ENTERPRISE ARCHITECTURE MEASUREMENT: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

A number of measurement solutions have been proposed to manage the development of Enterprise Architectures (EA) but this body of knowledge has not been analyzed to identify any strengths or weaknesses from a measurement perspective. Adopting a systematic literature review (SLR) approach this research identified 23 primary studies on EA measurement solutions. These studies were analyzed through five research questions looking into the types of EA entities being measured, sources and types of input data, mathematical operations, and measurement units used. The key findings are: 1) the selected studies measure four entity types - EA as an architecture, as a framework, as a project and as a program; 2) most of the input data to the measurement solutions are subjective data reflecting practitioner opinion; 3) mathematical operations used in the measurement solutions are mostly scores and weight multiplications without verification for valid mathematical operations; 4) most often they lack well-defined measurement units.

Keywords: *Enterprise Architecture (EA), Software Engineering Measurement, Metrology, Metrics.*

1. INTRODUCTION

In today's modern world, organizations are operating in fast-paced business environments that entail evolving technologies and changing business needs [1]. These challenges increase pressure on organizations to survive, and adapt to change [1,2]. To manage and align technology with business needs, enterprise architecture (EA) was introduced by Zachman in 1987 as a means to improve enterprise integration with change and reduce the gap between business and information technology (IT) [2]. Furthermore, EA is expected to improve decision-making, reduce IT costs, improve business processes, and enhance the reuse of resources [3-8].

These expected benefits have led to increased attention by practitioners and the creation of EA frameworks such as: the Zachman Framework, the Open Group Architecture Framework, and the Department of Defense Architecture Framework. In addition, Gartner [9] estimated that EA practitioners influence on IT budgets exceeded $1.1 trillion.

EA is also receiving increasing attention by governments worldwide [10]. For example, in the USA, the Federal Enterprise Architecture (FEA) implemented a number of public administration e-services, and more specifically it has been embedded within the Clinger-Cohen Act, a law on public IT acquisitions [11].

The focus on EA is not only on understanding but also managing it [12]: for the proper management of EA development, implementation and harvesting of expected benefits, EA should be measurable [7] and organizations must have the ability to track deviations from the organization's targets [13].

To capitalize on EA investments organizations should be able to:

- measure and know their returns on EA [14]
- justify to what degree EA benefits are being achieved
- update their EA according to measurement results
- improve their learning processes, and
- enable precise communication about performance and progress toward strategic goals [13].

EA measurement has been investigated by researchers [13-22] who proposed distinct measurement solutions to quantify, for example:

- the expected value of EA [13]
- balanced scorecard solutions providing a multi-perspective (e.g., financial, customer, internal,

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learning perspectives) to justify investments in EA [15,16]

- the factors that influence the EA implementation process [17,18], and
- [19] the value of EA on IT projects.

However, the challenge for practitioners and researchers is to analyze this set of dispersed EA measurement proposals, which have not been organized logically and evaluated independently, and determine its respective strengths and weaknesses.

On the one hand, with the growth of EA literature on a diversity of measurement solutions, it is useful and necessary to analyze this existing body of knowledge (BOK) in order to understand the state of the art, to organize it and to identify gaps and limitations.

On the other hand, there now exists measurement and metrology guidelines that have been adopted in the software engineering field [23]. These guidelines describe, for instance, design criteria for measurement methods which can be used to distinguish well designed measurement methods from weak quantification techniques.

The objective of this study is to identify the measurement solutions within this BOK in the EA literature, analyze and classify them according to the types of EA entities being measured, sources and types of input data, mathematical operations, and measurement units used.

The rest of this paper is organized as follows. Section 2 reviews the related work. Section 3 presents the selected SLR research methodology and the five related measurement research questions. Section 4 details the results, which are discussed in Section 5 together with implications for researchers and practitioners. Section 6 presents a summary of the key findings and suggestions for future work.

2. RELATED WORK

2.1 EA measurement solutions

For analysis of bodies of knowledge (BOK), medical research for instance, has built solid work in providing BOK summaries and classification schemes through systematic literature reviews (SLR) and systematic mapping studies (SMS) [24].

Such an SLR-SMS approach was adopted for our study. Table 1 presents a summary of the related work on evidence-based EA research.

