A Systematic Literature Review of Requirements Engineering for Self-Adaptive Systems

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Abstract: During 2003 to 2013, the continuous effort of researchers and engineers particularly has resulted in a hugely grown body of work on engineering self-adaptive systems. Although existing studies have explored various aspects of this topic, no systematic study has been performed on categorizing and evaluating the requirement engineering for self-adaptive activities. The objective of this paper is to systematically investigate the research literature of requirements engineering for self-adaptive systems, summarize the research trends, categorize the used modeling methods and requirements engineering activities as well as the topics that most described. a systematic literature review has been conducted to answer the research questions by searching relevant studies, appraising the quality of these studies and extracting available data. From the study, a number of recommendations for future research in requirements engineering for self-adaptive systems has been derived. So that, enabling researchers and practitioners to better understand the research trends.

Keywords: self-adaptive, requirement engineering, systematic literature review

1 INTRODUCTION

In the last decade, there are the increasing cost of handling the complexity of software systems to achieve robustness in handling unexpected conditions, changing priorities and policies governing the goals, and changing conditions (Laddaga, 2001). Welsh and Sawyer (2010) argued that the uncertainty about the environments is the reason why a system must be able to continue to operate in a range of contexts with different requirements or requirements trade-offs (Welsh & Sawyer, 2010). Cope with the increasing complexity, software systems must become more versatile, flexible, resilient, dependable, energy-efficient, recoverable, customizable, configurable and self-optimizing by adapting to changes that may occur in their operational contexts, environments and system requirements (Lemos, Giese, & Müller, 2013). From the explanation above, noted that the reason why the self adaptive systems should be conducted, are include: the cost handling of the complexity of systems to cope with unexpected condition and change goal priorities, the uncertainty about the environments that need the different requirements or requirements trade-offs, the increasing complexity of system inflict the system requirements more flexible, effective and efficient.

The self-adaptive is the capability of the system to adjust its behavior in response to the environment which the systems autonomously decide how to adapt or to organize themselves so that they can accommodate changes in their contexts and environments (Brun, Serugendo, & Gacek, 2009). Laddaga in (Laddaga, 2001) argued that self-adaptive software evaluates its own behavior and changes behavior when the evaluation indicates that it is not accomplishing what the software is intended to do, or when better functionality or performance is possible. The conception of self-adaptive system depends on user's requirements, system properties and environmental characteristics.

The primary appraise of success of a software system is the degree to which it meets the purpose for which it was intended (Kaur & Singh, 2010). Understandings the requirements of an adaptive software system is critical to successful development and deployment, as a means of taking advantage of adaptation semantics that describe how systems behave during adaptation (Macías-Escrivá, Haber, del Toro, & Hernandez, 2013). Deal with the uncertainty of unanticipated contexts that prompt new requirements, Sawyer et al. (2010) state that requirements for self-adaptive systems should be run-time entities that can be reasoned to understand requirements are satisfied, and to support adaptation decisions that can take advantage of the system (Sawyer, Bencomo, Whittle, Letier, & Finkelstein, 2010). Although software engineering still lacks a mature science of software behavior on which to draw, requirements engineers need such a science in order to understand how to specify the required behavior of software (Kaur & Singh, 2010). The important points of development and deployment of self-adaptive system successful, are included: understandings the requirements of an adaptive software system, the requirements for self-adaptive systems should be run-time entities, the needs a science in order to understand how to specify the required behavior of software.

Requirements engineering (RE) is known as the first stage in the lifecycle of software development, aiming at defining domain logic, identifying stakeholders' needs and documenting information for subsequent analysis and implementation (Nuseibeh & Easterbrook, 2000). Lamsweerde (2008) argued that requirements engineering is concerned with the elicitation, evaluation, specification, consolidation, and evolution of the objectives, functionalities, qualities, and constraints a software based system should meet within some organizational or physical setting (Van Lamsweerde, 2008).

Different from traditional requirement engineering, in (Yang, Li, Jin, & Chen, 2014) state that requirement engineering for self-adaptive systems focuses more on defining adaptation logic, since the self-adaptive systems need adaptation mechanisms. In consequence, the description of what to adapt, when to adapt, what changes in the environment and the system to be monitored and how to adapt during

requirement engineering for self-adaptive must be addressed by engineers.

During 2003 to 2013, the continuous effort of researchers and engineers particularly has resulted in a hugely grown body of work on engineering selfadaptive systems. In (Ganek & Corbi, 2003) has presented an overview of IBM's autonomic computing initiative. It examines the genesis of autonomic computing, the industry and marketplace drivers, the fundamental characteristics of autonomic systems, a framework for how systems will evolve to become more self-managing, and the key role for open industry standards needed to support autonomic behavior in heterogeneous system environments. Dobson et al. (2009) surveyed the state of autonomic communications research and identify significant emerging trends and techniques. As a general conclusion, these techniques fundamentally change the ways in which those designing, implementing, deploying, administering, and using highly-distributed adaptive systems will interact with those systems in the future (Dobson et al., 2006). Brun et al. (2009) explore the state-of-the-art in engineering self-adaptive systems and identify potential improvements in the design process. Researchers in this study argue that feedback loops are a key factor in software engineering of self-adaptive systems (Brun et al., 2009). Cheng et al. (2009) present the summary of state-of-the-art and to identify critical challenges for the systematic software engineering of self-adaptive systems. In this study researchers argue that the engineering of self-adaptive software systems is a major challenge and feedback loops is a major property in self-adaptive systems (Cheng, Lemos, & Giese, 2009). Salehie and Tahvildari (2009) have presented a landscape of research in self-adaptive software by highlighting relevant disciplines and some prominent research projects, as well as helps to identify the underlying research gaps and elaborates on the corresponding challenges. The research presents a taxonomy, based on concerns of adaptation, that is, how, what, when and where, towards providing a unified view of this emerging area (Salehie & Tahvildari, 2009). lemos et al. (2013) present the summary of state-of-the-art and identify research challenges when developing, deploying and managing self-adaptive software systems, as well as complements and extends a previous roadmap on software engineering for self-adaptive systems published in (Cheng et al., 2009). In these study, researcher argue that all these challenges result from the dynamic nature of self-adaptation, which brings uncertainty to the forefront of system design. (Lemos et al., 2013). Macías-Escrivá et al (2013) explore the review of recent progress on self-adaptivity based on the analysis of state-of-the-art approaches reported in the literature. The review provides an overarching integrated view of computer science and software engineering foundations. Moreover, various methods and techniques currently applied in the design of self-adaptive systems are analyzed, as well as some European research initiatives and projects. Finally, the main bottlenecks for the effective application of self-adaptive technology, as well as a set of key research issues on this topic, are precisely identified, in order to overcome current constraints on the effective application of self-adaptivity in its emerging areas of application (Macías-Escrivá et al., 2013).

