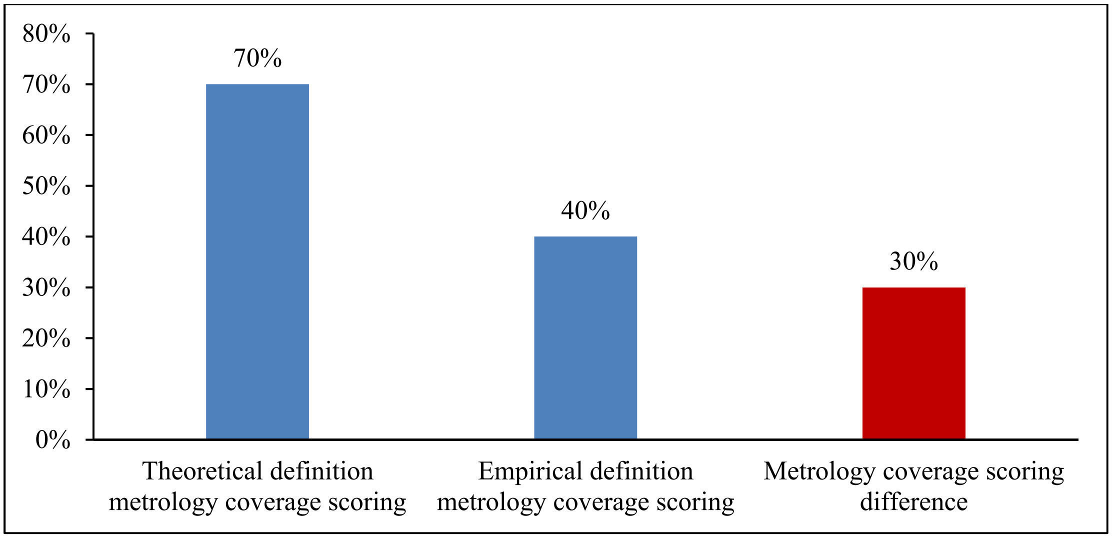

Figure 5.43 Overall comparison between theoretical & empirical definitions for EA frameworks attributes

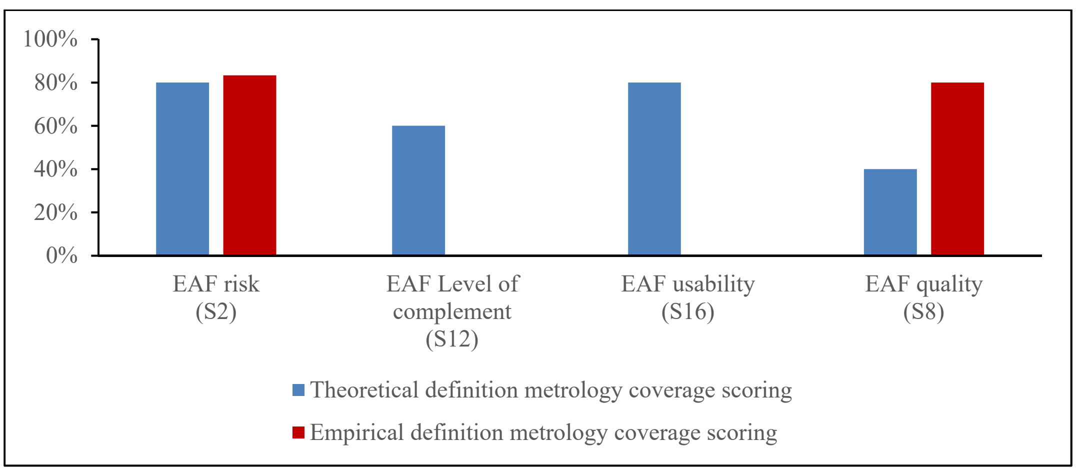

Figure 5.44 Theoretical vs. empirical definitions per EA framework attributes

5.6 Analysis of EA metrology coverage over time

Furthermore, in order to provide more analysis about the findings of this chapter, the normal distribution of the metrology coverage scoring data is tested. It is found that the metrology coverage scoring data is not on a Normal distribution. The scorings are skewed, and therefore, in order to perform statistical analysis on the metrology coverage scoring, the non-parametric Spearman's rank order correlation coefficient (r_s) is used. Spearman's correlation is used to determine the strength and direction of relationship between the theoretical definition metrology coverage with time (years), and the empirical definition metrology coverage with time (years). Spearman's coefficient is interpreted as follows: correlation value of (1) means that there is a strong positive relationship between the two variables, a correlation value of (−1) means a strong negative relationship between the two variables, and correlation value of 0 means that the two are variables are not correlated.

It is expected that both metrology coverage criteria have positive correlation with years, and therefore, indicating that metrology coverage is improving over time. Therefore, we define the null and alternative hypothesis as follows:

Null hypothesis: no relationship between metrology criteria and time (years)
Alternative hypothesis: there is a relationship between metrology criteria and time (years)

The results of this analysis are presented in Figures 5.45 & 5.46 as following:

- There appears to be a very weak positive correlation (r_s) value (+0.1468).There is a greater than 50% probability that the null hypothesis is correct p = > 0.50 (below 50% statistical significance level). Therefore, the null hypothesis is accepted, and it is concluded that there is no correlation: the metrology coverage of the theoretical definitions is not affected (i.e. improved) over time.
- There appears to be a very weak negative correlation (r_s) value (-0.0037). There is a greater than 50% probability that the null hypothesis is correct p = > 0.50 (below 50%

statistical significance level). Therefore, the null hypothesis is accepted, and it is concluded that there is no correlation: the metrology coverage of the empirical definitions is not affected (i.e. improved) over time.

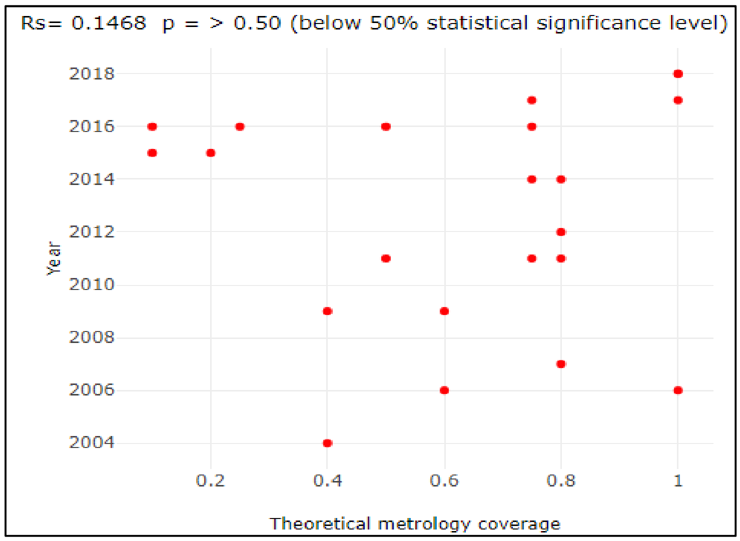

Figure 5.45 Spearman's correlation between the theoretical coverage scoring and time (years)

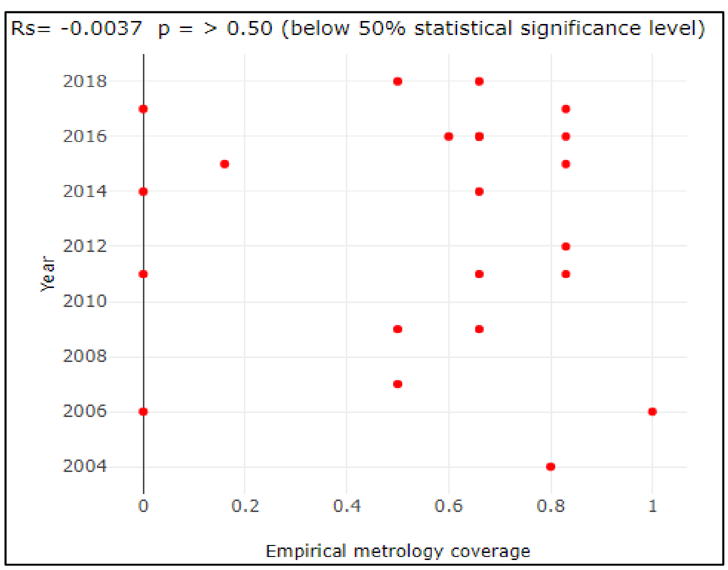

Figure 5.46 Spearman's correlation between the empirical coverage scoring and time (years)

5.7 Chapter summary

All of the existing EA measurement proposals were not developed according to the measurement context model and metrology criteria. The findings of the analysis in this chapter reveal that there is a lack of attention to attaining an appropriate metrology EA measurement proposal. All the EA measurement proposals are characterized with insufficient metrology coverage scoring, theoretical, and empirical.

- There is a lack of concern regarding the definition of EA attributes: this entails insufficient EA attribute characterization that leads to a lack of consensus on the related terminologies.
- The EA attributes are either decomposed into sub-attributes and without consensus, or alternatively not decomposed at all.
- EA attributes characterization is limited within the same primary study: this most often leads to overlaps with the same terminologies in other primary studies, however, with different characterization.

Missing EA entity types will limit the benefits expected from the EA measurement proposal, and will lead to difficulties in decision-making. Figure 5.47 shows an example of an EA project timeline. The project has identified some EA entities with the corresponding EA attributes, and other EA attributes with no EA entity type. EA measurement proposals of no entity type will not be beneficial as much as EA measurement proposals with EA entity type. For instance, if a measurement result indicated an increase of the EA risk, what can be improved to reduce the risk? What is entity type in the EA project that may reduce the EA project risk? The same applies when the EA value is high. It is hard to know what caused an EA project to produce high values, and therefore, the measurement results are useless.

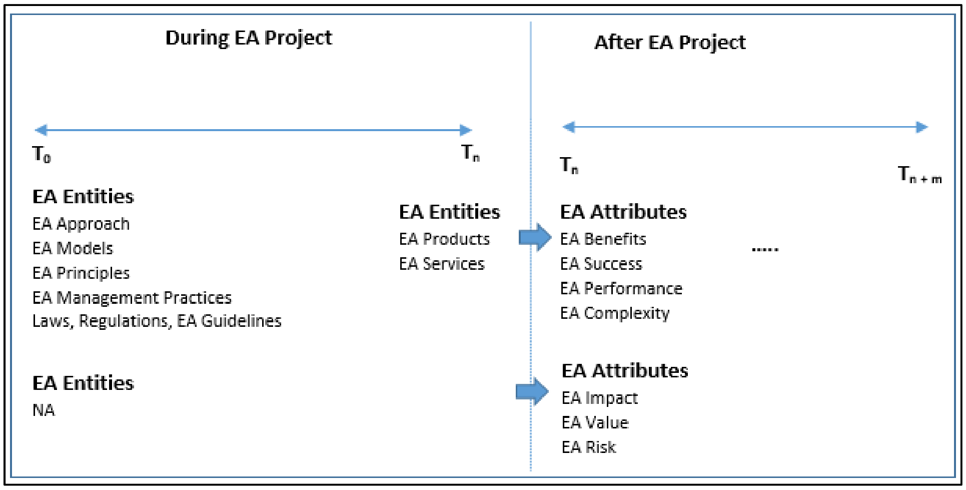

Figure 5.47 Expected effect of missing EA entity type

- There is a lack in assigning measurement units to EA attributes. Therefore, since measurement units are one of the critical elements of an adequate measurement proposal, the majority of the EA measurement proposals numbers without explicit meanings from a practical viewpoint: such numbers without measurement units cannot be compared, and interpreted the same way. More details on this topic are covered in the "Metrology & Quantification Issues in EA Measurement" Chapter 6.

The findings of this chapter are the first step to improve the EA measurement proposals. The analysis covered each EA entity and EA attributes from two perspectives: theoretical and empirical definitions. An overall summary of this analysis is presented in Figure 4.48 and Table 16 as follows:

- Figure 5.48 shows a comparison between the theoretical and empirical definitions of each entity type.
- Table 5.3 shows the rank of each EA entity concerning the theoretical and empirical definitions. This ranking will facilitate where to focus, and on what (theoretical vs. empirical definitions) in each EA entity type.

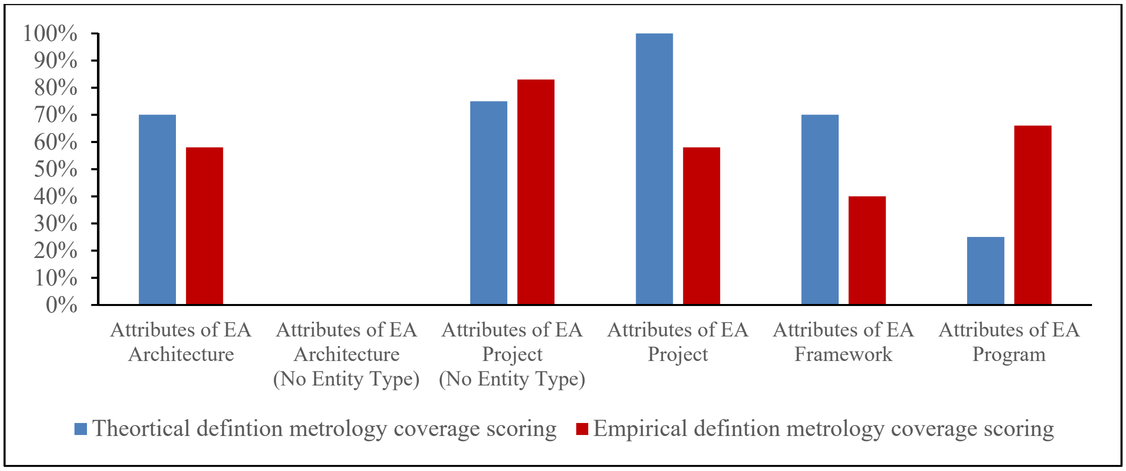

Figure 5.48 Summary of EA attributes per entity type

Table 5.3 Rank of EA entities based on metrology coverage evaluations (from highest to lowest)

EA Entity Type	**Rank of EA Entity Type (Theoretical Definition)**	**EA Entity Type**	**Rank of EA Entity Type (Empirical Definition)**
EA Project	1	EA Project (undefined entity)	1
EA Project (undefined entity)	2	EA Program	2
EA Framework	3	EA Architecture	3
EA Architecture	3	EA Project	3
EA Program	4	EA Framework	4
EA Architecture (undefined entity)	5	EA Architecture (undefined entity)	5

CHAPTER 6

METROLOGY & QUANTIFICATION ISSUES IN EA MEASUREMENT

The results of the metrology coverage evaluation have revealed that there are weaknesses in the theoretical and empirical definitions. Therefore, additional research and development is required to improve the metrology coverage of EA measurement solutions proposed. However, while the metrology coverage scoring of some primary studies show acceptable (e.g., modest-high) coverage scoring for the empirical definitions, we posit that a more in depth analysis on these empirical definitions will reveal more weaknesses and misconceptions. Therefore, this chapter focuses on the empirical definitions of EA measurement proposals for primary studies that have metrology coverage scoring above 0%; (in other words that satisfy some of the metrology criteria.)

This chapter presents the empirical definitions of the EA measurement proposals, the descriptions of these empirical definitions, the count and the references to these primary studies. Furthermore, it synthesizes the techniques used in the primary studies to quantify the EA concepts and attributes. The research objective of this chapter aims at providing answers to the following questions:

- Who is quantifying the EA attributes?
- How is the quantification done?
- Where is the quantification output used? and
- What are the main metrology issues in EA measurement research?

Section 6.1 presents the descriptions of the empirical definitions for EA projects. Section 6.2 presents the descriptions of the empirical definitions for EA architecture. Section 6.3 presents the descriptions of the empirical definitions for EA framework. Section 6.4 presents the descriptions of the empirical definitions for EA program. Section 6.5 presents the main metrology issues of input and output data. Section 6.6 presents examples of the main metrology issues in EA measurement proposals. Section 6.7 presents a mapping between ISO 15939 and the EA quantification techniques.

6.1 Description of empirical definitions in EA projects

From Table 6.1 it can be observed that:

- The source of input of EA project quantification are the EA practitioners who are involved in EA projects. Examples of such practitioners can be CIO or EA architects.
- The quantification is performed through expressing opinions based on the individual experience and knowledge, and through ordinal scale guidelines. For instance, an EA architect expresses his/her opinion based on the Likert Scale (1-5) for a given EA attribute.
- The opinions have different types. For instance, opinions can be a perception based on the past (previous experience), perception of the future (predictions), or a perception based on the present.

The description of the most frequent empirical definitions are highlighted in gray in Table 6.1. These denote to the most used quantification combinations in EA. For instance:

- the source of inputs for quantification is the EA practitioners and e-government initiatives,
- the most used type of input is opinions – perception of future,
- the most used quantification rule is the ordinal scale,
- the most used mathematical operation performed on output data is the partial least square estimation model, and
- the only used measurement units are dollar ($) – a standardized unit, and structural complexity unit (Scu) – not recognized by any international standard.

Table 6.1 Description of empirical definitions in EA projects

Empirical definition in EA projects	Description	Count	Primary studies
Source of input	EA practitioners (CIO, EA architects, system engineers, project managers, experts)	8	S4, S10, S15, S17, S19, S20, S21, S22
	E-government EA initiatives	1	S1
Type of input data	Actual historical data in $$	1	S1
	Opinions - perception of future	4	S4, S10, S20, S22
	Opinions - perception of present	3	S15, S17, S19
	Actual counting of elements	1	S23
Quantification rule	Ordinal scores	8	S4, S10, S15, S17, S18, S19, S20, S23
	Accepted formula for NPV and ROI	1	S1
Math on input data	Sessions formula for complexity	1	S23
	Fuzzy transformation	1	S19
Math on output data	Partial Least Square (PLS) structural equation	7	S4, S10, S15, S18, S20, S21, S22
	Least square log linear Regression	1	S1
	Fuzzy functions	1	S19
Measurement unit	Dollar ($)	1	S1
	Scu (a none standardized unit)	1	S23

6.2 Description of empirical definitions in EA architecture

From Table 6.2 it can be observed that:

- The source of input of EA architecture quantification are the EA practitioners who are involved in the architecture of EA. Examples of such practitioners can be CIO or EA architects.
- The quantification is performed through expressing opinions about the future architecture, perception of importance of EA attributes, and actual counting of EA elements. The quantification is mostly done through ordinal scale guidelines.

The descriptions of most frequent empirical definitions are highlighted in gray in Table 6.2. The descriptions show the most used quantification combinations in EA architecture. For instance:

- the only source of input for quantification is the EA practitioners,
- the most used type of input is opinions – perception of future,
- the most used quantification rule is the ordinal scale,
- mathematical operation on input data are fuzzy transformations and in-house formulas, and
- the majority did not use mathematical operation on output data. Only one (1) primary study used the DEA multi-criteria model, and one (1) used AHP.

Table 6.2 Description of empirical definitions in EA architecture

Empirical definition in EA architecture	Description	Count	Primary studies
Source of input	EA practitioners (CIO, EA architects, system engineers, project managers, Experts)	6	S3,S5,S6,S8,S9,S11

Table 6.2 Description of empirical definitions in EA architecture (continued)

Empirical definition in EA architecture	Description	Count	Primary studies
Type of input data	Opinions - perception about importance	1	S8
	Opinions - perception of future	3	S3, S5, S6
	Actual counting of elements	2	S9, S11
Quantification rule	Ordinal scores	3	S3, S5, S6
	Actual counting of elements	2	S9, S11
	Weights	1	S8
Math on Input data	fuzzy transformations	1	S3
	In-house Formula for computation	2	S9,S11
	NA	3	S5,S6, S8
Math on output data	NA	4	S6,S8,S9,S11
	DEA model	1	S3
	AHP	1	S5
Measurement unit	NA	6	S3,S5,S6,S8,S9,S11

6.3 Description of empirical definitions in EA framework

The descriptions of the most frequent empirical definitions in EA framework are highlighted in gray in Table 6.3. These denote to the most used quantification combinations in EA framework. For instance:

- the only source of input for quantification is the EA practitioners,
- the most used type of input is opinions – perception of future, and perception of importance,
- the most used quantification rule is the ordinal scale,

- mathematical operation on input data are fuzzy transformation (1 primary study) and in-house formula of multiplying weights and scores together (1 primary study), and
- the majority did not use mathematical operation on output data. Only one (1) primary study used fuzzy functions.

Table 6.3 Description of empirical definitions in EA frameworks

Empirical definition in EA framework	Description	Count	Primary studies
Source of Input	EA practitioners (CIO, EA Architects, System Engineers, Project Managers, Experts)	2	S2, S8
	NA	2	S12, S16
Type of input data	Opinions - Perception of future	1	S2
	NA	2	S12, S16
	Opinions - Perception about importance	1	S8
Quantification rule	Ordinal scores	2	S2, S8
	NA	2	S12, S16
Math on Input data	Fuzzy transformation	1	S2
	Score and weight multiplication	1	S8
	NA	2	S12, S16
Math on output data	NA	3	S8, S12, S16
	Fuzzy functions	1	S2
Measurement unit	NA	4	S2, S8, S12, S16

6.4 Description of empirical definitions in EA program

The description of the top empirical definitions in EA Program are highlighted in gray in Table 6.4. These denote to the most used quantification combinations in EA program. For instance:

- the only source of input for quantification is the EA practitioners,

- the only used type of input is opinions – perception of present,
- the only used quantification rule is the ordinal scale,
- the only used mathematical operation on input data is transformation of ordinal data to weights, and
- the absence of mathematical operation on output data.

Table 6.4 Description of empirical definitions in EA program

Empirical definition in EA program	Description	Count	Primary studies
Source of input	EA practitioners (CIO, EA architects, system engineers, project managers, experts)	1	S14
Type of input data	Opinions - perception of present	1	S14
Quantification rule	Ordinal scores	1	S14
Math on input data	Score and weight multiplication	1	S14
Math on output data	NA	1	S14
Measurement unit	NA	1	S14

6.5 Discussion about metrology issues and misconceptions

After presenting a synthesis and a description of the quantification techniques, next is a discussion about metrology issues and misconceptions.

6.5.1 Metrology issues about source of input & type of input data

From the empirical definitions in Tables 6.1 to 6.4 the majority of these primary studies attempt to obtain numbers through opinions, and some primary studies use these numbers in statistical analysis models for decision-making purposes. Since these numbers are obtained (e.g., quantified) through opinions they do not qualify from a metrology sense as a measurement exercise. These numbers are subjective: they are dependent on the EA practitioners' opinions, expertise, and are not reproducible nor repeatable. Hence, the numbers obtained in the primary studies that use such source of input data do not have numbers with metrology qualities (e.g., apply admissible mathematical operations), and therefore are limited to labels of ordering the

EA attributes based on EA practitioners' opinion (e.g., will have very limited admissible mathematical operations). In addition, the credibility of these numbers is under question.

In any measurement exercise, the main objective is to acquire knowledge of an entity of interest in the real world. The representational theory of measurement define measurement as the mapping of the real world (empirical) denoting what we want to measure, into the numerical world denoting numbers that represent (characterize) the empirical world. Therefore, the purpose of mapping (measuring) is to obtain numbers that represent the attribute of interest, and ultimately draw conclusions about the entity.