Table 1: Literature studies on EA

EA Topic	**Systematic literature review - SLR**	**Systematic mapping study - SMS**
Definition and common understanding	Nurmi, 2018 [1] Saint-Louis & Lapalme, 2018 [25]	(Saint-Louis & Lapalme, 2016) [26]
Value and benefits	Tamm *et al.*, 2011 [5] Gong & Janssen, 2019 [27] Wan *et al.*, 2013 [7]	
Evaluation	Andersen & Carugati, 2014 [28] Nikpay *et al.*,2015 [29]	
Readiness	Hussein *et al.*, 2016 [30]	
Visual analytics	Jugel *et al.*, 2017 [31]	
EA during past 10 years	Rasti *et al.*, 2015 [32]	
Measurement	Nkundla-Mgudlwa & C. Mentz, 2017 [33]	
EA in the public sector	Dang & Pekkola, 2017 [10]	
EA and enterprise integration		BanaeianJahromi, Smolander, 2014 [2]
Decision making	Roos & Mentz, 2018 [34]	
Implementation	Ansyori *et al.*, 2018 [35]	
EA and business – IT alignment	Zhang *et al.*, 2018 [8]	
Measurement		Abdallah & Abran, 2019 [36]

Of the 18 SLR-SMS on EA in Table 1 only four explicitly addressed measurement and evaluation:

- Andersen & Carugati, 2014 [28]
- Nikpay et al., 2015 [29]
- Nkundla-Mgudlwa & Mentz, 2017 [34]
- Abdallah & Abran 2019 [36]

However, the evaluation methods in these studies focused on business and IT alignment or on architecture maturity while ignoring all other parts of implementation [29].

The primary studies in [36] were analyzed thematically and classified according to ten mapping question including positioning of EA measurement solutions within EA schools of thought, analysis of consistency-inconsistency of the terms used by authors in EA measurement research, and an analysis of the references to the ISO 19539 measurement information model. The key findings in [36] are that these primary studies focused on the enterprise IT architecting school of thought, did not use rigorous terminology as found in science and engineering, and shows limited

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adoption of knowledge from other disciplines. Furthermore, these SLR-SMS did not use metrology and measurement criteria and the measurement solutions identified have not been examined from the perspective of measurement and metrology criteria.

Another study in [37] looked at the state of EA measurement to identify weaknesses and gaps in aligning and measuring EA components, EA structures and EA interrelationships from an IT perspective. Its focus was on measurement concepts that could contribute for aligning, measuring, and monitoring software-related projects within an EA strategy. In [37] the key findings were aligned within a Balance Scorecard (BSC) measurement approach, measurement of software structures and functionality within a service-oriented architecture (SOA).

Therefore, these four SLR-SMS above and the study in [37] did not provide analyses of EA measurement solutions from the measurement perspective itself as investigated in our study.

2.2 Measurement and metrology guidelines

In mature disciplines such as science and engineering, numbers are not all equal. For instance:

- Numbers acquired from a mature measurement method have metrological qualities and meet metrological criteria (e.g., a clearly defined measurement unit).
- Numbers acquired from opinions (e.g., subjective input data) do not have metrological qualities.

In the software engineering field, the measurement context model [23] introduces three metrological building blocks (steps) that provide criteria for the design, application, and exploitation of the measurement results, for instance in cost and quality estimation models – see Figure 1. This measurement context model can be used to verify that measurement solutions satisfy metrological qualities, and therefore that the measurement results obtained from these methods are trustworthy in decision making models.

This measurement context model presents criteria for the design of a measurement method. For instance, in step 1 (Figure 1) the design of the measurement method should include:

- A clear description of the source of input data to the measurement method. Example: a measurer or a measuring instrument.
- A clear description of its type of input data. Example: the functional user requirements in the functional sizing measurement standards.
- A clear description of its admissible mathematical operations. Example: multiplication operations using numbers on a ratio scale type.
- A clear description of its measurement unit. Example: a meter for the measurement of distance.

