Software Architecture Evaluation: A Systematic Mapping Study

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Abstract: Software architecture provides the big picture of software systems, hence the need to evaluate its quality before further software engineering work. In this paper, a systematic mapping study was performed to summarize the existing software architecture evaluation approaches in literature and to organize the selected studies according to six classification criteria: research types, empirical types, contribution types, software quality models, quality attributes and software architecture models. Publication channels and trends were also identified. 60 studies were selected from digital libraries.

1 INTRODUCTION

Software architecture (SA) started to emerge as a discipline during the mid nineties due to the increasing complexity of software systems which led to increased challenges for software industry (iso, 2011). SA is defined as "the set of structures needed to reason about the system, which comprise software elements, relations among them, and properties of both" (Clements et al., 2002). The SA highlights early design decisions that will have a tremendous impact on all software engineering work that follows (Bass, 2007). There is therefore a need for SA evaluation (SAE) approaches to minimize the negative impact of low quality SA on software implementation.

This paper presents the results of a systematic mapping study which was performed to obtain an updated overview of the current approaches used in SAE research. Many reviews have been conducted in this area (Babar et al., 2004; Ionita et al., 2002; Maurya, 2010; Bass and Nord, 2012), but to the best of our knowledge, no systematic mapping study of SAE approaches has been published to date. Eight mapping questions (MQs) are answered in this study and the papers which were selected after the search process are classified according to six criteria: research types, empirical types, contribution types, software quality (SQ) models, quality attributes and SA models, in addition to the main publication channels and trends.

The structure of this paper is as follows: Section 2 presents the research methodology. Section 3 reports the results. Section 4 discusses the findings. The conclusions and future work are presented in Section 5.

2 RESEARCH METHODOLOGY

The systematic mapping study principal goal is to provide an overview of a research area, and identify the quantity and type of research and results available within it. A mapping process consists of three activities: the search for relevant publications, the definition of a classification scheme and the mapping of publications (Petersen et al., 2008). A mapping study differs from a systematic literature review (SLR) as the articles are not studied in sufficient detail.

2.1 Mapping Questions

This study aims to gain insight into the existing SAE approaches. The systematic mapping study therefore addresses eight MQs. The MQs with the rationale motivating the importance of these questions are presented in Table 1. The search strategy and paper selection criteria were defined on the basis of them.

2.2 Search Strategy

The papers were identified by consulting the following sources: IEEE Digital Library, ACM Digital Library, Science Direct and SpringLink. Google scholar was also used to seek literature in the field. The search was done in January 2018. The following search string was applied in the title, abstract and keywords of the papers investigated to reduce the search results. "Software architecture" **AND** (evaluat* **OR** measur* **OR** assess*) **AND** (technique* **OR** appro-

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Table 1: Mapping questions.

ID	Mapping question	Rationale
MQ1	Which publication channels are the main targets for SAE research?	To identify where SAE research can be found as well as the good targets for publication of future studies
MQ2	How has the frequency of approaches related to SAE changed over time?	To identify the publication trends over time of SAE research
MQ3	What are the research types of SAE studies?	To explore the different types of research reported in the literature concerning SAE
MQ4	Are SAE studies empirically validated?	To discover whether research on SAE has been validated through empirical studies
MQ5	What are the evaluation approaches that were reported in SA research?	To discover the existing SAE approaches reported in the existing SAE literature
MQ6	Were SAE approaches reported in literature based on SQ model?	To discover if researchers take into consideration SQ models in SAE approaches design
MQ7	Which quality attributes were used to evaluate SA?	To identify the quality attributes used to evaluate SA in literature
MQ8	What are the models that were used in SAE literature?	To identify the models used in the SAE literature

ach* **OR** method* **OR** model* **OR** framework* **OR** tool*).