The representational theory of measurement posits that a measurement exercise should follow rules. Of these rules is the ''representation condition of measurement''. The representation condition of measurement asserts that the numbers obtained from the measurement exercise should preserve the properties of the real world. Therefore, by studying these numbers (i.e. measurement results), we can acquire knowledge about the real world. In addition, any measurement exercise that follows the representation condition is called homomorphism (that is there is a correspondence between the empirical and numerical worlds), and thus is a valid measurement (Abran, 2010).

Having said this, this section studies the EA measurement proposals with respect to the representation condition of measurement. Based on Tables 6.1 to 6.4, the quantification techniques used in these primary studies do not quantify the magnitude of the EA attributes per se. Rather; the quantification is performed on the individual opinion (EA practitioners) about EA attributes. Having said this, the theoretically defined EA concepts and attributes (of the real world) are not quantified. Rather they must be considered as latent variables that cannot be measured or quantified directly.

For example, indicator variables of these latent variables are introduced to correspond empirically to the EA latent variables. Therefore, in these EA measurement proposals,

questionnaires are designed to collect data from individuals to express their opinion about the questionnaire items. Having said this, and from a metrology perspective, the numbers that are obtained in these quantification techniques fail to represent the EA attributes of the entities we observe in the real world. Hence, we can deduce that there are missing connections between the theoretical and empirical definitions: what is quantified is not what is theoretically defined. Therefore, the measurement is not an homomorphism.
Some examples of each EA entity type are discussed next. These examples elaborate on the metrology issues about the source of input & type of input data.

Example from EA project:

Figure 6.1 illustrates a model of hypothetical relationships between different EA concepts (e.g., constructs) in primary study [S15]. This conceptual model is created to study the impact of EA principles on EA consistency and EA utility. Based on Tables 6.2 and 6.4 in the metrology coverage chapter, these concepts have some theoretical and empirical coverage scoring. However, a more in depth analysis reveals that the quantification is not performed on quantifying the magnitude of EA utility, nor EA consistency. These concepts are considered latent variables, which cannot be quantified directly. In other words, these are unobservable attributes.

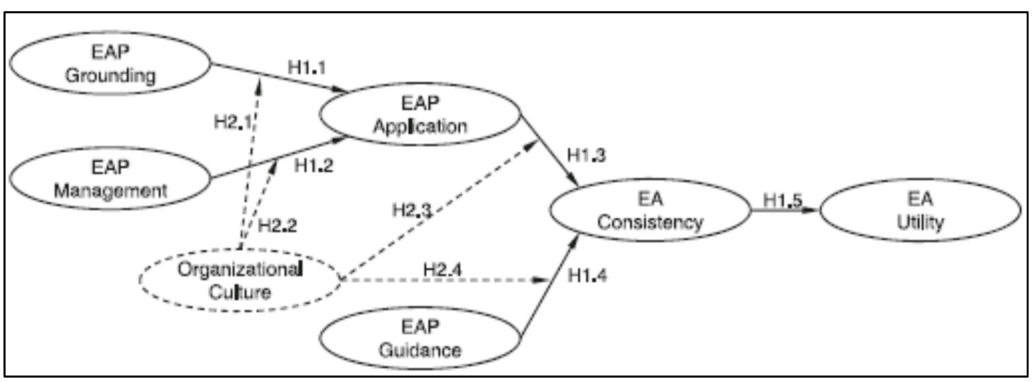

Figure 6.1 Conceptual hypothesis model
Taken from (Aier, 2014)

Therefore, questionnaire items (e.g., indicator variables) are created to account for quantifying the latent variable of EA concepts. Accordingly, EA practitioners involved in the data collection will answer the questionnaire items based on the identified quantification rules.

Table 6.5 presents examples of the primary studies that quantify, according to EA practitioners' opinions, the relationships between EA concepts. The first two columns illustrate the latent variables which the primary studies attempt to quantify. For instance, in [S15], the quantification is performed by the EA practitioners on indicator variables for EA principles & organizational culture and indicator variables for EA success as inputs to the model. Afterwards, the PLS regression analysis is performed to estimate the effect of and between the indicator variables, also known as exogenous (independent) variable and endogenous (dependent). Hence, the ultimate objective is to predict the influence or effect of EA principles & organizational culture on EA success through the indicator variables, and not to quantify the magnitude of EA success in the presence of defined EA principles of a given organizational culture. The same context applies for [S4, S10, S17, S18, S20, S21, and S22].

Having said this, some examples from the EA measurement proposals are presented next. These examples highlight the weaknesses of quantification techniques that do not satisfy the representation condition of measurement.

Example from EA architecture:

Primary study [S5] designed a questionnaire to collect numbers about the quality of EA scenarios and EA practitioners' opinions are used next within an analytic hierarchy process (AHP) to assign weights to different EA scenarios. The ordinal scores obtained from this quantification process represent the EA practitioners' opinions, and therefore do not preserve the properties of the real world: it does not quantify the EA quality per se) but rather quantify the EA practitioners' perception of the future about how the quality of EA scenarios could be.

Table 6.5 Primary studies with & without latent variables

Primary study	**EA project entity (Latent Variable)**	**EA project attribute (Latent variable)**	**Effect between exogenous and endogenous variables (Beta coefficient)**	**Regression (R)**
S1	-	Benefits	x	x
S10	-	EA maturity stage IT alignment Operational IT effectiveness Enterprise agility	x	x
S19	-	-	-	-
S21	-	Agile EA GADA active communication GDAD performance	x	x
S4	EA approach	EA benefits	x	x
S15	EA principles	EA success (EA utility & EA consistency)	x	x
	Organization culture			
S17	EA products	EA practices	x	x
S18	EA management practices	EA success	x	x
S20	Laws & regulations	EA performance	x	x
	Top management support			
	EA management systems			
	EA guidelines			
S22	EA Services	Project benefits	x	x
		Organizational benefits		
S23	EA Models	-	-	-

Example of EA framework:

Primary study [S2] collects information from EA practitioners about the risk of EA scenarios. EA practitioners' opinions are used next in fuzzy functions to assign weights to different EA scenarios. The ordinal scores are based on the results of this quantification process and represent the EA practitioners' opinions: they do not preserve the properties of the real world (i.e. not quantifying the EA risk per se) but quantify the EA practitioners' perception of the future. In other words how the risk of EA framework could be on the organization.

Example of EA program:

Primary study [S14] designed a questionnaire to collect numbers about the readiness of EA programs. EA practitioners' opinions are used within transformation to assign weights about EA program readiness. The ordinal scores representing the EA practitioners' opinions are not preserving the properties of the real world (i.e. not quantifying the EA program readiness per se) but rather quantify the EA practitioners' perceptions of about the how the readiness of EA program is.

To summarize, collecting EA practitioners' opinion about EA attributes might be acceptable to a wide range of people and the resulting numbers of this quantification might satisfy some decision makers. However, from a metrology sense:

- This does not preserve the properties of the entity of interest. Rather, the measured entity does not belong to the same EA entity anymore: the entity is the EA practitioner, and the attribute is the perception of the EA practitioner. Quantifying the perception of EA practitioners is not equivalent to measuring (or quantifying) EA entities and EA attributes – See Figure 6.2.

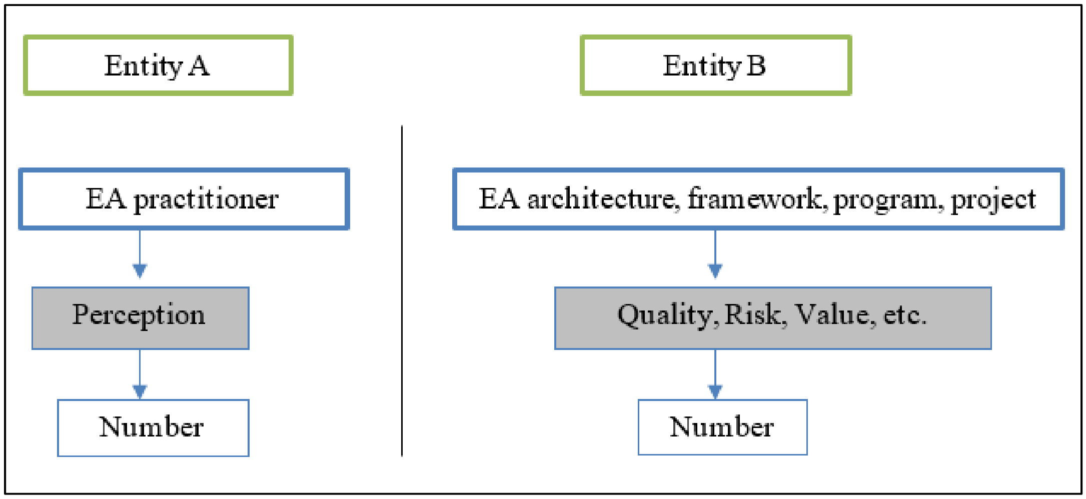

Figure 6.2 Quantifying Entity A is not as quantifying Entity B

- Such input data is dependent on time (i.e. EA practitioner's opinion might change a week later) and the environment they are made.

6.5.2 Metrology issues: mathematical operations on input data, quantification rules, and measurement units

As discussed earlier, the representational theory of measurement defines measurement as mapping the real world (empirical) denoting what we want to measure, into the numerical world denoting numbers that represent (characterize) the empirical world. Therefore, the purpose of mapping is to obtain numbers to represent the attribute under concern, and draw timely conclusions.

An example of the empirical world is the comparison between the heights of two (2) different people. For instance, we can observe that two people have the same height or that (person X) is taller than (person Y) is. Therefore, this empirical description can be followed with a measurement exercise to assign numbers (height) to (person X) and (person Y).

The representational theory of measurement posits that there are rules that should be followed and respected in performing measurement. These rules will facilitate the interpretation of the measurement results (numbers), and allow consistency (e.g., not adding 2 numbers with two different scale types) in the conduct of the measurement exercise (Abran, 2010) (Fenton & Bieman, 2015). The first rule (i.e. representation condition) was discussed earlier in the previous section. The second is the rule of mapping and can be summarised as follows:

- Rule of mapping: the quantification rules that map an attribute to a numerical world need to be identified, and respected. For instance, measuring the height of a person in centimeters (e.g., 170 cm), or transforming this (170 cm) to another measurement scale/unit (meters) by mapping to another numerical world through a mathematical system. Therefore, the quantification rules entail that the mapping should be a number, on a measurement scale type, and with a measurement unit. Furthermore, the mathematical operations applied on numbers should follow the rules of measurement scale type.

That is, the measurement scale type indicates the type of admissible mathematical operations to be accomplished (Abran, 2010) and there are five (5) measurement scale types:

1. Nominal,
2. Interval,
3. Ordinal,
4. Ration, and
5. Absolute

The properties of the measurement scale types and the corresponding admissible mathematical operations on these scales are shown in Tables 6.6 and 6.7: for example, nominal and ordinal measurement scale types do not represent numerical values on ratio scales and therefore, mathematical operations such as multiplication and parametric statistics (that require Gaussian assumption) are not allowed.

Table 6.6 Properties of scale types
Taken from Abran (2010, p.114)

Scale type	Description
Nominal	This scale type is used to name objects or events. It is used only in identifying requirements, and the only quantitative notion associated with it is that of equality. Only non-parametric statistics can be used.
Ordinal	This scale type is used to put objects in order, based on a criterion that may be subjective, but it is preferably objective. Ranking order statistics can be used, as well as those that apply to the nominal scale.
Interval	This scale type (also called the cardinal scale) is used to determine the difference between ranks. It is a continuum between two points which are not necessarily fixed. With this scale, objects can be distinguished and ranked; moreover, the differences between the ranks can be measured. The mathematical average can be used, as well as all the statistical methods that apply to the ordinal scale.
Ratio	In this scale type, it is significant to multiply a measurement by a non-negative value. It is then possible to say that an item X has *n* times the value of item Y with respect to a given attribute. It follows from this that the value zero has a special significance for that attribute. This allows us to distinguish a ratio scale from an interval scale. The calculation of percentages is allowed, as well as all the statistical methods that apply to the interval scale.
Absolute	The absolute scale type possesses a unique origin from which to start the measurement process. This allows us to count entities, and there is only one way to do this [Fenton, 1991]. Here, only the *identity* transformation ($f(x) = x$) is admissible. All the statistical methods for the previous types of scale apply.

Table 6.7 Measurement scale types and admissible transformations
Taken from Abran (2010, p.169)

Scale type	Admissible Transformation	Operations	Examples	
Nominal	(R,=)	f unique	Name, distinguish	Colors, shapes
Ordinal	(R,>=)	f strictly increasing monotonic function	Rank, Order	Preference, hardness
Interval	(R,>=,+)	f(x)= ax + b, a > 0	Add	Calendar time, temperature (degrees Celsius)
Ratio	(R,>=,+)	f(x) = ax, a > 0	Add, multiply, divide	Mass, distance, absolute temperature (degrees Kelvin)
Absolute	(R,>=,+)	f(x) = x	Add, multiply, divide	Entity count

Based on these rules, a number of issues in EA measurement proposals that describe more weaknesses are identified and discussed next, grouped per EA entity type.

6.5.2.1 Issues in EA project measurement proposals

Figure 6.3 summarizes the quantification process on how EA project concepts and attributes are quantified: the majority of the quantification rules are performed through assigning ordinal scale data to EA concepts and attributes. These ordinal scale data are afterwards used in statistical analysis models such as partial least square (PLS).

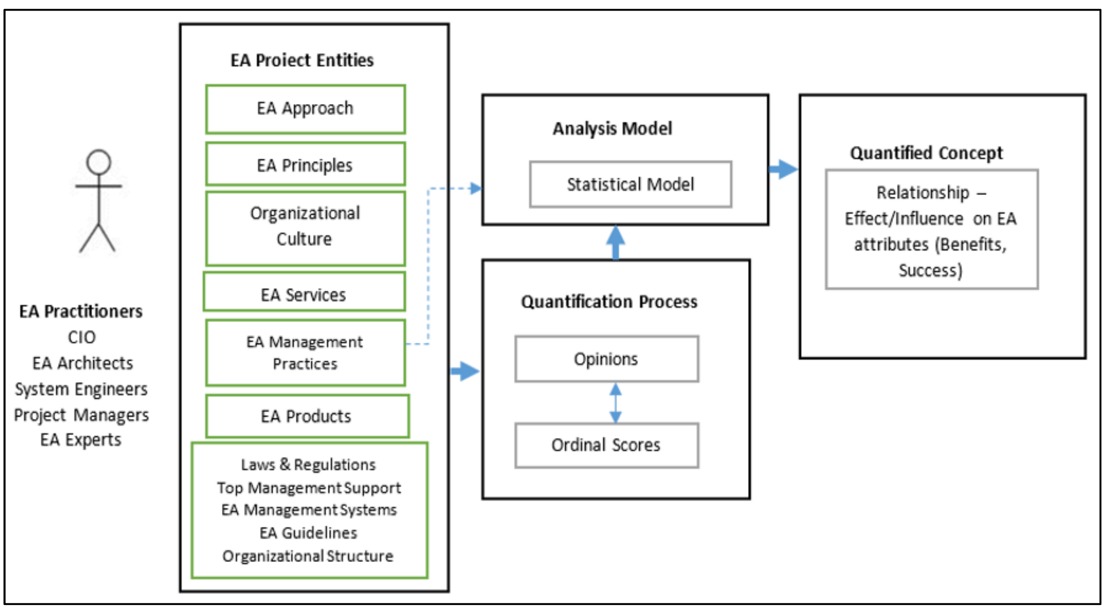

Figure 6.3 Quantification scheme in EA Projects

PLS, as any other statistical analysis techniques, uses arithmetic operations (i.e. addition, subtraction, multiplication, and division): for instance, in the PLS algorithm, there are steps that use arithmetic operations to calculate mean, standard deviation and, therefore, calculate the covariance between the constructs of the PLS model. Since the ordinal scale data are not numeric from a metrology sense, whereas based on Table 6.7 mathematical operations on ordinal scale type is limited to ranking and ordering, the mathematical operations in PLS using the ordinal scale type may not be admissible, and would therefore lead to an unspecified scale type for the outputs.

Some research papers posit that PLS is nonparametric: it works without distributional assumptions (such as normal distribution) and with nominal and ordinal scale variables (Michael Haenlein, 2004). However, (Russolillo, 2009) posits that handling categorical variables (nominal and ordinal scale type) is still an open issue in all PLS methodologies, and that PLS is mainly designed to handle variables on a ratio scale type.

Table 6.8 describes the measurement scale types in EA projects as follows: the input data, transformation scale type, admissible transformation, and the output scale type:

- All the input data of ordinal scale type have unspecified transformation scale, admissible transformation, and output scale type, and
- Only one (1) primary study [S1] is clear about the measurement scale type (ratio) of its inputs and outputs.

Table 6.8 Measurement scale types for EA projects

Primary study	**Measurement scale types**			
	Input scale	**Transformation scale**	**Admissible scale transformation**	**Output scale**
S1	ratio	NA	NA	ratio
S4	ordinal	unspecified	unspecified	unspecified
S10	ordinal	unspecified	unspecified	unspecified
S15	ordinal	unspecified	unspecified	unspecified
S17	ordinal	unspecified	unspecified	unspecified
S19	ordinal	unspecified	unspecified	unspecified
S20	ordinal	unspecified	unspecified	unspecified
S21	unspecified	unspecified	unspecified	unspecified
S22	unspecified	unspecified	unspecified	unspecified
S23	ratio	unspecified	unspecified	unspecified

Measurement unit is another metrology criterion that should be respected. From a metrology sense, any number requires a reference (Abran, 2010). Measurement unit (as a reference) will improve the understanding of the number, and therefore, the measurement will become meaningful. For example, if we say that the temperature is 30. This is only a number, and it is hard to understand it and use it for decisions. For instance, it is not clear if it is 30 Celsius or 30 Fahrenheit. However, if we say the temperature is 30 Celsius, then this is meaningful and using it for decisions about what cloth to wear is easier.

Table 6.9 shows the measurement units for input data, transformation unit if any, and for the output data of EA projects. The results show the follows:

- measurement unit is specified in only 1 primary study (S1) for input and output data,
- measurement unit label in (S23), is specified for output data, but unspecified for its input data, and
- measurement unit is unspecified for the majority of the primary studies.

From Tables 6.8 and 6.9, it is clear that there are weaknesses in specifying and correctly using the measurement scale type and units. Hence, these weaknesses affect the credibility of these numbers. These numbers are meaningless when derived from inadmissible mathematical operations. Inadmissible mathematical operations means that the measurement units and measurement scale types are not considered correctly within the mathematical operations (Abran, 2010).

Table 6.9 Measurement units in EA project

Primary study	**Measurement units**		
	Input unit	**Transformation unit**	**Output unit**
S1	$	NA	$
S4	unspecified	unspecified	unspecified
S10	unspecified	unspecified	unspecified
S15	unspecified	unspecified	unspecified
S17	unspecified	unspecified	unspecified

Table 6.9 Measurement units in EA project (continued)

Primary study	Measurement units		
	Input unit	Transformation unit	Output unit
S19	unspecified	unspecified	unspecified
S20	unspecified	unspecified	unspecified
S21	unspecified	unspecified	unspecified
S22	unspecified	unspecified	unspecified
S23	unspecified	unspecified	SCU

6.5.2.2 Issues in EA project measurement proposals

To understand how EA architecture concepts and attributes are quantified, Figure 6.4 summarizes the quantification process: the quantification rules are performed through assigning ordinal scale and counting numbers to EA concepts and attributes. These numbers are next taken as inputs to in-house formulas (i.e. formulas limited to the primary study), and fuzzy transformation(s).

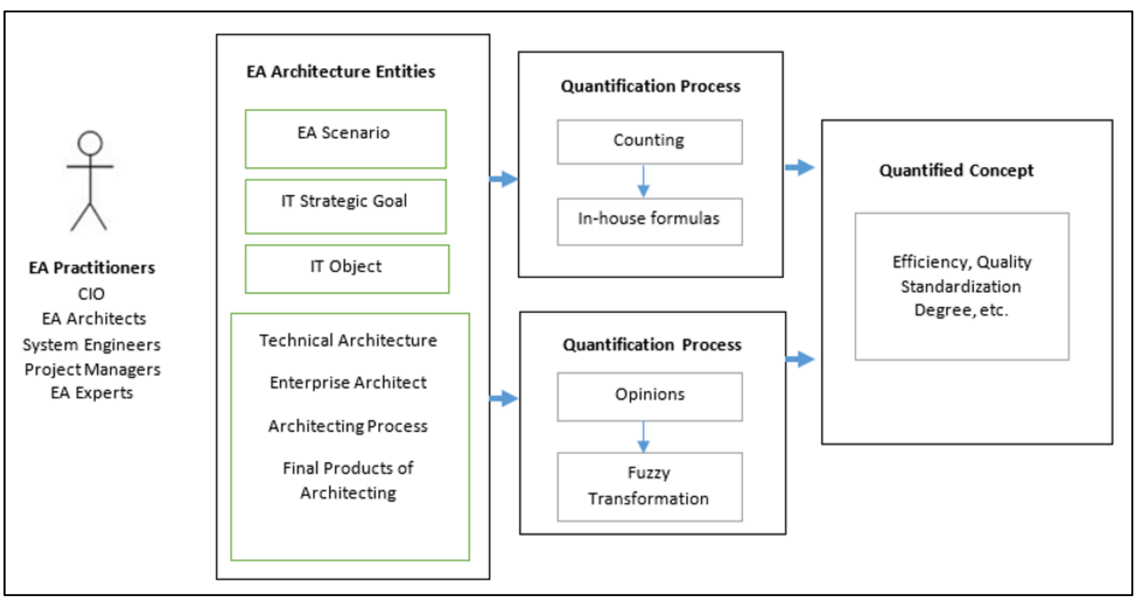

Figure 6.4 Quantification scheme in EA architecture

Table 6.10 describes next the measurement scale types in EA architecture, including: the input data, transformation scale type, admissible transformation, and the output scale type. In summary:

- three (3) of the input data of ordinal scale type have unspecified transformation scale, admissible transformation, and output scale type;
- two (2) primary studies [S9, S11] assign numbers through counting some elements. Therefore, the input data is on a ratio scale. In addition, the scale of the output data is on a ratio scale.

Table 6.10 Measurement scale types for EA architecture

Primary study	Measurement scale types			
	Input scale	**Transformation scale**	**Admissible scale transformation**	**Output scale**
S3	ordinal	unspecified	unspecified	unspecified
S5	ordinal	unspecified	unspecified	unspecified
S6	ordinal	unspecified	unspecified	unspecified
S9	ratio	unspecified	unspecified	ratio
S11	ratio	unspecified	unspecified	ratio

Table 6.11 shows next that no primary study has specified a measurement unit.

Table 6.11 Measurement units in EA architecture

Primary study	Measurement units		
	Input unit	**Transformation unit**	**Output unit**
S3	unspecified	unspecified	unspecified
S5	unspecified	unspecified	unspecified
S6	unspecified	unspecified	unspecified
S9	applications, business processes	unspecified	unspecified
S11	unspecified	unspecified	unspecified

From Tables 6.10 and 6.11, it is clear that there are a number of major weaknesses in these studies in terms of specifying and correctly using measurement scale type and units for the variables to be quantified and measured.