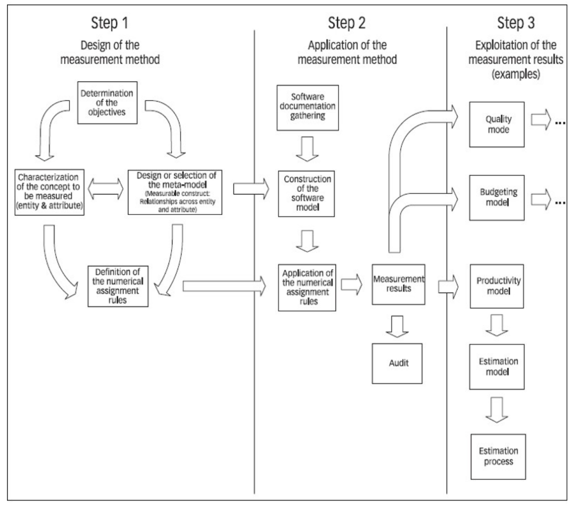

Figure 1: The measurement context model [23]

3. SLR RESEARCH METHODOLOGY

An SLR helps to identify, evaluate, and interpret all available research relevant to a research question or topic area of interest. For this study on the BOK on EA measurement solutions, we followed Kitchenham's guidelines [38] organizing our review procedure as follows: research questions, search strategy, study selection, and data extraction.

3.1 SLR research questions

To investigate the research issue, five research questions (RQ) on the measurement solutions proposed in the selected primary studies were formulated based on the empirical criteria of the measurement context model:

- RQ1: What EA entities are measured?
- RQ2: What is the source of input data?
- RQ3: What type of input data is used for the measurement method?
- RQ4: What mathematical operations are used?
- RQ5: What measurement units are used or derived?

3.2 SLR search strategy

The search strategy included selecting the electronic databases, defining, and applying the search strings from 2004 to 2019. The six (6)

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databases selected are: AIS, Compendex, IEEE, Inspec, Scopus, and SpringLink. The defined search strings were used in the search fields of the databases and were customized according to the settings of each database:

<<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. String 8 Enterprise architecture” AND "Quantitative analysis". String 9 “Enterprise architecture” AND Performance.>>

3.3 SLR study selection

Exploration of the databases using the search strings in section 3.2, identified 774 candidate primary studies. Since the 774 studies are the outcome of searching six databases, duplicates may exist among the six databases for each search string, and among the six databases overall. Therefore, pivot tables were used to remove duplicates, reducing the studies to a set of 236. To select the most relevant for the research topic, the following inclusion and exclusion criteria were defined.

Inclusion criteria: the studies meeting the following criteria were included in the scope of the SLR:

- Exact keyword “enterprise architecture” is present in the title.
- Exact keyword “measurement, or (evaluation, assessment, analysis)” is present in the title and/or the entire text.
- Only the most recent publication of a study reported more than once.
- Discusses an EA measurement solution - this can be, but not limited to, method, theory, framework, and tool.
- Journal papers.
- Conference papers that:
  - Provide answers to all RQs.
  - Mention ISO 15939, or propose measurement units with a mathematical basis.

Exclusion criteria: primary studies not meeting the inclusion criteria above were excluded from the scope of this SLR.

The application of the inclusion and exclusion criteria led to a set of 23 primary studies listed in the Appendix. This SLR extended the publication years to include 2019 and includes 1 new primary study not included in the SMS in [36].

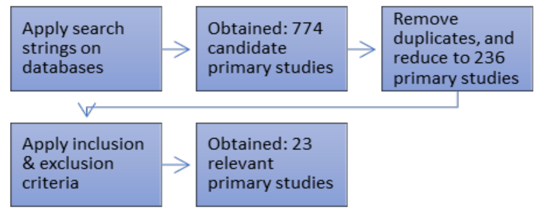

Figure 2: Primary studies selection

3.4 SLR data extraction

The text and content of the selected studies from section 3.3 represent the raw data of this SLR. To interpret and extract data for content analysis, a significant data extraction technique [36] was selected. Content analysis begins with reading the primary studies (raw data) and then assigning codes (labels) to the text where these codes can be inductive (data driven) and/or deductive (pre-defined list).

Assigning codes is an iterative process where the researcher can create additional codes and/or merge with others. Hence, the codes will eventually allow creation of a theme [39]. A theme is a coherent integration that captures something important about the data with respect to the research questions. It reduces a large amount of text into smaller units, which allows the researcher to build a level of abstraction. Therefore, it is an expression of the latent (hidden) content of the text [40].

Table 2 shows the data extraction form created as an Excel spreadsheet and completed for each selected study.