2.3 Paper Selection Criteria

Each paper was retrieved by the author and the information about it was filed in an excel file. The first step after the application of the search string was to eliminate duplicate titles, and titles clearly not related to the review. The inclusion criteria were limited to the studies that address evaluation, measurement or assessment of the SA in overall or through quality attributes. The studies that met at least one of the following exclusion criteria (EC) were excluded:

EC1 Papers that focus on software design.

EC2 Papers whose subject was one or many quality characteristics which were not used for SAE.

In total, 217 papers were identified after the removal of duplicates. When the same paper appeared in more than one source, it was considered only once according to our search order. Thereafter, 158 studies were excluded based on the inclusion and exclusion criteria leaving for the final result 60 selected studies.

2.4 Data Extraction Strategy

The publication source and channel of the papers selected respond to **MQ1**, while the publication year responds to **MQ2**. A research type (**MQ3**) can be classified in the following categories (Ouhbi et al., 2015): (1) evaluation research: existing SAE approaches are implemented in practice and an evaluation of them is conducted; (2) solution proposal: an SAE solution is proposed. This solution may be a new SAE approach or a significant extension of an existing approach. The potential benefits and the applicability of the solution could be shown with an empirical study or a good argumentation; or (3) other, e.g. experience paper, review. The empirical type of the selected study can be classified for **MQ4** as a (Ouhbi et al., 2013): (1) case study: an empirical inquiry that investigates an SAE approach within its real-life context; (2) survey: a method for collecting quantitative information concerning an SAE approach, e.g. a questionnaire; (3) experiment: an empirical method applied under controlled conditions to evaluate a SAE approach; or (4) theory: non-empirical research approaches or theoretical evaluation of an SAE approach. An approach (**MQ5**) can be classified as (Ouhbi et al., 2014): process, method, tool-based technique, model, framework, data mining technique, or other, e.g. guidelines.

A SQ model (**MQ6**) can be classified as (Ortega et al., 2003): McCall model (Company et al., 1977), Boehm model (Boehm et al., 1978), Dromey model (Dromey, 1996), ISO/IEC 9126 standard (ISO/IEC-9126-1, 2001), ISO/IEC 25010 standard (ISO, 2011), or other. A quality attribute (**MQ7**) can be classified into one of the internal and external quality characteristics proposed by ISO/IEC 25010: Functional suitability, reliability, usability, performance efficiency, maintainability, portability, compatibility, security or other. A SA model (**MQ8**) can be classified as (Vogel et al., 2011): UML, 4+1 view model, an architectural description language (ADL), or other.

3 RESULTS

This section describes results presented in Table 2.

Table 2: Classification Acronyms: SP: Solution proposal, ER: Evaluation research, EP: Experience paper, M: Maintainability, S: Security, Pe: Performance, Po: Portability, U: Usability, C: Compatibility, R: Reliability, F: Functional suitability.

