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ORIGINAL ARTICLE

Empirical research in requirements engineering: trends and opportunities

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Abstract Requirements engineering (RE) being a foundation of software development has gained a great recognition in the recent era of prevailing software industry. A number of journals and conferences have published a great amount of RE research in terms of various tools, techniques, methods, and frameworks, with a variety of processes applicable in different software development domains. The plethora of empirical RE research needs to be synthesized to identify trends and future research directions. To represent a state-of-the-art of requirements engineering, along with various trends and opportunities of empirical RE research, we conducted a systematic mapping study to synthesize the empirical work done in RE. We used four major databases IEEE, ScienceDirect, SpringerLink and ACM and Identified 270 primary studies till the year 2012. An analysis of the data extracted from primary studies shows that the empirical research work in RE is on the increase since the year 2000. The requirements elicitation with 22 % of the total studies, requirements analysis with 19 % and RE process with 17 % are the major focus areas of empirical RE research. Non-functional requirements were found to be the most researched emerging area. The empirical work in the sub-area of requirements validation and verification is little and has a decreasing trend. The majority of the studies (50 %) used a case study research method followed by experiments (28 %), whereas the experience reports are few (6 %). A common trend in almost all RE sub-areas is about proposing new interventions. The leading intervention types are guidelines, techniques and processes. The interest in RE empirical research is on the rise as whole. However, requirements validation and verification area, despite its recognized importance, lacks empirical research at present. Furthermore, requirements evolution and privacy requirements also have little empirical research. These RE sub-areas need the attention of researchers for more empirical research. At present, the focus of empirical RE research is more about proposing new interventions. In future, there is a need to replicate existing studies as well to evaluate the RE interventions in more real contexts and scenarios. The practitioners' involvement in RE empirical research needs to be increased so that they share their experiences of using different RE interventions and also inform us about the current requirements-related challenges and issues that they face in their work.

Keywords Evidence-based software engineering · Requirements engineering · Systematic review · Mapping study

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1 Introduction

The degree of success and failure of a software system depends upon the level and quality of services it provides, as required by its users and stakeholders. Requirements engineering (RE) is the process of eliciting, analyzing, documenting, validating and managing these requirements. There are a number of challenges related to each of the sub-processes within RE such as requirements articulation problem. These challenges and problems have motivated researchers to carry out research in different areas of RE, since its origin in 1990s.

RE evolved tremendously with a research span of more than 20 years. This journey of RE research has delivered various outcomes in terms of processes, tools, techniques, methods and frameworks as have been reported in various RE conferences and Journals [1, 2]. A vast amount of research is underway in various areas of RE. New RE researchers need to have a sound knowledge of the current state of the RE research, covering various trends, to have an idea of the future research opportunities in this field. Few researchers have made attempts for providing a walk-through of the research within the RE field. Nuseibeh and Easterbrook [3] made the first attempt in the year 2000 for providing an overview of the field and highlighted some key open research issues for the future. Later, in the year 2007, Cheng and Atlee [4] presented the research directions of RE by following the same pattern as of 2000s RE Roadmap. There was also another attempt of aggregating RE research, in the year 2007, by Davis et al. [5], by covering a huge amount of RE publications, focusing on thousands of RE research papers. All of these three attempts were beneficial in their respective contributions; however, these attempts covered both empirical and non-empirical literature and thus lacked much evidence coming from the empirical research [6]. This notion has also been highlighted by many researchers [7, 8], who noted that a lot of RE research papers just propose new solutions to existing problems without fully validating them. Empirical studies are significant, as they determine the real value of the research results in any field, to present progress in that field [9, 10]. One of the major reasons behind the lack of empirical studies in RE is the difficulty of aggregation of empirical results [10]. So, it will be interesting to know "what has been done empirically in RE field?" by considering the evidence-based paradigm [11] to aggregate RE empirical results.