6.5.2.3 Issues in EA project measurement proposals

To understand how EA architecture concepts and attributes are quantified, Figure 6.5 summarizes the quantification process in primary studies on EA frameworks: the quantification rules are performed through assigning ordinal scale to EA concepts and attributes. These numbers are next used as the inputs to scores and weights multiplication and fuzzy transformations.

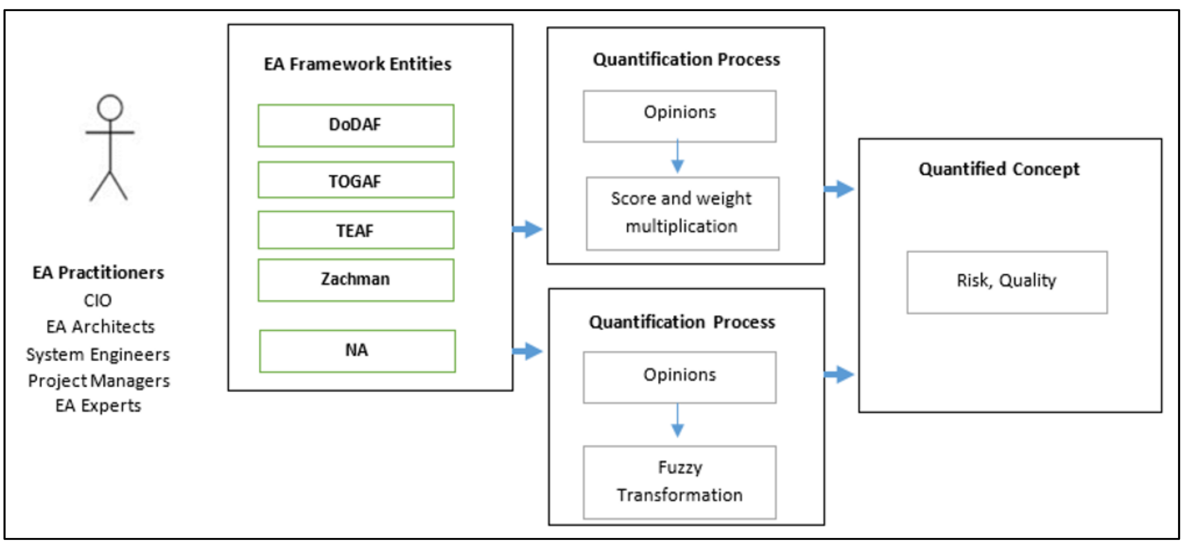

Figure 6.5 Quantification scheme in EA framework

Table 6.12 describe summarizes the measurement scale types in EA framework, including the input data, transformation scale type, admissible transformation, and the output scale type. The description shows the following:

- Both input data of ordinal and interval scale types have unspecified transformation scale, admissible transformation, and output scale type.

Table 6.12 Measurement scale types for EA framework

Primary study	Measurement scale types			
	Input scale	**Transformation scale**	**Admissible scale transformation**	**Output scale**
S2	interval	unspecified	unspecified	unspecified
S8	ordinal	unspecified	unspecified	unspecified

Table 6.13 shows next that no primary study has specified a measurement unit.

Table 6.13 Measurement units in EA framework

Primary study	Measurement units		
	Input unit	**Transformation unit**	**Output unit**
S2	unspecified	unspecified	unspecified
S8	unspecified	unspecified	unspecified

6.5.2.4 Issues in EA project measurement proposals

To understand how EA program concepts and attributes are quantified, Figure 6.6 summarizes the quantification process. The quantification rules are performed through assigning ordinal scale to EA concepts and attributes and these numbers are the inputs to scores and weights multiplication.

Table 6.14 describes next the measurement scale types in EA framework. In summary, again the input data of ordinal and interval scale types have unspecified transformation scale, admissible transformation, and output scale type.

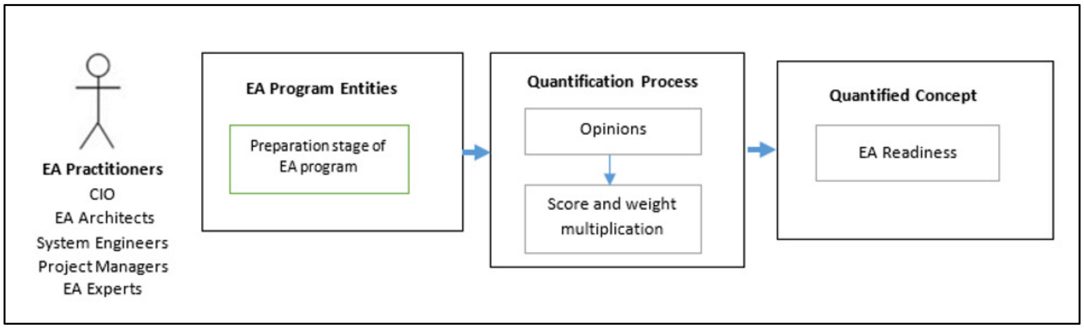

Figure 6.6 Quantification scheme in EA program

Table 6.14 Measurement scale types for EA Program

Primary study	Measurement scale types			
	Input scale	Transformation scale	Admissible scale transformation	Output scale
S14	ordinal	unspecified	unspecified	unspecified

6.6 Examples of metrology issues in EA measurement proposals

The more detailed analysis on the empirical definitions of EA measurement proposals has revealed that there are hidden weaknesses from a metrology perspective. To elaborate on these weaknesses, some additional examples of metrology issues found in the primary studies that obtained high metrology coverage scoring in chapter 5 are presented next.

6.6.1 EA complexity formula

Primary study [S23] proposes a quantification technique to measure the structural complexity of EA. The quantification technique is performed on a multilevel EA model: e.g., from a metrology perspective, it attempts to quantify the complexity of different EA entities (e.g., EA roadmap, EA target architecture, and EA solution architecture) – see Figure 6.7.

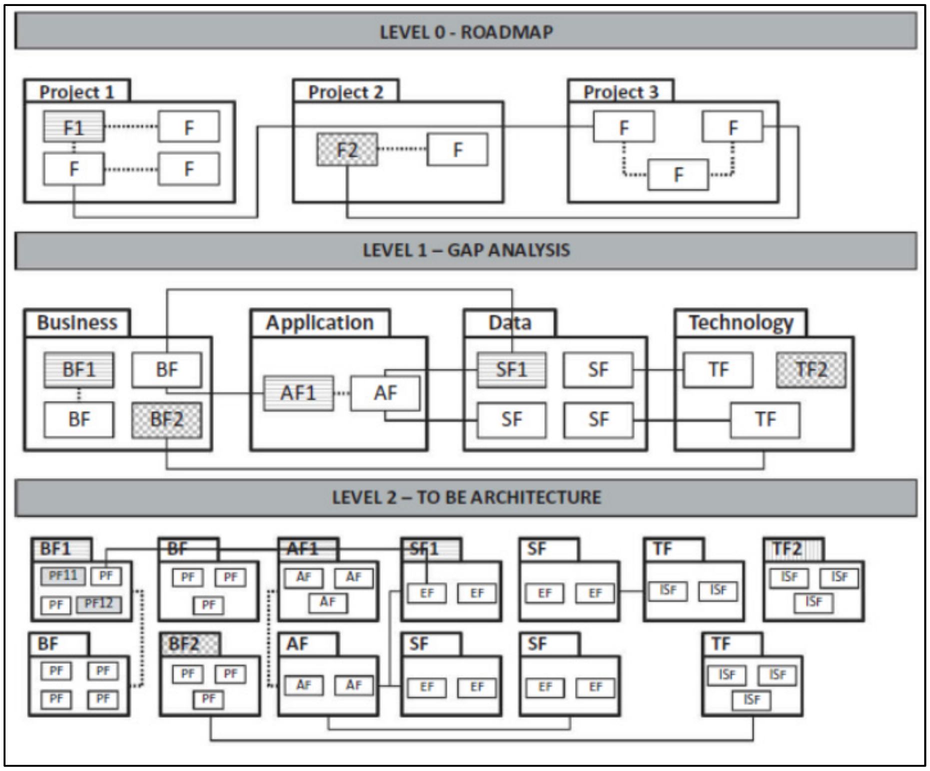

Figure 6.7 Proposed EA model to calculate complexity [S23]
Taken from (González-Rojas *et al.*, 2017)

The proposed mathematical formula to calculate the complexity of EA entities is based on (Sessions, 2011) and is expressed using the arithmetic addition operation on two (2) attributes: functionality (F) and dependency (D) – See Equation (6.1).

$$Structural\ Complexity\ (SCU) = F^{3.11} + D^{3.11} \tag{6.1}$$

The inputs to the equation are the counts of the number of functionalities (F) and dependencies (D) in each EA entity. The result of this equation is claimed to be a number with a structural complexity unit referred to as SCU.

The data gathered from this formula of EA entities complexity are used next in data analysis: for instance, to perform an analysis between different designs of solutions (proposal 1 and proposal 2) based on these complexity numbers – See Figure 6.8 with a log-scale vertical axis. Such analysis may lead to various conclusions, such as for level zero (i.e. EA roadmap), proposal 1 (i.e. 385 SCUs) is approximately three times more 'complex' than the design of proposal 2 (i.e.137 SCUs).

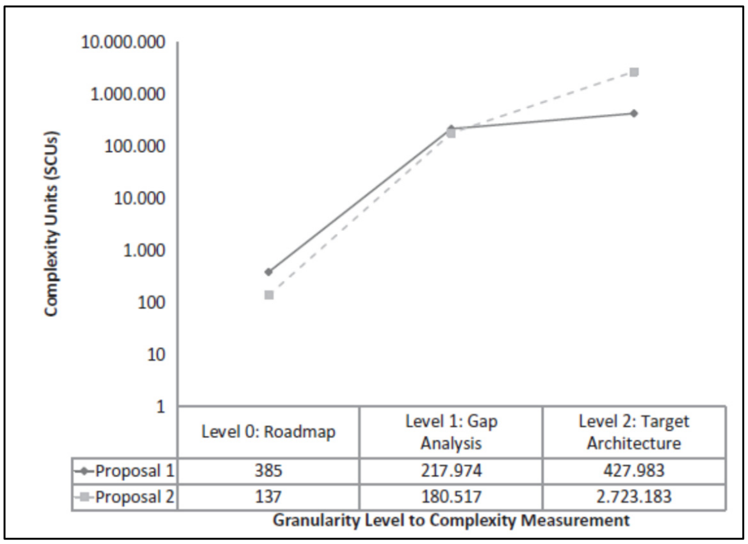

Figure 6.8 EA complexity results from [S23]
Taken from (González-Rojas *et al.*, 2017)

However, such conclusions and analysis are not precise and might lead to risky and costly decisions: adding the "functionalities" to "dependencies" is an improper usage of additions of distinct measurement units. Assuming that "functionalities" has unit (F) and "dependencies" has a unit (D), then adding them together will not derive a new complexity unit (SCU). It is not theoretically proven how the complexity unit (SCU) is derived from the addition of "functionalities" and "dependencies" – See Equation (6.2).

$$Structural\ \ Complexity\ (SCU\ ?) = F^{3.11}(unit?) + D^{3.11}(unit?) \tag{6.2}$$

It is assumed (but not proven) within the primary study that the outputs of the equation are on a ratio scale. Furthermore, the mathematical validity of the equation itself is not supported and to the present time, this is still a major issue. Therefore, any usage of numbers derived from such a formula is fraught with dangers.

6.6.2 In-house formulas & score weights computations

This section discusses the following quantification techniques of in-house formulae proposed and their usage in scores and weights computations:

- In-house formulae: these refer to formulae that are locally proposed in primary studies, and are not internationally standardized.

  For example: [S9] proposes computation formulae for EA quality. In order to quantify EA quality, the quality is characterized and assigned possible EA quality metrics. For example: In order to quantify “usability,” the “possible client application (PCAF)” metric is proposed in Equation (6.3).

$$(PCAF) = 1 - \frac{\#\ IT\ Applications}{\sum_{i=1} IT\ Applications\ \times\ NPCA} \tag{6.3}$$

Where, NPCA stands for the number of possible client application families that can work with the IT application.

Looking carefully to the PCAF formula, the following issues can be noticed:

1. The numerator is a number with unspecified explicit measurement unit in the primary study. However, for the sake of the example, we assume the measurement unit is (applications). Example: 10 applications (unit). Note: unit1 and unit2 are hypothetical measurement units for the sake of the example.
2. The denominator is a mix of the multiplication of two (2) measurement units: applications and families of applications.

$$(PCAF\ ) = 1 - \frac{\#\ IT\ Applications\ (unit\ 1)}{\sum_{i=1} IT\ Applications\ (unit\ 1)\ \times\ NPCA\ (unit\ 2)} \tag{6.4}$$

3. The resulting number of this formula is a number with no measurement unit

$$(PCAF\ unit: ?\ ) = 1 - \frac{''applications''\ (unit\ 1)}{?} \tag{6.5}$$

The same weakness holds true for the other formulae is primary study [S9].

Primary study [S11] proposes a computation formula to quantify the standardization of IT objects (ITO) in IT landscapes. To learn more about the ITO and be able to quantify it, the quantification technique proposed in [S11] takes into account the lifecycle of the ITO. The lifecycle of an ITO can be:

- Proposed: meaning the ITO is suggested to replace an existing ITO,
- Test: meaning an ITO in the testing phase,
- Productive: meaning the ITO is integrated part of the application, and
- Standard: meaning the ITO is officially released and can be used by other applications.

The following computation formula for ITO standardization degree (SD) is proposed next:

$$(SD) = \begin{cases} \dfrac{\sum_{ITO \in K} g_{ITO}\ \ \delta_{ITO}}{ST_{sub} + Prod_{sub}}, & if\ 1 \leq ST_{sub} \leq 2 \\ 0, & otherwise \end{cases} \tag{6.6}$$

Where, ST_{sub} is defined as the number of ITO(s) that have the standard lifecycle status, and $Prod_{sub}$ is defined as the number of ITO(s) that have the productive lifecycle status.

Where, δ_{ITO} (retrieves the status of an ITO), and is defined for each ITO such that:

$$\delta_{ITO} = \begin{cases} 1, & if\ status\ (ITO) = standard\ or\ productive \\ 0, & otherwise \end{cases} \tag{6.7}$$

Where, g_{ITO} is defined for each ITO such that:

$$g_{ITO} = \begin{cases} 1, & if\ status\ (ITO) = standard \\ gP_{ITO}, & if\ status\ (ITO) = productive \end{cases} \tag{6.8}$$

It is worth noticing that the process of determining the lifecycle status of the ITO is subjective and includes no objective measurement. The status of the ITO is decided through a subjective process between EA architects and the management team. The process is an analysis phase to answer questions such as “is there an actual need for a new ITO or can the demands be met by an already existing object or is the request of a strategic importance?”

Where, gP_{ITO} (retrieves the contribution of an ITO), and is defined for each productive ITO such that:

$$gP_{ITO} = \begin{cases} 0, \quad if \quad \dfrac{\#applications\ | ITO\ \in application}{\#\ applications} \leq TV \\ \\ \dfrac{\#applications\ | ITO\ \in application}{\#\ applications}, \quad otherwise \end{cases} \tag{6.9}$$

Where TV is a threshold value set subjectively by enterprise architects based on their perceptions of business requirements. In this primary study, it is set at 0.05.

The analysis of the structure of the $SD\ (K)$ formula, and taking into account the other formulae that substitute in and form the $SD\ (K)$ formula, allows identifying the following issues:

1. The numerator is a number resulting from multiplying two variables δ_{ITO} and g_{ITO} , where:
    a. variable δ_{ITO} is assigned numbers as labels (1 or 0) based on the categories (standard, productive or otherwise) of the ITO. This label number represents that status of the ITO, and is afterwards used in addition and multiplication,
    b. variable g_{ITO} is assigned numbers as labels (1 or 0) based on the categories (standard or productive) of the ITO. This label number represents the contribution of the ITO in applications, and is afterwards used in addition and multiplication, and
    c. variable gP_{ITO} is 1 if the status is standard, fraction if the status is productive, and zero if ITO contribution is less than TV.

Therefore, the numerator is the product of two (2) possible measurement units that capture distinct attributes about an ITO. One represents the contribution of the ITO in applications, and the second represents the status of the ITO. It is unspecified if the resulting number of this multiplication has a measurement unit,

$$(SD) = \begin{cases} \frac{\sum_{ITO \in K} (contribution\ of\ ITO\ in\ applications)\ (status\ of\ ITO)}{standarized\ ITOs + productive\ ITOs}, & if\ 1 \leq ST_{sub} \leq 2 \\ 0, & otherwise \end{cases} \qquad (6.10)$$

2. The denominator in $SD\ (K)$ formula is a number resulting from the addition of the same measurement unit (ITO). Example: 10 standardized ITOs + 5 productive ITOs = 25 ITOs. However, with a loss of information about the status of the ITOs.

3. The resulting number of the $SD\ (K)$ formula is a percentage between (0 and 1). However, the percentage should be the result of two numbers on the same measurement unit. Which is not the case in this primary study.
4. Furthermore, not to underestimate the weakness of the subjective inputs to these formulas. Therefore, the same ITO might result with different standardization degrees.

5. Scores and weights computations: this refers to calculations that include arithmetic operations on ordinal scale type in order to calculate a score and a weight for some EA indicators.

As an example of this, primary study [S14] attempts to quantify the EA readiness. The quantification technique starts from using a Likert scale (ordinal scale from 1-5) in order to assign numbers to EA indicators. Next, the following numbers are calculated:

1. Weighted mean for each EA indicator.
2. A score for each EA indicator.
3. Both, the weighted mean and the score are derived using the Likert scale; however, no calculations are presented that support the derived numbers.
4. For each EA indicator, the score and the weight are multiplied.
5. The score of the EA factor is derived through the addition (sum) of the indicators weight and scores.

From the analysis of the structure of these calculations, the following issues are noticed:

1. the transformation of the ordinal scale type to weights is not valid, and therefore, it is an inadmissible mathematical operation,
2. all the related calculations that follow point number one (1) is therefore inadmissible mathematical operation, and
3. the related conclusions made of using these numbers are not mathematically valid when considering the scale types.

6.6.3 Analytic hierarchy process (AHP)

AHP is a multi-criteria decision making technique used to evaluate different elements based on pairwise comparison between the variables. The comparison in AHP is based on evaluating which of the variables (i,j) is more important and by how much more important. The evaluation is done based on a certain scale, and the scale is an ordinal scale type – see Figure 6.9.

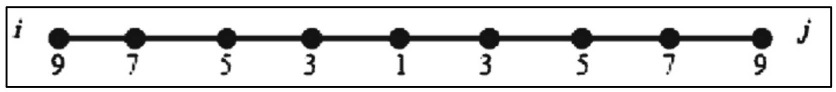

Figure 6.9 AHP scale for comparison [S5]
Taken from (Razavi, Aliee, & Badie, 2011)

There are rules (quantification rules) in AHP that assist in the pairwise comparison. Each point in the scale has different meanings, for example:

- Select (1) if both variables are of an equal importance,
- Select (3) if one variable is slightly more important,
- Select (5) if one variable is highly more important,
- Select (7) if one variable is very highly more important, and
- Select (9) if one variable is extremely more important.

In EA, primary study [S5] proposes a quantification technique to measure (quantify) EA views, and EA quality attributes (maintainability and interoperability). The quantification technique is based on AHP, and the result of this quantification is assigning numbers to EA attributes, and decides about the best EA scenario (architecture) based on these numbers.

The data collection in the primary study is based on a questionnaire. The numbers in the questionnaire are obtained through a pairwise comparison based on the subjective opinion of the EA practitioner. Next, the numbers are used in matrices that involve arithmetic operations to calculate the relative weights of the different variables.

The primary study uses the ordinal scale in Figure 6.9 as the basis of all the calculations. For example, in one of the steps, the primary study produces importance (weights) of EA views in the context of the EA attributes. Figure 6.10 show the weights of each EA view in the context of EA maintainability. The weights are derived from the ordinal scale through applying arithmetic operations to obtain the weighted average for the EA views, in other words, the priority of the EA views.

Architecture view	Weight
Business architecture view	0.49
Data architecture view	0.31
Software architecture view	0.15
Technology architecture view	0.05

Figure 6.10 Prioritized list of EA views in the context of EA maintainability [S5]
Taken from (Razavi *et al*., 2011)

From a metrology perspective, what does not make sense is the mathematical transformation from ordinal to ratio scale type. AHP, as other multi-criteria and outranking techniques, is considered to represent inadmissible mathematical operations and (Fenton & Bieman, 2015) posits that AHP and other multi-criteria and outranking techniques do not depend on well-defined and meaningful transformations.

Moreover, none of the steps in AHP specifies a measurement unit. Therefore, in the context of EA, it is still not supported whether the EA measurement proposal on EA quality that depend on AHP is valid or not, and if the related numbers and conclusions are meaningful and trustworthy.

6.6.4 The DEA model

The DEA model is a benchmarking technique that deals with evaluating the efficiency of different decision-making units (DMUs), also known as alternatives; DEA is considered as one the success stories in operation research (Bouyssou, 1999): it is used in productivity analysis and it aims to minimise the inputs and maximise the outputs using linear programming.

In EA measurement proposals, one primary study [S3] is proposing the DEA model as a possible solution that can assist in selecting the right (most efficient) EA scenarios (architectures).

The EA practitioners are asked to express their opinion about EA scenario outputs in terms of the Control Objectives for Information and Related Technologies (COBIT) – such as (define a strategic IT plan, define the information architecture, manage IT investment, etc.)

The quantification technique starts from considering EA scenarios as the decision-making units. Next, EA practitioners' express their opinion about the EA scenarios based on a fuzzy format [0-10]. Next, EA practitioners' opinions are used in arithmetic operations to obtain efficiency scores.

$$\text{Ideal EA scenario efficiency} = \sum_{r=1}^{k} u_r {y^s}_{ro} \tag{6.11}$$

Where, u_r is the weight of the rth EA output according to sth expert opinion. And ${y^s}_{ro}$ is the jth output of DMU according to the sth expert opinion.

Based on Equation 6.11, the ideal efficiency scores of EA scenario according to EA practitioner for instance can be (Efficiency= 0.81), and the rank of the EA scenario can be (Rank=9)

That is, the efficiency of the EA scenarios (DMUs) is a number. However, the following issues are noticed about this number:

1. It is unclear in the primary study how u_r (the weight of the rth EA output according to sth expert opinion) is calculated. In other words, it is not clear if the weight is a number obtained using an admissible mathematical operation.

2. It is unclear in the primary study what is the scale type of ${y^s}_{ro}$ (the j[th] output of DMU according to the s[th] expert opinion).
3. It is unclear if the arithmetic operation between u_r and ${y^s}_{ro}$ is an admissible mathematical operation.
4. It is unspecified how EA practitioners' fuzzy opinion is transformed to this efficiency score number. The efficiency score number might seem to be on a ratio scale; however, it is unspecified in the primary study.
5. It is unspecified if the efficiency score number is assigned a reference measurement unit. Therefore, the number is meaningless from a metrology sense, and it is hard to interpret it.

