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MEASUREMENT SOLUTIONS IN THE ENTERPRISE ARCHITECTURE LITERATURE: A METROLOGY EVALUATION

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ABSTRACT

The literature on enterprise architecture (EA) proposes several measurement solutions to demonstrate the benefits expected by aligning IT initiatives with business objectives. This study presents the first evaluation of these EA measurement solutions by applying a metrology-coverage evaluation method based on evaluation theory, metrology guidelines, and best practices from the software measurement literature. This evaluation method was applied to four EA entities (EA architecture, project, program, and framework) and identified strengths and weaknesses in the theoretical and empirical designs of the proposed EA measurement solutions. This research will assist EA practitioners in understanding the limitations of the measurement solutions proposed and select those with stronger designs. EA researchers can also leverage these evaluation results to improve the current designs of the EA measurement solutions and propose new ones with a stronger metrology foundation.

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

1. INTRODUCTION

The enterprise architecture (EA) was introduced by Zachman in 1987 to improve enterprise integration and reduce gaps between business and information technology (IT) [1], [2]. EA is defined in the literature as:

- A set of management system components and their structures, interrelationships, and interdependencies [3];
- A coherent whole of principles, methods, and models that are used in the design and realization of an enterprise's organizational structure, business processes, information systems, and infrastructure" [4];
- A discipline to manage the architectures of organizations and support the transition from a current (as-is) to a future (to-be) state [5].

EA is also expected to improve decision-making, reduce IT costs, improve business processes, and enhance resource reuse [6–10]. Therefore, EA has received increasing attention from researchers and practitioners, and the motivation for EA has shifted from understanding to managing EA [5].

Organizations benefit from EA when measurable outcomes such as return on investment (ROI) materialize [11]. For proper management of development, implementation, and harvesting of expected benefits, EA should be measurable [9]. Measurement and evaluation capabilities are perceived as essential for enterprise architecture and adaptation. The literature acknowledges the difficulty of assessing the impact of EA, that most of the proposed measures are qualitative, and that the development of measurement and evaluation capabilities is a concern for researchers and practitioners [12].

A recent systematic mapping study [13] reported that while a number of solutions for EA measurement have been proposed, there is limited adoption of knowledge from other disciplines for such measurement solutions, and that the current research in EA lacks the terminology rigor found in science and engineering.

In addition, a systematic literature review (SLR) [14], [15] identified that EA measurement solutions attempt to measure four EA entity types: EA as an architecture, project, framework, and program. The

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SLR also suggests evaluating measurement solutions with respect to metrology criteria to quantify their robustness. A measurement solution can be considered trustworthy in decision-making models when it meets the metrology rigor. This study presents the design and application of a metrology-coverage evaluation method. The method is based on evaluation theory, a number of measurement and metrology guidelines, and best practices from the software measurement literature, including the measurement context model [16]. This metrology-coverage method was used in this study to evaluate the 23 EA measurement solutions selected in [14].

The aim is to assist practitioners in understanding the limitations and metrology weaknesses of the proposed EA measurement solutions, so as to able to select the ones with stronger designs. Researchers would then be able to leverage these evaluation results to improve the current designs of measurement solutions from a metrology perspective and propose new ones with a stronger metrology foundation.

The remainder of this paper is organized as follows. Section 2 presents the related work. Section 3 describes the design of the metrology-coverage evaluation method. Section 4 details the evaluation of the EA measurement solutions in the selected studies. Section 5 discusses the metrology coverage from three perspectives: across EA entity types, improvements over time, and within each type of study included in this study. Conclusions and suggestions for future work are discussed in Section 6.

2. RELATED WORK

Researchers have proposed EA measurement solutions from a variety of perspectives. For instance:

- Reference [17] proposed a solution that attempts to measure the expected EA value.
- References [18], [19] proposed a solution based on the balanced scorecard providing a multi-perspective framework (e.g., financial, customer, internal, and learning perspectives) in an attempt to justify EA investments.
- Reference [20] proposed a solution to measure the EA functional size based on adopting the common software measurement international consortium (COSMIC) and EA modeling language (ArchiMate).

Other researchers have proposed solutions to quantify:

- EA complexity [21], [22].
- Factors that could influence the EA implementation process [23].
- Quantification of EA value on IT projects [24].

Other EA measurement attempts are presented in [25–28].

There are also a number of EA evaluation models focusing on business and IT alignment or on architecture maturity while ignoring all other parts of implementation [29].

Some researchers have reported on the weaknesses of some EA practices and pointed out a number of challenges, such as adoption and application, managing the enterprise life cycle, and assessing infrastructure stress [5], [30–32]. Other researchers have also reported that incomplete, complex, and incoherent definitions of EA affect the ability of organizations to measure EA itself and to realize the expected benefits, value, and impacts [32].

A few researchers have noticed other issues in the studies on EA measurement itself, including:

- Insufficient practices for all EA functions and processes for evaluation and measurement [28].
- A number of drawbacks in evaluation [28].
- Organizational challenges in how to measure the value of EA [17].
- Lack of the terminology rigor found in science and engineering [13].

The SLR on EA measurement [14], [15] showed that researchers have attempted to measure four EA entity types: EA as an architecture, a project, a framework, and a program (including related attributes and sub-attributes).

2.1 EA as an architecture

Measurement solutions of the EA architecture entity type consider that architecting within an organization requires an in-depth consideration of the various elements that affect the architecture of the organization, such as the technology, business, culture, strategy, and the interconnections and interrelationships between them. Therefore, measurement solutions of the architecture entity attempt to quantify the concepts related to the architecture and deal with the underlying decisions and factors that may influence achieving an optimal architecture, such as:

- Quality of the architecture,
- Architecture risk, and

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- Expected business value to be generated from EA architecture on IT management and organization in general.

2.2 EA as a project

Some of the measurement solutions of EA as a project entity type refer to the projects through three stages: EA (As-Is), EA (To-Be), and EA transition to the desired architecture. Other solutions refer to the project as a set of stages: initiation, control, and sustainability of implementation. An EA project is similar to any project: it has a timeline and outputs to its environment. Therefore, measurement solutions of EA projects attempt to quantify different project concepts, including the anticipated benefits of an EA project on the organization.

2.3 EA as a framework

The measurement solutions of the EA framework entity type attempt to evaluate or measure concepts and attributes within the frameworks proposed to the EA community. EA frameworks are expected to provide benefits to organizations through guidance on how to create and use EA. In the literature, different frameworks provide such guidance and the more EA framework alternatives with possible contradictory criteria, the more complex is the decision to select a particular framework as the best alternative for an organization. Different frameworks have been characterized with both weaknesses and strengths, none of which being ideal or 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 architecture development process within an organization [33]. Therefore, some EA measurement solutions were designed to evaluate EA frameworks and help select one appropriate for the organization.

2.4 EA as a program

The measurement solutions of EA as a program entity type focus on evaluating or measuring concepts within such a program. EA program planning involves factors that affect its success, including securing a budget and ensuring that the organization has human capital to execute the program. Therefore, a measurement solution of this entity type aims to quantify the readiness of an EA program before its execution (i.e., during the preparation stage of a program).

3. RESEARCH METHODOLOGY

The metrology-coverage evaluation method designed for this research consists of three steps (see Figure 1).

1. Identifying the components of the metrology-coverage method (subsection 3.1).
2. Defining the criteria and guidelines for scoring metrological coverage (subsection 3.2).
3. Appling the proposed evaluation method (section 4).

3.1 Identifying the components of the metrology-coverage method

In this study, a metrology-coverage evaluation method for EA measurement solutions was designed using a combination of evaluation theory [34], a measurement context model [16], and a representational theory of measurement [16], [35].

1) Evaluation theory

Evaluation is the act of determining the worth, merit, or significance of a given object [34]. There are a number of evaluation methods categorized as follows [36]:

- 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.