To present a state of the art of RE based on empirical RE studies, one needs to filter an enormous collection of RE research papers. We need to extract evidence from empirical research reported on tools, techniques, frameworks, etc. to gain insights into broader aspects of this field. There is also a need to present the strength of these empirical RE studies, and presenting various trends and opportunities of this field. Such an investigation will help RE researchers and practitioners identify RE areas, rich in terms of tools, techniques, frameworks, and guidelines and areas deprived of much research. It will facilitate the practitioners and researchers in directing them to the areas that need their attention.

There have been few attempts by various researchers to aggregate research studies related to specific areas of RE. However, the focus of these surveys was limited to a specific area of RE. Also, a large number of such attempts involved in aggregating results related to both empirical as well as non-empirical studies of RE (shown in Appendix 1). The individual surveys do not present the themes and trends emerging from an overall analysis of the empirical literature of RE. A single attempt to aggregate all the empirical studies of RE is required to present a state of the art of this field. The purpose of this paper is to report a systematic mapping study that has been conducted to aggregate empirical studies of RE up to the year 2012. This paper presents an overall analysis of the RE field, having various trends and hinting toward various research opportunities in it.

The main motivation of this systematic mapping study (SMS) is to aggregate and synthesize empirical studies of the whole discipline of RE. The research questions (RQ) of the review include:

RQ1: What is the state of the art in empirical studies of RE?
RQ2: What is the strength of empirical evidence in empirical requirement engineering literature?

RQ1 aims at finding existing empirical studies in RE, to identify trends, emerging areas and future research directions. RQ2 aims at finding the strength of evidence of empirical research in RE by analyzing the employed research methods, data collection techniques, and type of participants involved. RQ1 is further divided in the following sub-questions:

- Which era of RE research has maximum progress in terms of new advances?
- Which country is frequently involved in RE research and in which era, these countries showed maximum progress?
- In which context, these empirical studies of RE have been carried out over the period of RE research?
- How empirical research in various RE knowledge areas has evolved over the years?
- What types of interventions have been proposed or investigated in RE research?

- In which channels the empirical studies of RE are published?
- How the research method, type, intervention and domains are related to RE core areas?

RQ2 has following sub-questions:

- Which research method is frequently used in primary studies?
- What kind of research participants are frequently involved in primary studies?
- Which data collection method is frequently used in the investigation of research in primary studies?
- What is the frequency of different research types of primary studies?
- How rigorous is the reported research in different RE core areas?

The themes emerged from overall aggregation and synthesis of RE studies; present various interesting results that are of benefit to both industry and academia, in terms of research trends and opportunities. The protocol of this SMS has already been reported in [12], while this paper presents the results of the SMS to present a state-of-the-art of RE, highlighting various trends and opportunities in RE research. The rest of the paper is organized as follows: Sect. 2 presents background and related work; Sect. 3 describes the research process; results are presented in Sect. 4 and further discussed in Sect. 5; study limitations are discussed in Sect. 6; lastly Sect. 7 concludes the paper.

2 Background and related work

This section deals with a terse background of evidence-based requirements engineering and the work regarding existing systematic reviews from the RE field.

2.1 Evidence-based requirements engineering

Since the last decade, there has been an inclination toward evidence-based software engineering (EBSE) [11], with a focus on systematic and empirical-based research methods. Systematic mapping study (SMS) and systematic literature review (SLR) are the two main tools used in EBSE. The SLRs are performed to evaluate available literature on a research topic in a rigorous, unbiased and auditable way [13]. The primary studies in an SLR are evaluated more rigorously to critically appraise the reported evidence.

SMSs, on the other hand, provide a broader overview on a research topic, and identify and quantify the available evidence on a research area [12]. Their findings can be used to plan future systematic reviews and also primary studies on the identified topics/trends [12]. In a SMS, large number of primary studies can be included, as the evaluation and critical appraisal are not very rigorous. Moreover, the SMS is preferred over SLR in situations when the area is too broad [13]. Therefore, we used the SMS methodology to investigate the whole field of RE.