Table 2: Data extraction form

Primary study ID:	
Primary study title:	
Classification	
(RQ1)	EA entities measured
(RQ2)	Source of input data
(RQ3)	Type of input data
(RQ4)	Mathematical operations used
(RQ5)	Measurement units used or derived

4. SLR RESULTS

This section presents the SLR coding results and answers to the five research questions.

4.1 EA entities measured (RQ1)

Figure 3 presents the relative distribution of the EA entities measured, together with references to the related studies. Figure 3 also lists the related primary studies, labeled from S1 to S23 in the Appendix. In summary:

- 52% measure EA projects,
- 26% measure EA architectures,
- 22% measure EA frameworks, and
- 4% measure EA programs.

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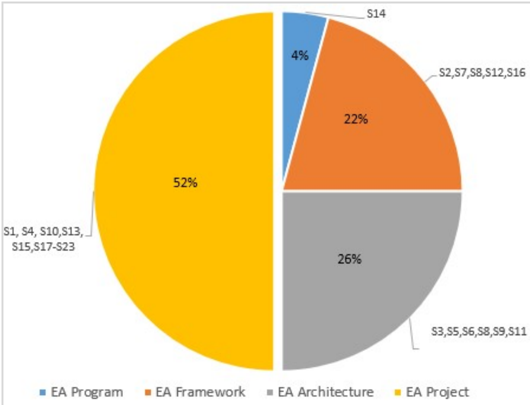

Figure 3: EA entities measured

4.2 Source of input data (RQ2)

Figure 4 presents the distribution of the sources of input data to the EA measurement solutions for each entity type:

- For projects:
  - 67% are EA practitioners.
  - 25% are not identified (NA - not available).
  - 8% are from E-government EA initiatives.
- For architectures: 100% are practitioners.
- For frameworks:
  - 60% are not identified.
  - 40% are EA practitioners.
- For programs: 100% are practitioners.

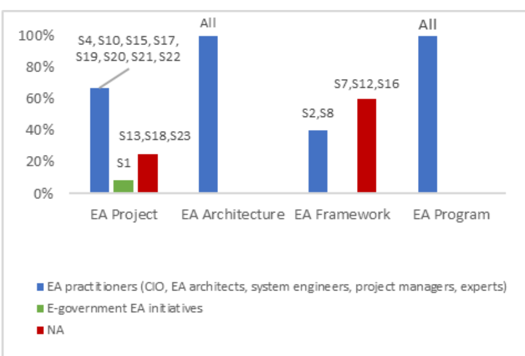

Figure 4: Sources of input data to the measurement entities (RQ2)

4.3 Types of input data (RQ3)

Figure 5 presents the distribution of the types of input data in the EA measurement solutions of each entity type:

- For projects: 33% of the types of input data were opinions – perception of future.
- For architectures: 50% of the types of input data were opinions – perception of future.
- For frameworks: 60% of the types of input data were not identified. For programs: 100% of the types of input data were opinions – perception of present.

4.4 Mathematical operations used (RQ4)

Figure 6 presents the distribution of the mathematical operations used on the input data in the EA measurement solutions:

- Projects: 75% of the mathematical operations were not identified.
- Architectures: 50% of the mathematical operations were not identified.
- Frameworks: 60% of the mathematical operations were not identified.
- Programs: 100% of the mathematical operations were score and weight multiplications.
- The remaining used formulae for complexity, fuzzy transformations, accepted formulae for ROI, and in-house formulae.

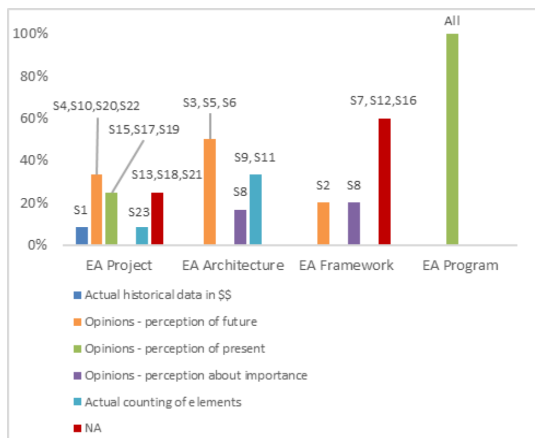

Figure 5: Types of input data to the EA measurement solutions (RQ3)