Ref. & Year	Channel	Res. T.	Emp. Res.	Contr. T.	SQ Model	Quality attributes	Model
(Abowd et al., 1997)	Other	SP	Theory	Framework	-	F., Pe., other.	-
(Barbacci et al., 1997)	Other	SP	Theory	Method	Boehm, Other	R., other	-
(Dueñas et al., 1998)	Workshop	SP	Theory	Model	ISO/IEC 9126	All	ADL, UML
(Bergey et al., 1999)	Other	SP	Theory	Process		Others.	-
(Kazman et al., 2000)	Other	SP	Theory	Method	-	Pe., S., others	-
(Van Gurp and Bosch, 2000)	Conference	SP	Case study	DataMining	McCall	M.,R., U., Pe., others	-
(Bosch and Bengtsson, 2001)	Conference	SP	Case study	Method	-	M.	-
(Ionita et al., 2002)	Workshop	Other	Theory	Method	-	Po., F.,M., U., Pe., others	UML, 4+1 view
(Choi and Yeom, 2002)	Conference	SP	Other	Method	-	Pe., R., others	All
(Tvedt et al., 2002b)	Conference	SP	Case study	Process	-	S., R., M., others	-
(Tvedt et al., 2002a)	Conference	SP	Case study	Process	-	M.	-
(Clements, 2002)	Other	ER	Case study	Method	-	Pe., S., R., M., Po., others	-
(Lindvall et al., 2003)	Journal	ER	Case study	Process	-	M.	-
(Clements et al., 2003)	Other	SP	Theory	Method	-	Pe., R., S., Po., F., others	-
(Folmer et al., 2003)	Workshop	SP	Theory	Method	ISO/IEC 9126	U.	4+1 view
(Barbacci et al., 2003)	Other	ER	Case study	Method	-	Pe., S., R., M., Po., others	4+1 view
(Bahsoon and Emmerich, 2003)	Conference	Other	Theory	Method	-	Others	ADL
(Babar et al., 2004)	Conference	Other	Theory	Framework	McCall	M., others	ADL
(Zhu et al., 2004)	Conference	SP	Other	Process	McCall, ISO/IEC 9126	-	-
(Subramanian and Chung, 2004)	Conference	SP	Theory	Framework	-	Other	-
(Bashroush et al., 2004)	Conference	SP	Theory	Tool	-	-	ADLARS
(Maheshwari and Teoh, 2005)	Journal	SP	Theory	Tool	-	S., other	-
(Liu and Wang, 2005)	Conference	SP	Theory	Method	ISO/IEC 9126	Other	-
(Gorton and Zhu, 2005)	Conference	EP	Experiment	Tool	-	Others	UML
(Graaf et al., 2005)	Conference	ER	Case study	Method	-	M.	UML, 4+1 view
(Mattsson et al., 2006)	Conference	Other	Theory	Method	Other	Pe., M., Po., other	-
(Babar et al., 2006)	Conference	SP	Experiment	Framework	-	-	-
(Mårtensson, 2006)	Other	SP	Case study	Method	-	Pe., M., Po., other	UML
(Babar et al., 2007)	Conference	ER	Other	Other	-	M., U., Pe., S.	-
(Kim et al., 2007)	Conference	SP	Experiment	Other	-	Pe., R., U., other	-
(Jin-hua, 2007)	Journal	SP	Theory	Method	-	others	UML
(Svahnberg and Mårtensson, 2007)	Journal	EP	Experiment	Method	ISO/IEC 9126	-	-
(Babar et al., 2008)	Journal	ER	Experiment	Framework	-	R., M., Pe., other	-
(Erfanian and Shams Aliee, 2008)	Conference	SP	Case study	Method	-	Pe., S., U., others	UML
(Salger et al., 2008)	Conference	SP	Case study	Framework	ISO/IEC 9126	U., R.	-
(Roy and Graham, 2008)	Other	Other	Theory	Method	ISO/IEC 9126, McCall, Boehm	All	All
(Ali Babar, 2008)	Conference	ER	Experiment	Framework	-	S.	-
(Lee et al., 2009)	Journal	SP	Case study	Method	-	Pe., U., others	-
(Duszynski et al., 2009)	Conference	SP	Theory	Tool	-	-	-
(Babar, 2009)	Conference	SP	Experiment	Framework	-	M., others	-
(Salger, 2009)	Workshop	EP	Theory	Framework	-	-	-
(Bergey, 2009)	Other	SP	Other	Plan	-	Pe., S., others	-
(Alkussayer and Allen, 2010)	Conference	SP	Theory	Framework	-	S.	-
(Maurya, 2010)	Journal	Other	Theory	Method	-	M.,Pe., others	-
(Reijonen et al., 2010)	Conference	ER	Experiment	Method	ISO/IEC 9126	All	-
(Martens et al., 2011)	Journal	ER	Experiment	Method	-	Pe.	UML
(Shanmugapriya and Suresh, 2012)	Journal	Other	Theory	Method	-	-	4+1 view
(Bass and Nord, 2012)	Conference	Other	Theory	Framework	-	-	-
(Akinnuwesi et al., 2012)	Journal	SP	Theory	DataMining	-	Pe., others	-
(Sharafi, 2012)	Journal	SP	Other	Method	-	R., Pe., other	UML
(Bouwers, 2013)	Other	SP	Survey	Model	ISO/IEC 25010	M.	UML
(Akinnuwesi et al., 2013)	Journal	SP	Experiment	DataMining	-	Pe.	-
(Zalewski and Kijas, 2013)	Journal	SP	Case study	Method	ISO/IEC 9126	M., U., Pe., R., S., others	-
(González-Huerta et al., 2013)	Conference	Other	Experiment	Method	ISO/IEC 25000	-	-
(Knodel and Naab, 2014)	Conference	EP	Case study	Method	-	Pe.	UML
(Santos et al., 2014)	Workshop	Other	Theory	Method	-	Pe., R., C., others	ADLARS
(Patidar and Suman, 2015)	Conference	Other	Theory	Method	-	-	-
(Gonzalez-Huerta et al., 2015)	Journal	ER	Experiment	Model	ISO/IEC 25000	R., Pe.	UML
(Upadhyay, 2016)	Journal	SP	Other	Framework	-	M., others	-
(Abrahão and Insfran, 2017)	Conference	ER	Experiment	Method	-	R., Pe.	-