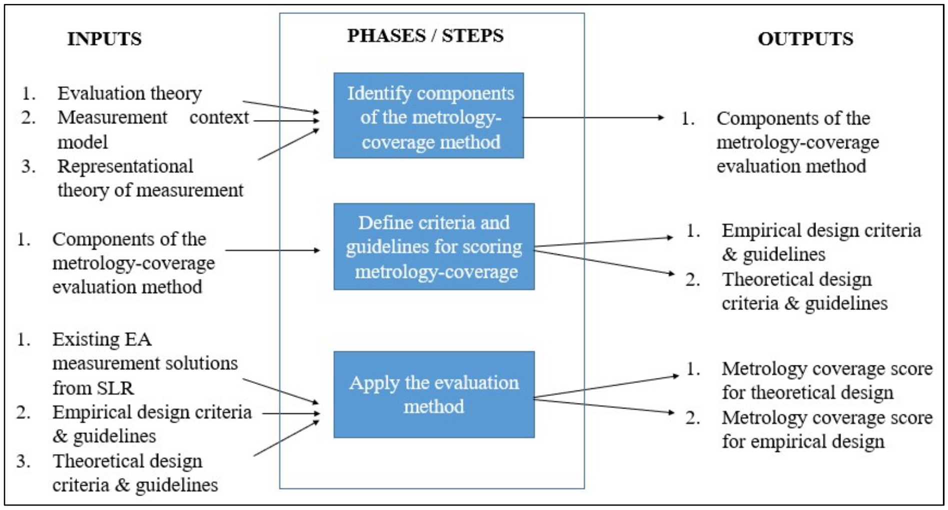

Figure 1: Research methodology for the design of a metrology coverage evaluation method of measurement solutions

Table 1: Basic components of evaluation methods

Basic component	Definition
Target	Object under evaluation.
Criteria	Characteristics of the target to be evaluated.
Yardstick	Ideal target, which against the target is to be compared.
Data gathering techniques	Techniques needed to obtain data to analyze each criterion related to the target.
Synthesis techniques	Techniques used to judge each criterion and, in general, to judge the target, obtaining the results of the evaluation.

To conduct an evaluation using any of these evaluation methods, an evaluation process should identify the mandatory and basic components, as summarized in Table 1.

These basic components should be identified prior to conducting the evaluation. The characteristics (criteria) of the target can be determined using several techniques, such as:

- Functional analysis of the target: a 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.

Regarding data gathering techniques in the software engineering field, López [34] reported the 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.

Hence, we obtain Table 2 which lists the basic components of our evaluation method associated with a metrology-coverage description.

The first basic component, the *target,* is represented by EA measurement solutions that attempt to measure four types of entities, including attributes and sub-attributes of each measured entity type [14]: EA as an architecture, a project, a framework, and a program.

The other components of the evaluation method are:

- Criteria: use the measurement context model (section 2) and representational theory of measurement (Section 3).
- Yardstick: defining the metrology criteria and scoring guidelines (Section 3.2).
- Data gathering techniques: apply the document review technique based on the SLR in [14].

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Table 2: Basic components of the metrology-coverage evaluation method

Basic component	Description
Target	EA measurement solution.
Criteria	Scientific standard: measurement and metrology criteria.
Yardstick	Metrology coverage score (theoretical and empirical criteria).
Data gathering techniques	Assignation: documentation review of EA measurement solution.
Synthesis techniques	Figures and tables of the evaluation results.

- Synthesis techniques: apply and present results of the evaluation method (section 4).

2) Measurement context model

The measurement context model in Figure 2 introduces three (3) building blocks (steps) that provide the criteria to design, apply, and exploit the measurement results [16]. These criteria can be used to verify that the design of measurement solutions satisfies the metrology qualities, and therefore lead to measurement designs that are trustworthy measurement solutions. The measurement results obtained from measurement methods that meet these criteria can then be used as a sound basis in decision-making models (for example, in cost and quality estimation models).

This measurement context model presents theoretical and empirical criteria for designing a measurement method (i.e., Step 1 in Figure 2):

(1) The theoretical design criteria are:
- The design should include a clear definition of the measured attribute.
- The design should include a clear characterization (decomposition) for the measured attribute.
- The relationship between the sub-attributes and attributes should be clearly defined (e.g., the meta model).

(2) The design of the measurement method should identify the intended use(s) of the measurement. The empirical design criteria should include the clear descriptions of:
- The input data source. Example: a measurer, a visual sensor, etc.
- The type of input data. Example: The measurement input is of a ratio scale type.
- The admissible mathematical operations used. Example: multiplication operations on ratio-scale data inputs.
- The accepted (e.g., internationally recognized) measurement units used. Example: a meter.

(3) Representational Theory of Measurement

The representational theory of measurement posits that there are rules to be followed when performing measurements. These rules will facilitate the interpretation of the measurement results (numbers) and allow consistency (e.g., not adding two numbers with two different scale types) in the conduct of the measurement exercise [16], [35].

The representation condition of measurement, the first rule of the representational theory of measurement, asserts that the numbers obtained from the measurement exercise should preserve the properties of the real world. Therefore, by studying these numbers (e.g., measurement results), we can acquire knowledge about the real world. In addition, any measurement exercise that follows the representation condition is called a homomorphism (that is, there is a correspondence between the empirical and numerical worlds), and thus is a valid measurement [16].

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 defines measurement as the mapping of the real world (empirical), or what we want to measure, into the numerical world, or 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 observed in the real world.

The rule of mapping—the second rule of the representational theory of measurement—asserts that the quantification rules that map an attribute to a numerical world need to be identified and respected.

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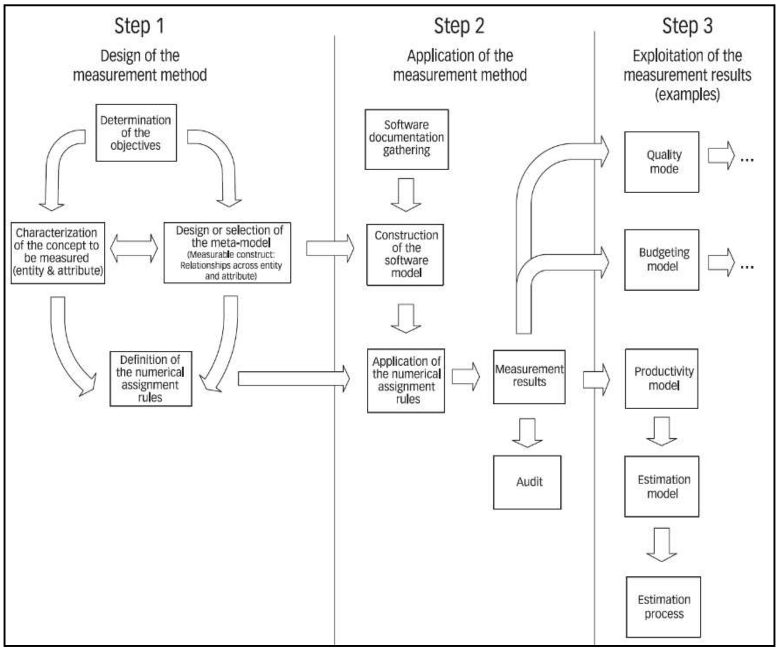

Figure 2: The measurement context model [16]

For instance, measuring the height of a person in centimeters (e.g., 170 cm) and converting this (170 cm) to another measurement scale/unit (m for 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 with a measurement unit. Furthermore, the mathematical operations applied on numbers should be admissible and follow the rules of the measurement scale types presented in Figure 3.

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

Figure 3: Measurement scale types and admissible transformations [16]

3.2 Define the metrology criteria and the scoring guidelines

The sub-steps required to design a measurement method (e.g., left side of Figure 2) were used as a template to formulate the theoretical and empirical criteria. These metrology criteria, as well as best practices and guidelines for measurement, were adopted to develop the evaluation yardstick.

1) Theoretical Design Criteria

- Are the measured or quantified concepts defined in the measurement solution?
- Are the measured or quantified concepts decomposed to a granular level which will allow quantification?
- Are the measured or quantified sub-concepts defined within the measurement solution?
- Is the intended use of the measurement results identified?

2) Empirical Design Criteria

- Is the point of view (perspective) of quantification identified?
- Is the data input (subjective or objective) determined?
- Are the rules on how to quantity the EA entity and its concepts identified?
- Is there any mathematical operation performed on the collected input data prior to its use in the analysis models?
- Is there a standard measurement unit used when quantifying the EA entity?