However, no systematic study has been performed on categorizing and evaluating the requirement engineering for self-adaptive activities. Thus, there is no clear view on where the researches are conducted and where the results are published, what extend requirement engineering for self-adaptive activity is studied, how the quality of studies varies against each activity and what the most active topics are.

The objective of this paper is to systematically investigate the research literature of requirements engineering for self-adaptive systems, summarize the research trends, categorize the used modeling methods and requirements engineering activities as well as the topics that most described. To conduct the investigation and report analysis results, the research methodology of systematic literature review in (Kitchenham & Charters, 2007) and (Brereton, Kitchenham, Budgen, Turner, & Khalil, 2007) have been performed.

The rest of the paper is structured as follows. Section 2 briefly describes the research method. Section 3 discusses the results and discussion and threats to validity in Section 4. Related roadmap and survey presented in Section 5, followed by the conclusion and future works in Section 6.

2 RESEARCH METHOD

A systematic literature review (SLR) in (B. A. Kitchenham & Charters, 2007) is a well-defined approach to identify, evaluate and interpret all relevant studies regarding a particular research question, topic area or phenomenon of interest. By following the SLR process, the review protocol divided in seven stages: specify research questions, define search scope and strategy, specify data items, select primary studies, extract required data, analyze data and write review report. Figure 1 shows an overview of the main phases that adopted from (Brereton, Kitchenham, Budgen, Turner, & Khalil, 2007).

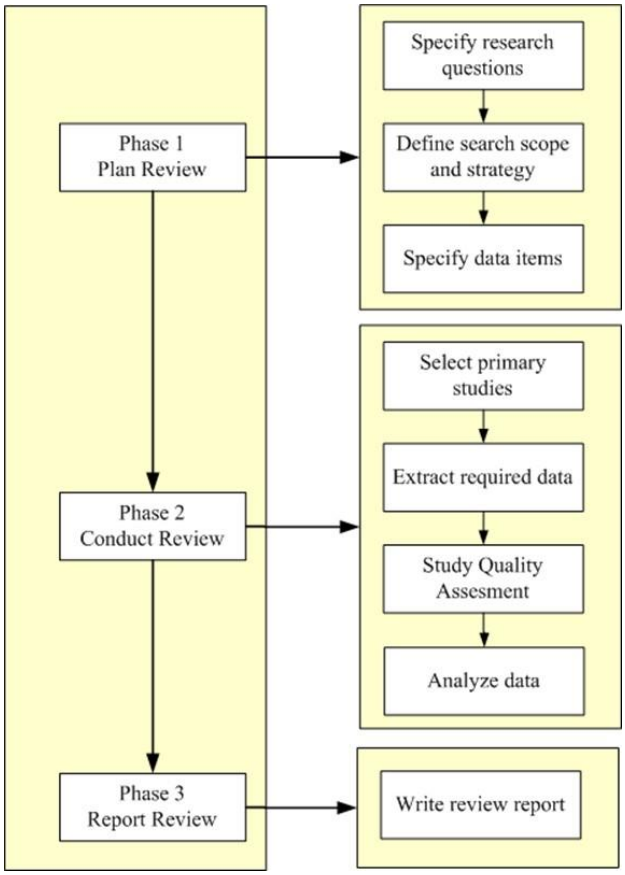

Figure 1. Overview of The Systematic Literature Review

In review planning, the researchers defined the review protocol as described in this document. The review protocol includes the definition of research questions, the search strategy and scope, the data items that had to be collected, and the approach for data analysis and presentation of the results. In the next phase, the researchers have to conduct the review

by through selecting primary studies based on the search criteria and data has to be collected as specified in the protocol defined in phase 1. Furthermore, the data derived from the primary studies has to be collated and summarized to answer the research questions defined in the protocol. Finally, the review report has to be produced in phase 3. The final report will be cross checked by a supervisor researcher that will be used to improve the description and correct minor issues.

2.1 SPECIFY RESEARCH QUESTIONS

To formulate the research questions, the implementation of Goal-Question-Metric (GQM) approach in (Basili, Caldiera, & Rombach, 1994) that provide approach aim at developing meaningful metrics for questions have been conducted. The goal of this literature research is to review the existing research work in the literature of requirements engineering for self-adaptive systems. To achieve this goal by decomposing into four sub-goals:

1. To provide the basic publication information and to assist identifying the most appropriate sources of research information in requirements engineering for self-adaptive systems.
2. To assist identifying the range of methods currently available in requirements engineering for self-adaptive systems.
3. To identify which methods and activities are more widely studied and to provide the hint whether any methods and activities are mature enough to be applied futher.
4. To identify principal research trends and to highlight active research topics that related with requirements engineering for self-adaptive systems.

To achieve the sub-goals, we design 10 research questions (RQ) in Table 1.

Table 1. The Research Questions

Research Quetions		Type	Related Goal
RQ1	What is the time of the publications?	Publication	1
RQ2	What is the veneu of the publications?		
RQ3	Who are the most active and influential researchers?		
RQ4	What activities are most studied?	Content	2
RQ5	What modeling are used to model requirement engineering for self adaptive system?		
RQ6	Which quality attributes can be concerned in Requirement Engineering for Self Adaptive?		
RQ7	What application domain are used for illustration?		
RQ8	Which methods are better applied and have more rigorous evaluation?	Quality	3
RQ9	Which RE activities are presented and discussed more detailedly?		
RQ10	What is the relationship between topics, activities and modeling methods?	Topic	4

To achieve first sub-goal, RQ1, RQ2 and RQ3 supported by providing the basic information related with trend of literature and relevant vanue of publication as well as the most active researchers who contributed on a research area. From RQ4 to RQ7 provide the summaries of analysis activities, modeling, quality attribute and application domain to achieve the second sub-goal. RQ8 and RQ9 achieve the third sub-goal by providing the measurement results of quality studied and activities are discussed detailedly. To fullfill the fourth sub-goal, RQ10 support us by providing the summaries of relationship between topics, activities and modeling method. For the Metric part of the GQM method, we will illustrate how to derive available information in the data extraction section.