3.1 MQ1. Publication Channels

48.3% of the selected papers were presented at conferences, 25% were published in journals, 11.7% were published as technical reports, 8.3% appeared in workshops, 3.3% are books and 3.3% are PhD thesis. 10% of the selected papers were published by Software Engineering Institute as technical reports.

3.2 MQ2. Publication Trend

Fig. 1 presents the number of articles published per year from 1997 to 2017.

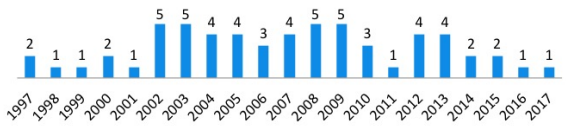

Figure 1: Number of articles published per year.

3.3 MQ3. Research Types

Fig. 2 shows the research type of the selected papers. Around 57% of the selected papers were solution proposal studies, 18% of the selected papers were under-

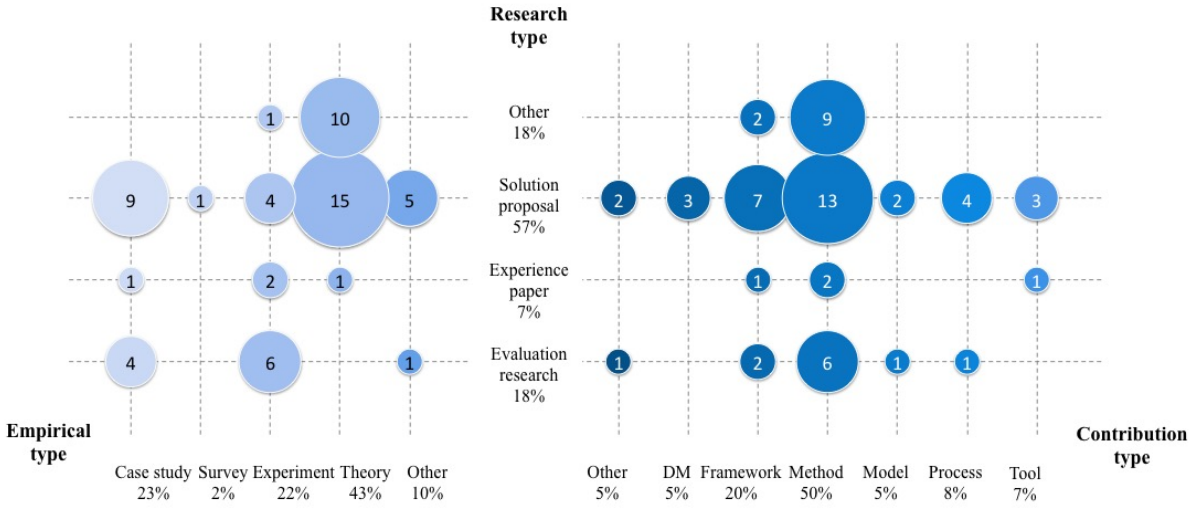

Figure 2: RQ3, RQ4 and RQ5 results.