Based on the observed issues above, we deduce that there are weaknesses from a metrology sense in using DEA model in related EA quantifications. Furthermore, we support this observation with the remark of (Bouyssou, 1999) about DEA where the manipulations are supposed to be measured on interval (or ratio) scale types and, if not, this raises serious conceptual and computational difficulties.

6.6.5 Fuzzy transformation

Fuzzy logic was first developed by Zadeh in 1965 to address problems related to fuzzy phenomena. In a universe of discourse X, a fuzzy subset Ã of X is defined with a membership function that maps each element in X to a real number in the interval [0, 1]. The membership function assigns numbers (degrees of truth) for each element in X. This is the opposite of crisp numbers, where the mapping is not to an interval of [0, 1], but rather to a Boolean data set (0, 1).

Fuzzy logic deals with fuzzy phenomena such as handling the verbal expressions and linguistic variables of human subjective opinions. In EA measurement proposals, it is found that the data are not crisp data. In other words, human subjective opinions (not crisp) are the main inputs to most quantification techniques. Therefore, some primary studies propose to use Fuzzy logic, with trapezoidal fuzzy numbers, in order to quantify some EA concepts. For instance, the trapezoidal fuzzy number of $700 can be (690, 700, 701, or 702). However, the crisp number for $700 is (700, 700, 700, 700).

Primary study [S2] proposes a multi-criterion quantification technique based on Fuzzy logic. The objective in S2 is to quantify the risk of EA frameworks, and be able to select the right EA framework. The steps of the quantification technique in [S2] can be summarised as follows:

Step 1. Have EA practitioners estimate subjectively the impact, probability of occurrence and probability of detection of certain risks involved in the selection of EA frameworks.

Example: estimate the ‘’impact value’’ of EA frameworks: EA practitioners uses a fuzzy set [1–10] to assign an impact number (I) to each EA framework, where the inputs are trapezoidal fuzzy number. The same fuzzy set [1–10] is used to estimate the probability of occurrence and probability of detection of EA risks.

Step 2. Aggregate across EA practitioners by forming a weighted average of EA practitioners' opinions. Example: constructing the fuzzy weighted collective EA framework. The following formula is applied in order to calculate the impact value:

$$Weighted\ Impact(I) = \frac{\sum_{k=1}^{l}(w(vp)_k)\ [\tilde{e}\ (I)]}{\sum_{k=1}^{l}(w(vp)_k)} \tag{6.12}$$

Such that, $[\tilde{e}\ (I)]$ is the trapezoidal fuzzy number for the impact of a given EA risk, and $(w(vp)_k$ is the voting power of EA practitioners.

Next is an illustrative example to understand the formula:

1. Assume that 5 and 4 represent the voting power of the EA practitioners with a measurement unit labelled “voting power”,

2. Assume that 1 and 2 represent the impact of EA risk based on EA practitioners opinion with a measurement unit labelled “impact”,

The resulting formula is as following:

$$Weighted\ Impact\ (I) = \frac{(5_{voting\ power} \times 1_{impact}) + (4_{voting\ power} \times 2_{impact})}{9_{voting\ power}} \qquad (6.13)$$

Looking carefully to the weighted impact formula, the following issues can be noticed:

1. The nominator is a result of unknown measurement unit. Multiplying voting power by impact will result into a number with unspecified measurement unit.
2. The division of unspecified measurement unit by the voting power will result into a number with unspecified measurement unit.
3. The resulting number might seem to be on a ratio scale: however, it is meaningless and hard to interpret. For instance, in the example, the result of this formula is 1.44. However, what does it mean?

$$Weighted\ Impact\ (I_{unit:\,?}) = \frac{(5_{unit:\,?}) + (8_{unit:\,?})}{9_{voting\ power}} = 1.44 \qquad (6.14)$$

The same issue in calculating the impact of EA risk holds true for calculating the detection and likelihood values of EA risk.

Step 3. Constructing the fuzzy risk priority number (RPN) matrix using the following formula:

$$RPN = \tilde{e}\ (I) \times \tilde{e}\ (L) \times \tilde{e}\ (D) \qquad (6.15)$$

Where, $\tilde{e}\ (L)$ is the likelihood values of the EA framework, and $\tilde{e}\ (D)$ is the detection values of the EA framework. Both (i.e. the likelihood and detection values) are calculated using a formula similar to formula (6.12). Therefore, have the same metrological weaknesses.

Since the inputs to this formula depend on the calculations performed in the previous step (i.e. step 2), then the rpn will not produce a meaningful number from a metrology sense. For example:

- The RPN of organization risk for EA framework (FEAF) = 5.44, and
- The RPN of user risk for EA framework (FEAF) = 4.50.

What decision can we make out of these numbers if the meaning and the resulting measurement scale type are unknown? Can these two numbers be compared from a metrology sense?

Therefore, is it unknown if the mathematical operations are admissible or not. In addition, the consecutive steps in [S2] mix different measurement scale types. For instance, based on the ordinal rank matrix, the weighed vector of EA framework risks is produced. The transformation from the ordinal scale type to the ratio (assuming it is ratio) is not supported. Therefore, the resulting numbers are of an unspecified scale type, and unspecified measurement unit.

6.6.6 Measuring EA financial returns

EA financial returns are expected to result in more benefits, fewer costs, and more return on investments (ROI) for organizations. Therefore, EA financial indicators are proposed in primary study [S1] as an attempt to assist in measuring the financial impact of EA projects.

Since this section focuses on the metrology and quantitative aspect of EA financial returns, this subsection presents an analysis of some of the formulas of the proposed financial indicators in primary study [S1].

1. Costs compared to the total money spent on EA, and are measured using the following formula.

$$Costs = \sum_{i=1}^{n} Cost_i \tag{6.16}$$

The input data to this formula in [S1] is the historical data of costs from governments. From a metrology perspective, the formula is valid and performs admissible mathematical operations for the following reasons:

- The input data are on a ratio scale type,
- The input data have a measurement unit (dollars), and
- The output is a number on a ratio scale, with a standard measurement unit (dollars).

2. Benefits compared to the total amount of money gained from EA, and are measured using the following formula.

$$Benefits = \sum_{i=1}^{n} Benefits_i \tag{6.17}$$

The input data to this formula is the historical data of benefits from governments. From a metrology perspective, the formula is valid, and performs admissible mathematical operations for the following reasons:

- The input data are on a ratio scale type,
- The input data have a measurement unit (dollars), and
- The output is a number on a ratio scale, with a standard measurement unit (dollars).

3. Benefit to cost ratio is the ratio of benefits to costs, and is measured using the following formula.

$$Benefit\ to\ cost\ ratio = \frac{Benefits}{Costs} \tag{6.18}$$

The input data to this formula is the historical data of costs and benefits from governments. From a metrology perspective, the formula is valid, and performs admissible mathematical operations for the following reasons:

- The input data are on a ratio scale type,
- The input data have a measurement unit (dollars), and
- The output is a number on a ratio scale, with a standard measurement unit (dollars).

4. Return on investments (ROI) is the ratio of the amount of additional profits produced due to a certain investment, and is measured using the following formula.

$$ROI = \frac{Benefits - Costs}{Costs} \times 100\% \tag{6.19}$$

The input data to this formula is the historical data of costs and benefits from governments. From a metrology perspective, the formula is valid, and performs admissible mathematical operations for the following reasons:

- The input data are on a ratio scale type,
- The input data have a measurement unit (dollars), and
- The output is a number on a ratio scale.

From points (1-4), primary study [S1] is measuring the financial returns of EA based on well-defined EA formulas from a metrology sense. In particular, the formulas are not mixing different measurement scale types, nor mixing different measurement units. Therefore, the metrology coverage in [S1] is relatively high.

This primary study presents next a quantitative estimation technique using log linear regression. Next is a brief discussion on the quality of the estimation model used.
The estimation model in [S1] is used to estimate EA benefits for different government agencies. The input data used to build this model consists of EA costs, benefits, ROI, etc. Next, the resulting estimation technique (log linear regression) is used to estimate the benefits for EA for different government agencies.

According to (Abran, 2015), these statistical estimation techniques use input data and assume that these inputs are correct and reliable. However, these techniques are unable to distinguish unreliable input data from the reliable ones, and the builders of these techniques should ensure that input data are of a high quality (i.e. correct and reliable) by using relevant statistical techniques, for instance to detect and handle adequately statistical outliers in the inputs to these models. Furthermore, (Abran, 2015) highlights for decision makers not to except high quality estimated results when input data is of poor quality.

Some examples of poor quality in the input data can be:

- Input data that consist of numbers with weak metrology properties,
- Input data that consist of numbers with weak statistical properties. For instance, some statistical techniques require input data to be Normally distributed.
- Etc.

Therefore, to ensure that the estimation technique will result in trustworthy outputs, verifying the input data is mandatory. An example is presented next to illustrate the weaknesses of input data identified in the primary study [S1].

A graphical analysis of the input data of [S1] is presented in Figure 6.11 where the horizontal axis (x) represents the actual costs of EA projects and, the vertical axis (y), the actual benefits of EA projects. From Figure 10 the following can be observed (and could be confirmed using one of the statistical tests for outliers mentioned in (Abran, 2015) :

- Points 1 and 3 could be outliers on the vertical axis,
- Point 8 could be an outlier on the horizontal axis, and
- The sample size is relatively small (e.g., much less than 30).

Therefore, input data with outliers is not a high quality data set, and will suggest that the corresponding variable(s) is not Normally distributed. The resulting estimation technique based on not normally distributed data would be weak within the ranges of data values with very few corresponding data points in the input data, and may distort both the estimation parameters and corresponding assessment criteria. Therefore, on estimation technique may often lead to wrong interpretations and decisions.

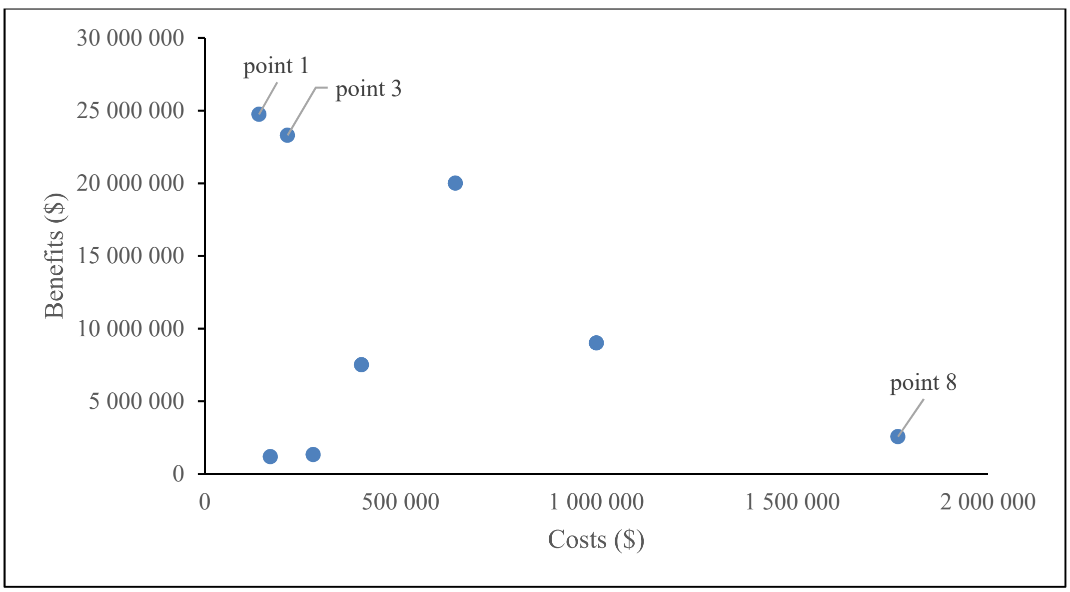

Figure 6.11 Graphical representation of input data in [S1]

Furthermore, there are some observations about the input data that raise the flag about the credibility of the data. For instance, in the specific data set in Figure 6.11:

- 2 data points (i.e. point 1 and point 3) represent 7% of the EA costs on the horizontal axis, but represents a 48% (on the vertical axis) disproportionate share of the EA benefits across this data set 8 projects.

It is highly surprising that these two data points amongst the lowest EA costs are generating almost half of the total EA benefits across the eight projects.

6.7 Mapping EA quantification techniques to ISO 15939

The detailed analysis on the empirical definitions of EA quantification proposals has revealed that there are hidden weaknesses from a metrology perspective. Moreover, the additional examples about the metrology issues clarified some of these hidden weaknesses.

In this last section, more examples are provided by mapping some EA quantification proposals to the ISO 15939 Information Model. ISO 15939 defines the necessary steps in order to design information products from measurable concepts and includes the following steps:

1. A measurement method is designed or already designed to produce base measures. The base measure is a number with metrological properties such as a measurement unit.
2. The values of bases measures can be used to produce a derived measure through an admissible mathematical operation.
3. The derived measures are next used in analysis models in order to understand relationships and to obtain an indicator (a number).
4. The indicator is interpreted based on some criteria, and decisions are made accordingly.

Figures 6.12 to 6.14 show the steps of ISO 15939, and show the mapping with EA quantification techniques discussed in the previous sections of this chapter, and this section presents a number of examples of this mapping.

Figure 6.12 shows an example of mapping the ranking techniques (such as AHP, DEA, and Fuzzy logic) with ISO 15939:

1. Measurement method in ISO 15939 is mapped to EA quantification techniques. Based on the previous discussions about the metrology weaknesses in AHP, DEA, and Fuzzy logic, subjective inputs are their quantification techniques.

2. Base measures in ISO 15939 are mapped to numbers. Based on the weaknesses discussed earlier in this chapter, the outcomes of these techniques do not have metrological properties. Therefore, they are badly designed base measures, and are not considered base measures with high metrological qualities.
3. Data preparation section is mapped to the Fuzzy logic steps (i.e. fuzzication and de-fuzzication). The inputs to this section are badly designed base measures, and the outputs are badly designed derived measures.
4. The indicator in ISO 15939 is mapped to weights and ranking.
5. Based on these rankings some decisions are made. Example of the decision criteria can be:
    a. the highest quality rank is the best EA scenario,
    b. the highest efficiency score is the best EA scenario, and
    c. the lowest risk score is the best EA framework.

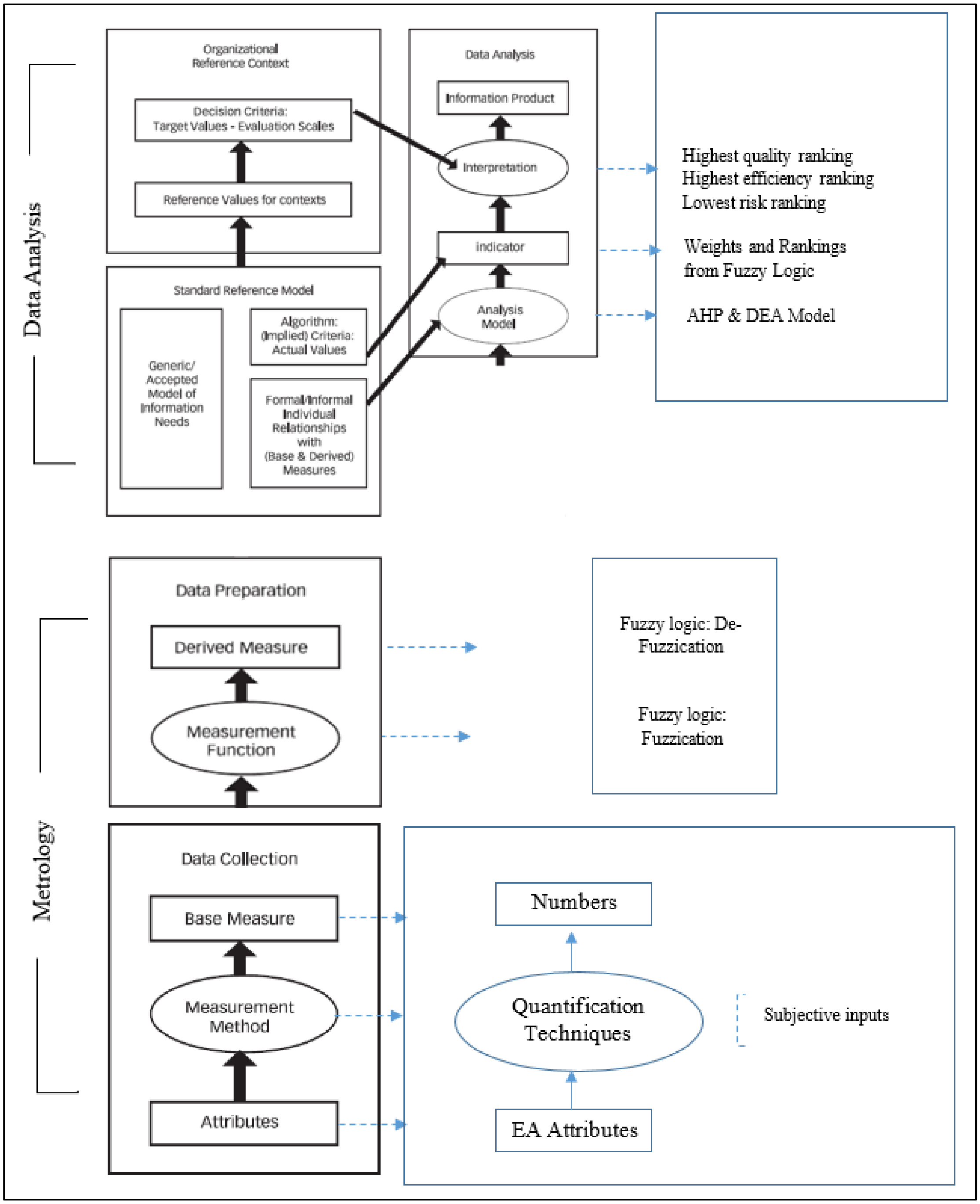

Figure 6.12 Mapping AHP, DEA and Fuzzy techniques with ISO 15939

Figure 6.13 shows an example of mapping techniques that only collect subjective data based on opinions, and use these opinions in regression analysis. The mapping is as follows:

1. Measurement method in ISO 15939 is mapped to EA quantification techniques. Based on the previous discussions about the metrology weaknesses in opinions-based numbers, these techniques do not have the metrological properties. Therefore, they are not considered measurement methods per se.
2. Base measures in ISO 15939 are mapped to numbers. Based on the weaknesses discussed earlier in this chapter, the outcomes of these techniques do not have metrological properties. Therefore, they are not considered base measures.
3. Data preparation section has no corresponding mapping.
4. The indicator in ISO 15939 is mapped to regression coefficients.
5. Based on these coefficients some decisions are made. Example, high coefficients explain the relationship between EA constructs.

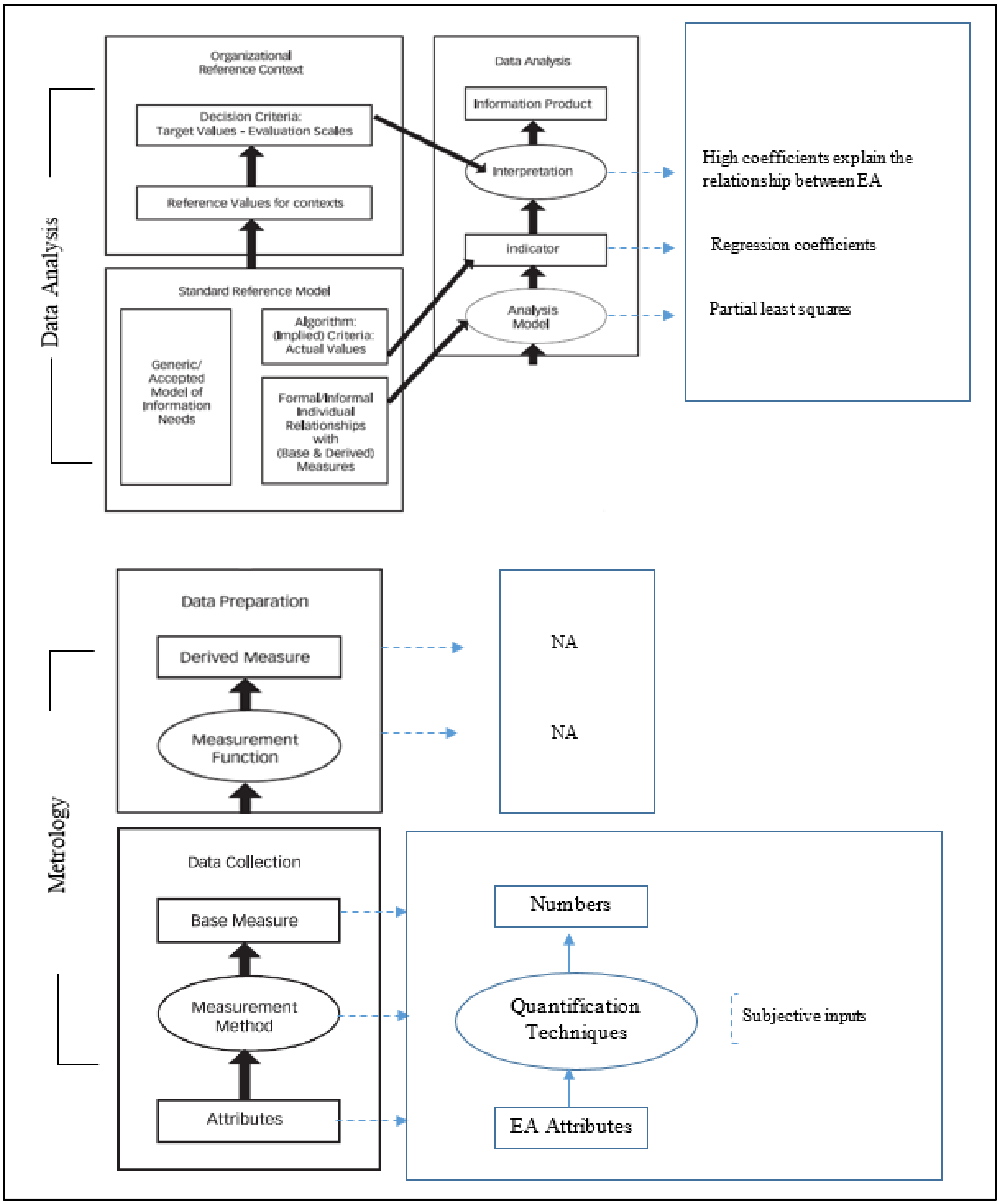

Figure 6.13 Mapping techniques with subjective inputs only with ISO 15939

Figure 6.14 shows an example of mapping EA measurement techniques that use counting as a quantification technique. The mapping is as follows:

1. Measurement method in ISO 15939 is mapped to EA quantification techniques. Based on the previous discussions about the metrology weaknesses of ITO standardization and EA complexity, these techniques do not have the metrological properties. Therefore, they are not considered measurement methods per se.
2. Base measures in ISO 15939 are mapped to numbers. Based on the weaknesses discussed earlier in this chapter, the outcomes of these techniques do not have metrological properties. Therefore, they are not considered base measures.
3. Data preparation section is for example mapped to weak ITO standardization degree formula and multilevel complexity formula.
4. Analysis model has no corresponding mapping.
5. The indicator in ISO 15939 is mapped to numbers assigned to EA complexity, and ITO standardization.
6. Based on these numbers some decisions are made. Example, lowest EA complexity is the best, and highest ITO standardization degree is the best architecture.