3) Yardstick

The yardstick is employed to evaluate whether EA measurement solutions satisfy the metrology criteria, which is referred to as 'metrology coverage'. The metrology coverage is calculated using (1):

$$\text{Metrology coverage} = \frac{\sum_{i=1}^{n} \text{Metrology coverage score}}{n} \quad (1)$$

Where:

- n = the number of metrology criteria (theoretical or empirical).
- Metrology coverage score = 1 when the measurement solution satisfies the metrology criteria.
- Metrology coverage score = 0 when the measurement solution does not satisfy the metrology criteria.

A detailed description of the evaluation scoring guidelines from a theoretical perspective is presented in Table 3 and from an empirical perspective in Table 4.

Table 3: Metrology coverage – theoretical design: evaluation scoring guidelines

Theoretical design 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
Decompose 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 the intended use of measurement	If the intended use is explicitly defined, score = 1 If the intended use is not explicitly defined, score = 0

Table 4: Metrology coverage – empirical design: evaluation scoring guidelines

Empirical design criteria (Yardstick)	**Metrology coverage score**
Identify the source of the inputs	If the source of input is explicitly identified, score = 1 If the source of input is not explicitly identified, score = 0
Identify the type of the inputs	If the type of input is explicitly identified, score = 1 If the type of input is not explicitly identified, score = 0
Identify the quantification rule(s)	If the quantification rule is explicitly identified, score = 1 If the quantification rule is not explicitly identified, score = 0
Identify the mathematical operations	If the math operations are explicitly identified, score = 1 If the math operations are not explicitly identified, score = 0
Identify the measurement unit	If the measurement unit is explicitly identified, score = 1 If the measurement unit is not explicitly identified, score = 0

4. METROLOGY EVALUATION OF THE EA MEASUREMENT SOLUTIONS

The metrology evaluations of the EA measurement solutions are presented separately for each EA entity type: architecture entity in 4.1, project entity in 4.2, program entity in 4.3, and framework entity in 4.4.

4.1 EA Architecture Entity: Metrology Coverage Evaluation

From Table A.1 in the Appendix, six studies propose measurement solutions for the architecture entity: S3, S5, S6, S8, S9, and S11.

1) Theoretical Design Evaluation

The metrology coverage for the theoretical definitions was calculated using (1) and Table 3. The evaluation results are presented in Figure 4 for each design criterion for the theoretical definitions of the architecture entity. Figure 4 also lists the related studies for the respective scoring for each criterion. For example, for the 'Define attribute' criterion, the scoring = 1 for S5, S8, and S11. In summary:

- Key theoretical design strengths (in blue in Figure 4):
  - 67% decompose the measured attribute into sub-attributes.
  - 83% identify the intended use of measurement results (right side of Figure 4).
- Key theoretical design weaknesses (in red in Figure 4):
  - 67% do not define the sub-attributes.
  - 50% do not definite the attributes.
  - 50% do not provide a clear definition of additional attributes by identifying the corresponding sub-attributes.

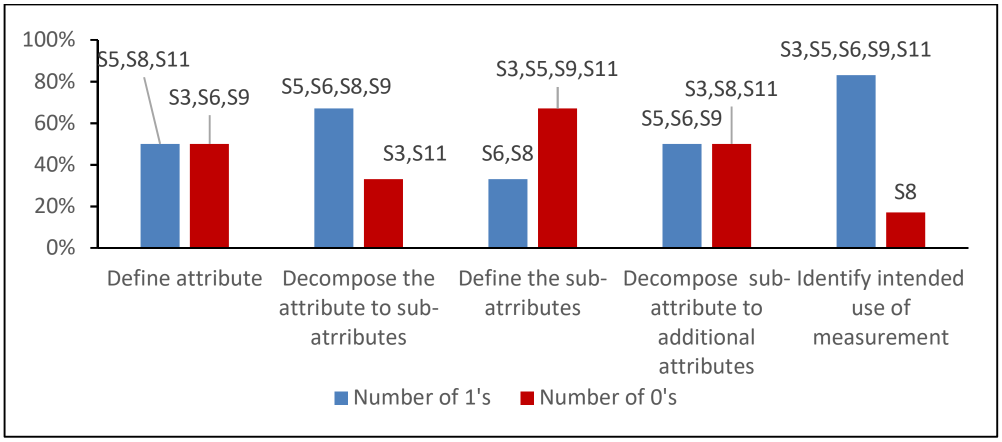

Figure 4: EA architecture – theoretical design: metrology coverage

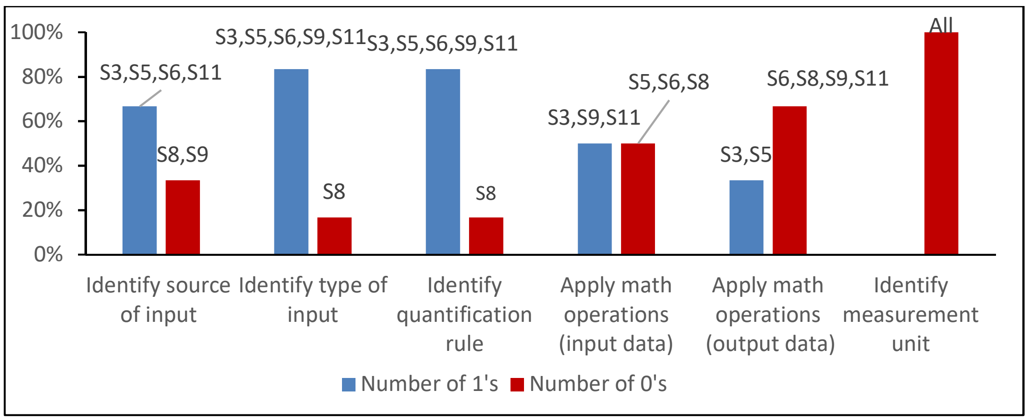

Figure 5: EA architecture - empirical design: metrology coverage

2) Empirical Design Evaluation

The metrology coverage for the empirical design was calculated using (1) and Table 4. The results are presented in Figure 5, illustrating the strengths and weaknesses of each metrology criterion for the analyzed measurement solutions. In summary:

- Key empirical design strengths (in blue in Figure 5):
  - 67% identified the source of input to quantify the architecture attributes in four studies (S3, S5, S6, S11) but not in the other two (S8, S9).
  - 83% identified the quantification rules in five studies (S3, S5, S6, S9, S11) but not in (S8).
  - 83% identified the type of input to quantify the architecture attributes.
- Key empirical design weaknesses (in red in Figure 5):
  - 50% do not apply mathematical operations on input data.
  - 67% do not apply mathematical operations on output data.
  - None of the measurement solutions identify a measurement unit.

3) EA Architecture Attributes Evaluation

On a more granular level, Figure 6 shows the metrology coverage scoring of each architecture attribute obtained from the SLR [14] according to the criteria of the theoretical and empirical designs. In summary:

- Efficiency (defined in S3): the coverage scoring of the theoretical design of 'efficiency' is much lower than its empirical design.
- Quality (defined in S5 and S6), business value (defined in S6), and value (in S9): the coverage scoring of their theoretical design is higher than their empirical design.
- Standardization degree (defined in S11): the coverage scoring of its theoretical design of the attributes is lower than its empirical design.

4.2 EA Project Entity: Metrology Coverage Evaluation

From Table A.1 in the Appendix, 12 studies propose measurement solutions for the project entity

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type (S1, S4, S10, S13, S15, S17, S18, S19, S20, S21, S22, and S23).

1) Theoretical Design Evaluation

The evaluation of the metrology coverage of the EA project for the theoretical designs was calculated using (1) and Table 3. The results are presented in Figure 7, where we can observe, for example, that the project attribute is defined in ten studies (S1, S4, S10, S13, S15, S17, S18, S21, S22, S23) but not in two others (S19, S20), and the sub-attributes are defined in eight studies (S1, S4, S13, S17, S18, S19, S21, and S22) but not in four others (S10, S15, S20, S23). In summary, Figure 7 shows that most have very high theoretical metrology coverage:

- 83% define the measured attributes,
- 92% decompose the measured attribute to sub-attributes.
- 67% decompose the measured sub-attribute to additional attributes.
- 92% identify the intended use of measurement results.