2.2 DEFINE SEARCH SCOPE AND STRATEGY

The activities related with search strategy include, selecting digital library, defining the search string, executing a pilot search, refining the search string and retrieving an initial list of primary studies from digital libraries matching the search string. Selecting digital library performed by chosing an appropriate set of databases so that the probability of finding highly relevant papers fullfilled. To ensure thorough retrieval, we choose four popular databases library that cover the requirements engineering for self-adaptive literature, as follows:

1. IEEE eXplore (ieeexplore.ieee.org)
2. ACM Digital Library (dl.acm.org)
3. SpringerLink (springerlink.com)
4. ScienceDirect (sciencedirect.com)

Kitchenham et al. have described the steps for constructing the search string. We present Kitchenham's steps in Figure 2.

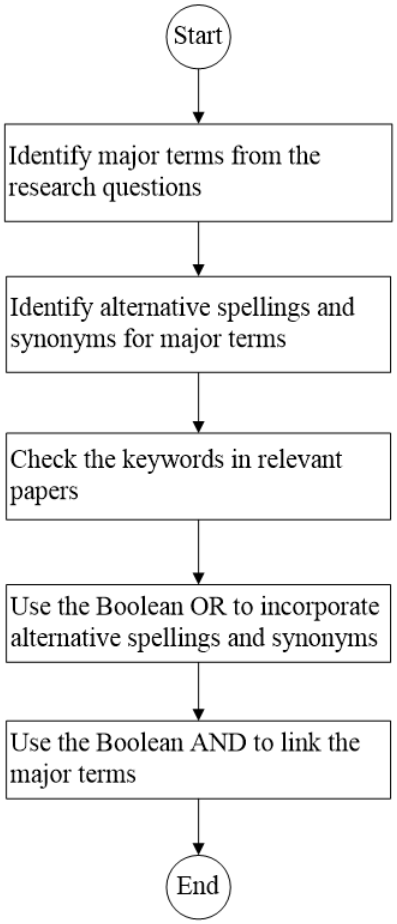

Figure 2. The Construction Steps of Search Strings

The derived search strings presented in Table 2. The use of the search strings can be combined with Boolean operator as: S1 AND S2.

Table 2. Derived Search Strings

S1	S2
Self-Adaptive	Requirements
("self-adaptive systems" OR "dynamically adaptive systems" OR "adaptive system" OR "Adaptive software" OR"self-adaptive software" OR "adaptive service" OR "self-adaptation" OR "socio-technical system" OR "self-adjusting systems" OR "autonomic computing" OR "self-adapting software" OR "self-reconfiguration" OR "self-repair" OR "self-healing" OR "self-tuning" OR "context-awareness")	("model requirements" OR "modeling requirements" OR "Requirements modeling" OR "specify requirements" OR "specifying requirements" OR "requirements specifying" OR "requirements specification" OR "monitor requirements" OR "monitoring requirements" OR "requirements monitoring" OR "aware requirements" OR "requirements-aware" OR "requirements awareness" OR "requirements-awareness" OR "diagnose requirements" OR "diagnosing requirements" OR "requirements diagnosing" OR "requirements diagnosis" OR "detect requirements" OR "detecting requirements" OR"requirements detection" OR "verify requirements" OR "verifying requirements" OR "requirements verifying" OR "requirements verification" OR "satisfy requirements" OR"satisfying requirements" OR "requirements satisfying" OR "requirements satisfaction" OR "evolution requirements" OR "requirements evolution")

The adjustment of the search string are conducted, but the original one is kept, since the adjustment of the search string would dramatically increase the already extensive list of irrelevant studies. The search string was subsequently adjusted to suit the specific requirements of each database. The databases are searched by title, keyword and abstract. The search was limited by the year of publication: 2000-2014. Two kind of publications, journal papers and conference proceedings, were included. The search was limited only to English.

2.3 SPECIFY DATA ITEMS

The data items aim to support availability data in order to answer each research questions. For each primary study, the data items shown in Table 3 have to be fullfilled as long as conduct selecting primary studies.

Table 3. Data Items

ItemId	Field	Use
F1	Title	Documentation
F2	Year	RQ1
F3	Veneu	RQ2
F4	Indexed Scopus	RQ2
F5	Authors	RQ3
F6	Activity	RQ4,RQ10
F7	Modeling Method	RQ5,RQ10
F8	Quality Attribute	RQ6
F9	Application Domain	RQ7
F10	Context	RQ10
F11	Topic	Documentation
F12	High-Level Problem Statement	Documentation
F13	Quality Score of Problem Statement	RQ8,RQ9
F14	Quality Score of Context	RQ8,RQ9
F15	Quality Score of Modeling Method	RQ8,RQ9
F16	Quality Score of Activity	RQ8,RQ9
F17	Quality Score of Application Domain	RQ8,RQ9

According to Table 3, the data items such as title (F1) and high-level problem statement (F11) are used for documentation. To answer RQ1 to RQ3, the data items that used, include: year (F2), venue (F3), indexed scopus (F4) and authors (F5). Activity (F6), modeling method (F7), quality attribute (F8), application domain (F9) are used to answer RQ4 to RQ7. To answer the questions related with quality score such as RQ8 and RQ9, the quality score of data items that used, include: activity (F6), modeling method (F7), application domain (F9), context (F10), topic (F11), and problem staement (F12) jointly.

2.4 SELECT PRIMARY STUDY

The Inclusion criteria and exclusion criteria are defined for selecting relevant studies. Retrieved papers are firstly checked with exclusion criteria.The paper will be excluded if such paper meets any one of the exclusion criteria. The remaining papers are checked with inclusion criteria. If one paper meets all the inclusion criteria then it will be included. These criteria are shown in Table 4.

Table 4. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Published time between 2000 - 2014	Publised In form Books, web sites, technical reports, and master theses or short paper (less than 6 pages)
Focus on Requirement Engineering for Self-Adaptive	Papers that Focus on summarizes the existing research work, roadmap or survey
Related with Requirement Engineering Activity	Publications in which focus on RE but is not clearly understandable or covered in insufficient detail
Involve concrete Measurement methods and evaluation to the methods	Studies without a strong validation or including experimental results
Publised in Form Doctoral Dissertation	Publised in Journal that not indexed in Scopus

As shown in Figure 3, the study selection process was conducted in two steps: the exclusion of primary studies based on the title and abstract and the exclusion of primary studies based on the full text. The literature review studies should be excluded when not explain the activity of requirement engineering for self-adaptive. And the other hand, the studies that deal with requirement engineering for self-adaptive as clearly, it must included.