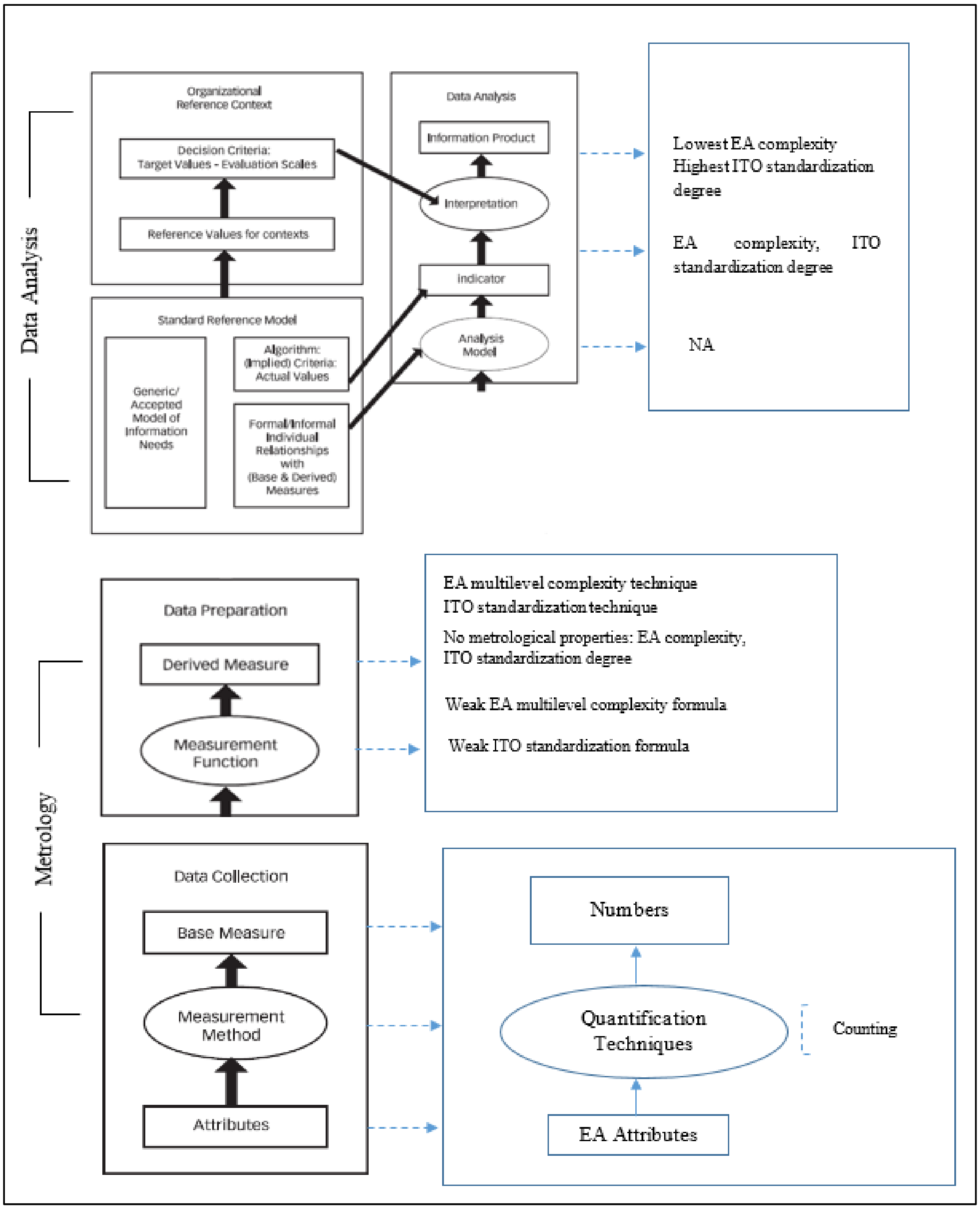

Figure 6.14 Mapping techniques with counting inputs only with ISO 15939

6.8 Chapter summary

This chapter has presented an in-depth analysis of EA quantification proposals. It has highlighted some of the hidden and unknown metrology and quantification weaknesses related to EA measurement. The results of this in-depth analysis confirm that EA quantification proposals are not mature from a metrology sense, and therefore, do not qualify yet as measurement methods.

Mapping EA quantification techniques to ISO 15939 has produced three (3) different mappings. Furthermore, the mapping to ISO 15939 has shown that the techniques do not correspond to the metrology section (data collection and preparation sections). These techniques are classified as quantification attempts to produce numbers. These numbers are afterwards used for decision-making based on some defined criteria.

Hence, the EA quantification proposals are only attempts to describe the real world of EA by producing numbers that make EA practitioners “feel good” instead of sound and well-proven engineering measurement methods with strong metrological properties. The quantification proposals are only an aggregation of informal and partial practitioners’ knowledge. The meaning of this aggregation is unspecified: this produces numbers that result from mathematical operations with losses of information and unspecified meaning. In addition, it is unclear whether it is valid or not to be added or multiplied together such numbers. Therefore, these numbers are of very low quality from a metrology perspective, and may lead to improper decisions with costly and risky consequences.

CHAPTER 7

A NOVEL APPROACH FOR EA MEASUREMENT

The research objective in this chapter aims at helping the EA community improve the metrology coverage in EA measurement proposals. To achieve this objective, a novel approach for EA measurement is proposed in this chapter by first adopting COSMIC as the measurement standard and ArchiMate as the modelling standard for EA. Next, combining the use of both standards to produce a new EA measurement approach that satisfies the metrological properties.

Section 7.1 presents first an overview of ArchiMate, followed in section 7.2 by an overview of COSMIC. Section 7.3 presents next the proposed mapping between ArchiMate and COSMIC and illustrates it in section 7.4 with an example from the insurance industry. Section 7.5 presents next an overview of early sizing in software measurement and a proposal for building blocks for early sizing in EA measurement.

7.1 EA modelling (ArchiMate)

The EA literature posits that EA provides a coherent overview for organizations. Such overview includes insights about the communications and alignments between business and IT architectures. In addition, it is expected that this overview will enable organizations to understand better the consequences of complex change decisions. These changes can include decisions that change the structure of the business process, IT infrastructure, data management, etc. Therefore, EA is expected to deliver a coherent overview about the consequences that might affect the organization.

There are different EA frameworks that can guide organizations to design and benefit from EA, such as TOGAF, Zachman, and DoDAF. According to (Qurratuaini, 2018), TOGAF (an EA framework that facilitates EA design, planning, implementing, and governing) is rated higher compared to other frameworks. The advantages of TOGAF include the interconnection and integration between different architectural layers, and alignment with industry standards – see Table 7.1 for the complete criteria of EA frameworks comparison from (Qurratuaini, 2018).

According to (Lankhorst, 2017), designing EA in organizations is not a trivial task. EA design is complex: it includes various steps that are not standardized and TOGAF was introduced as a framework that attempts to standardize the steps of EA design in organizations.

In most organizations, separate architectural layers are distinguished. For instance, business, information, and application layers are not the same. Each EA architectural layer has its own concepts, modelling techniques, tool support, and visualisation. Unfortunately the disadvantage of the distinct EA architectural layers is the difficulty to obtain a coherent overview of the organization (Jonkers *et al*., 2003).

To this end, and in order for EA practitioners to express and describe the architectural layers, most organizations define their own notations and conventions: these notations are informal and consensus on their meaning is not well defined (Lankhorst, 2017).

Table 7.1 Comparison between EA frameworks
Taken from (Qurratuaini, 2018)

Attributes/Criterias	**Zachman**	**TOGAF**	**DoDAF**	**FEA**	**Gartner**
Business alignment with information technology / business focus	1	3	1	1	4
Taxonomy guide	4	2	2	3	1
Reference model	1	3	2	4	1
Completeness of process	1	4	1	2	3
Rating of maturity	1	2	2	3	3
Governance support	1	2	3	3	3
Interoperability / flexibility	2	4	3	3	2
Knowledge repository / information availability	2	4	2	2	1
Standards (architecture, industry, government)	2	4	3	3	1
Best of breed / Best fit	2	4	2	3	1
Integration / Connectivity between layers	3	4	2	3	2
Business alignment with information technology / business focus	2	4	2	3	1

Therefore, the Open Group introduced a modelling architecture language: ArchiMate. ArchiMate is a uniform modelling language that supports enterprise architects in describing, analysing and visualising the relationships among layers based on well defined concepts (Lankhorst, 2017). It (e.g., ArchiMate) is expected to enable organizations to obtain a coherent overview about the architecture.

In contrast to other modelling languages, ArchiMate is capable to deliver a high-level overview about the relationships in the architecture. ArchiMate is not EA layer specific, while other modelling languages, such as UML, are specific to modelling applications and technology and provide detailed descriptions about them. Moreover, BPMN is specific to business process modelling, and does not support the application and technology layers. Therefore, (Gill, 2015) reports a growing interest in applying ArchiMate for high-level enterprise architecture modelling.

ArchiMate provides two (2) high levels of detail:

1. High level modelling within each domain (layer), and
2. Relations between domains (layers) - see Figure 7.1.

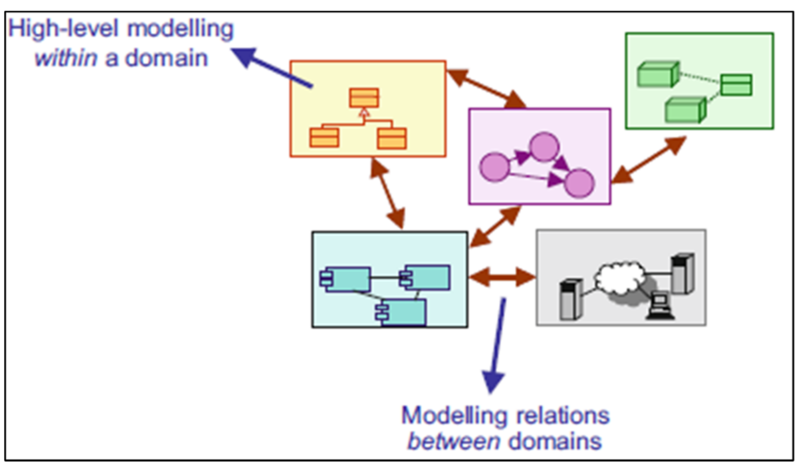

Figure 7.1 The role of the ArchiMate language
Taken from Lankhorst (2017, p.75)

The structure of ArchiMate corresponds to the three (3) architectural layers of TOGAF's Architecture Development Method (ADM) – see Figure 7.2. ADM and ArchiMate share the same ground, as both are TOGAF standards.

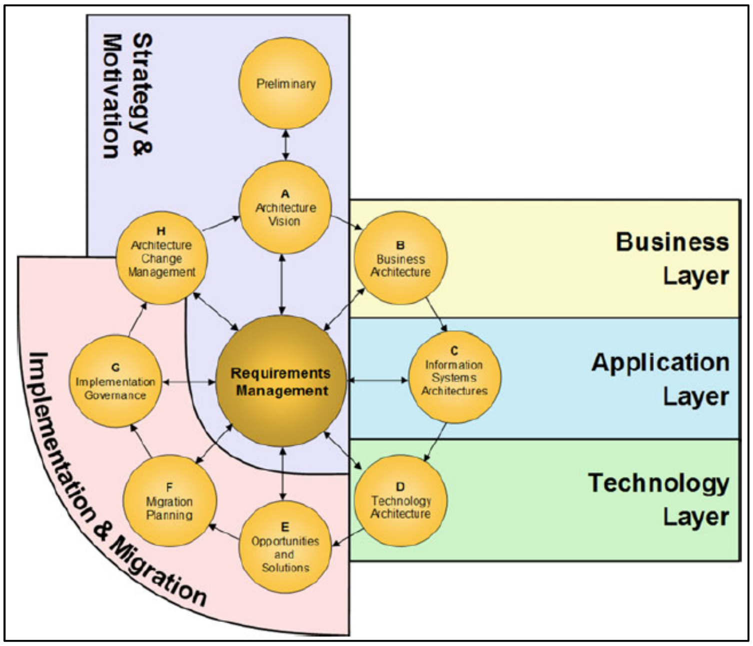

Figure 7.2 Correspondence between ADM
and Architmate Language.
Taken from Lankhorst (2017, p.140)
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In ArchiMate, the relationship between the three (3) architectural layers in Figure 7.2 is service oriented: the central role that manages the relations between the architectural layers is the service concept. In ArchiMate, service is one of the core concepts of the modelling language. From bottom up, each layer provides services to the higher architectural layer. In addition, the relationships in each architectural layer are based on the services within each layer.

Other ArchiMate core concepts are the structural and behavioural concepts, with similar meanings amongst the three layers:

1. Structural concepts divided into:

- Active structure concepts that represent a subject (e.g., a business actor or a device) that represents (or displays) a behaviour, and
- Passive structure concepts that represent an object (e.g., a data object) on which a behaviour is performed.

2. Behavioural concepts, which represent a verb or an action (e.g., business process, application process).

Next is a description of the three (3) architectural layers, including the structural and behavioural concepts. Appendix IV shows some related definitions of these concepts.

1. Business layer concepts. The ArchiMate concepts of this layer are:
   - business structure concepts (e.g., business actor)
   - business behaviour concepts (e.g., business service)

2. Application layer concepts. The ArchiMate concepts of this layer are:
   - Application structure concepts (e.g., application component)
   - Application behaviour concepts (e.g., service)

3. Business – Application Alignment. ArchiMate is capable to link the business and application layers discussed above through two (2) types of relations: serving and realisation relationships – see Appendix IV.

4. Technology layer concepts. The ArchiMate concepts of this layer are as follows:
   - Technology structure concepts (e.g., node)
   - Technology behaviour concepts (e.g., technology service)

5. Application – Technology Alignment. ArchiMate is capable to link the application and technology layers discussed above through two (2) types of relations: serving and realisation relationships – see Appendix IV.

The definitions are based on a reference on ArchiMate. For a complete description about the related definitions, see (Lankhorst, 2017).

Since other modelling languages, such has UML and BPMN, exist and are already used by organizations with defined notations and conventions, the Open Group selected and reviewed them. The objective of this review was not to re-invent the wheel by proposing ArchiMate as a new alternative, but rather to follow the notations and conventions in these languages so that organizations can easily adopt ArchiMate as a high level modelling language.

Therefore, in the proposal of ArchiMate, the Open Group builds on top UML and BPMN. The ArchiMate relations (i.e. notations and conventions) are presented in Tables 7.2 and 7.3.

Table 7.2 ArchiMate structural relations
Taken from Lankhorst (2017, p.108)
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Association	*Association* models a relation between objects that is not covered by another, more specific relationship
Influence +/-	The *influence* relation models that an element affects the implementation or achievement of some motivation element
Access	The *access* relation models that behavioural elements can observe or act upon passive structure elements
Serving	The *serving* relation models that an element offers its functionality to another element
Realisation	The *realisation* relation indicates that an entity plays a critical role in the creation, achievement, sustenance, or operation of a more abstract entity
Specialisation	The *specialisation* relation indicates that an element is a particular kind of another element
Assignment	The *assignment* relation expresses the allocation of responsibility, performance of behaviour or execution
Aggregation	The *aggregation* relation indicates that an element groups a number of other elements
Composition	The *composition* relation indicates that an element consists of a number of other elements

Table 7.3 ArchiMate behaviour relations
Taken from Lankhorst (2017, p.110)

Triggering ——▶	The triggering relation describes a temporal or causal relationship between elements
Flow - - - - -▶	The flow relation represents transfer from one element to another
Junction ● ○	A junction is used to connect relations of the same type. Regular (or and-) junctions signify a combination; or-junctions denote alternatives

7.2 Common software measurement international consortium (COSMIC)

COSMIC is a method for measuring the functional size of software. In 2002, it was accepted by ISO/IEC as an international standard, and referred to as ISO/IEC 19761.

According to (Abran, *et al*. 2009), COSMIC is not technology dependent. It includes a set of principles and rules applied to the functional user requirements (FUR) of a given piece of software. FUR are descriptions of what the software does or should do to the functional users. The functional users might be human or any application software that communicates through data.

According to (Abran *et al*., 2009), the interaction between the functional users and software applications is through a functional component referred to "data movement". COSMIC defines four (4) types of data movements:

- Entry (E): data moved from a functional user to a software.
- Exit (X): data moved from a software to the functional user.
- Write (W): data moved from the software to a persistent storage.
- Read (R): data moved from a persistent storage to the software.

The functional size in COSMIC is calculated by adding the data movements. The COSMIC measurement unit is a COSMIC function point (CFP), which represents one data movement of one data group.

The concepts in COSMIC can be applied to various functional domains such as: business application software, real-time software, and combination of the two. The Generic Software Model for a busniess application presented in Figure 7.3 show these concepts. From the Generic Software Model:

- Human functional users interact with the software through Entry and Exit data movements,
- Software interacts with the persistent storage through Read and Write data movements, and
- Software application interacts with a peer software application through Entry and Exit data movements.

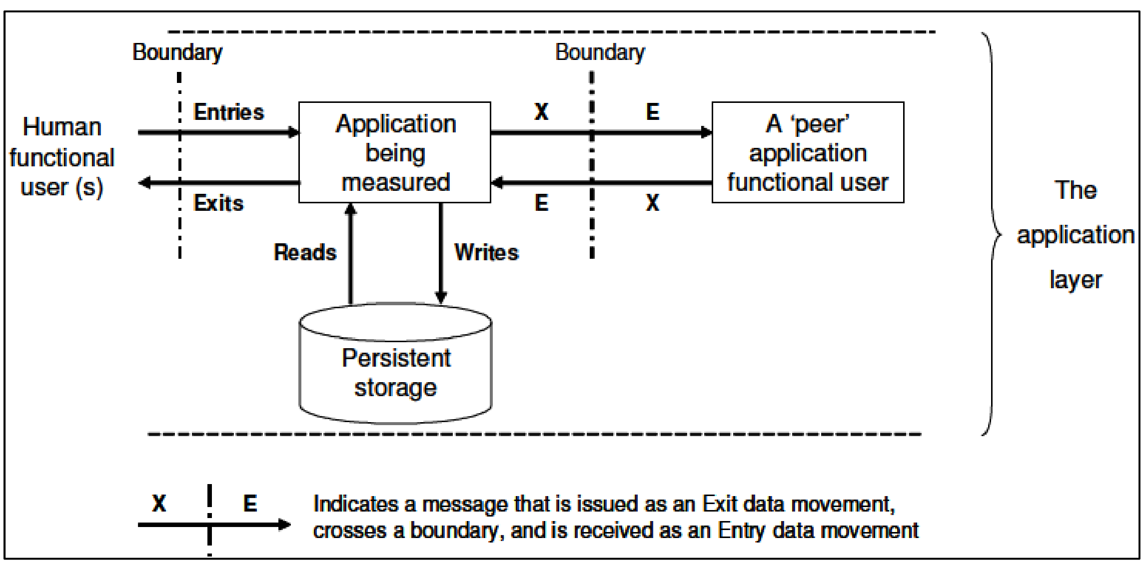

Figure 7.3 A business application with both humans and another 'peer' application as its functional users (Abran *et al*., 2009)

The Generic Software Model for a real-time software in Figure 7.4 show these concepts. From the Generic Software Model:

- Functional user (device) interact with the software through Entry and Exit data movements, and
- The application interacts with the persistent storage through Read and Write data movements.

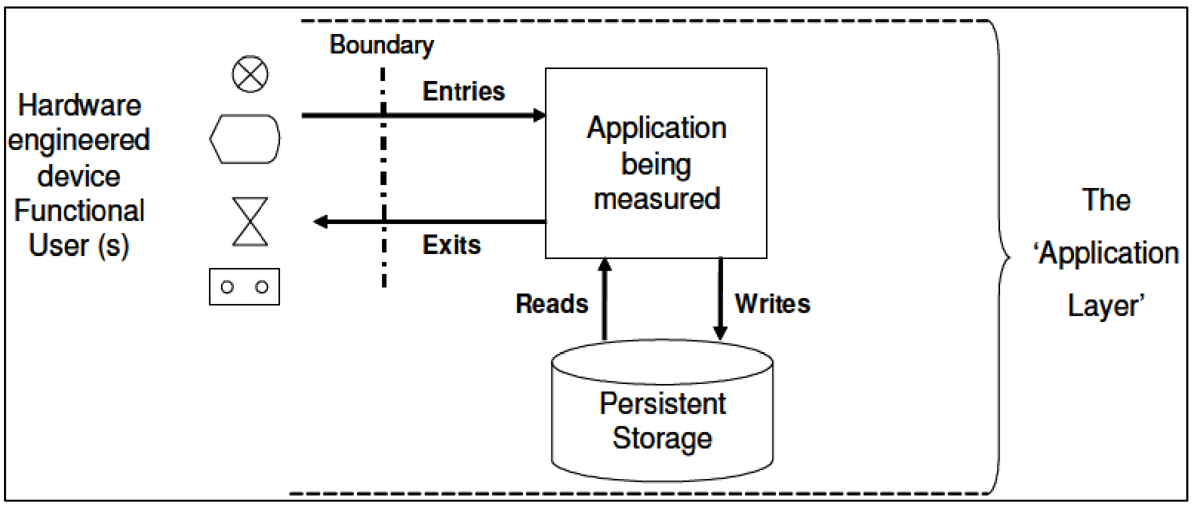

Figure 7.4 A real-time software application with various hardware engineered devices as its functional users (Abran *et al*., 2009)

COSMIC defines other elementary components: functional process (FP) and triggering event. According to (Abran *et al*., 2009), a functional process is an elementary component of a set of functional user requirements comprising a unique, cohesive and independently executable set of data movements. The functional process is triggered by a data movement from the functional user.

The triggering event is something that happens, and causes a functional user of the piece of software to initiate ('trigger') one or more functional processes – see Figure 7.5.