2.2 Related work

A number of SLRs, e.g. [14–16], have been reported in software engineering since the introduction of the EBSE methodology. Dealing with requirements engineering, a number of researchers have conducted systematic reviews, mainly focusing on some specific sub-area of RE. Dieste and Juristo [17] performed a systematic review on requirements elicitation techniques based on 26 empirical studies published till the year 2005. They aggregated the results in terms of five guidelines for RE practitioners. Using the results of the same systematic review, Davis et al. [18] looked at the effectiveness of the requirements elicitation techniques. Pacheco and Garcia [19] performed an SLR on stakeholder identification during requirements elicitation based on 47 primary studies dated from 1984 to 2011. They found that identified approaches are not able to cover all aspects of stakeholder identification during requirements elicitation.

SLRs have also been reported in requirements specification area. Nicolas and Toval [20] presented an SLR of 30 studies on the generation of textual requirements from software models. Fernandez et al. [21] performed a systematic mapping study to identify what aspects of software requirement specifications (SRS) are empirically evaluated, in which context and by using which research methods. They found that the understandability was the most commonly evaluated feature of SRS, and the majority of the primary studies are experiments performed in an academic setting to evaluate requirements specifications. Amyot and Mussbacher [22] performed an SLR on the first 10 years of development of User Requirements Notation (URN) and also highlighted ongoing improvement efforts. The SLR's results showed that the URN is a growing requirements modeling language in terms of its users and contribution.

A number of SLRs have also been performed in the requirements management area, focusing on specific topics within requirements management such as requirements evolution management [23], requirements prioritization [24], requirements traceability [25], requirements related errors finding [26], causes of requirements change [27], requirements triage and selection [28] and requirements reuse [29].

Requirements engineering have also been investigated within global software development (GSD) context. Lopez et al. [30] performed an SLR to compile a repository of risk factors that arise when RE is done in distributed software

development environment, along with a collection of safeguards to overcome these risks. The SLR just presented the risks and safeguards repository without its validation on some real GSD project. Peng and Lai [31] performed a review to study all the wikis (well-known knowledge management tools that support collaborative work) used to carry out requirements engineering activities in distributed development. The main goals of the review were to gain an insight into how and to what degree current distributed requirements engineering-related wikis could support the RE activities, and also to identify the future research directions.

Blain et al. [32] conducted an SLR to synthesize RE literature relevant for multi-agent systems. The aim of the review was to investigate which requirements engineering techniques have been applied in the development of multi-agent systems (MAS) and how they were applied. This SLR was based on 58 primary studies, but only 5 % of the papers provided some empirical evidence about the effectiveness of their approaches. Alves et al. [33] performed an SLR to critically appraise the available evidence on RE for software product lines. The SLR included 49 primary studies covering 20 years from 1990 to 2009. They found that the evidence for adoption of the methods in the included 49 primary studies mainly consists of toy examples and is therefore not mature.

A list of these SLRs with their overall summary is presented in Appendix 1. However, all of these SLRs focus on some sub-areas of RE, respectively, and cover empirical studies related to that specific area only. To the best of our knowledge, no SLR has aggregated results of the existing interventions in the whole RE discipline. Furthermore, some of the existing SLRs have also included non-empirical primary studies [34]; contrary to it, our SMS is based on only empirical studies of RE. Our SMS is an attempt to add to the RE body of knowledge in its own specific way, with the aim to aggregate results from the whole RE empirical literature, presenting various trends and future opportunities for RE researchers and practitioners.

3 Research method

We followed the guidelines provided in [11, 35] for conducting this mapping study. In this section, we describe the activities of the research process we followed.

3.1 Protocol development

The initial step of this research was the development of the SMS protocol. The authors collaboratively worked with each other during its development. The protocol included research questions, decisions for search strategy, data extraction strategy, criteria for inclusion/exclusion and data synthesis strategy.