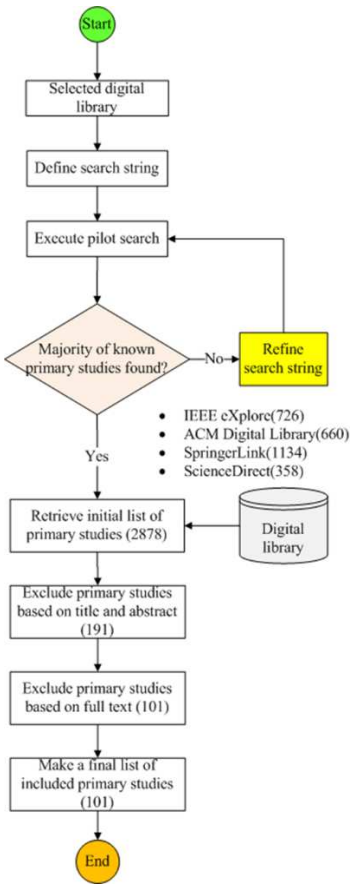

Figure 3. Search and Selection of Primary Studies

By conducting each phase of the search process, the final list of selected primary studies included 101 primary studies.

Then full texts were analyzed for 101 primary studies. In addition to the inclusion and exclusion criteria, the quality of the primary studies, their relevance to the research questions and study similarity were considered. Similar studies by the same authors in various journals were removed. 101 primary studies remained after the exclusion of studies based on the fulltext. The complete list of selected studies is provided in the Section Systematic Literature Review References.

2.5 EXTRACT REQUIRED DATA

Data extraction performed in order to accumulate the corresponding information from the selected primary studies that have been extrated. The corresponding information are collected to the data extraction form that was designed to answer the research questions. For each of the 101 selected primary studies, the data extraction form was completed. In table 5 presented the 4 properties that identified to answer the research questions. The process of data extraction is performed in an iterative manner.

Table 5. Data Extraction Properties Mapped to Research Questions

Property	Research Questions
Publication	RQ1, RQ2, RQ3
Content	RQ4, RQ5, RQ6, RQ7
Quality	RQ8, RQ9
Topic	RQ10

2.6 STUDY QUALITY ASSESMENT

Table 6 defined the quality assessment checklist based on the assessment items that adopted from (B. Kitchenham & Charters, 2007) and (Dybå & Dingsøyr, 2008). The quality of each primary studies is assessed accordance with optional answer score, and then the assessment result is used to answer the quality assement question such as RQ8 dan RQ9. The checklist is not used to evaluate whether a content of study is good or not, but use it to evaluate whether the content of study is maturely presented in the literature.

Table 6. Quality Assessment Checklist

No	Quality Assesment Questions	Optional Answer Score
1	How clearly is the problem of study described?	Explicitly=1; Vague=0.5; No description=0
2	How clearly is the research context stated?	Explicitly=1; Generally=0.67;Vague=0.33; No description=0
3	How detailedly is the modeling method presented?	Explicitly=1; Generally=0.67;Vague=0.33; No description=0
4	How detailedly is the activity of RE in self-adaptive elaborated?	Explicitly=1; Generally=0.67;Vague=0.33; No description=0
5	How clearly is the application domain presented?	Explicitly=1; Generally=0.67;Vague=0.33; No description=0

2.7 ANALYZE DATA

Data Analysis performed by assesing the quality of studies that used to guide the interpretation of the synthesis findings as well as to define the strength of the elaborated inferences. The data analysis aim at aggregating data from the selected studies in order to answer the research questions. The data extracted in this review include both quantitative data and qualitative data. Different strategies are employed to synthesize the extracted data pertaining to different kinds of research questions. The data were tabulated in a manner consistent with the questions. And to enhance the presentation of the distribution of requirement engineering in self-adaptive systems, usage of some visualization tools include bar chart, pie chart, and tables can be utilized. Based on the synthesis, conclusions and recommendations for future research in the field will be derived, and limitations of the review have to be identified. Finally, the results of the review are presented in a review report.

3 THREATS TO VALIDITY

The concentration of this study is to analyze the studies on requirement engineering in self-adaptive systems. This study are not aware of biases may have had for choosing the studies. The paper searching is not based on manual reading of titles of all published papers in journals. It means that this review probably have excluded some related research papers which exist in some conference proceedings or journals.

This study include the papers from conference proceedings, because experience reports are mostly published in conference proceedings. Some systematic literature reviews related with self-adaptive systems, as examples in (Yang et al., 2014), (Weyns, Iftikhar, Malek, & Andersson, 2012) and (Weyns & Ahmad, 2013) that included papers in conference proceedings as the primary studies.

4 RESULT AND DISCUSSION

This Section presents the results of research questions and discuss them briefly one by one. For each research question, we give a graphical overview and also we analyses of our data by statistically. At the end of each research question, we give a summary of that research question, in which we discuss that what we learned from this research question.

4.1 TIME DISTRIBUTION OF THE PUBLICATIONS

The time distribution of the publication is presented to show how the attention in the topic has changed over time. Figure 4 presented the overview of the distribution studies over years.

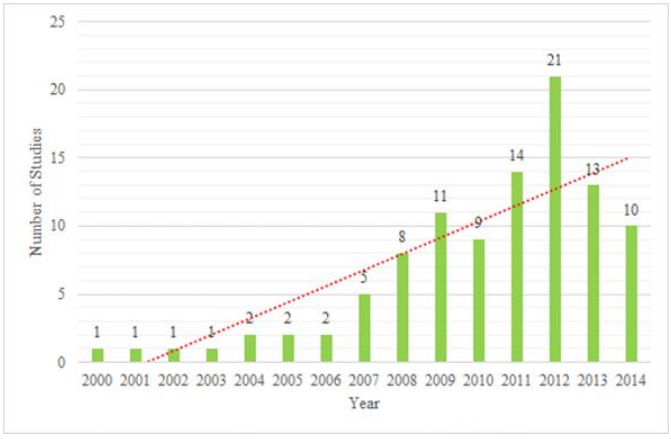

Figure 4. Time Distribution of Publications

Since 2007, an increase of publication caused by increased activity of requirement specification. This increase was driven by improvement in the model approach , as example in (Bresciani, Perini, Giorgini, Giunchiglia, & Mylopoulos, 2004) presented goal-based model that called TROPOS, in (Garlan, Cheng, Huang, Schmerl, & Steenkiste, 2004) presented architecture-based self-adaptation that called RAINBOW that provide model approach in order to fullfill the requirement of

stakeholders and requirements engineering language namely Relax in (Whittle, Sawyer, Bencomo, Cheng, & Bruel, 2010). Figure 4 also shows that the research field on Requirement Engineering in self-adaptive systems is still very much relevant to this day.