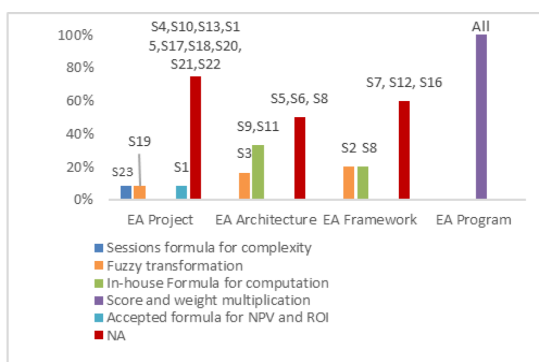

Figure 6: Mathematical operations on input data in EA measurement solutions (RQ4)

Figure 7 presents the mathematical operations used on the output data in the EA measurement solutions:

- Projects: 58% of the mathematical operations were partial least square (PLS) structural equations.
- Architectures: 67% of the mathematical operations were not identified (e.g., NA).
- Frameworks: 80% of the mathematical operations used were not identified.
- Programs: 100% of the mathematical operations used were not identified.
- The remaining used fuzzy functions, data envelopment analysis (DEA) model, analytic hierarchy process (AHP) and regression analysis.

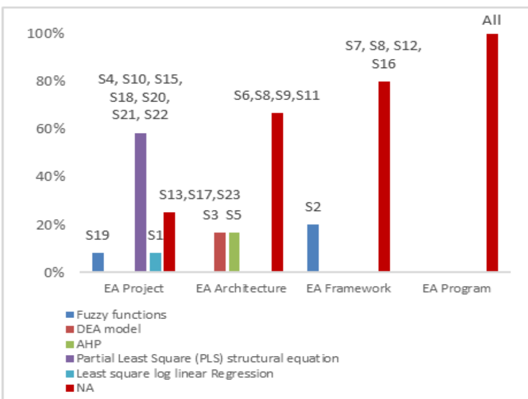

Figure 7: Mathematical operations on output data of EA measurement solutions (RQ4)

4.5 The measurement units used or derived (RQ5)

Figure 8 presents the distribution of the measurement units used or derived in the EA measurement solutions:

- For projects: most (84%) did not identify measurement units, with the exception of Dollar ($) and a non-standardized measurement unit referred to as structural complexity (Scu).
- For architectures, frameworks, and programs: not a single measurement unit was identified.

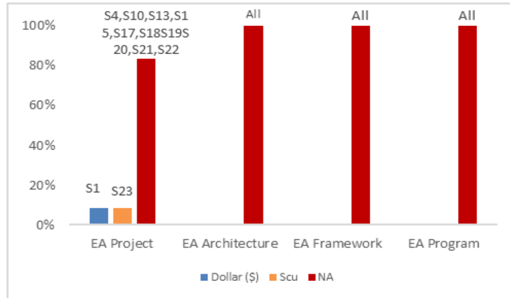

Figure 8: Measurement units used or derived in EA measurement solutions (RQ5)

5. DISCUSSION & IMPLICATIONS FOR RESEARCHERS AND PRACTITIONERS

5.1 RQ1 discussion

The results and answers to RQ1 in Figure 3 on EA entities show that:

- 52% of the studies measure or evaluate concepts within ‘EA projects’ including anticipated benefits to organizations. Some of the primary studies under this category refer to projects through three stages: EA (As-Is), EA (To-Be), and EA transition to the desired architecture.
- 26% of the studies measure “EA architecture” where authors 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, and strategy, as well as the interconnections and interrelationships among them.
  Some studies under this category posit that the fundamental impact of EA on organizations relies on selecting or designing the optimal architecture for the organization. Since EA entails financial investments, studies in this category posit that the right architecture should be designed or selected with care. Therefore, some studies attempt to quantify and analyze the quality of the architecture, architectural risk factors and the expected generated business value from the architecture on IT management, and on the organization as a whole. Other studies attempt to measure how EA can, through its strategic IT goals, add value (e.g., be rewarded for IT governance toward a better alignment between business and IT).

- 22% of the primary studies measure or evaluate concepts within EA frameworks. Frameworks help manage EA through an integral perspective of the organization by decomposing EA into different domains and layers. Therefore, EA architects use frameworks to implement EA in organizations in order to manage the interdependencies between the various elements (e.g., people, and technology) in organizations.