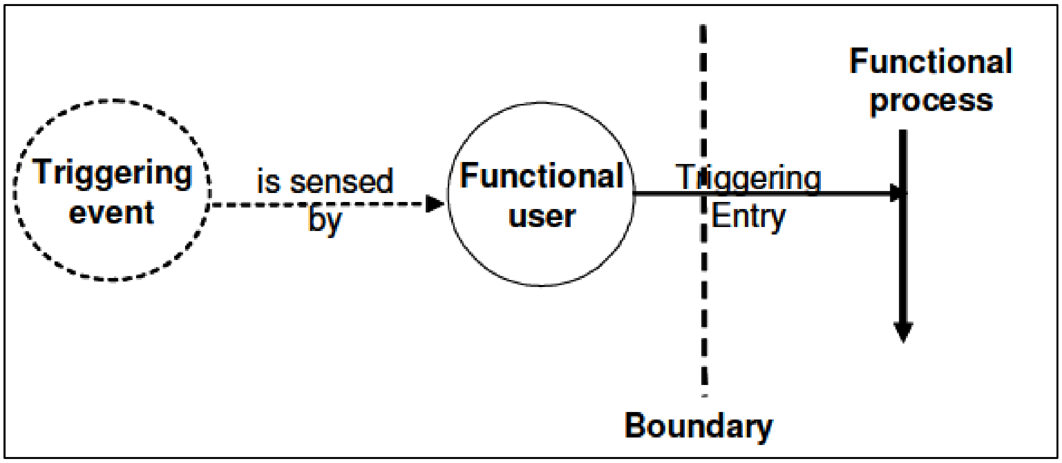

Figure 7.5 Relation between triggering event, functional user and functional process (Abran *et al*., 2009)

In each functional process, COSMIC measurement function assigns a value to the data movements. COSMIC defines a standard measurement unit (1 CFP) as an equivalent of one single data movement. In other words, the value assigned to the data movements is the functional size in units. For any functional process, the functional sizes of individual data movements shall be aggregated into a single functional size value in units of CFP by arithmetically adding them together (Abran *et al*., 2009), see equation (7.1).

$$Size\ (FP) = \sum Size_{Entries} + Size_{Exits} + Size_{Reads} + Size_{Writes} \quad (7.1)$$

7.3 Mapping ArchiMate and COSMIC concepts

Overviews of TOGAF, modelling EA layers using ArchiMate, and COSMIC concepts were presented in the previous sections. This section focuses now on mapping ArchiMate to COSMIC, and an emphasis on how the mapping is achieved.

Since the concepts of COSMIC are designed to be applied to various domains, and given the weaknesses in EA quantification techniques discussed in chapters 4 and 5, this section attempts to utilize COSMIC concepts in measuring the functional size in EA.

ArchiMate is introduced as a TOGAF standard that attempts to obtain a coherent view (visualization) amongst and within the different EA layers. This sub-section extends the use of ArchiMate, not only as a modelling language, but also as an enabler to measure the functional size in EA.

Figure 7.6 shows the proposed approach. To our knowledge, this approach is the first attempt that maps COSMIC concepts to ArchiMate. The objective of this mapping is to improve measurement in EA, and overcome the metrology coverage weaknesses discussed in chapters 5 and 6. The approach is summarized as follows and refers to the three (3) EA layers of TOGAF:

- Each EA layer should be modelled using ArchiMate modelling language,
- Each modelled EA layer should be mapped to COSMIC,
- Apply COSMIC measurement function in each EA layer, and
- The resulting mapping of ArchiMate and COSMIC (ArchiMate COSMIC V1) should produce functional sizes for each distinct EA layer with a measurement unit (CFP).

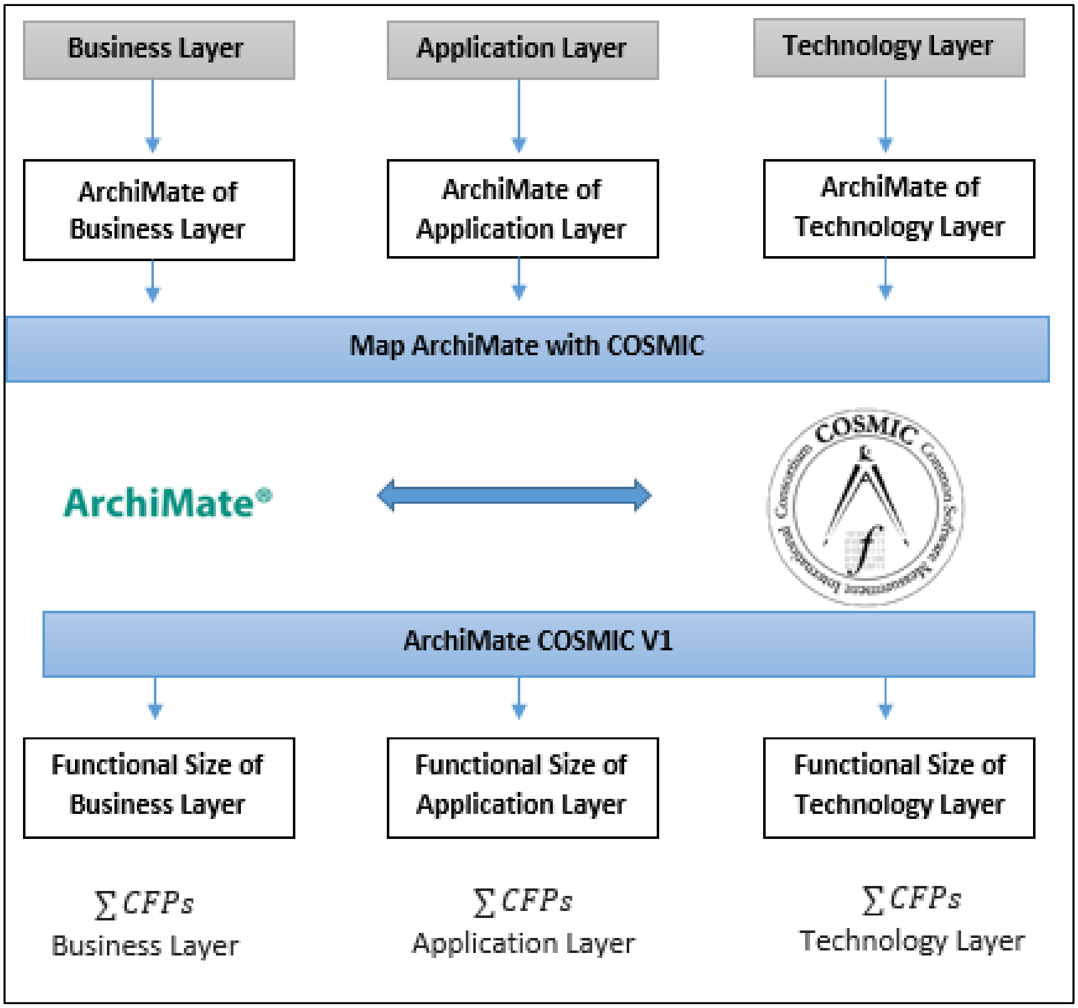

Figure 7.6 Proposed approach for EA measurement with ArchiMate and COSMIC

In this thesis, the mapping ArchiMate to COSMIC is achieved through building on top of some previous work on COSMIC, Business Process Model and Notation (BPMN), and ArchiMate as follows – see Figure 7.7.

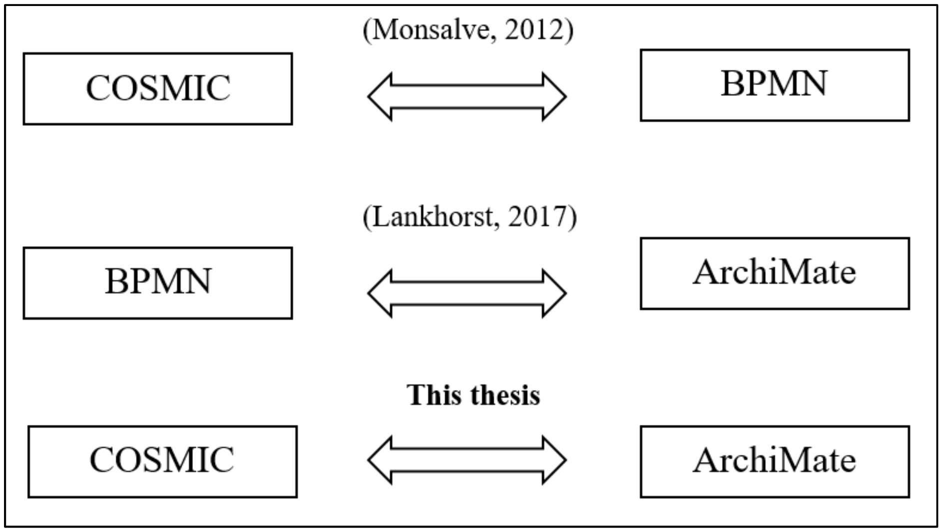

Figure 7.7 Mapping COSMIC & ArchiMate based on previous works

Next is a description of these mappings, and a presentation of the final mapping between ArchiMate and COSMIC.

7.3.1 Mapping between BPMN and COSMIC

(Monsalve, 2012) developed a procedure to measure the functional size of a software application based on the business process models representing the software application: BPMN, as a standard to model the business process, was used to develop this procedure. In order to measure the functional size of a software application based on the business process models, (Monsalve, 2012) mapped BPMN to COSMIC: this mapping includes defining a set of mapping rules between the BPMN modeling notations and the COSMIC concepts – see Table 7.4.

Table 7.4 Mapping between COSMIC and BPMN
Taken from (Monsalve, 2012)

COSMIC FSM Method V.3.0.1	BPMN 1.2	Comments
Functional User	Lane and pool	Those who interact with the lane of the software to be measured
Boundary	The lane that represents the software to be measured	
Functional Process	Pool	Those that contain the lane that represents the software to be measured
Triggering Event	Start Event	
Data Group	Name of a message	Between pools
	Data Object	When a persistent storage must be accessed
Entry	An incoming message or sequence flow	
Exit	An outgoing message or sequence flow	
Read	An upstream association with a data object	
Write	A downstream association with a data object	

7.3.2 Mapping between BPMN and ArchiMate

(Lankhorst, 2017) proposed that BPMN and ArchiMate be used in combination with:

- ArchiMate to model high-level processes, and
- BPMN to model fine-grained (detailed modelling) for sub-processes.

Their mapping includes defining a set of mapping rules between the BPMN and ArchiMate modeling notations – see Table 7.5.

Table 7.5 Mapping between BPMN and ArchiMate
Taken from Lankhorst (2017, p.134)

BPMN	*ArchiMate*
Participant/Pool, Lane	Business Actor, Role, Application Component
Collaboration	Business/Application Collaboration
Process	Business/Application Process
Sequence flow	Triggering
Data association	Access
Inclusive and parallel gateways	Junction
Exclusive and event-based gateways	Or-junction

7.3.3 Mapping between ArchiMate and COSMIC

Based on the mappings in Tables 7.4 and 7.5, the first attempt to map COSMIC concepts to ArchiMate modeling notations emerges. The mapping rules (e.g., rule 1 to rule 12) are shown in Table 7.6.

Table 7.6 Mapping COSMIC to ArchiMate V1

Mapping Rules	**COSMIC**	**ArchiMate**
Rule 1	Functional User	Business Actor, Role, Application Component, Business service, Business process
Rule 2	Functional Process	Business/Application Process
Rule 3	Entry	Incoming message (flow) or Triggering relation
Rule 4	Exit	Outgoing message (flow) or Triggering relation
Rule 5	Read	Access
Rule 6	Write	Access
Rule 7	Boundary	Unspecified
Rule 8	Unspecified	Collaboration
Rule 9	Unspecified	Junction
Rule 10	Unspecified	Or-Junction
Rule 11	Triggering Event	Triggering Event
Rule 12	Data Group	Data Object (Business object, Application object,) Name of service Or messages between functional users

7.4 Measuring the functional size of EA layers

This section illustrates the mapping between ArchiMate and COSMIC with an example from the insurance industry.

Example: In an insurance company, a claim is received about a damage, causing an insurant to enter the claim data, and causing other functional processes and data movements to occur in the EA business and application layers.

According to the approach proposed in Figure 7.6, and in order to measure the functional size, the steps to follow are:

1. Refer to TOGAF EA layers. In this example, we select the EA business and application layers.
2. Model the EA layers using ArchiMate. The EA business and application layers of the insurance company are presented in Figures 7.8 and 7.9 respectively.
3. Use the mapping rules in Table 7.6.
4. Determine the functional processes in the EA business and application layers.
5. Measure the functional size of the EA business and application layers.

7.4.1 Measuring the functional size of the EA business layer

Based on the above, Figure 7.8 shows the ArchiMate model of the business layer from (Lankhorst, 2017). The ArchiMate model shows an example of the "handle claim" business process, and the related sub-processes.

The "handle claim" business process, and the related sub-processes contain information flow and data movements. For instance, the customer needs to register his/her claim, the business need to accept or reject, access the customer profile, and eventually allow payments.
The data movements of the "handle claim" business process will be the basis of calculating the functional size of the EA business layer.

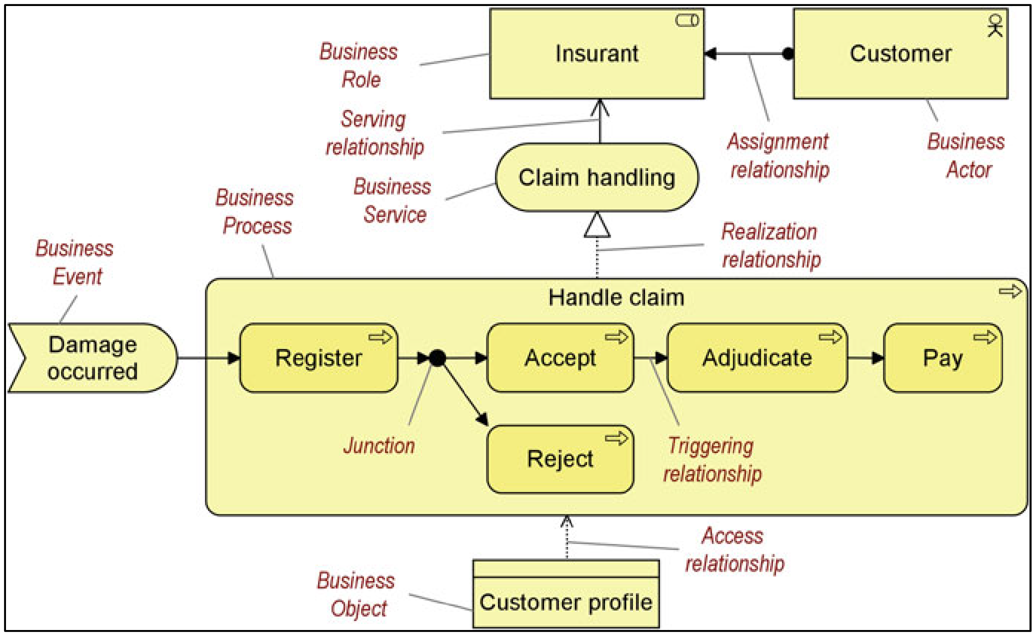

Figure 7.8 Example of EA business layer in insurance industry
Taken from Lankhorst (2017, p.88)
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The description of the data movements of the "handle claim" business process is presented in Figure 7.9. For instance, from Figure 7.9: a damage has occurred, and the customer is submitting a claim to the insurance organization. In turn, the organization handles the claim through the "handle claim" business process. This business process triggers data movements, and are described as following:

- Entry (E) and Exit (X) data movements to/from the "Register" sub-process,
- Entry (E) and Exit (X) data movements to/from the "Reject" sub-process,
- Entry (E) and Exit (X) data movements to/from the "Accept" sub-process,
- Entry (E) and Exit (X) data movements to/from the "Adjudicate" sub-process,
- Entry (E) and Exit (X) data movements to/from the "Pay" sub-process, and
- Read (R) data movement on the customer profile.

The detailed description of the data movements visible at the business layer including the corresponding functional sizes are presented in Table 7.7, and the total functional size of EA business layer is presented in Table 7.8.

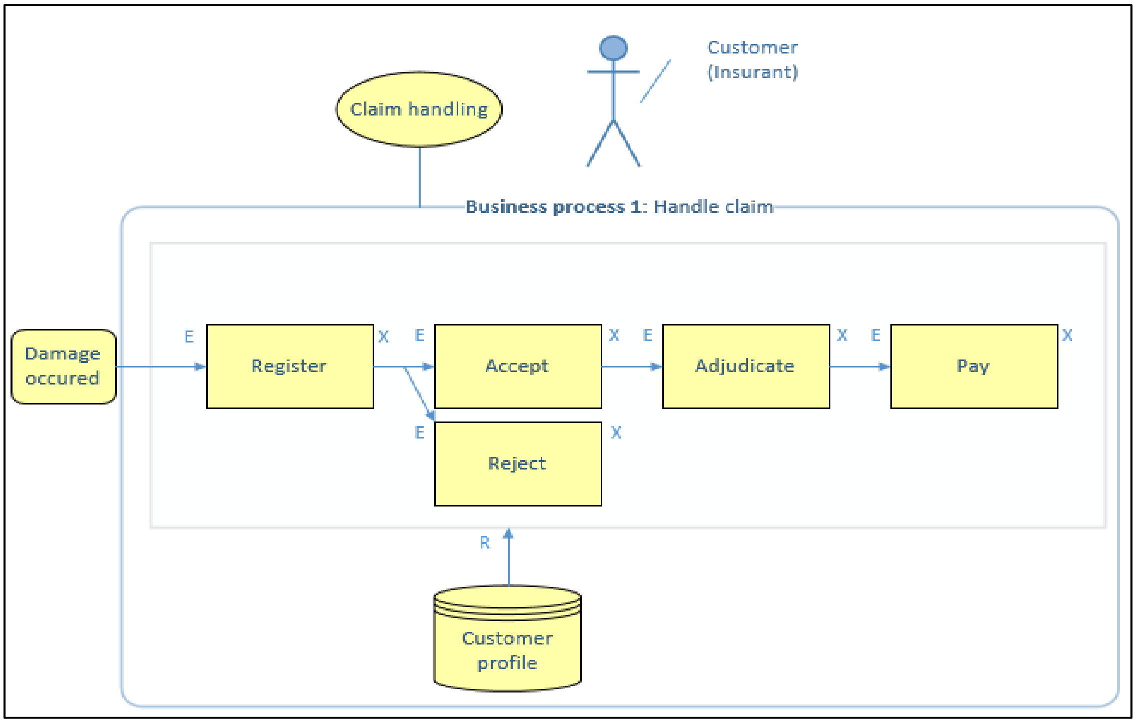

Figure 7.9 Data movements of the "handle claim" business process in EA business layer
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Table 7.7 Detailed description of "handle claim" business process

Business Process 1 : Handle claim **Triggering Event**: Damage occurred				
Functional User	**Sub-processes**	**Name of Data Group**	**Data Movement**	**CFP**
Insurant (Business Role)	Register	Registration Data	E,X	2
	Accept	Accept Data	E,X	2

Table 7.7 Detailed description of "handle claim" business process (continued)

Business Process 1 : Handle claim **Triggering Event**: Damage occurred				
	Adjudicate	Adjudicate Data	E,X	2
	Pay	Pay Data	E, X	2
	Reject	Reject Data	E, X	2
	Access	Customer profile	R	1
Total size for Business Process 1 = 11 CFP x scale				

Table 7.8 Total functional size for EA business layer

Total functional size
$Size\ (business\ process) = \sum business\ process\ 1$
EA business layer functional size = 11 CFP x scale

7.4.2 Measuring the functional size of the EA application layer

The description of the ArchiMate model for the EA application layer for handling the claim is presented in Figure 7.10.

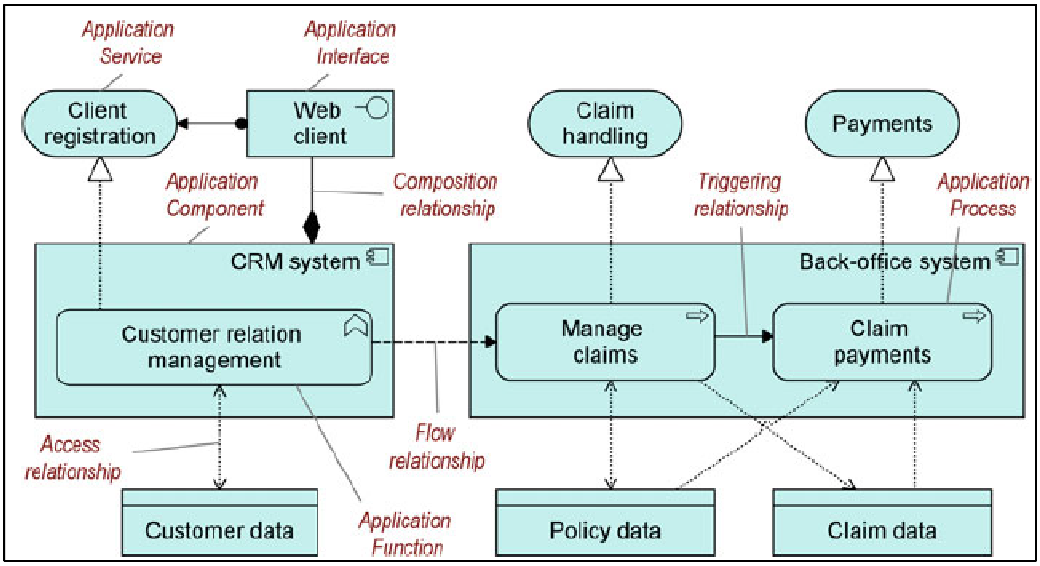

Figure 7.10 Example of EA application layer in insurance industry
Taken from Lankhorst (2017, p.96)
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The application layer serves the business layer through application processes and data movements as follows:

- Entry (E) and Exit (X) , Read (R) and Write (W) data movements in Application process 1,
- Entry (E) and Exit (X) , Read (R) and Write (W) data movements in Application process 2, and
- Entry (E) and Exit (X), Read (R) and Write (W) data movements in Application process 3.

The description of the data movements of the three (3) application processes is presented in Figure 7.11. In addition, the detailed description of the data movements visible at the application layer including the corresponding functional sizes are presented in Table 7.9 to 7.11, and the total functional size of the EA application layer is presented in Table 7.12.