4.2 VENEU DISTRIBUTION OF PUBLICATIONS

From 101 primary studies that collected, there are 60 studies from journals, while 41 papers from conference proceedings. Figure 5 and 6 show the percentage of the distribution of studies per venue. Presented that Lecture Notes in Computer Science (LNCS) is the most popular journal to publish papers on Requirement engineering in self adaptive systems with 43% of the studies, while SEAMS is the most prominent conference with 22% of the studies.

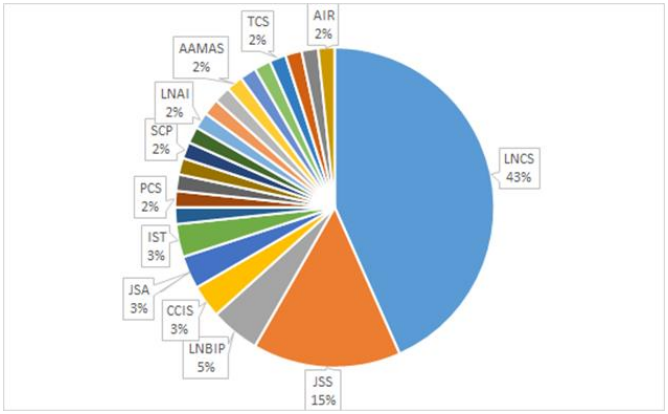

Figure 5. Venue Distribution of Journal

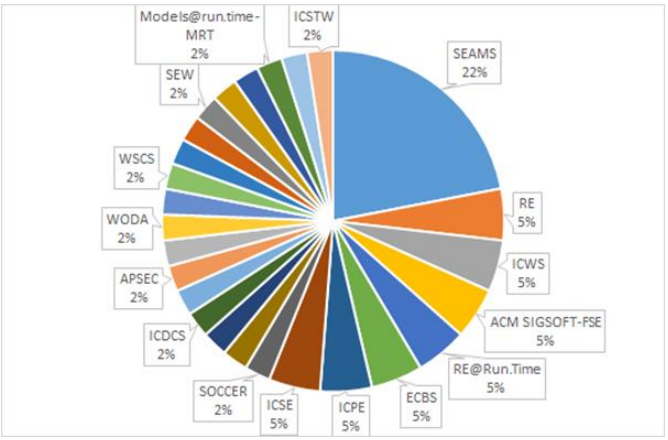

Figure 6. Venue Distribution of Conference Proceedings

Table 7 shows the Scimago Journal Rank (SJR) value and Q categories of the most important journals. Journal publications are ordered by frequency value. Table 8 presents the Scimago Journal Rank and ERA Rank of conference proceedings.

Table 7. Scimago Journal Rank (SJR) of Journal

Journal Article	Freq.	%	HI	SJR	Q Category
LNCS	26	43%	118	0.31	Q2 In Computer Science
JSS	9	15%	60	0.82	Q1 In Hardware and Architecture
LNBIP	3	5%	13	0.25	Q2 In Business, Management and Accounting
IST	2	3%	54	1.07	Q1 In Software
JSA	2	3%	30	0.39	Q3 In Software
CCIS	2	3%	12	0.14	Q4 In Computer Science
AIR	1	2%	40	1.24	Q2 In Artificial Intelligence
AAMAS	1	2%	46	1.57	Q1 In Artificial Intelligence
CACM	1	2%	131	1.82	Q1 In Computer Science
Computer	1	2%	112	0.72	Q1 In Computer Science
CSRD	1	2%	13	0.36	Q2 In Computer Science
ESE	1	2%	39	1.29	Q1 In Software
ESA	1	2%	85	149	Q1 In Computer Science Applications
FAC	1	2%	27	1.05	Q1 In Software
IEEE Software	1	2%	72	0.84	Q3 In Software
JISA	1	2%	7	0.88	Q1 In Computer Networks and Communications
LNAI	1	2%	118	0.31	Q2 In Computer Science
PCS	1	2%	15	0.28	Computer Science (miscellaneous)
RE	1	2%	32	0.98	Q3 In Software
SCP	1	2%	44	0.67	Q2 In Software
TCS	1	2%	74	0.93	Q1 In Computer Science
WIAS	1	2%	15	0.32	Q3 In Computer Networks and Communications
Total	**60**				

Table 8. Scimago Journal Rank (SJR) and ERA Rank of Proceedings

Conference Proceedings	Freq.	%	HI	SJR	ERA Rank
SEAMS	9	22%	7	0	A
ACM SIGSOFT-FSE	2	5%	39	0.74	A
ECBS	2	5%	3	0.17	B
RE	2	5%	4	0.29	A
ICPE	2	5%	2	0.18	N/A
ICWS	2	5%	8	0.2	A
RE@Run.Time	2	5%	2	0.2	N/A
ICSE	2	5%	2	0.1	C
ACM SAC	1	2%	35	0.31	B
APSEC	1	2%	16	0.2	C
Internetware	1	2%	0	0.1	N/A
CIT	1	2%	6	0	C
COMPSAC	1	2%	17	0.19	B
DEAS - ACM SIGSOFT	1	2%	17	0	N/A
EASe	1	2%	2	0.16	A
ACM SIGSOFT-QoSA	1	2%	2	0.17	A
ICDCS	1	2%	3	0.16	A
ICSTW	1	2%	7	0.25	C
Models@run.time - MRT	1	2%	1	0.11	N/A
NOTERE	1	2%	4	0.12	N/A
RAISE	1	2%	2	0.11	N/A
REV	1	2%	1	0	B
SOCCER	1	2%	1	0	C
SEW	1	2%	1	0.1	C
WODA	1	2%	1	0.1	N/A
WSCS	1	2%	4	0	N/A
Total	**41**				

4.3 MOST ACTIVE AND INFLUENTIAL RESEARCHERS

From the selected primary studies, the researchers who contributed very well and who are active on the requirement engineering in self-adaptive systems research field are investigated and identified. Figure 7 shows the active and influential researchers in requirement engineering in self-adaptive systems field. The researchers are listed according to the number of studies included in primary studies. However, it can be noted that Betty Cheng, Pete Sawyer, Anna Perini, John Mylopoulos, Andres Ramirez and Nelly Bencomo are active researchers on requirement engineering in self-adaptive systems.