2) Empirical Design Evaluation

The empirical evaluation of the metrology coverage of the project entity is calculated using (1) and Table 4, and the results are presented in Figure 8 for each metrology criterion.

The key empirical design strengths are:

- 75% identify the source of input to quantify the architecture attributes.
- 75% identify the type of input data to quantify the architecture attributes.
- 67% identify quantification rules.
- 75% apply mathematical operations on output data.

The key empirical design weaknesses are:

- only 25% apply mathematical operations on input data.
- only 17% identify a measurement unit.

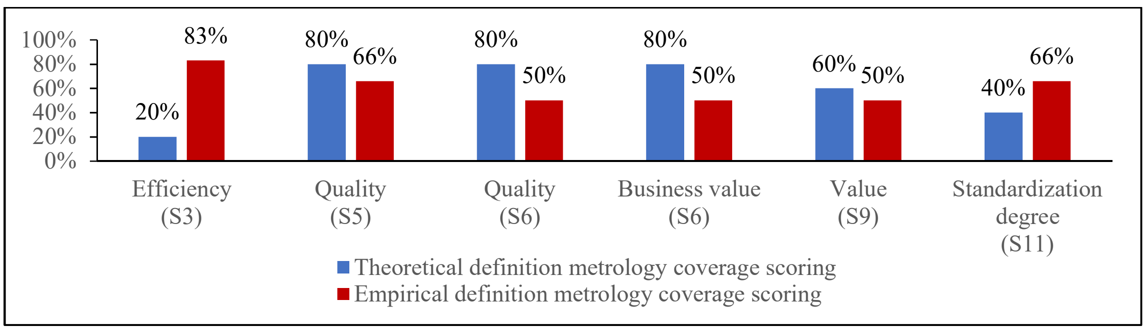

Figure 6: EA architecture attributes - theoretical vs. empirical metrology coverage

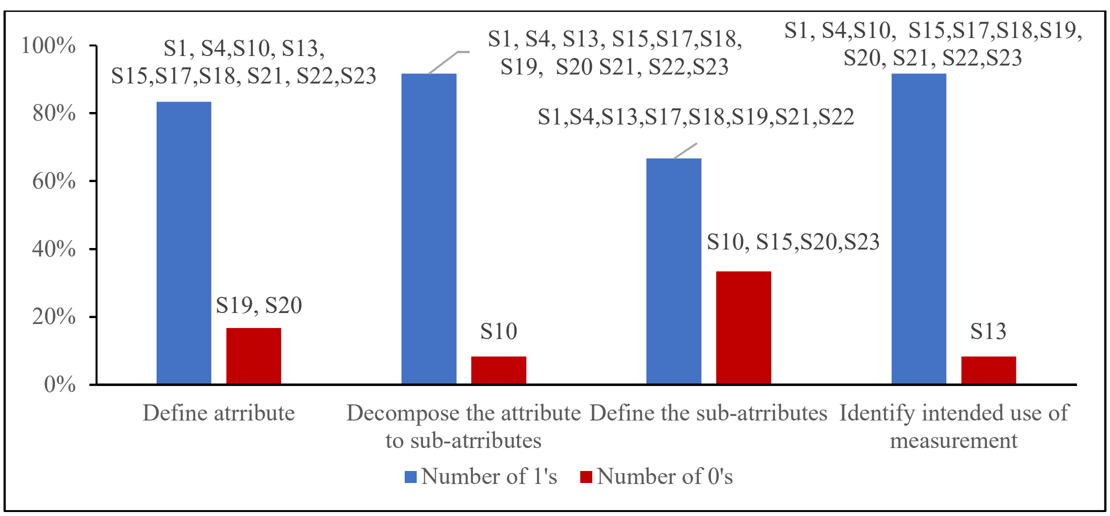

Figure 7: EA project – theoretical designs: metrology coverage

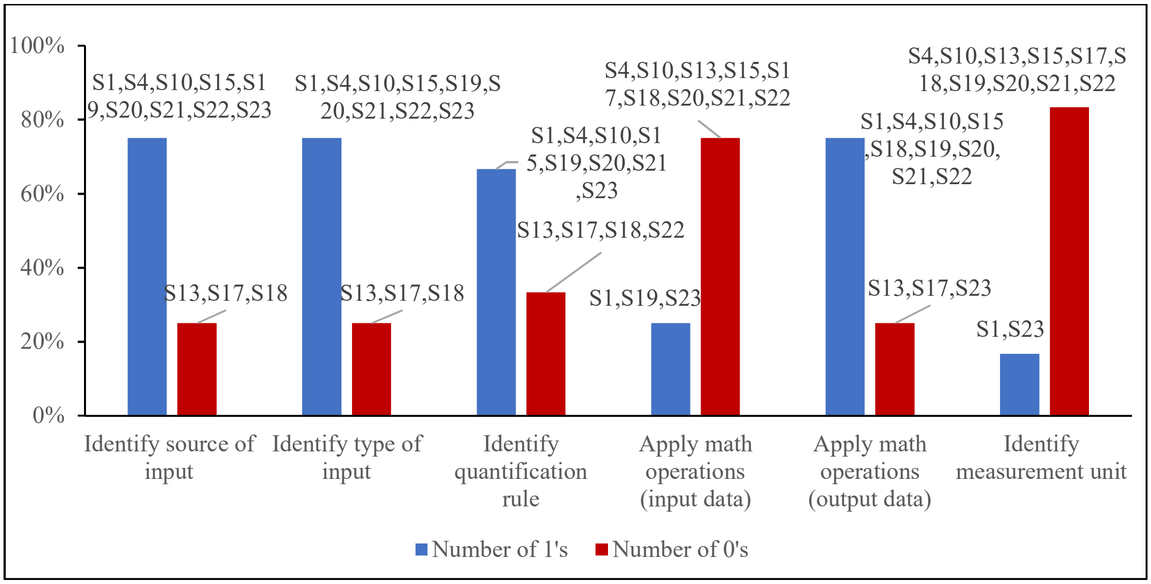

Figure 8: EA project – empirical designs: metrology coverage

3) EA Project Attributes Evaluation

On a more granular level, Figure 9 shows the metrology coverage scoring of each project attribute according to the criteria of theoretical and empirical designs:

- Impact (defined in S1): the coverage scoring of the theoretical and empirical designs are both fully covered at 100%.
- Benefits (defined in S4): while the theoretical design is fully covered, the empirical design is only 66%.
- Maturity (defined in S10): the coverage scoring of the theoretical design of the attributes is lower than that of the empirical design.
- Value (defined in S13): while the theoretical design is 75% covered, the empirical design is not covered at all.
- Success (defined in S15): the coverage score of the theoretical design is higher than that of the empirical design.
- Practices (defined in S17): while the theoretical design is fully covered, the empirical design is not covered at all.
- Success (defined in S18): while the theoretical design is fully covered, the empirical design is only 16% covered.
- Risk (defined in S19): the coverage scoring of the theoretical design of the attributes is lower than that of the empirical design.
- Performance (defined in S20): the coverage scoring of the theoretical design of the attributes is lower than that of the empirical design.
- Agile EA (defined in S21): while the theoretical design is fully covered, the empirical design is only 66% covered.
- Project benefits (defined in S22): while the theoretical design is fully covered, the empirical design is covered at only 50%.
- Complexity (defined in S23): the coverage scoring of the theoretical design of the attributes is high at 75%, while the scoring is slightly higher for the empirical design.

4.3 EA Framework Entity: Metrology Coverage Evaluation

From Table A.1 in the Appendix, four studies propose measurement solutions for the framework entity type (S2, S8, S12, S16).

4.3.1 Theoretical design evaluation

The detailed metrology coverage evaluation of the theoretical design for each metrology criteria is illustrated in Figure 10. For example, the framework attribute is defined in a single study (S2) but not in the other three (S8, S12, S16), while sub-attributes are defined in three studies (S2, S12, S16) but not in (S8). In summary, from Figure 10 the key strengths are:

- 100% decompose the attribute into sub-attributes.
- 75% define the sub-attributes.
- 100% identify the intended use of measurements.