3.2 Search string

The search string was formulated by considering the keyword *software* along with two sets of keywords *X* and *Y*, where:

X: All related terms of "requirements engineering."
Y: All related terms of "empirical."
Z: software

The final search string was like: ((All related terms of requirement engineering ORed) AND (All related terms of empirical studies ORed) AND software)). The final string consisted of the terms shown in Table 1.

A generic query string was developed to search various databases as:

(Software AND ("requirements engineering" OR "requirements process" OR "requirements elicitation" OR "requirements gathering" OR "requirements identification" OR "requirements discovery" OR "requirements analysis" OR "requirements validation" OR "requirements verification" OR "requirements specification" OR "requirements development" OR "requirements documentation" OR "requirements management" OR "requirements change management" OR "requirements negotiation" OR "requirements testing" OR "requirements checking") AND ("case study" OR "industrial

Table 1 Search string terms

X1: requirements engineering	Y1: case study
X2: requirements process	Y2: industrial report
X3: requirements elicitation	Y3: experiment
X4: requirements gathering	Y4: experience report
X5: requirements identification	Y5: empirical
X6: requirements discovery	Y6: observational study
X7: requirements analysis	
X8: requirements validation	
X9: requirements verification	
X10: requirements specification	
X11: requirements development	
X12: requirements documentation	
X13: requirements management	
X14: requirements change management	
X15: requirements negotiation	
X16: requirements testing	
X17: requirements checking	
Z: software	

report" OR experiment OR "experience report" OR empirical OR "observational study")).

The search string was validated by applying it iteratively on the databases, for checking few (8–10) well-known papers from RE, during pilot testing steps of the protocol. This generic string of a query was modified to specific queries according to each database. The query was also broken down into sub-queries due to the limitations provided by each database for the maximum number of terms in a query. The queries were applied on the title and abstracts of the papers. We have applied queries in the databases in the year of 2012.

3.3 Search strategy

An automated search process was employed to find all the relevant studies of RE. Four major databases were searched:

- Association for Computing Machinery (ACM).
- The Institute of Electrical and Electronics Engineers (IEEE).
- ScienceDirect.
- SpringerLink.

During protocol development, we also planned to search EI Compendex, but later on at the execution phase of the SMS, we failed to cover this database because of unavailability of it due to subscription issues. The items to be searched included:

- Journal papers.
- Conference papers.
- Peer-reviewed workshop papers.

The publication period of the studies included in the SMS was decided to be from the start of the period specified in various databases till the year 2012, and only the papers in the English were included.

3.4 Inclusion and exclusion criteria

The study was decided to be included that would fit the criteria as:

- The study was about RE.
- OR the study was about any of the sub-areas of RE.
- AND the study had empirical evidence (i.e., it is a case study, experiment, survey, or experience report-based).

The study was decided to be excluded that was:

- In the form of books, literature surveys, SLRs, mapping studies, thesis, unpublished articles, tutorials, summaries, discussions, prefaces, comments and editorials.
- OR the study did not directly address RE or any of its sub-areas.
- OR the study lacked empirical evidence.
- OR the study was not in the English language.

3.5 Quality assessment strategy

Quality assessment is used to evaluate the quality of the empirical evidence described in the primary studies. These criteria were adopted from the SLR guidelines [13, 36–39]. Appendix 2 shows various sections of the checklist with respective questions of each section. The questions included in the checklist were answered either "yes," "no" or "partial," rated as 2, 1 or 0, respectively. The sum of the scores for all these questions was used to assess the quality of a primary study. We, however, did not exclude any study based on its quality score; rather, this score just depicts quality rank of the primary studies.

3.6 Data extraction strategy

Appendix 3 enlists the data items we extracted from each primary study. To find various core/main and sub-areas of RE in the data extraction scheme, we consulted *SWEBOK* [40] and *REBOK* [41]. The type of research in data extraction scheme had been formulated according to the research types provided in [42]. The rest of the items were extracted to carry out a rich analysis and present various themes and trends as advised in [35].