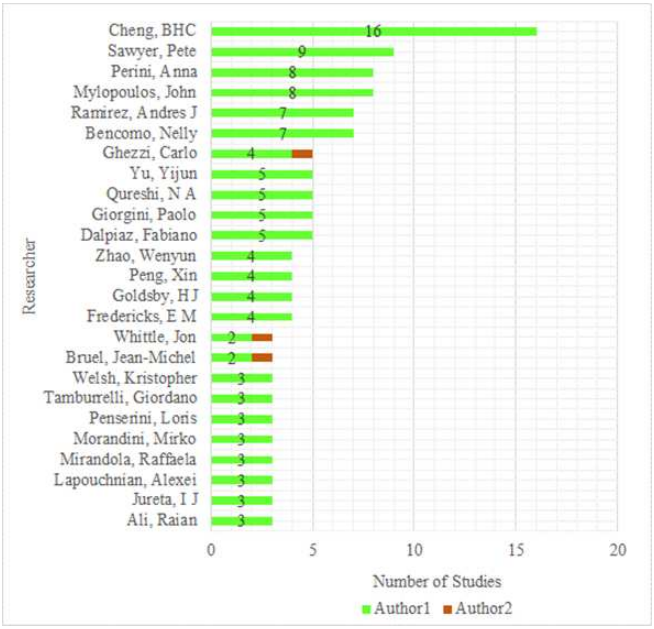

Figure 7. Influential Researchers and Number of Studies

4.4 THE MOST STUDIED ACTIVITIES

Figure 8 presents the categories of RE activities and the corresponding frequency of studies. From the selected primary studies, requirement specification is the activities that most studied on requirement engineering in self-adaptive systems. it can be noted that the 5 activities of research on requirement engineering in self-adaptive systems that most studied, include: requirement specification, requirement modeling, requirement verification, requirement monitoring and adaptation mechanism.

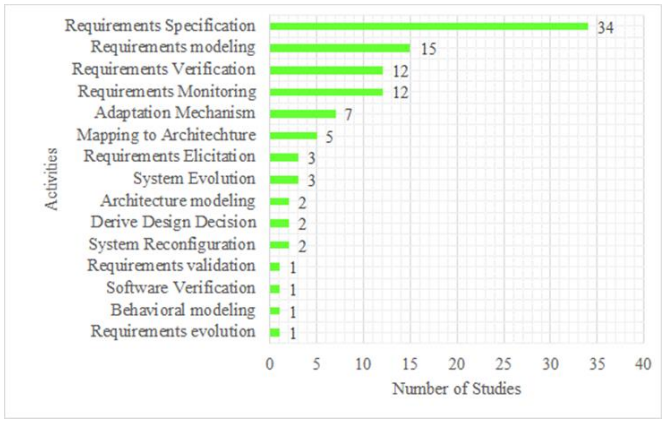

Figure 8. Requirement Engineering Activities based on Frequency of Studies

4.5 THE MOST USED MODELING METHODS

Figure 9 presents the modeling methods and the corresponding frequency of studies. Tropos, i* and KAOS are Goal-oriented methodologies that became most popular requirements modeling methods in the literature. They can describe intension of stakeholders and systems' requirements as clearly. In addition, UML models are used to model behavior of systems. Transition systems including Markov Chain, DTMC, Petri Net and State and Transition System are implemented to describe systems' states and state transitions. Feedback control mechanism are to design the adaptation mechanism. LTL, FBTL and Mathematical Logic are used as specification languages which are utilized to specify the properties that should be held by the system. And to capture the environmental properties can be built by context models. Business process model and domain-specific model focus more on business logic and domain logic.

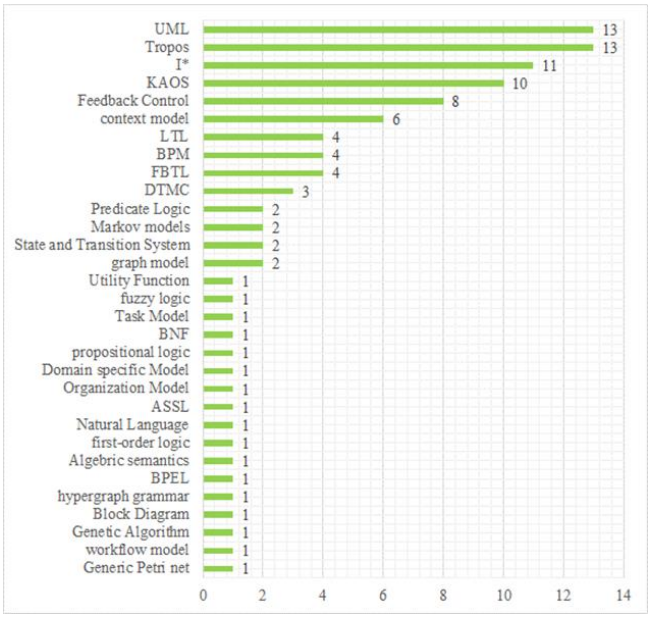

Figure 9. Modeling Methods based on Frequency of Studies

4.6 THE MOST CONCERNED OF QUALITY ATTRIBUTE

In this chapter, quality attributes are investigated based on ISO 9126-1 (http://www.iso.org). Related with definition of each quality attributes do not elaborated, but explain the relations implied behind. Figure 10 presents the distrbution of quality attributes.

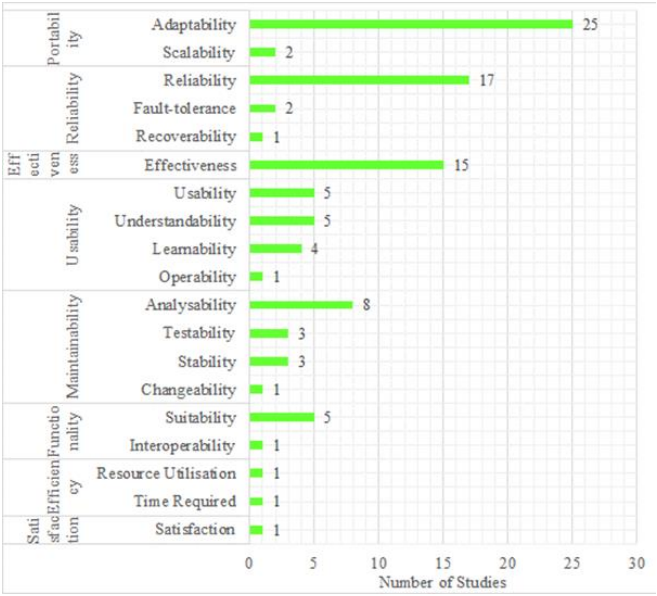

Figure 10. Quality Attributes and Number of Studies

From selected the primary studies, noted that the 7 most concerned of quality attributes on requirement engineering in self adaptive, include: adaptability, reliability, effectiveness, analysability, understandability, usability and suitability. Adaptability is involved in the studies of building adaptation mechanism or runtime adaptation. Reliability is studied in the work on the topic of verification. Effectiveness involved in the studies that specify goals with accuracy and completeness.