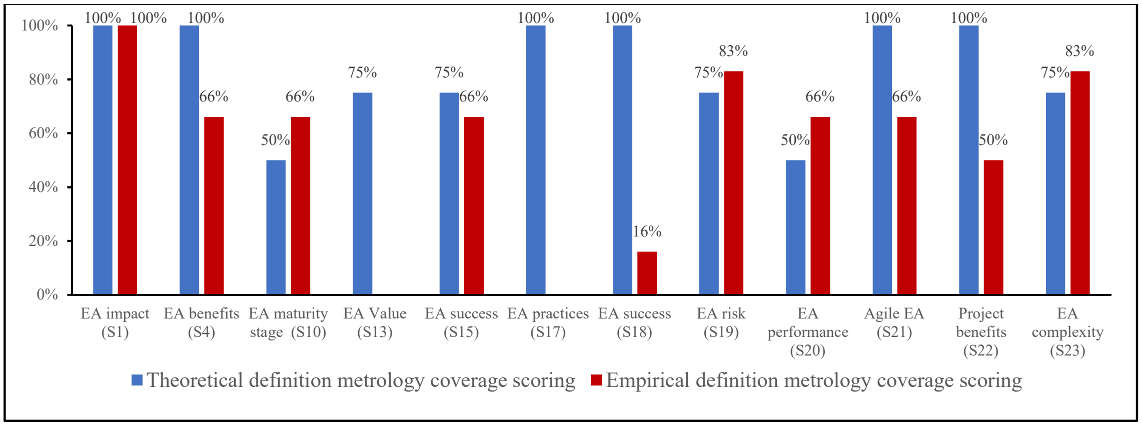

Figure 9: EA project attributes - theoretical vs. empirical metrology coverage

The key weaknesses are:

- 75% do not define the attribute.
- 50% do not decompose sub-attributes into additional attribute.

4.3.2 Empirical design evaluation

The metrology coverage of EA framework for the empirical design is presented in Figure 11. There are no major strengths and quite a number of weaknesses for each metrology criterion:

- 50% do not identify the source of input to quantify the architecture attributes.
- 50% do not identify the type of input data to quantify the architecture attributes.
- 50% do not identify quantification rules.
- 50% do not apply mathematical operations on input data.
- 75% do not apply mathematical operations on output data.
- 100% of the measurement solutions do not identify a measurement unit.

4.3.3 EA framework attributes evaluation

On a more granular level, Figure 12 shows the metrology coverage scoring of each framework attribute according to the criteria of theoretical and empirical designs:

- Risk (S2): the coverage scorings of the theoretical and empirical designs are fairly high (80%) and almost equal.
- Level of complement (S12): there is no empirical design coverage.
- Usability (S16): there is no empirical design coverage.
- Quality (S8): the 40% coverage scoring of the theoretical design is much lower than the 80% empirical design coverage.

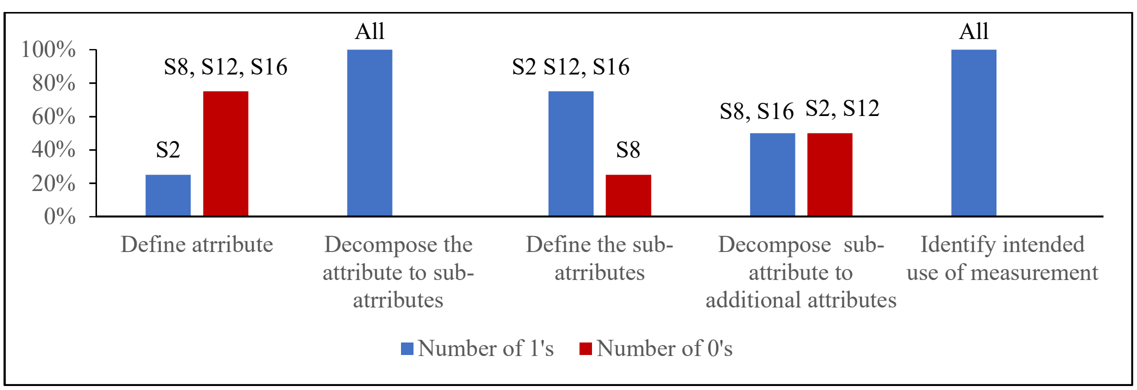

Figure 10: EA framework – theoretical design: metrology coverage

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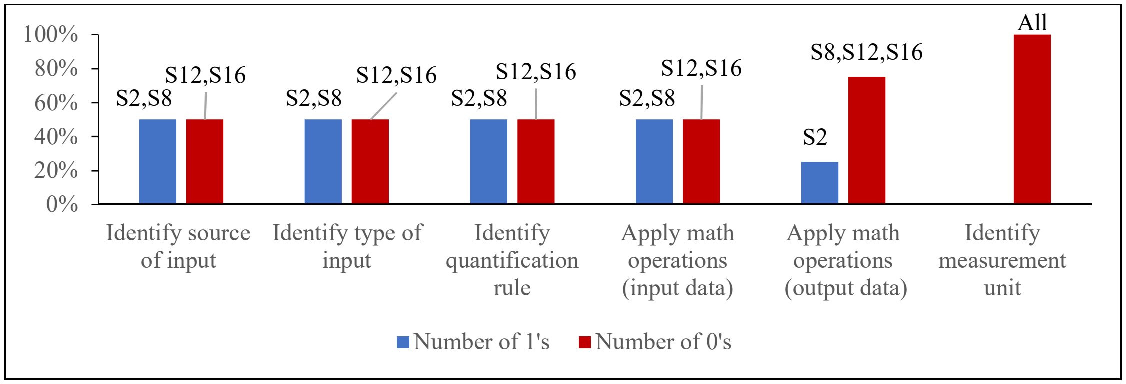

Figure 11: EA framework – empirical design: metrology coverage

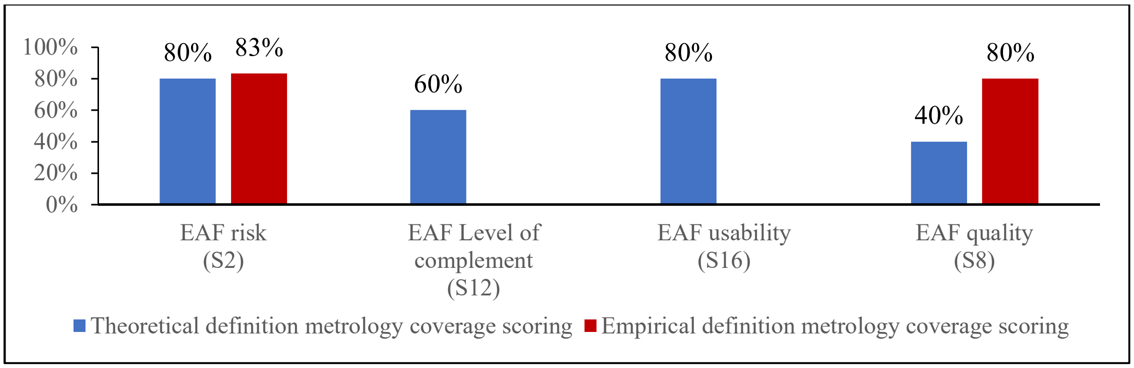

Figure 12: EA framework attributes - theoretical vs. empirical metrology coverage

4.3.4 EA program entity: metrology coverage evaluation

From Table A.1 in the Appendix, a single study proposes a measurement solution for the EA program entity (S14). Its detailed metrology coverage evaluation for each metrology criterion ise presented in Table 5.

In summary: it has a very low metrology coverage of 20% with only the intended use of measurement present while none of the other criteria are met.

Next, the evaluation of the empirical design is presented in Table 6 for each criterion.

The key strengths of the empirical design are:

- Identifies the source and type of input to quantify the architecture attributes.
- Identifies the quantification rules.
- Applies mathematical operations on input data.

The key weaknesses are:

- Does not apply mathematical operations on output data.
- Does not identify a measurement unit.