The data of this SMS were extracted and saved in Microsoft Excel sheets where data for each primary study was saved in a separate row of excel sheet with *a reference ID* corresponding to its *ID* in endnote library (that contained all the references in it). Use of excel sheets for saving data and its analysis saved a lot of time, as it was easier for cross-referencing of primary studies. The next section describes the whole process of the SMS.

3.7 Review process

The overall process of this mapping study has been divided into four phases: phase 1 involves the research questions and search strategy formalization, phase 2 involves searching the references from the databases by using search strings, saving of references in endnote, and then removing duplicates, phase 3 involves studies' screening (level 1 and level 2) and data extraction, while phase 4 involves the quality assessment of the studies. The whole process of the mapping study is shown Fig. 1.

The initial search string yielded thousands of research papers, which were exported to endnote, which is a widely

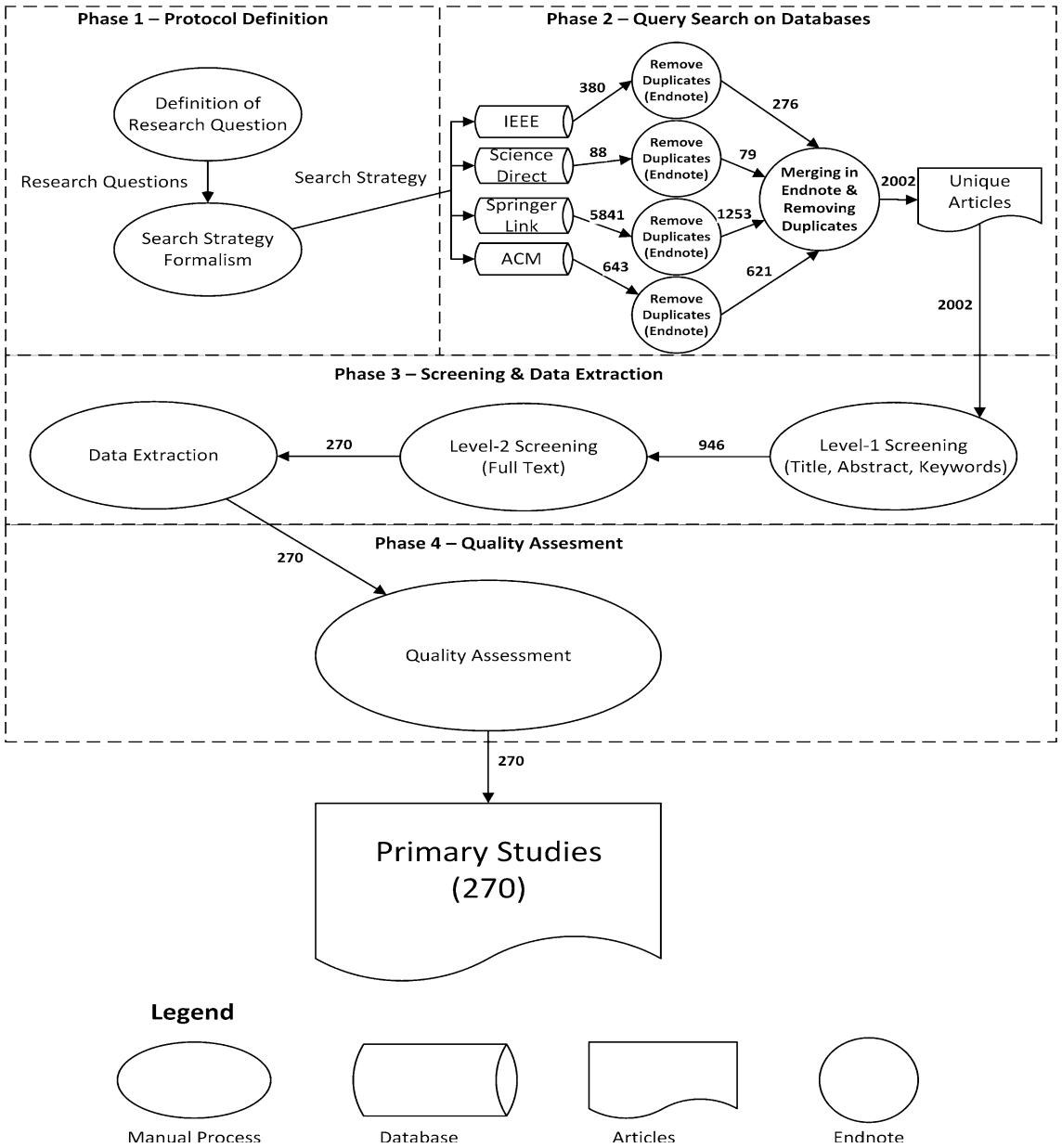

Fig. 1 Systematic mapping study process

used tool for reference management. Separate endnote libraries were created for the set of research papers obtained by applying queries on ACM, SpringerLink, IEEEXplore and ScienceDirect. Duplicates were removed from each database endnote library, after that all the research paper references from the four databases libraries were merged and again duplicates were removed.

The final endnote library contained all the research papers' references contained in four separate libraries of databases, merged into a single endnote library. It was the final set of references on which level 1 screening was applied. Level 1 screening involved studying the paper title, abstract and keywords to find:

- The study was relevant to RE field.
- And the study was also empirical based.

Initial query application on the four databases yielded 380 results from IEEE, 88 from ScienceDirect, 5841 from SpringerLink and 643 from ACM. It is worth mentioning here that the criteria of paper search from the four databases were initially set to be based on the empirical nature of the study. Therefore, queries applied to databases contained empirical factors to get only empirical studies. After individual searches from the four databases, there were a total of 6952 studies retrieved. A total of 2229 studies were left after discarding duplicates from the search results of

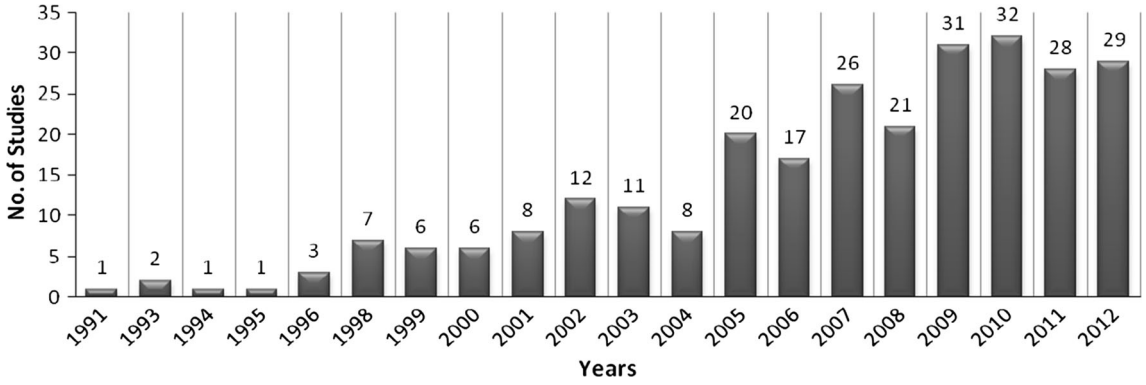

Fig. 2 Year-wise distribution of RE studies

the four databases. All of these studies in separate endnote files, belonging to the four databases, were then merged into a single master file of endnote, and there emerged 227 duplicates again from all the references' merger. We removed these duplicates and a total of 2002 studies were finally left, on which level 1 screening was applied.

During level 1 screening, each of the 2002 studies was screened by reading the title, abstract and keywords, to find if the study was relevant to the RE field and was also empirical. We found that a large number of abstracts of the studies were not detailed enough to prove its empirical nature, so we had to pass these studies to the next level (level 2), for further screening. Level 1 screening was the primary responsibility of the first author, while third author reviewed a randomly selected sample (10 %) of these studies to validate the results.