Analyzability is considered in the studies of monitoring or diagnosing requirements. Understandability is involved in the study of producing more understandable requirements model. Usability is considered in the studies deal with context-awareness system. Suitability is studied in the work on the topic of formal method that provide an appropriate set of functions for specified tasks and user objectives.

4.7 THE MOST USED OF APPLICATION DOMAIN

From the selected primary studies, noted that 43 application domains have been used to support the experiment to the research of requirement engineering in self-adaptive systems. Figure 11 presents the 15 application domains that most used to illustrate the experiment of research.

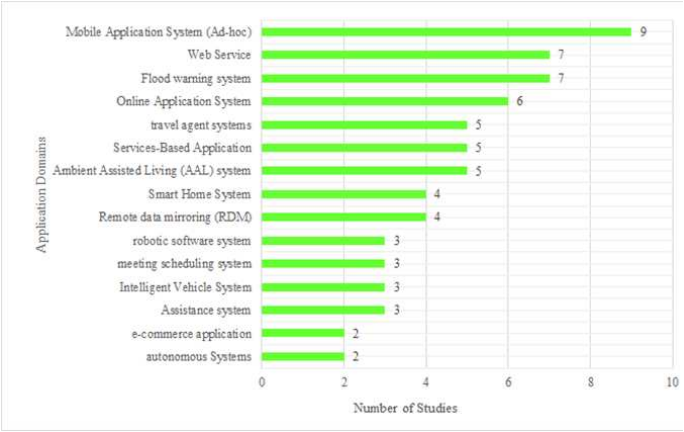

Figure 11. Application Domains and Number of Studies

Mobile application system is application domain that used to the research which deal with specifying requirement on context-awareness system. In the context of service-oriented systems, web service is application domain that illustrate the experiment of the research. In order to support the activities of specification, monitoring and modeling requirements in dynamically adaptive systems (DAS), the researcher most used flood warning system as application domains. Related with the activities that cope with non-functional requirement satisfaction, most researcher used remote data mirroring (RDM) as application domains.

In order to support the research related with non-functional requirement issue, Table 9 describe that remote data mirroring (RDM) is the application domain that most clearly elaborated to support non-functional requirement satisfaction research.

Table 9. Application Domain and Quality Score based on Research Topic

Application Domain	Deal with Non-Functional Requirement	Deal With Trade Off Analysis
Assistance system		4,50
e-commerce application	4,34	
Happy Hour Organizer (HHO)	3,84	
Intelligent Vehicle System	4,00	
load balancer system	4,00	
meeting scheduling system		3,67
Mobile Application System (Ad-hoc)		4,09
Online Application System	3,67	
Personal Emergency Response System (MPERS)	4,17	
Positioning System	4,33	
Remote data mirroring (RDM)	5,00	
Services-Based Application	3,33	
tour guide system	4,34	
urban transportation management	3,67	
Web Service	3,50	3,67

4.8 RIGOROUS EVALUATION METHODS

The primary studies are assessed according to the quality assessment checklist in Table 6. Figure 12 depicts that KAOS, i*, Tropos have high score, because most research topic proposed have clear evaluation.

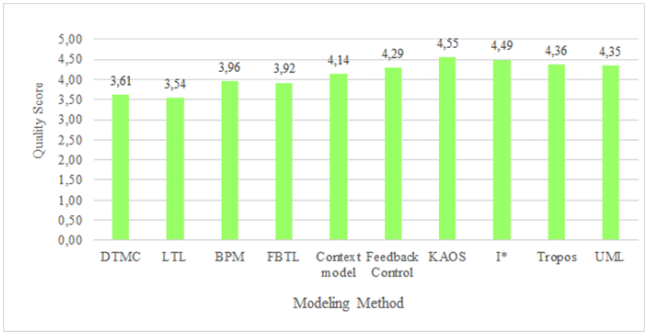

Figure 12. Quality Score of Modeling Methods and Number of Studies

In Table 10 present the quality score of modeling method based on research topic. However, the important note that such goal based models have high score in several research topic but lack in cope with non-funtional requirement issues.

Table 10. Quality score of Modeling Method based on Research Topic

Modeling Method	Cope with Complexity	Cope with Uncertainty	Deal with Adaptation Mechanism	Deal with Non-Functional Requirement
hypergraph grammar			3,01	
fuzzy logic				3,50
LTL	3,54			
Genetic Algorithm		3,67		
propositional logic			3,67	
BPM	4,01			3,33
BNF			3,83	
graph model	3,67	4,00		
FBTL		3,84		4,00
Utility Function				4,00
Block Diagram		4,00		
Algebric semantics	4,00			
DTMC			4,17	3,84
context model	4,34		4,67	3,92
State and Transition System	4,34		4,17	
Feedback Control	3,50	4,50	4,50	4,34
UML	4,67		4,19	4,34
Predicate Logic			4,34	
Organization Model	4,34			
I*		4,67	4,67	3,67
Tropos	4,29	4,67	4,34	
KAOS	4,34	4,53	4,34	
Task Model			4,50	
Markov models		4,67		4,34
Natural Language		4,67		
ASSL		4,67		

4.9 DETAILEDLY DISCUSSED ACTIVITIES

In Table 11 present the quality score of detailedly discussed activities based on view of research topic side. Described that requirement specification is activities that discussed in most research topic as detailed. Software verification, requirement validation and system reconfiguration are the 3 most detailed discussed activities and have high quality score average than others. However, such activities are lack discussed in several research topics.

Table 11. Quality Score of Detailed Discussed Activities based on Research Topic

Activities	Cope with Complexity	Cope with Uncertainty	Deal with Adaptation Mechanism	Deal with Change of Requirement	Deal with Non-Functional Requirement	Deal With Trade-Off Analysis	Dynamic Context	Average of Quality Score
System Evolution		3,67	3,01			3,67		3,45
Derive Design Decision	2,99		4,00					3,50
Requirements Elicitation					4,01		3,67	3,84
Requirements Monitoring	3,61	4,59	3,79		3,67	4,50		4,03
Requirements Evolution		4,00						4,00
Architecture modeling	3,67						4,67	4,17
Requirements modeling	4,28	4,17	4,61	4,67	2,92		4,34	4,16
Requirements Verification	4,34	5,00	4,34	2,83	4,06		4,51	4,18
Adaptation Mechanism		4,67	4,17	4,17		3,51	5,00	4,30
Behavioral modeling							4,33	4,33
Mapping to Architechture	4,34		4,50			3,67	5,00	4,38
Requirements Specification	4,14	4,45	4,56	3,50	4,50	4,67	4,54	4,34
System Reconfiguration		4,67			4,34			4,51
Requirements validation	4,67							4,67
Software Verification			4,67					4,67
Average of Quality Score	4,01	4,40	4,18	3,79	3,91	4,00	4,51	4,17

4.10 THE RELATIONSHIP BETWEEN TOPICS, ACTIVITIES AND MODELING METHODS

The primary studies have been segmented into 15 activities and 7 topics in order to make the analysis of relationships between activities, topics and modeling method. Table 12 presents the relationship between research activities and research topics. Table 13 presents the relationship between modeling method and research topics. The such tables present the relative frequency of each modeling method.