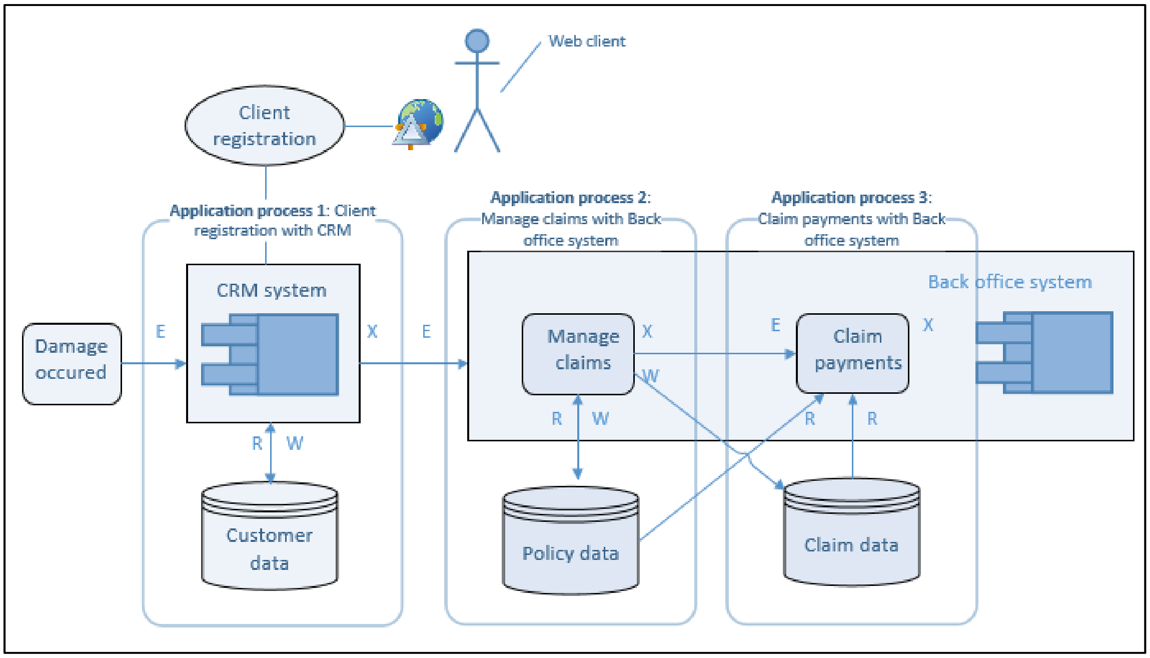

Figure 7.11 Data movements of three application processes in EA application layer
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Table 7.9 Client registration with CRM in EA application layer

Application Process 1: Client registration with CRM **Triggering Event**: Damage Occurred				
Functional User	**Sub-processes**:	**Name of Data Group**	**Data Movement**	**CFP**
Web client	Customer relation management	Client registration	E,X	2
	Access	Customer data	W,R	2
Total Size for Application Process 1 = 4 CFP x scale				

Table 7.10 Manage claims with Back office system in EA application layer

Application Process 2: Manage Claims with Back office system **Triggering Event**: Damage Occurred				
Functional User	**Sub-processes**:	**Name of Data Group**	**Data Movement**	**CFP**
Web client	Manage Claims	Manage Claims	E,X	2
	Access Policy data	Policy data	W,R	2
	Access claim data	Claim data	W	1
Total Size for Application Process 2 = 5 CFP x scale				

Table 7.11 Claim payments with Back office system in EA application layer

Application Process 3: Claim payments with Back office system **Triggering Event**: Damage Occurred				
Functional User	**Sub-processes:**	**Name of Data Group**	**Data Movement**	**CFP**
Web client	Claim payments	Claim payments	E, X	2
	Access claim data	Claim data	R	1
	Access policy data	Policy data	R	1
Total Size for Application Process 3 = 4 CFP x scale				

Table 7.12 Total functional size for EA application layer

Total functional size
$Size\ (application\ process) = \sum application\ process\ 1 + application\ process\ 2 + application\ process 3$
EA Application Layer Functional Size = 13 CFP x scale

7.5 Early sizing in COSMIC

This section consists of identifying the basic building blocks for an early sizing framework for the EA measurement approach proposed earlier in Figure 7.6.

As described earlier in section 7.2, the main input to COSMIC is the set of functional requirements. Based on these requirements, the data movements will be identified, and the functional size can be measured accordingly. Therefore, the measurement is dependent on the description and identification of the functional requirements, and their corresponding levels of functional details.

However, (Ungan, Trudel, & Abran, 2018) mentions that at the early stages of the software development lifecycle, it is unlikely to have complete descriptions and a full list of the functional requirements. At the early stages of the lifecycle, little is known about the detailed functional requirements, and progressively over time, additional information about these requirements can be gathered. Therefore, the measured functional size at the early stages of the lifecycle will be different from the functional size measured at the end (or at the closure) of the lifecycle. This difference is referred to "gap" between initial size and true (final) size.

Moreover, (Ungan *et al.,* 2018) identified some of the sources and factors that cause this gap, such as:

- Hidden functionality: lower level functionality, not detailed in the initial set of requirements, and implemented as part of the higher level requirement;
- Undocumented functionality: implemented but not fully documented in the initial requirements; and
- Added functionality: added as the project progresses.

To tackle the challenge of the gap between initial size and true (final) size, (Abran *et al.,* 2015) proposed guidelines for early or rapid COSMIC functional size measurement by using approximation techniques, such as:

- Average functional process
- Fixed size classification
- Equal size bands
- Average use case
- Functional size measurement patterns
- Early and quick COSMIC sizing
- Easy Function Points

These early sizing techniques are useful when the FURs are not specified in sufficient detail for a precise size measurement (i.e. applying the count of data movements of the functional processes). These techniques are based on using the available high-level requirements to compute the estimated size using the scaling factors specific to each approximation technique.

According to COSMIC guidelines (Abran *et al.,* 2015), scaling factor are defined as following: "a scaling factor is a ratio that is used to convert measurements on locally-defined high-level artifacts to sizes expressed in CFP".

That is, a scaling factor is a number with metrological properties, and is 'locally' defined in the sense that the scaling factor is limited to the environment used in. For instance, it is limited to a given software documentation, and to a given category of documented requirements in an organization. For example, based on a well-defined and detailed set of FUR, and using the collected data of completed projects, an organization 'X' can use the average size technique to estimate the functional size of functional processes. Assuming that the average functional size with a scaling factor = 8 CFP, estimating the functional size of 40 new added functional processes can be calculated as = 8 X 40= 320 CFP – see Figure 7.12.

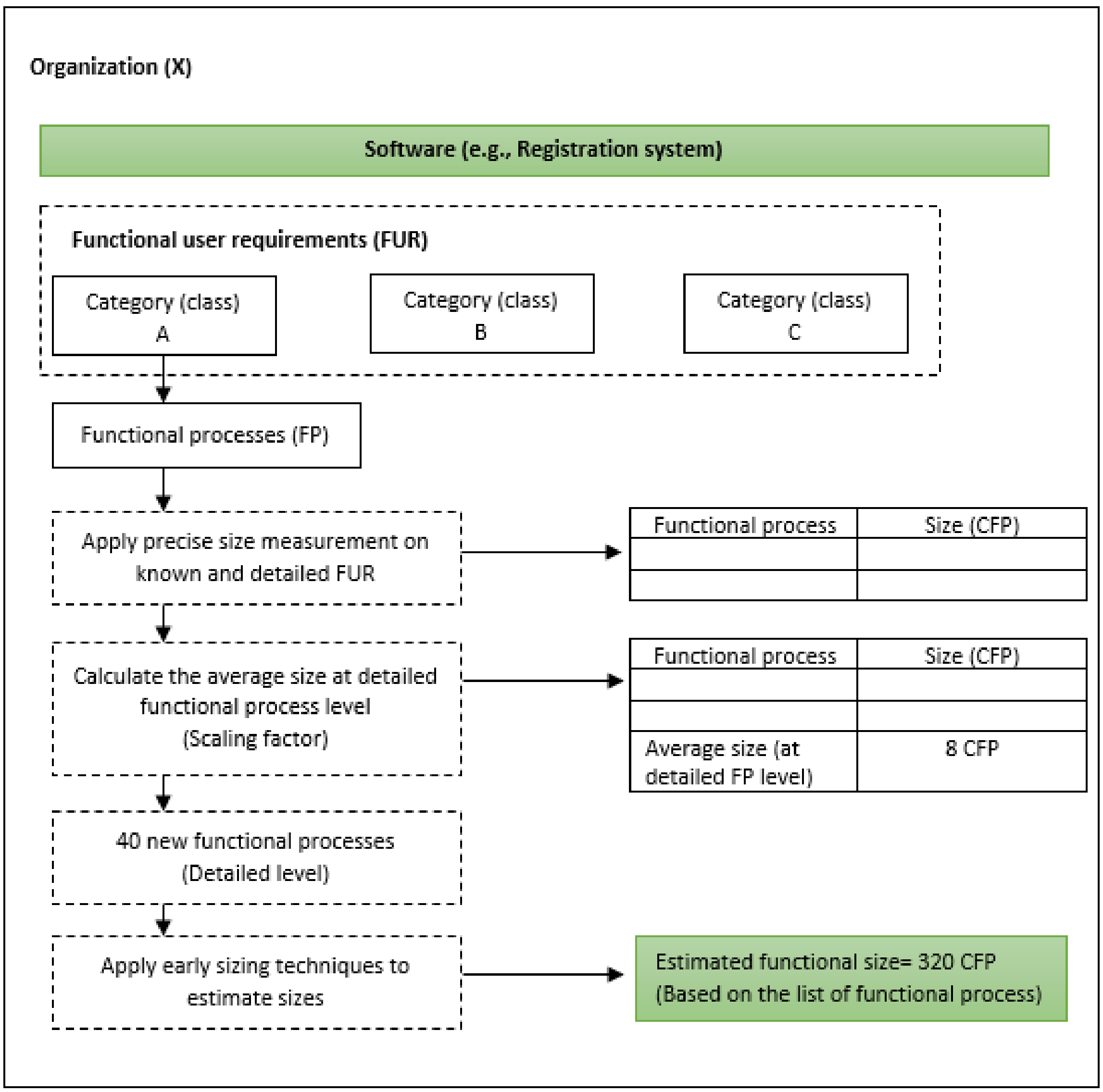

Figure 7.12 Example of early size measurement of a software with the average functional process technique as scaling factor

In the context of EA, and in particular the proposed EA measurement approach presented in Figure 6, we posit that the same concepts are applicable.

The EA factors that contribute to the gap between the initial functional size and true (final) size can be:

- Hidden functionality in EA layers: some functionality may be modelled at a high level. Hence, not allowing all the data movements to be identified.
- Undocumented functionality in EA layers: some functionalities may be omitted from the documentations. For instance, EA practitioners might intuitively not document some usual functionalities.
- Added functionality in EA layers: for instance, in order to satisfy customer requirements, or for competitive advantage reasons, stakeholders in EA layers may add new functionalities during the EA project.

The pros, cons and recommended application areas of early sizing estimation techniques are documented in the related COSMIC guideline in (Abran *et al.,* 2015). Therefore, future research directions may recommend early sizing guidelines about the best-fit early size estimation technique for the proposed EA measurement approach presented earlier in Figure 7.6.
In addition, the COSMIC guideline mentions that these techniques are based on quantitative analysis and can be used by organizations that collect data of completed projects. Therefore, organizations need to consider this by collecting data related to EA projects.

The COSMIC guideline mentions two (2) more concepts for the early size estimation:

- the level of decomposition (level resulting from dividing a piece of software into components), and
- the granularity of software (level of expansion of the description of a single piece of software).

Mapping these concepts (i.e. the level of decomposition and granularity) to the proposed EA measurement approach leads to the following:

1. The level of decomposition, dividing EA according to the three (3) TOGAF layers:
    - EA business layer functional requirements
    - EA application layer functional requirements
    - EA technology layer functional requirements
2. The level of granularity, each EA layer has a central role component. The level of granularity in each EA layer can be determined through the central components as follows:
    - Business actor functional requirements
    - Application component functional requirements
    - Node functional requirements

Each of these central components can result into more granular functional requirements, and can be modelled using ArchiMate accordingly. Therefore, early size estimation techniques can be mapped to EA concepts, and used to estimate early the functional size of EA layers – see Figure 13 (the differences between Figures 7.12 and 7.13 are highlighted in Figure 7.13, that is Figure 7.13 shows an example of an estimation of early sizing for EA application layer)

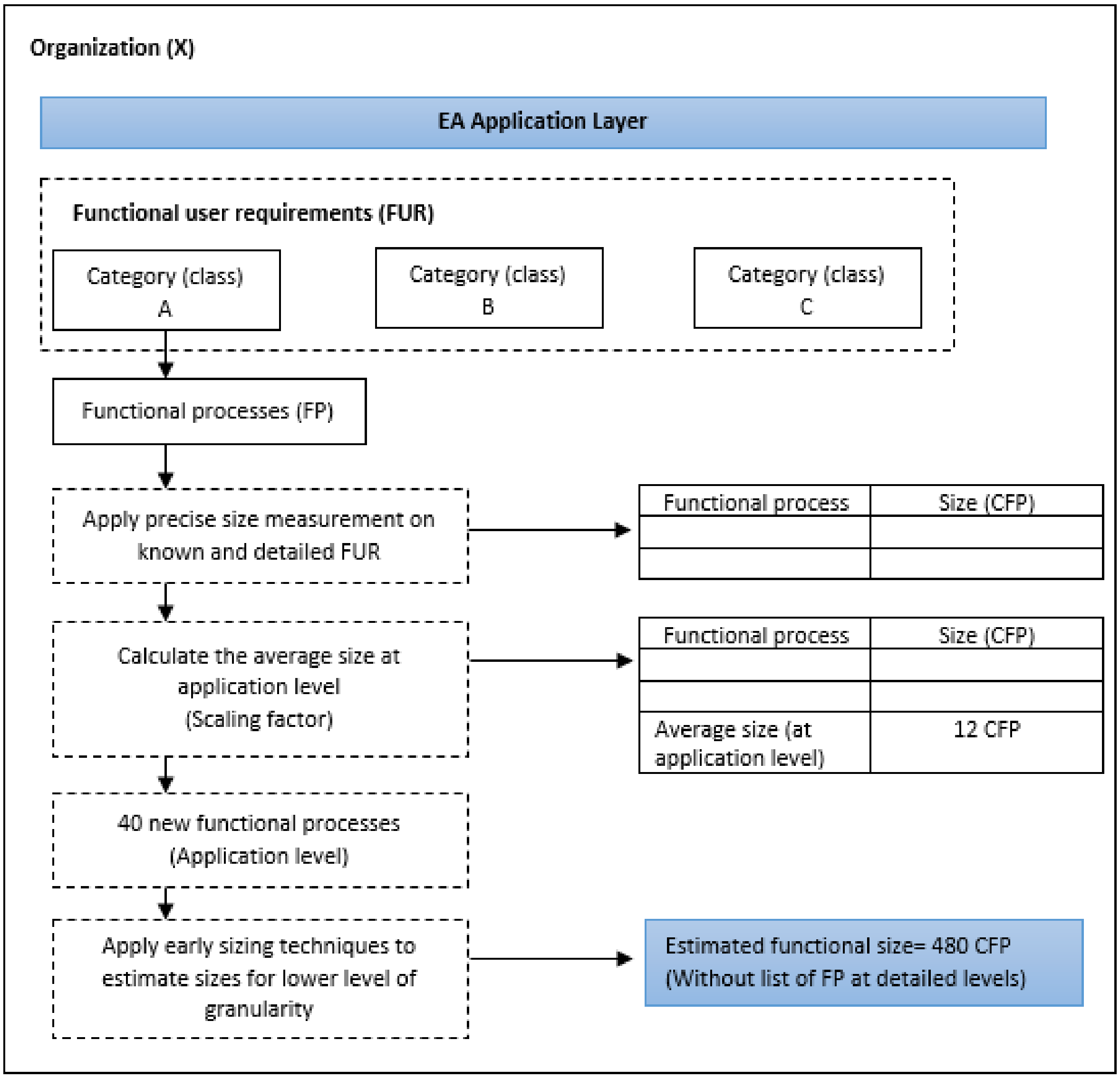

Figure 7.13 Example of early sizing for EA application layer with the average functional process technique as scaling factor

7.6 Chapter summary

The metrology coverage weaknesses discussed in chapters 5 and 6 revealed that measurement in EA research does not satisfy all the metrology properties, and that the related EA measurement proposals are limited to quantification attempts. Therefore, the research objective in this chapter aimed at helping the EA community improve the metrology coverage in EA measurement proposals using state-of-art and recognized standards.

This chapter addressed two standards associated with EA and measurement research topics:

1. The first standard is related to EA modelling language, and the usefulness of using ArchiMate to represent high-level descriptions of complex and interrelated relations in EA.
2. The second is related to a measurement standard in software engineering field, and the importance of using COSMIC to measure functional size, COSMIC early sizing techniques, and the capability of COSMIC to be applied in various domains.

To achieve this research objective, a novel approach for EA measurement was presented. The approach is based on adopting TOGAF EA layers, modeling EA layers using ArchiMate, applying COSMIC concepts on the ArchiMate model, and measuring the functional size of EA layers. Applying COSMIC concepts on ArchiMate is possible through the mapping of COSMIC concepts to ArchiMate.

This mapping phase between COSMIC concepts and ArchiMate was achieved by building on top of previous research attempts that mapped COSMIC with conceptual notations such as BPMN, and subsequent map between two conceptual notations, BPMN and ArchiMate.

To our knowledge, mapping COSMIC concepts and ArchiMate is the first attempt toward adopting COSMIC concepts in EA measurement research. This mapping is expected to improve the metrology coverage of EA measurement proposals. Since the proposed approach is based on recognized international standards, it is expected that the approach can be handy for EA practitioners, and easy to adopt by organizations.

According to COSMIC guidelines, when the FUR is specified in sufficient detail, the novel approach for EA measurement can be used through precise size measurement. Otherwise, early sizing approaches are useful when the FURs are not specified in sufficient detail for a precise size measurement.

In order to generalize the novel EA measurement approach, further research is required, including:

1. Conduct case studies to collect data from EA and metrology practitioners about the completeness of the approach.
2. Revise the completeness of the mapping COSMIC concepts to ArchiMate. For instance, the relationship between the three (3) architectural layers is service oriented. Therefore, it is required to extend the mapping rules to cover the measurement of the data movements between the distinct EA layers.
3. Establish ArchiMate modelling guidelines to handle the levels of abstraction. Different modelling notations might result in different functional sizes.
4. Establish a framework based on COSMIC early sizing to handle fine-grained modelling. In-depth modelling will increase the functional size; therefore, COSMIC early sizing approaches can estimate the EA measurements of fine-grained (granular) details.

CONCLUSION

The literature on enterprise architecture (EA) posits that EA is of considerable value for organizations due to its significant benefits towards helping organizations achieve their business and effectiveness goals by aligning IT initiatives with business objectives. However, while the EA literature documents a number of proposals for EA measurement solutions, some researchers report that there is a little guidance on EA measurement. In addition, there is little evidence-based research to support the achievements, and theoretical limitations and gaps of EA measurement research findings. In other words, few researchers have performed systematic reviews (evidence-based research) on EA measurement topics.

Therefore, in this thesis, we conducted an evidence-based research including a systematic mapping study (SMS) and a systematic literature review (SLR). In the conduct of this thesis, we adopted the guideliens of (Kitchenham & Charters, 2007) for systematic reviews, and (Krippendorff, 2018) for content analysis. This thesis identified 23 relevant primary studies as follows: 21 published in journals and two (2) published in conferences from 2004 to the end of 2018, and analyzed them according to SMS and SLR objectives.

The objective of the SMS was to explore from various perspectives including, but not limited to, positioning of the EA measurement proposals within an EA project life cycle, analysis of consistency-inconsistency of the terms used by authors in EA measurement research, and an analysis of references to the ISO 15939 measurement information model.

The SMS also undertook a classification of the research area within the primary studies revealing significant gaps and limitations. For instance, the findings indicate a limited adoption of knowledge from other disciplines in proposing an EA measurement solution and, in addition, that current EA research lacks the terminology rigor that found in science and engineering.

The objective of the SLR was to evaluate the EA measurement proposals with respect to the measurement and metrology best practices adopted from (Abran, 2010). In order to perform this evaluation, we used the principles of the evaluation theory to develop the evaluation process including the guidelines and yardsticks.

The findings of this evaluation reveal that there is a lack of attention to attaining an appropriate metrology EA measurement proposal. All the EA measurement proposals are characterized with insufficient metrology coverage scoring, theoretical, and empirical definitions. For such, an insufficient EA attribute characterization that leads to a lack of consensus on the related terminologies and the lack in assigning measurement units to EA attributes. Furthermore, Spearman's correlation was used to determine the strength and direction of relationship between the theoretical definition metrology coverage with time (years), and the empirical definition metrology coverage with time (years). The results indicated that both the empirical and theoretical definitions are not improving over time in the literature. This indicates a serious issue about the metrology rigor of the forthcoming EA measurement proposals.

In addition to evaluating the metrology coverage scoring, theoretical, and empirical definitions, this thesis presented a detailed description and discussion about the major metrology issues found in EA measurement proposals. The discussion highlighted some of the hidden and unknown metrology and quantification weaknesses related to EA measurement. Moreover, presented a detailed description of six (6) examples of metrology weaknesses found in the primary studies that obtained a high metrology coverage.

This thesis also presented a mapping between the EA quantification techniques (also referred to as EA measurement proposals) and ISO 15939. The mapping revealed that the techniques do not correspond to the metrology section (data collection and preparation sections) of ISO 15939.

In addition, following the analysis of the limitations, theoretical and empirical metrology weaknesses found from the conduct of the SMS and SLR, we proposed a novel EA measurement apporach.

The novel measurement apporach was deveopled based on combining two (2) international standards: ArchiMate known as the standard modelling language for EA, and COSMIC known as the standard method that defines rules for measuring the functional size of a software. To our knowledge, this thesis is the first attempt that maps the COSMIC concepts to ArchiMate, and it introduces COSMIC and its principles to EA measurement.
This novel measurement apporach was developed, explained, and executed on an example from the insurance industry.

Implications of this research

To our knowledge, this thesis is to date the largest study on this topic. We consider our results relevant for both EA researchers who can leverage our findings to design future studies, and EA practitioners who can consult our analysis to better understand the weaknesses of the state-of-the-art on EA measurement, and gain knowledge of the metrology qualities required in the design of EA measurement solutions.

The results of this thesis notify that while the EA measurement proposals do not have the metrology rigor, adopting such proposals, and/or designing such quantification techniques might lead to improper decisions with costly and risky consequences.

For example, primary studies that attempt to measure EA architecture posit that EA entails financial investments (e.g., costs) and that the optimal architecture should be designed or selected with care. Some of the decisions that can be made of measuring the architecture can include decisions related to IT consolidation such as cutting maintenance costs, reduce IT redundancy, and improve development time. Other decisions can be related to measurement of systems availability and reliability. While the proposed EA measurement solutions are characterized with metrology weaknesses, in other words are not trustworthy, the related decisions based on these measurement results may lead to undesired consequences in the organization (e.g., increase the cost instead of reducing it, wrong system reliability measure that increase system failures).

Furthermore, primary studies that attempt to measure EA projects may increase the likelihood of EA risk. For example, measurement results of EA risk characterized with metrology weaknesses in one phase of the EA project life cycle will flow (i.e. span) throughout the entire EA project life cycle. Hence, these measurement results will affect the EA project service and product capabilities.

Recommendations for future research avenues

Future research avenues should consider the following:

1. Designing EA measurement solutions that can contribute to the different EA schools of thought.
2. Designing EA measurement solutions that can support the full EA project life cycle.
3. Resolving the issues regarding consistency-inconsistency of using distinct terminologies such as “measurement,” “evaluation,” “analysis” and “assessment.”
4. Resolving the overlap of various measured concepts and sub-concepts to ensure widely accepted EA measurement solutions. Adopting knowledge from mature disciplines that provide guidelines and best practices on measurement and metrology.
5. Measurement units and scale types in AHP.
6. Measurement units and scale types in DEA model
7. Measurement units and scale types in fuzzy transformations.
8. Measurement units and scale types in any in-house mathematical calculations.
9. Measurement units and scale types in EA complexity formula.
10. Insure that the metrology properties are preserved when applying regression techniques such as PLS or any other statistical technique.

11. Obtain objective and non-subjective input data so that the numerical world preserves the properties of the empirical and real world of EA.
12. Standardize and apply the novel EA measurement approach presented in this thesis (ArchiMate COSOMIC V1).

Contributions and outcomes of this research

1. Revealing the hidden and unknown weakness in EA measurement research.
2. Revealing the hidden and unknown metrology weakness in EA measurement proposals.
3. The mapping rules between COSMIC and ArchiMate (Table 7.6).
4. The proposal of a novel measurement approach (ArchiMate COSMIC V1).