Table 5: EA program attributes – theoretical design: metrology coverage

Measurement solution	Project attributes	Define the attribute	Decompose the attribute	Define the sub-attributes	Decompose the sub-attribute	Identify intended use of measurement	Number of scores = 1	% Metrology coverage
S14	Readiness	0	0	0	0	1	1	20%

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Table 6: EA program attribute – empirical design: metrology coverage

Measurement solution	Project attributes	Identify source of input	Identify type of input	Quantification rule	Math on input data	Math on output data	Measurement unit	Number of scores = 1	% Metrology coverage
S14	Readiness	1	1	1	1	0	0	4	66%

5. DISCUSSION

This section discusses the evaluations of the EA measurement solutions through three questions:

1. Has the metrology coverage improved over time?
2. How do the theoretical and empirical metrology coverages vary across EA entity types?
3. Which studies present the best theoretical and empirical metrology coverage?
4. What are the implications for EA practitioners and researchers in software engineering and information systems engineering?

5.1 Has EA metrology coverage improved over time?

The 23 studies [14] span a period of 16 years: has the metrology coverage of EA measurement solutions improved over that period of time?

To provide a timeline analysis on the metrology coverage, the distribution of the metrology coverage scoring data was analyzed by calculating the median and mean of the scoring data.

First, the data distribution was analyzed to verify whether or not the data was normally distributed. The test findings indicate that the median is greater than the mean, which means, the metrology coverage scoring data are skewed (e.g., a non-normal distribution). Therefore, to perform statistical analysis on the metrology coverage scoring, the non-parametric Spearman's rank order correlation coefficient (rs) was used. Spearman's correlation is used to determine the strength and direction of the relationship between the theoretical design metrology coverage over time (years), and the empirical design metrology coverage over time (years). The Spearman's coefficient is interpreted as follows:

- Correlation value of (1): a strong positive relationship between the two variables,
- Correlation value of (−1): a strong negative relationship between the two variables,
- Correlation value of 0: the two variables are not correlated.

It is expected that both metrology coverage criteria have positive correlation with years, thus indicating that metrology coverage is improving over time. Therefore, the null and alternative hypotheses are defined as follows:

Null hypothesis: no relationship between metrology coverage criteria and time (years).

Alternative hypothesis: there is a relationship between metrology coverage criteria and time (years).

The result of the analysis is presented in Figure 13 with the theoretical coverage on the left and empirical on the right. For both, the correlation is very weak:

- +0.1468 for theoretical - left side of Figure 13;
- -0.0037 for empirical - right side of Figure 13.

Also, there is a greater than 50% probability that the null hypothesis is correct p = > 0.50 (below 50% statistical significance level) for both theoretical & empirical coverage. Therefore, the null hypothesis is accepted for both theoretical and empirical coverage, and it is concluded that:

- the metrology coverage of the theoretical design is not affected (i.e., improved) over time.
- the metrology coverage of the empirical design is not affected (i.e., improved) over time.

5.2 How do the theoretical and empirical metrology coverages vary across EA entity types?

A comparison of the overall coverage scoring of theoretical and empirical designs for the four entity types is presented in Figure 14 based on their median coverage scoring. In summary, it can be observed that:

1. Architecture attributes (six studies): with a respective coverage of 60% and 58% the measurement solutions have a large number of both theoretical and empirical metrological weaknesses:
   - When the attributes to be measured are not well defined and the sub-concepts that characterize them identified and defined (see Figure 4) this requires that the measurers use their own subjective interpretations of these attributes. This cannot ensure consistency in the interpretation of such measurement results.

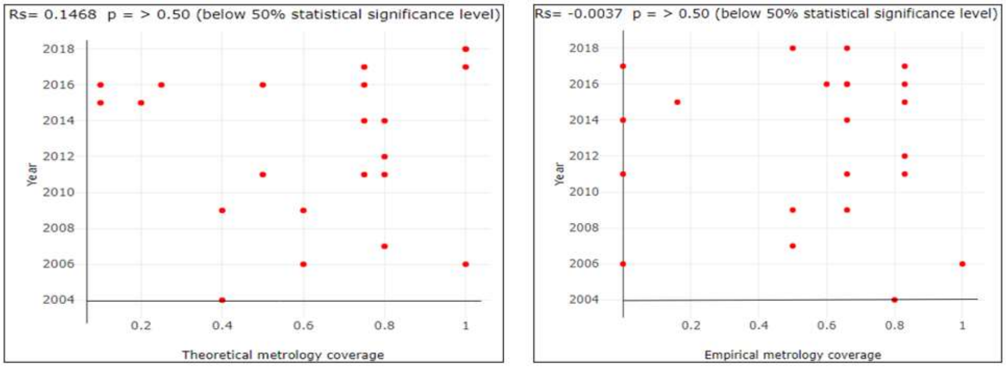

Figure 13 :Spearman's correlation between the theoretical & empirical

- Most authors document the sources, types, and rules to quantify the inputs to their measurement solutions, but do not discuss the validity of the mathematical operations and do not specify the resulting measurement units (see Figure 5). Users of such measurement results end up with numbers, but without explicit and uniform meaning nor much assurance of their trustworthiness.

2. Project (12 studies): the metrology coverage of 80% for the theoretical designs and of 68% for the empirical designs of measurement solutions are the highest of the four types of measured entities (Figures 8 and 9). Many of these come from existing measurement solutions in classical project management and benefit from more mature bodies of knowledge.
3. Framework (four studies): the metrology coverage of the theoretical designs is relatively high at 70%, while for the empirical designs it is much lower at 33% (see Figures 11 and 12). This indicates that while the elements of frameworks are well identified and decomposed, there is a lack of procedural knowledge documented for the actual implementation of such measurement solutions in terms of inputs and how to quantify them. Hence, considerable additional effort is needed to improve the empirical designs in the framework quantification.
4. Program (one study): with a theoretical design coverage of 20%, only the relevance of a measurement solution for 'program readiness' was identified but without a specific measurement design to quantify such 'readiness' (see Table 5). In contrast, the empirical coverage provides indications on the sources and types of inputs, as well as quantification rules, but again without a measurement unit (see Table 6). Therefore, even though the empirical coverage is high, what is to be measured is not well defined and measurement results leaves much to interpretation.

Table 7 presents the ranking of each EA entity concerning theoretical and empirical designs. This ranking is based on calculating the median of the metrology coverage scores, which facilitates where to focus, and on what (theoretical vs. empirical designs) in each entity type. It can be observed from Table 7:

- Theoretical designs:
  - Project entity type: has the highest (Rank=1) that meets the metrology criteria for theoretical design.
  - Program entity type: has the lowest (Rank=4) for metrology criteria for theoretical design.
- Empirical designs:
  - Project entity type: has the highest (Rank=1) that meets the metrology criteria for empirical design.
  - Framework entity type: has the lowest (Rank=4) that meet the metrology criteria for empirical design.

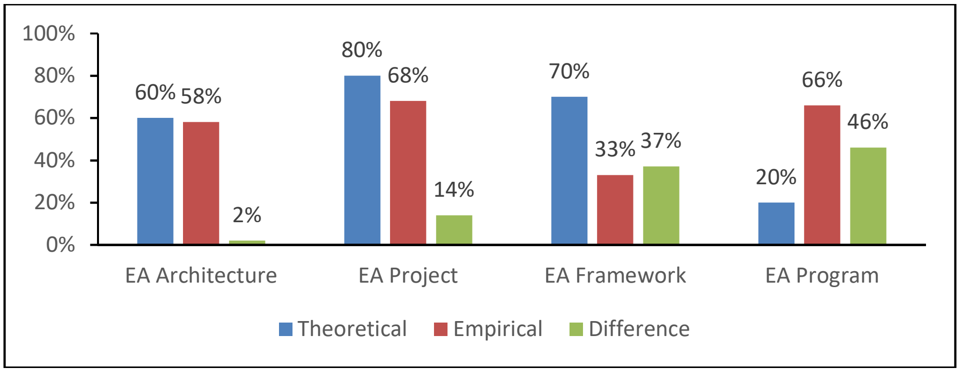

Figure 14: Overall comparison of theoretical vs. empirical metrology coverage

Table 7: Ranking by EA entity type of the measurement solutions based on metrology coverage evaluation (from highest to lowest) – theoretical & empirical designs

EA entity type	Theoretical design		Empirical design	
	Median % metrology coverage	Rank of entity type	Median % metrology coverage	Rank of entity type
Project	80%	1	68%	1
Framework	70%	2	33%	4
Architecture	60%	3	58%	3
Program	20%	4	66%	2

From Table 7, we can infer that EA project measurement solutions are more mature than the other three entity types.