To elaborate how different modeling methods are implemented to a certain research topics and how a modeling method can be adopted into different research topic, table 12 and table 13 respectively can be the references. New topic or new activities can be generated by incorporating uncertainty into the existing topics, since in requirements engineering for self-adaptive systems have made the uncertainty as a first class concept.

Table 12. The Relationship between Topics and Research Activities

	Research Topics							
Research Activities	Cope with Complexity	Cope with Uncertainty	Deal with Adaptation Mechanism	Deal with Change of Requirement	Deal with Non-Functional Requirement	Deal With Trade-Off Analysis	Dynamic Context	Grand Total
Requirements Specification	6	9	6	1	3	1	8	34
Requirements modeling	3	3	3	1	2		3	15
Requirements Monitoring	3	2	4		2	1		12
Requirements Verification	2	1	3	1	3		2	12
Adaptation Mechanism		1	3	1		1	1	7
Mapping to Architechture	2		1			1	1	5
Requirements Elicitation					2		1	3
System Evolution		1	1			1		3
Architecture modeling	1						1	2
Derive Design Decision	1		1					2
System Reconfiguration		1			1			2
Behavioral modeling							1	1
Requirements Evolution		1						1
Requirements validation	1							1
Software Verification			1					1
Grand Total	**19**	**19**	**23**	**4**	**13**	**5**	**18**	**101**

Table 13. The Relationship between Topics and Modeling Methods

Modeling Method	Research Topics							
	Cope with Complexity	Cope with Uncertainty	Deal with Adaptation Mechanism	Deal with Change of Requirement	Deal with Non-Functional Requirement	Deal With Trade-Off Analysis	Dynamic Context	Grand Total
Tropos	4	2	2	1		1	3	13
UML	2		6		2		3	13
I*		2	3	1	2		3	11
KAOS	1	6	1				2	10
Feedback Control	1	1	3	1	1		1	8
context model	1		1		2		2	6
BPM	2				1	1		4
FBTL		2			1		1	4
LTL	4							4
DTMC			1	1	1			3
graph model	1	1						2
Markov models		1			1			2
Predicate Logic			1			1		2
State and Transition System	1		1					2
Algebric semantics	1							1
ASSL		1						1
Block Diagram		1						1
BNF			1					1
BPEL						1		1
Domain specific Model							1	1
first-order logic							1	1
fuzzy logic					1			1
Generic Petri net						1		1
Genetic Algorithm		1						1
hypergraph grammar			1					1
Natural Language		1						1
Organization Model	1							1
propositional logic			1					1
Task Model			1					1
Utility Function					1			1
workflow model							1	1
Grand Total	**19**	**19**	**23**	**4**	**13**	**5**	**18**	**101**

5 CONCLUSION AND FUTURE WORKS

The objective of this chapter is to systematically investigate the research literature of requirements engineering for self-adaptive systems, summarize the research trends, categorize the used modeling methods and requirements engineering activities in research studies published between January 2000 and June 2014. During systematic review process many questions arose. Kitchenham and Charters (2007) provides a set of guidelines for conducting a systematic literature review, which provides steps for formulating research questions to be answered to the review and developing a review protocol (B. Kitchenham & Charters, 2007).

The increasement of publication caused by increased activity of requirement specification since 2007. The increasement was driven by improvement in the model approach such goal based model namely Tropos in (Bresciani et al., 2004), architecture-based self-adaptation called Rainbow in (Garlan et al., 2004) and requirements engineering language namely Relax in (Whittle et al., 2010). Related with venue distribution of publication, from primary studies that collected, there are 60 studies from journals, while 41 papers from conference proceedings. Presented that Lecture Notes in Computer Science (LNCS) is the most popular journal to publish papers on Requirement engineering in self adaptive systems of the studies, while SEAMS is the most prominent conference of the studies. The researchers are listed according to the number of studies included in primary studies among others Betty Cheng, Pete Sawyer, Anna Perini, John Mylopoulos, Andres Ramirez and Nelly Bencomo are active and influential researchers on requirement engineering in self-adaptive systems.

Related with content of studies, from 101 primary studies that collected the 5 activities of research on requirement engineering in self-adaptive systems that most studied, include: requirement specification, requirement modeling, requirement verification, requirement monitoring and adaptation mechanism. Goal-oriented methodologies such as Tropos, i* and KAOS that became most popular requirements modeling methods in the literature. the quality attributes on requirement engineering in self adaptive, include: adaptability, reliability, effectiveness, analysability, understandability, usability and suitability are the most concerned in the selected primary studies. In order to support support the experiment to the research of requirement engineering in self-adaptive systems, mobile application system is application domain that used to the research which deal with specifying requirement on context-awareness system. In the context of service-oriented systems, web service is application domain that illustrate the experiment of the research. In order to support the activities of specification, monitoring and modeling requirements in dynamically adaptive systems (DAS), the researcher most used flood warning system as application domains. Related with the activities that cope with non-functional requirement satisfaction, most researcher used remote data mirroring (RDM) as application domains.

To deal with studies quality, goal based models have high score in several research topic but lack in cope with non-funtional requirement issues. So it takes the development of goal-based models to be able to handle the NFR satisfaction. Requirement specification is activities that discussed in most reseach topic as detailedly. Software verification, requirement validation and system reconfiguration are the 3 most detailedly discussed activities and have high quality score average than others. However, the such activities are lack discussed in several research topics.

The analysis of relationships between activities, topics and modeling method presented that the primary studies have been segmented into 15 activities and 7 topics. New topic or new activities can be generated by incorporating uncertainty into the existing topics, since in requirements engineering for self-adaptive systems have made the uncertainty as a first class concept.

Future work focuses on further are investigating the high-level problem statements in requirements engineering for self-adaptive systems and solution to cope with such problems. Additionally, the relationship between topics and application domain need to be explored.

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