taken to evaluate SAE existing approaches, 7% were reporting the authors' experience with SAE and the remaining papers were classified as others. Among the other types that we have identified: 8 reviews, 2 position papers (Bahsoon and Emmerich, 2003; Santos et al., 2014) and one replication study (González-Huerta et al., 2013). This result shows that the main concern of researchers in the SAE domain is to propose and develop approaches to enhance SAE. Fig. 2 shows also that 44% of solution proposals were not empirically validated and that 38% of the suggested solutions are methods.

3.4 MQ4. Empirically Types

Fig. 2 shows if the selected studies were empirically validated and presents the empirical types used in the validation of SAE approaches. A percentage of 43% of the selected studies were not evaluated empirically. 23% of the selected papers undertook case studies to evaluate SAE approaches and 22% were evaluated with experiments. One paper (Bouwers, 2013) has used a survey and another paper (Babar et al., 2007) used focus group to evaluate SAE approaches while the remaining papers used illustration examples to demonstrate the applicability of their approaches.

3.5 MQ5. Contribution Types

Fig. 2 presents the SAE approaches extracted from the selected papers. The approaches most frequently reported are methods (50% of the selected papers) followed by frameworks (20%). Processes, tool-based techniques, models, and data mining techniques were also identified in the selected studies. Other techniques in this study were also identified, such as a AHP technique (Kim et al., 2007).

3.6 MQ6. SQ Models

The results shown in Fig. 3 reveal that around 69% of SAE papers do not cite any well-known SQ model. The principal model cited in the selected studies was the ISO/IEC 9126 standard. McCall model and Boehm model were also cited. Note that only one paper (Bouwers, 2013) has cited ISO/IEC 25010 but it has been insinuated in two papers (Gonzalez-Huerta et al., 2015; González-Huerta et al., 2013) as they have mentioned ISO/IEC 25000. Some papers cited different models and standards that helped them in the design of SAE techniques, such as: IEEE 610.12-1990 cited by (Mattsson et al., 2006) and IEEE 1061 cited by (Barbacci et al., 1997).

3.7 MQ7. Quality Attributes

15% of SAE papers did not mention any quality attribute. Fig. 4 shows how often a quality attribute has been mentioned in SAE literature. It is worth mentioning that some papers dealt with the evaluation of SA through only a unique quality attribute. Table 3 presents these characteristics.

3.8 MQ8. SA Description Models

Around 65% of the studies selected didn't specify any SA model. Fig. 5 presents how often the SA models have been reported in the remaining 21 studies.

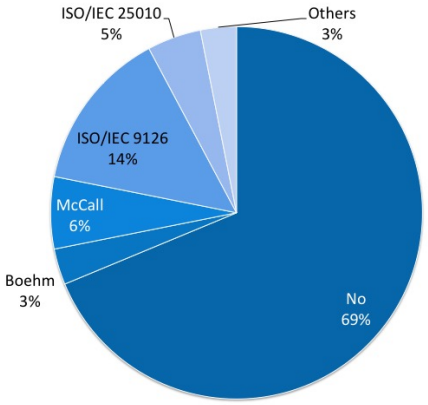

Figure 3: SQ models in SEA literature.

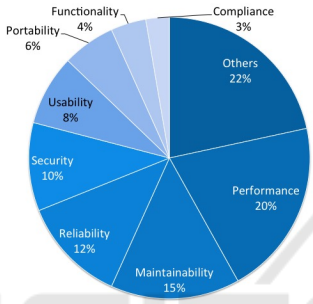

Figure 4: Quality attributes in SEA literature.