5.3 Which studies present the best theoretical and empirical metrology coverage?

The metrology coverage evaluation has identified some strengths as well as a large number of weaknesses in the theoretical and empirical designs of most of the measurement solutions proposed for each study individually, but not at the overall evaluations on the entity level. To identify which studies present the highest theoretical and empirical metrology coverage, this sub-section presents the consolidation for each study of the metrology coverage evaluations.

5.3.1 Theoretical design evaluation

Table 8 provides an overview of the evaluation results of the theoretical designs of the measurement solution in each study. In Table 8, the studies with a theoretical metrological coverage of 80% and more are highlighted in gray: this indicates that the following studies present the best metrology theoretical coverage by entity type:

- Architecture: studies S5, S6 and S16.
- Project: S1, S4, S17, S18, S19, S21, S22 and S23.
- Framework: S2 and S16.
- Program: none.

On the one hand, this means that the practitioners will find in these respective studies the best-defined measurement solutions and that they could use these with greater confidence. Researchers can also find in these studies some of the best practices for theoretical design of measurement solutions.

On the other hand, the other studies with lower scorings provide researchers identification of theoretical metrological gaps in proposed measurement solutions: these represent research opportunities that may be tackled with the best practices documented in the studies with the highest metrological coverage.

5.3.2 Empirical design evaluation

Table 9 provides an overview of the evaluation results of the empirical design for the proposed measurement solution in each study. In Table 9 the studies with a theoretical metrological coverage of 80% or more are highlighted in gray: this indicates that the following studies present the best metrology empirical coverage by entity type:

- Architecture: study S3.
- Project: S1, S19, S20 and S23
- Framework: S2.
- Program: none.

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5.3.3 Summary of metrology findings

It can be observed from Tables 8 and 9 that:

- The theoretical design metrology criteria that is most strongly met is "intended use of measurement identified" – present in 21 of the 23 primary studies.
- The empirical design metrology criteria that is most poorly met is "measurement unit", which is absent in 21 of the 23 primary studies.
- A majority of the measurement solutions do not identify the valid mathematical operations admissible on the inputs and outputs of their empirical measurement designs.

This also means that the practitioners will find in Tables 8 and 9 the best theoretical and empirical designs of measurement solutions in the studies with the highest rankings, which may be implemented with greater confidence.

Researchers can also find in the studies with the highest rankings some of the best practices for empirical designs of measurement solutions. The other studies with lower scorings can be improved by using the best practices documented in the studies with the highest metrological coverage.

Table 8: Evaluation results of the theoretical designs in each study

EA Entity	Primary study	Define the attribute	Decompose attribute to sub- attribute	Define the sub-attributes	Decompose the sub-attribute	Identify intended use of measurement	% Metrology coverage
Architecture	S3	0	0	0	0	1	20%
	S5	1	1	0	1	1	80%
	S6	0	1	1	1	1	80%
	S8	1	1	1	0	0	60%
	S9	0	1	0	1	1	60%
	S11	1	0	0	0	1	40%
	S8	0	1	0	1	1	60%
	S12	0	1	1	0	1	60%
	S16	0	1	1	1	1	80%
Project	S1	1	1	1	1	1	100%
	S4	1	1	1	1	1	100%
	S10	1	0	0	1	1	60%
	S13	1	1	1	0	0	60%
	S15	1	1	0	0	1	60%
	S17	1	1	1	0	1	80%
	S18	1	1	1	0	1	80%
	S19	0	1	1	1	1	80%
	S20	0	1	0	0	1	40%
	S21	1	1	1	1	1	100%
	S22	1	1	1	0	1	80%
	S23	1	1	1	0	1	80%
Framework	S2	1	1	1	0	1	80%
	S8	0	1	0	1	1	60%
	S12	0	1	1	0	1	60%
	S16	0	1	1	1	1	80%
Program	S14	0	0	0	0	1	20%

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Table 9: Evaluation results of the empirical designs in each study

EA Entity	Primary study	Source of input identified	Type of input identified	Quantification rule	Math on input data	Math on output data	Measurement unit	% Metrology coverage
Architecture	S3	1	1	1	1	1	0	83%
	S5	1	1	1	0	1	0	66%
	S6	1	1	1	0	0	0	50%
	S8	0	0	0	0	0	0	0%
	S9	0	1	1	1	0	0	50%
	S11	1	1	1	1	0	0	66%
	S8	1	1	1	1	0	0	66%
	S12	0	0	0	0	0	0	0%
	S16	0	0	0	0	0	0	0%
Project	S1	1	1	1	1	1	1	100%
	S4	1	1	1	0	1	0	66%
	S10	1	1	1	0	1	0	66%
	S13	0	0	0	0	0	0	0%
	S15	1	1	1	0	1	0	66%
	S17	0	0	0	0	0	0	0%
	S18	0	0	0	0	1	0	16%
	S19	1	1	1	1	1	0	83%
	S20	1	1	1	1	1	0	83%
	S21	1	1	1	0	1	0	66%
	S22	1	1	0	0	1	0	50%
	S23	1	1	1	1	0	1	83%
Framework	S2	1	1	1	1	1	0	83%
	S8	1	1	1	1	0	0	66%
	S12	0	0	0	0	0	0	0%
	S16	0	0	0	0	0	0	0%
Program	S14	1	1	1	1	0	0	66%

5.4 What are the implications for EA practitioners & researchers in software engineering and information systems engineering?

This research study is important for decision makers, practitioners, and researchers. The following implications have been identified:

1. Implications for EA decision-makers

When the proposed EA measurement solutions do not have metrology-strong designs, adopting such solutions, and/or designing such quantification techniques might lead to improper decisions with costly and risky consequences on organizations.

For example, EA measurements 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. When 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).

2. Implications for EA practitioners in software engineering and information systems engineering

The EA architectural layers (business layer, application layer, and technology layer) include components and elements ranging from business processes and products, through software applications, to the technical infrastructure of the enterprise – Figure 15. The business processes impose a workload on the software applications and infrastructure, while the lower layers (e.g., software

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applications) impact the performance of the higher layers (e.g., business processes) [4].

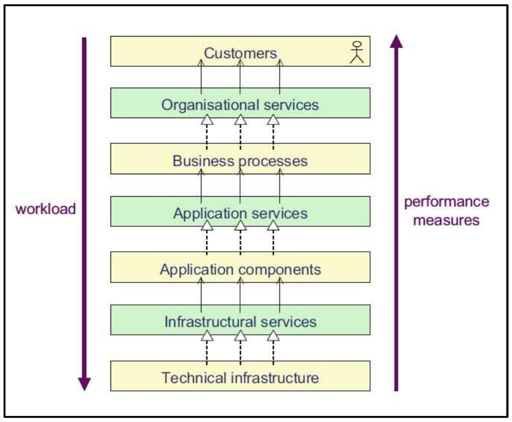

Figure 15: EA architectural layers [4]

EA measurement solutions, with metrology-strong designs, can assist enterprise architects, software engineers, and other EA practitioners in several directions. For instance, EA measurement can help architects to compare alternative EA designs and take well-informed decisions when making trade-offs between EA attributes such as cost, quality, risk, value, etc. [4].

It can also be used to measure different entities and attributes in the EA architectural layers. For instance, a metrology-strong measurement design for quantifying the software components of IT infrastructures has been proposed in an EA context in [20]. This EA measurement solution is based on adopting The Open Group Architecture Framework (TOGAF) EA layers, modeling EA layers using ArchiMate [4], applying COSMIC concepts [37] on the ArchiMate model, and measuring the functional size of EA layers.

The COSMIC-ISO 19761 standard is the second generation of international standards for the measurement of the functional size of software applicable to various layers of software within an IT architecture. This COSMIC method allows the measurement of the functional size of a software application through the business and engineering functionalities implemented in program code at various levels within an IT architecture [38].

The COSMIC measurement units are independent of the programming and development technologies and can therefore be used to normalize all other technology-dependent indicators through the size of the related business and engineering functions [38].