The development of this thesis has produced outcomes that are published or in-progress for publication at the following conferences and journals:

1. A. Abdallah, J. Lapalme and A. Abran, "Enterprise Architecture Measurement: A Systematic Mapping Study" *2017. 4'th International Conference on Enterprise Systems (ES)*, Melbourne, VIC, 2016, pp. 13-20.
2. A. Abdallah, A. Abran, "Enterprise Architecture Measurement: An Extended Systematic Mapping Study" *2019. International Journal of Information Technology and Computer Science (IJITCS)* (Accepted)
3. A. Abdallah, A. Abran, "Towards the Adoption of International Standards in EA Measurement" 2019. *International Conference on Data Science, E-learning and Information Systems* (In-progress)
4. A. Abdallah, A. Abran, "Metrology Coverage of Enterprise Architecture Measurement Proposals" (Journal paper TBD)
5. A. Abdallah, A. Abran, "Metrology Issues in Enterprise Architecture Measurement Proposals" (Journal paper TBD)

Limitations

1. This thesis aimed to analyze journal articles only in order to keep the data sources to a handy size.
2. The results of the search strategy retrieved primary studies from various digital libraries and saved in Excel sheets. In order to differentiate journal papers from conferences and other publications, we used the filter tool in Excel. Some of these papers were accurately tagged as journal papers, and some of them were inaccurately tagged as journal papers due to different tags and titles across the various digital libraries. The impact of this on this thesis is the result of two (2) primary studies published in two (2) distinct conferences. These two (2) conference papers were part of the selected primary studies and analyzed in the SMS and SLR accordingly. Due to time constrains and careful consideration, we anticipated that there would be no benefit (i.e. significant results) of removing the two (2) conference papers. Therefore, it is decided to keep them part of this thesis.
3. Future research on this topic can include other data sources, such as conference articles, books, and white papers.
4. Since the results of this thesis are based on content analysis done by coders (researchers), it is recommended to calculate the inter-coder agreement coefficient (e.g., Krippendorf's alpha) to increase the validity and the generalization of the research results.

ANNEX I

CODEBOOK FOR SMS

Coding instructions for MQ1 &2:

- **Title:** The title of the primary study.
- **Publication Year:** The year of publication of the primary study.
- **Journal:** The journal that has published the primary study.

Coding instructions for MQ3:

Objective: Concur from each primary study the EA definition they use to build their EA (measurement, evaluation …) solution. In other words, on what EA definition do you think this EA measurement solution is designed? What type of EA is the author trying to measure?

Screen: Find the statements that define EA in the primary study

- The first mentioned EA definition (school of thought) in the primary study could be misleading. In other words, the author might be only mentioning other definitions only to educate the reader. The author is likely to distinguish between EA definition (school of thought) in the literature and EA definition (school of thought) in the context of his/her primary study. Most often, author's school of thought and EA literature are homogeneous
- **Where to find the code in the primary study:** Can be found in the abstract introduction, and body of the primary study. Note: first, it is recommended to read the full primary study

Outcome (codes): Tag the article with the EA school of thought. In the context of the primary study, and the EA measurement solution: determine the EA definition statement. Tag where you find the definition with one of the following codes:

Code 1: Enterprise IT architecting

- Definition: Statement, or belief that EA is about aligning an enterprise's IT assets (through strategy, design, and management) to effectively executing the business strategy and various operations using proper.
- Example: "The importance of EA is closely related with strategic alignment of IT business operations, stable operation of complex information systems, and interoperability of IT resources."

Code 2: Enterprise integrating

- Definition: Statement or belief that EA is about designing all facets of the enterprise. The goal is to execute the enterprise's strategy by maximizing overall coherency between all of its facets including IT.
- Example: "The importance of EA is closely related with strategic alignment of IT business operations, stable operation of complex information systems, and interoperability of IT resources."

Code 3: Enterprise ecological adaption

- Definition: Statement, or belief that EA is about fostering organizational learning by designing all facets of the enterprise including its relationship to its environment to enable innovation and system-in-environment adaptation.
- Example: "The scope of AEA includes people, processes, information, and technology of the enterprise, and their relationships among each other and to the external environment."

<u>Coding instructions for MQ4:</u>

Objective: Concur from each primary study the relevant EA life cycle in the primary studies

Screen:

The coder is advised to read the full primary study in order to aggregate a comprehensive meaning about the related EA life cycle. However, if not possible, the coder can read the following sections: Abstract, introduction, and conclusion. In specific, the text should meet the following characteristics:

- The related text should explicitly contain discussion about EA life cycle. The scope of the discussion should be focused on the relation between the EA life cycle and the EA solution (artifact) of the primary study. The text may not (some instances are) be explicit about using words such as "before EA implementation", "after EA development." However, the understanding of related text should be interpreted according to the definitions bellow (codes).
- The text should exist. Otherwise, the primary study should be tagged with "NA." The coder is not allowed to conduct analysis on implicit meanings about EA life cycle.

Outcome: the result of this exercise is a list that determines the relevant codes for each primary study.

Code 1: Development, the development phase, the EA is developed and maintained –this phase is before EA implementation.

Example: "Before an organization takes up a particular EA framework, there is need to consider and evaluate the possible alternative frameworks, and then select an appropriate one through a collaborative effort involving all key stakeholders"

Code 2: Realization is where projects are defined and carried out to implement the changes defined in the EA – this phase is EA implementation.
Example: "In this study, we used organizational performance and change theory to determine factors that contribute to the successful implementation of EA."

Code 3: Use, after the implementation changes have been implemented in the organization and the promised benefits should materialize - post EA implementation.

Example: "We seek to complement and extend the existing works by developing knowledge about EAM success factors at a post-implementation stage"

<u>Coding instructions for MQ5:</u>

Objective: Concur from each primary study the intention/motivation to propose an EA measurement solution.

Screen:

- The coder is recommended to read the full primary study in order to aggregate full meanings about the **Intention** of the primary study. The coder is required to search during his/her reading for text that represents the **Intention** of the primary study. Sometimes the primary study clearly use words such as: "**Intention**" by explaining the benefits of their research and what value, and solution their research will bring.
- After the coder has found related text about the research motivation, he/she is required to tag the text with a code (word, title) that summaries the meaning of the text.
- <u>Hint</u>: **Intention can be found in the text in the following phrases:**
  - The proposed "……." provides "……"
  - The key contribution is "……."
  - The research problem (question) is to address "……"
  - The purpose of this paper is to "……"
  - The main contribution of this research is to "……"
  - The purpose of this study is to "……"
  - The aim of this research is to "……"
  - This investigation helps organizations to "……."

Outcome: the coder will eventually tag the primary study with the intention such as:

- Assist organizations to understand EA financial values
- Facilitate decision making (EA framework selection)
- Facilitate decision making (EA scenario selection)
- Establish theory of how EA add value (benefits) to organizations

Coding instructions for MQ6:

Objective: Concur from each primary study the type of the research conducted in measurement research.

Screen: The coder is recommended to read the full primary study in order to aggregate full meanings about the type of research. Codes for this question can be found mainly in the research methodology, results, discussion, and conclusion sections.

Outcome: the coder will eventually tag the primary study with the research type such as:

Code1: Validation research, for a primary study that meets the following:

- The primary study use surveys or questioners to test their hypothesis about EA measurement or evaluation, assessment, analysis.
- The measurement solution is not yet implemented in practice with an industry partner.

Code2: Evaluation research, for a primary study that meets the following:

- Has an industry partner
- Implements the EA measurement solution in practice with the industry partner.
- A case study with an industry partner where the author implements the measurement solution is an example of an evaluation research. The case study should be done within the primary study itself. For example, if the case study is in another reference, this is not considered an evaluation research.

- Sometimes, the author may receive feedback from the industry partner about their measurement solution.

Code3: Solution proposal**,** for a primary study that meets the following:

- has no industry partner
- is not testing any hypothesis
- is not yet implemented in practice
- explain in paragraphs the potential benefits of the EA measurement solution
- provide a conceptual measurement solution

Code4: Philosophical research, for a primary study that meets **ONE** of the following:

- provide a classification on topic related to EA measurement research
- structure the EA measurement research filed & provide a new way of looking and understanding EA measurement literature
- technically, it should not match any of the criteria for: **Validation Research, Evaluation Research, Solution Proposal**

Coding instructions for MQ7:

Objective: Concur from each primary study the type of the foundation/background used to propose an EA measurement solution.

Screen: The coder is recommended to read the full primary study in order to aggregate full meanings. Answers to this question can be found in literature review, related work, and discussion sections.

Outcome: the coder will eventually tag the primary study with the research type such as:

Code 1: Financial Principles, if the primary study is using Financial Principles such as cost, ROI to design or provide an EA measurement solution. Mentioning Financial Principles such

ROI in the text does not mean using it; the primary study should explain how these Financial Principles are used.

Code 2: Fuzzy weighted multi-criteria method, if the primary study is using the Fuzzy weighted multi-criteria method to design or provide an EA measurement solution. Mentioning the Fuzzy weighted multi-criteria method in the text does not mean using it, the primary study should explain how the Fuzzy weighted multi-criteria method is used.

Code 3: Fuzzy data envelopment analysis, if the primary study is using the Fuzzy data envelopment analysis to design or provide an EA measurement solution. Mentioning the Fuzzy data envelopment analysis in the text does not mean using it, the primary study should explain how the Fuzzy data envelopment analysis is used.

Code 4: Analytical hierarchy process (AHP), if the primary study is using the Analytical hierarchy process (AHP) to design or provide an EA measurement solution. Mentioning (AHP) in the text does not mean using it, the primary study should explain how (AHP) is used.

Code 5: Balanced scorecard, if the primary study is using the Balanced Scorecard to design or provide an EA measurement solution. Mentioning the Balanced Scorecard in the text does not mean using it, the primary study should explain how the Balanced Scorecard is used.

Code 6: IS success model, if the primary study is referring to the IS success model to design or provide an EA measurement solution. Mentioning the IS success model in the text does not mean using it, the primary study should explain how the IS success model is used.

Code 7: Agile framework, if the primary study is referring to the Agile Framework to design or provide a measurement solution. Mentioning the Agile Framework in the text does not mean using it, the primary study should explain how the Agile Framework is used in the measurement solution.

Code 8: Resource-based theory, if the primary study is referring to the Resource-Based Theory to design or provide a measurement solution. Mentioning the Resource-Based Theory in the text does not mean using it, the primary study should explain how the Resource-Based Theory is used in the measurement solution.

Code 9: EA Literature, if the primary study collects information, criteria, and factors from EA field to design or provide an EA measurement solution. The design of EA measurement solution should be dependent on EA Field without referring to any reference from another Field. Or to any of the listed above foundations. This option serves as “none of the above”

Coding instructions for MQ8:

Objective: Concur from each primary study the used terminology to describe the EA measurement solution, and to synthesis, the EA concepts, and attributes under concern.

How to determine what is the terminology used to describe the EA measurement solution measured in each EA primary study?

Screen: Find the statements that describe the EA measurement solution

- The coder is required to read together the title and the abstract of the primary study. Most likely, the coder will be able to determine the terminology used to describe the EA measurement solution in the title and the abstract of the primary study.
- “Terminology” means the term the author(s) of a given primary study is naming their EA measurement solution.
- If the coder is unable to find the terminology, he/she is advised to read the introduction and the conclusion of the primary study.

Outcome: the coder will eventually tag the primary study with the type of the EA measurement solution such as:

Code 1: Framework

- Definition: We do not focus on interpreting the meaning of "Framework" in the primary study. We only search for the existence of the word in the text.
- Example: "A Framework for Measuring ROI"

Code 2: Model

- Definition: We do not focus on interpreting the meaning of "Model" in the primary study. We only search for the existence of the word in the text.
- Example: "A fuzzy group multi-criteria enterprise architecture framework selection model"

Code 3: Method

- Definition: We do not focus on interpreting the meaning of "Method" in the primary study. We only search for the existence of the word in the text.
- Example: "A hybrid method for evaluating enterprise architecture implementation"

How to determine what is measured in each EA primary study (EA concepts and attributes)?

Screen:

- The coder is required to read the full primary study
- The coder needs to find instances related to answer: what do I measure, evaluate, assess, etc., if I apply the EA (measurement, evaluation, assessment, etc.…) solution found in the primary study? The coder is required to determine two levels: concepts and attributes.
- NOTE: to measure an attribute, the concept to be measured should be defined and characterized. Characterization is done by identifying the type of entity (e.g., a piece of software code), and defining how the sub-concepts are organized. In this mapping question, we aim to identify which EA concept and related attributes (breakdown of the EA concepts) are used in the EA (measurement, evaluation, assessment, etc...) solutions.

Outcome: the coder will eventually tag the primary study with a concept & attribute.

Possible codes for EA concepts:

Code 1: Impact, is the noun/concept that the author is trying to measure.
Example: "As shown in Table 3, the **impact** of enterprise architecture can be measured using six metrics: (a) costs; (b) benefits; (c) benefit to cost ratio; (d) return on investment

Code 2: Risk, is the noun/concept that the author is trying to measure.
Example: These fuzzy numbers are used to prioritize the EA frameworks with respect to the impact of the **risk** criteria

Code 3: Scenario is the noun/concept that the author is trying to measure.
Example: In this study, a hybrid methodology is proposed to decide the most efficient EA **scenario** among the existing alternatives through a multi-criteria group decision-making process.

Code 4: Effectiveness is the noun/concept that the author is trying to measure.

Example: This paper discusses these methods and suggests strategies for measuring the **effectiveness** of enterprise architectures.

Other codes: benefits, business value & impact, value, EA maturity stage, IT alignment, operational IT effectiveness, IT standardization degree, EA frameworks, readiness, EA principles, usability

Possible codes for EA attribute (sub-concepts):

Code 1: ROI is the noun/sub-concept that the author is trying to measure.

Example: Table3. A framework of metrics and models for **measuring return on investment** of enterprise architecture

Code 2: List of risk criteria, is the noun/sub-concept that the author is trying to measure.
Example: "organizational risk, user risk, requirement risk, and team risk"
Code 3: Efficiency, is the noun/sub-concept that the author is trying to measure
Example: "The efficiency of an EA scenario is affected by the process of COBIT supposed as the criteria model in this paper"

Code 4: IT system quality attributes and business value is the noun/sub-concept that the author is trying to measure.
Example: "The literature review resulted in the following list of quality attributes for IT systems:"

Other codes: list of EA quality characteristics and their metrics, list of IT alignment measures, metrics for the standardization degree, EA benefit enablers, list of usability criteria, list of risk factors, list of success measures & success factors.

Coding instructions for MQ9:

Objective: Concur from each primary study the usage of the words "Measurement," "Evaluation", "Assessment", "Analysis"

Screen:

- Read the full primary study to find all statements, figure, tables that contain "Measurement," "Evaluation", "Assessment," "Analysis" in the context of the EA measurement solutions.

- It is important to read the full primary study and determine the words. Most often, if the author is interchangeably using the words, the coder will not figure out unless he/she read the full text and find all the instances that may lead to deduce that the author is interchangeably using the words.

- Interchangeably means: the author use for instance “measurement & analysis” for the same meaning. In other words, the author my use “measure” in the introduction, and within the same context, use “assess” in the body. It can be found that the author switches between the words without an explanation that distinguish the theory and definition behind the words.
- The coder can use the search tool in order to facilitate his/her primary study screening. However, it requires the coder to read in the search results and identify if the words are used interchangeably.

Outcome:

- The coder should determine the semantics used in the primary study
- The coder should determine if the words are found interchangeably in the primary study. The coder needs to determine what combination is found (i.e. Measurement & Evaluation, Measurement & Assessment, etc.…), and therefore, what semantic does the primary study fit. The different emerged semantics are:

Measurement semantic: refers to primary stuides using the term “measurement”, and does not interchangeably mix together “measurement” with other terms.

Possible codes:

Code 1: Measurement, the author is using the term “measurement” within the context of the EA measurement solution when presenting the measurement solution in the primary study.
Example: “Enterprise architecture **measures** of effectiveness”
Measurement + other semantics: refers to the primary studies that use the term “measurement”, and interchangeably mix with other terms such as: evaluation, assessment, or analysis.

Code 1: Measurement & evaluation, the presence of the words "Measurement & Evaluation" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Measurement & Evaluation".
Example: "Each of these five factors has its own set of criteria that can be used to **measure** the usability in the respective layer of EA." In addition, in another sentence, the following text is found: "One of the qualitative characteristics is usability, which should be **evaluated** in EA frameworks as an essential element of the whole system."

Code 2: Measurement & assessment, the presence of the words "Measurement & Assessment" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Measurement & Assessment".

Code 3: Measurement & analysis, the presence of the words "Measurement & Analysis" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Measurement & Analysis".

Code 4: Measurement & evaluation & assessment, the presence of the words "Measurement & Evaluation & Assessment" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Measurement & Evaluation & Assessment."

Code 5: Measurement & evaluation & analysis, the presence of the words "Measurement & Evaluation & Analysis" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Measurement & Evaluation & Analysis."

Code 6: Measurement & assessment & analysis, the presence of the words "Measurement & Assessment & Analysis" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Measurement & Assessment & Analysis."

Code 7: Measurement & evaluation & assessment & analysis, the presence of the words "Measurement & Evaluation & Assessment & Analysis" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Measurement & Evaluation & Assessment & Analysis."

Evaluation, assessment, or analysis semantics: refers to the primary studies that do not use the term "measurement", and instead, use other terms such as: evaluation, assessment, or analysis.

Code 1: Evaluation & assessment, the presence of the words "Evaluation & Assessment" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between Evaluation & Assessment".

Code 2: Evaluation & analysis,the presence of the words "Evaluation & Analysis" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Evaluation & Analysis.

Code 3: Evaluation & assessment & analysis, the presence of the words "Evaluation & Assessment & Analysis" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Evaluation & Assessment & Analysis".

Code 4: Assessment & analysis, the presence of the words "Assessment & Analysis" in the text. We search for if the author is interchangeably switching between these words without a clear statement that states the difference between "Assessment & Analysis".

Coding instructions for MQ10:

Objective: Concur from each primary study the presence of ISO 15939 in the design of EA measurement proposals.

Screen: perform a quick search in the references list of each primary study

Outcome:

Code 1: ISO 15939 is not present

Code 2: ISO 15939 is present

ANNEX II

CODEBOOK FOR SLR

Coding instructions for RQ1:

Objective: Concur from each primary study the existence of metrological concepts (codes)

Screen: Tag each primary study with the pre-defined metrology codes. NOTE: measurement solution is an in-house term used in this thesis to denote to the measurement attempts of EA measurement literature.

Outcome: Each primary study will be tagged with and subsequently evaluated using the following codes and tables:

Code 1: EA entity type: is equivalent to an EA object being measured (quantified).
Code 2: EA (concept) attribute: is the characteristic(s) of the EA entity used to measure (quantify) the EA entity.
Code 3: Source of input data: is the description of the inputs (inputs to the measurement solution) to measure (quantify) the EA entity/attribute.
Code 4: Type of input data: is the description weather the inputs are objective or subjective.
Code 5: Math on input/output data: is the mathematical operations applied in the primary study on the inputs and outputs of the measurement solution.
Code 6: Measurement unit: is a defined and accepted international unit attached to quantities.
Code 7: Quantification rule: is the rule (s) defined and used in the primary study to assign numbers to the EA entity/attribute.

ANNEX III

SELECTED PRIMARY STUDIES

Primary Study ID	Primary Study Title	Publication Source	Year of publication	Type of publication
S1	A Framework for measuring ROI of EA	Journal of Organizational and End User Computing	2006	Journal
S2	A fuzzy group multi-criteria enterprise architecture framework selection model	Expert Systems with Applications	2012	Journal
S3	A novel credibility-based group decision making method for enterprise architecture scenario analysis using data envelopment analysis	Applied Soft Computing	2015	Journal
S4	A theory building study of enterprise architecture practices and benefits	Information Systems Frontiers	2015	Journal
S5	An AHP-based approach toward enterprise architecture analysis based on enterprise architecture quality attributes	Knowledge and Information Systems	2011	Journal

Primary Study ID	Primary Study Title	Publication Source	Year of publication	Type of publication
S6	An IT management assessment framework Evaluating enterprise architecture scenarios	Information Systems and e-Business Management	2007	Journal
S7	Applying design science research in enterprise architecture business value assessments	Communications in Computer and Information Science	2012	Conference
S8	Enterprise architecture measures of effectiveness	International Journal of Technology, Policy and Management	2004	Journal
S9	Enterprise architecture metrics in the balanced scorecard for IT	Information Systems Control Journal	2009	Journal
S10	Enterprise architecture, IT effectiveness and the mediating role of IT alignment in US hospitals	Information Systems Journal	2012	Journal
S11	Evaluating enterprise architecture management initiatives - How to measure and control the degree of standardization	Enterprise Modeling and Information Systems Architectures	2009	Conference

Primary Study ID	Primary Study Title	Publication Source	Year of publication	Type of publication
	of an IT landscape			
S12	Evaluation of ARIS and Zachman frameworks as enterprise architectures	Journal of Information and Organizational Sciences	2006	Journal
S13	How does EA add value to organizations	Communications of the Association for Information Systems	2011	Journal
S14	Measurement of enterprise architecture readiness	Business Strategy Series	2010	Journal
S15	The role of organizational culture for grounding, management, guidance and effectiveness of enterprise architecture principles	Information Systems and e-Business Management	2014	Journal
S16	Usability elements as benchmarking criteria for enterprise architecture methodologies	Jurnal Teknologi (Sciences and Engineering)	2014	Journal
S17	A hybrid method for evaluating enterprise architecture implementation	Evaluation and Program Planning	2017	Journal
S18	An empirical analysis of the factors and	European Journal of	2016	Journal

Primary Study ID	Primary Study Title	Publication Source	Year of publication	Type of publication
	measures of enterprise architecture management success	Information Systems		
S19	Identifying and evaluating enterprise architecture risks using FMEA and fuzzy VIKOR	Journal of Intelligent Manufacturing	2016	Journal
S20	Transformational and transactional factors for the successful implementation of enterprise architecture in public sector	Sustainability (Switzerland)	2016	Journal
S21	A measurement model to analyze the effect of agile enterprise architecture on geographically distributed agile development	Journal of Software Engineering Research and Development	2018	Journal
S22	Achieving benefits with enterprise architecture	Journal of Strategic Information Systems	2018	Journal
S23	Multilevel complexity measurement in enterprise architecture models	International Journal of Computer Integrated Manufacturing	2017	Journal

ANNEX IV

LIST OF APPENDICES ON CD-ROM

The following is the list of appendices referenced within this thesis and that can be found on the attached CD-ROM:

Table-A I-1 List of appendices referenced within this thesis

Appendix #	File Name	Description
I	Coding results of SMS.pdf	Detailed results of the execution of the systematic mapping study (SMS)
II	Coding results of SLR.pdf	Detailed results of the execution of the systematic literature review (SLR)
III	Evaluation results of EA measurement solutions.pdf	Detailed results of the evaluation process of the proposed EA measurement solutions
IV	Relevant ArchiMate examples.pdf	Figures showing the serving relationship between EA layers using ArchiMate

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