4 DISCUSSION

The interest on SAE began after the publication of technical reports by the Software Engineering Institutes in 1997. This interest was at it most during the last decade where many researchers have based their research on the outcomes of these technical reports mainly on the Architecture Tradeoff Analysis Method (ATAM). However, this interest started to fade since 2014, which indicates that there is a need for novel SAE techniques, particularly with the emerging new technologies such as the IoT and the Big Data (Krco et al., 2014; Gorton and Klein, 2015). The majority of the papers were evaluated using case studies, it is easier to evaluate SA of existing systems rather than developing a system only for the purpose to evaluate its architecture. In fact, SA requires an early software engineering activity which is the specification of stakeholders needs, also known as requirements engineering (Ouhbi et al., 2013). This step is critical to identify the quality attributes that will influence SA design and description. Working with case study reduce the effort required to specify requirements and quality attributes. Around half of SAE selected studies present methods to evaluate SA. The majority of these methods are based on ATAM and few researchers (Clements, 2002; Svahnberg and Mårtensson, 2007; Graaf et al., 2005) based their methods on the Software architecture analysis method (SAAM) (Kazman et al., 1994). SAAM is a method for analyzing the properties of SA and not for SAE, for this reason the study by (Kazman et al., 1994) was not included in this mapping study.

Table 3: Papers which have focus on one quality attributes.

Quality attrib.	Ref.	Total
Maintainability	(Bosch and Bengtsson, 2001) (Bouwers, 2013) (Graaf et al., 2005) (Lindvall et al., 2003) (Tvedt et al., 2002a)	5
Performance	(Akinnuwesi et al., 2013) (Knodel and Naab, 2014) (Martens et al., 2011) (Reijonen et al., 2010)	4
Security	(Ali Babar, 2008) (Alkussayer and Allen, 2010)	2
Usability	(Folmer et al., 2003)	1
Adaptability	(Liu and Wang, 2005)	1
Changeability	(Subramanian and Chung, 2004)	1

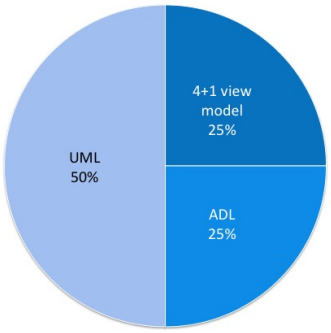

Figure 5: SA models reported in 21 studies.

Few researchers based their solutions on SQ models. ISO/IEC 9126 standard was the most used due to the fact that it is the most well-known SQ model during the last decade before it was replaced by ISO/IEC 25010 in 2011. Recent studies have used the ISO/IEC 25010 to analyze SQ requirements and to specify quality attributes. Implementing quality attributes makes it is easier for the software architect to evaluate the quality of SA (Witt et al., 1993). The most quality attribute cited in SAE literature is Performance. This could be explained by the fact that this attribute affects runtime behavior and overall user experience. The main SA model used to describe and evaluate SA is UML, due to the fact that UML is a standardized and popular modeling language know by the software development community. 4+1 view model and ADLs were also cited in few papers, more precisely ADLARS in (Bashroush et al., 2004; Santos et al., 2014) which is a relational ADL for software

families (Brown et al., 2003). All these models are related. In fact, UML is considered as an ADL as it serves to describe SA. Moreover, 4+1 view model uses UML diagrams to describe the logical, process, development, physical and scenario views of a SA.

5 CONCLUSION AND FUTURE WORK

The overall goal of this study is to conduct a thematic analysis and identify publication fora as regards SAE approaches. The findings of this systematic map have implications for researchers and practitioners who work in the SA domain, since this study will allow them to discover the existing SAE approaches and techniques in the literature. The presented empirical studies may also provide an overview of the efficiency of each approach. For future work, we intend to conduct an SLR of empirical evidence on SAE.

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