  Since there are various EA frameworks available in the literature, the more framework alternatives with possible contradictory criteria, the more complex is the decision for selecting a framework.
  In addition, the literature reports that there is no consensus about which framework should be used or should be considered as the best alternative for the organization.
  Different frameworks are characterized with various weaknesses and strengths and no EA framework is complete. For instance, the Zachman Framework aligns roles and ideas in a structured way in the organization, while the Open Group Architecture Framework (TOGAF) offers steps that support the architectural development process in the organization. Therefore, studies on EA frameworks suggest that before an organization selects a framework, all relevant frameworks should be evaluated in terms of defined criteria (attributes), and the appropriate framework should be selected accordingly.
- 4% of the studies measure “EA program”. The authors posit that performing EA should not be mistaken with a project that has a start and an end: 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 program, including securing a budget and ensuring that the organization has the human capital to execute the program. Therefore, study [S14] for example, attempts to quantify EA readiness of the program before being executed (i.e., during the preparation stage of the EA program).

5.2 RQ2 and RQ3 discussion

The results and answers to RQ2 and RQ3 revealed that the measurers (e.g., the sources of input data to EA measurement solutions) are mainly EA practitioners, limited governmental data or not identified at all. Furthermore, the results indicate that most of the input data to EA measurement solutions are subjective data, reflecting practitioner opinions. Since subjective opinions lack metrological rigor, using these inputs in measurements and decision-making models should be dealt with cautiously.

5.3 RQ4 and RQ5 discussion

The results and answers to RQ4 and RQ5 revealed the type of mathematical operations on both input and output data in EA measurement solutions. Some studies used fuzzy logic, accepted financial formulae such as ROI, regression analysis, and others. However, it is unknown yet whether or not the use of these mathematical operations is admissible from a metrological perspective: mathematical operations should preserve the rules of scale types and the transformations of input data and output data in the measurement solutions. Furthermore, they should use (or derive) admissible measurement units for these mathematical operations. The results also indicate a very low implementation of standard measurement units in the design of these measurement solutions.

6. SUMMARY AND FUTURE WORK

The literature posits that EA is of considerable value to organizations due to expected significant benefits which help organizations achieve their business and effectiveness goals by aligning IT initiatives with business objectives. To verify such a claim a number of studies have proposed EA measurement solutions. While three SLR studies have previously reported surveys of EA measurement solutions, they have neither classified nor analyzed them. The objective of the study reported in this paper was to analyze and classify them according to EA entities being measured, sources and types of input data, mathematical operations, and measurement units used.

This SLR selected 23 primary studies on EA measurement solutions and analyzed them thematically through five research questions.

The first major finding from RQ1 is that the EA measurement solutions in the literature aim to measure four EA-related entity types, of which only 26% of the studies directly addressed EA itself, while the other 74% looked into subsidiary

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concepts of EA projects, frameworks and programs – many of these referring to concepts neither specific to nor tailored for EA.

Each measurement solution was then analyzed with respect to sources of input data (RQ2), type of input data (RQ3), mathematical operations used (RQ4), and measurement units (RQ5).

The key findings of this study are:

- Most of the input data to EA measurement solutions are subjective data reflecting EA practitioner opinion rather than objective data.
- The type of mathematical operations used in the measurement solutions vary from generally accepted financial formulae such as ROI, complexity sizing, customized formulae without analysis of their mathematical structure, and fuzzy logic.
- Most do not explicitly specify the measurement unit, except when referring to costs.

The analysis carried out in this paper used measurement and metrology guidelines that have been adopted in the software engineering field [23]. These guidelines describe, for instance, design criteria for measurement methods which can be used to distinguish well designed measurement methods from weak quantification techniques. The key findings indicate that these criteria have not been used by the EA community and EA measurement solutions have neither been designed nor examined from the perspective of measurement and metrology guidelines.

From these findings a number of gaps and weaknesses have been identified, each requiring additional research. For instance, future research should analyze the metrology utilized in each proposed measurement solution, identify the gaps and weaknesses, and related proposed improvements in their design. For instance, future research should note whether the metrology uses only valid mathematical operations, has well specified sub-concepts and well-defined measurement units. This will reveal the degree of robustness of the proposed measurement solutions to ensure their trustworthiness and whether or not the measurement results have a sound foundation for use in decision making models. The scope of the SLR can also be extended to include conference papers.

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