The software size measured and other measured business and IT components (i.e., entities and attributes), with metrology-strong designs, can be used to:

1. Compare various IT solutions with each other, planning, and tracking the progress of an IT project, and to estimate the effort spent on IT solution development projects.
2. Convert the measured entities and attributes to units of labor intensity to be used as the main factor for estimating the cost of software development projects.
3. Optimize the EA including the business and IT architectures, by quantifying the effect, value, quality of alternative EA design choices.
4. Obtain measures to quantify the impact of change in the different EA architectural layers. Since these layers are interconnect, changes can include decisions that affect the structure of the business process, IT infrastructure, data management, etc.

The key findings from this study can assist practitioners to understand the limitations and metrology weaknesses of measurement solutions and select ones with stronger designs. More specifically, practitioners can use Tables 9 and 10 to identify the best theoretical and empirical designs of measurement solutions in the studies with the highest rankings and implement these with greater confidence.

3. Implications for EA researchers

The discussion in Section 5.1 identified that the metrology coverage of proposed measurement solutions has not improved in these studies over the 16-year period from 2004 to 2019.

The discussion in Section 5.2 highlighted that metrological coverage varies across EA entity types. In summary from Tables 7 to 9:

- The theoretical metrology coverage is best and remarkably high for the project entity type, and relatively weak for the other three.
- The empirical metrology coverage is best for the project and the framework types, but still with a significant number of weaknesses.
- Table 10 also highlights a large number of weaknesses that practitioners should become aware of, and that researcher should address in future work.

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6. CONCLUSIONS & FUTURE WORK

The EA literature posits that by aligning IT initiatives with business objectives significant benefits would accrue towards helping organizations achieve their targets. It is also reported in [39] that EA can help organizations to become more successful in their IT investment decisions. However, while the literature proposes a number of EA measurement solutions, these were not independently evaluated.

This study presented our evaluation research approach based on evaluation theory, a number of measurement and metrology guidelines and best practices from the software measurement literature, including the measurement context model [16]. Then, using this metrology-coverage approach, we evaluated the measurement solutions identified in 23 studies [14].

This evaluation identified a number of metrological strengths as well as a large number of weaknesses in the theoretical and empirical designs of the measurement solutions proposed for each of four EA entity types: architecture, project, framework and program. Many of the measurement solutions lack metrological rigor expected in day-to-day measurement practices and therefore there is no assurance of their robustness and that the measurement results can be considered trustworthy for use in decision making models.

In particular, the lack of measurement units across almost all the measurement solutions will lead to numbers without recognized measurement units, which means there is no assurance that the results are comparable and can be interpreted the same way. The key metrology evaluation findings are presented by entity type in Table 10 in terms of strengths and weaknesses of theoretical and empirical metrology designs.

Finally, the discussion in sub-section 5.3 identified the specific studies with the best theoretical or empirical metrology coverages: the measurement solutions from these studies would be trustworthy for practitioners and the weaknesses reported will help practitioners identify off-hand a number of their limitations.

For future work, researchers could employ the metrology-based approach used in this evaluation study as a new strategy to tackle the design of stronger EA measurement solutions. For instance, researchers can:

- Find in the studies with the highest rankings some of the best practices for theoretical and empirical designs of measurement solutions.
- Find in the studies with lower scorings measurement solutions that could significantly be improved by using the best practices documented in the studies with the highest metrological coverage.
- Leverage these evaluation results and best practices to propose new ones with a stronger metrological foundation.

In summary, the findings of this research can assist practitioners and researchers to understand the limitations and metrology weaknesses of EA measurement solutions and select those with stronger designs. Researchers can also leverage these evaluation results to improve the current designs of measurement solutions from a metrology perspective and to propose new ones with a stronger metrology foundation.

While the metrology-based evaluation approach presented in this study has been applied specifically to evaluate EA measurement solutions, future work could also look at the relevance and feasibility of using such a metrology evaluation approach to evaluate measurement solutions already proposed outside of the EA domain and to design new ones.

Table 10: Key metrology evaluation findings by entity type

Entity type	Theoretical design		Empirical design	
	Key strengths	Key weaknesses	Key strengths	Key weaknesses
Architecture	Intended usage of measurement results always identified. Attributes mostly decomposed into sub-attributes.	Attributes and sub-attributes often not clearly defined.	Types, sources, and quantification rules of the measurement inputs are identified.	Measurement units are never identified. When there are mathematical operations, they are not verified from a metrology perspective.
Project	Most criteria met.		Type of inputs and sources of inputs are sometimes identified.	When there are mathematical operations on the inputs, they are not verified from a metrology perspective. Measurement units almost never identified.

Entity type	Theoretical design		Empirical design	
	Key strengths	Key weaknesses	Key strengths	Key weaknesses
Framework	Attributes are decomposed and defined	The attributes themselves are seldomly well defined.		Types, sources, and quantification rules of the measurement inputs are identified. When there are mathematical operations on the outputs, they are not verified from a metrology perspective. Measurement units never identified.
Program		Most criteria not met	Types, sources, and quantification rules of the measurement inputs are identified.	Measurement units not identified.

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APPENDIX A

Table 11.1: Selected Primary Studies

Study code	Authors	Title	Source	EA entity type
S1	Rico, David	A framework for measuring ROI of EA	J. of Organizational and End User Computing	Project
S2	Faramak, and Tavana	A fuzzy group multi-criteria enterprise architecture framework selection model	Expert Systems with Applications	Framework
S3	Fasanghari et al.	A novel credibility-based group decision making method for enterprise architecture scenario analysis using data envelopment analysis	Applied Soft Computing	Architecture
S4	Foorthuis, Ralph et al.	A theory building study of enterprise architecture practices and benefits	Information Systems Frontiers	Project
S5	Razavi et al.	An AHP-based approach toward enterprise architecture analysis based on enterprise architecture quality attributes	Knowledge and Information Systems	Architecture
S6	Gammelgård et al.	An IT management assessment framework evaluating enterprise architecture scenarios	Information Systems and e-Business Management	Architecture
S7	Meyer et al.	Applying design science research in enterprise architecture business value assessments	Communications in Computer and Information Science	NA
S8	Morganwalp and Sage	Enterprise architecture measures of effectiveness	International J. of Technology, Policy and Management	Architecture Framework
S9	Schelp and Stutz	Enterprise architecture metrics in the balanced scorecard for IT	Information Systems Control Journal	Architecture
S10	Bradley et al.	Enterprise architecture, IT effectiveness and the mediating role of IT alignment in US hospitals	Information Systems Journal	Project
S11	Brückmann et al.	Evaluating enterprise architecture management initiatives - how to measure and control the degree of standardization of an IT landscape?	Enterprise Modeling and Information Systems Architectures	Architecture
S12	Kozina, Melita	Evaluation of ARIS and Zachman frameworks as enterprise architectures	J. of Information and Organizational Sciences	Framework
S13	Tamm et al.	How does EA add value to organizations?	Communications of the Association for Information Systems	Project
S14	Jahani, et al.	Measurement of enterprise architecture readiness	Business Strategy Series	Program
S15	Aier, Stephan	The role of organizational culture for grounding, management, guidance and effectiveness of enterprise architecture principles	Information Systems and e-Business Management	Project
S16	Bijarchian and Rosmah	Usability elements as benchmarking criteria for enterprise architecture methodologies	J Teknologi (Sciences and Engineering)	Framework
S17	Nikpay et al.	A hybrid method for evaluating enterprise architecture implementation	Evaluation and Program Planning	Project
S18	Lange et al.	An empirical analysis of the factors and measures of enterprise architecture management success	European Journal of Information Systems	Project
S19	Safari et al.	Identifying and evaluating enterprise architecture risks using FMEA and fuzzy VIKOR	Journal of Intelligent Manufacturing	Project
S20	Lee et al.	Transformational and transactional factors for the successful implementation of enterprise architecture in public sector	Sustainability	Project
S21	Alzoubi, Yehia Ibrahim, et al.	A measurement model to analyze the effect of agile enterprise architecture on geographically distributed agile development	Journal of Software Engineering Research and Development	Project
S22	Shanks et al.	Achieving benefits with enterprise architecture	Journal of Strategic Information Systems	Project
S23	González-Rojas et al.	Multilevel complexity measurement in enterprise architecture models	International J. of Computer Integrated Manufacturing	Project