Level 2 screening involved reading the whole text of the studies obtained from level 1 screening, with the same criteria as for level 1 screening. Here, the studies were excluded based on two factors: either their main focus was not on RE or the studies did not present a real empirical work. While reading the whole text of the papers, we found that most of the studies that employed case study methodology did not employ it in a real manner. These studies presented examples and scenarios rather than cases from the real world. Therefore, such studies were not selected as primary studies. During level 2 screening, some of the studies were selected as candidate primary studies, while some were rejected. The third category contained the studies about which the primary reviewer had some doubt to include or exclude, so these studies were then discussed with secondary reviewers and resolved. Unfortunately, we could not have access to the full text of 35 studies. After level 2 screening, by reading the whole text of the papers, there were 270 studies that had finally been selected as primary studies of the SMS. A complete list of these primary studies is provided online (a link at [43]). The third author of this paper contributed during level 2 screening also, by reviewing a randomly selected sample (8 %) of studies to validate the results. The next section describes the results of this SMS.

4 Results

This section describes the results along with the analysis of the data extracted from the studies, to answer both the research questions of this SMS.

4.1 State of the art in empirical studies of RE (RQ1)

To answer the first research question, we formulated few sub-questions to investigate various aspects of primary studies. This section describes the details of the state of the art in RE.

4.1.1 Which era of RE research has maximum progress in terms of new advances?

This SMS includes 270 primary studies spanning over the era of two decades. Figure 2 shows the frequency of RE empirical studies reported in the period from 1991 up to 2012. The Empirical work in RE started in the era of 1990s. The empirical work in RE was not significant till the year 2000; however, there has been an increased attention paid by researchers toward empirical RE studies during the last decade of reported RE studies.

4.1.2 Which country is frequently involved in RE research and in which era, these countries showed maximum progress?

It is interesting to know the regions where the empirical research of RE has been conducted. There are 29 different countries involved in reporting empirical RE research. Figure 3 shows the frequency of studies reported from the top 20 countries involved in RE research. The maximum frequency of studies is reported from USA (39 studies).

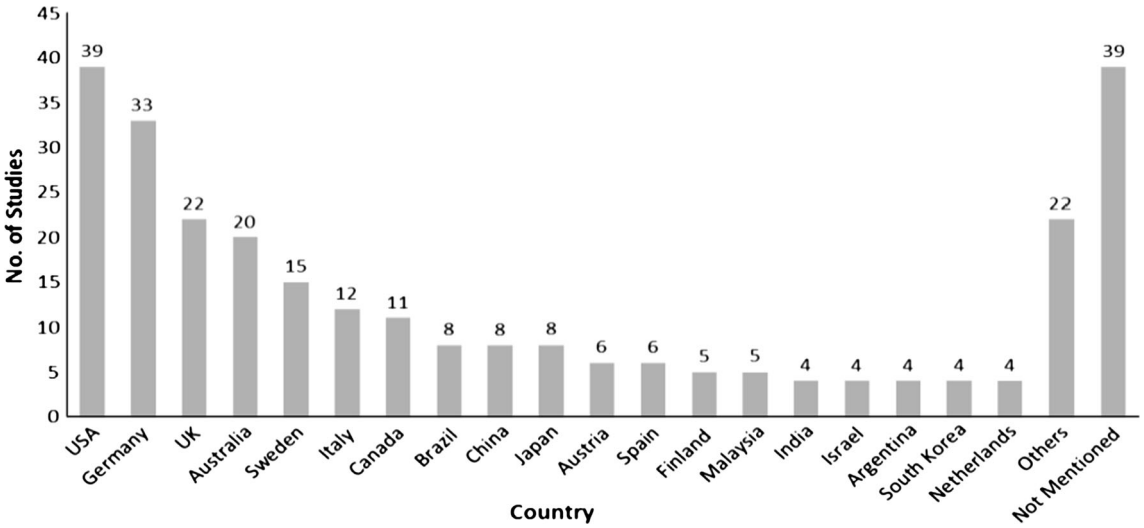

Fig. 3 Countries involved in RE studies

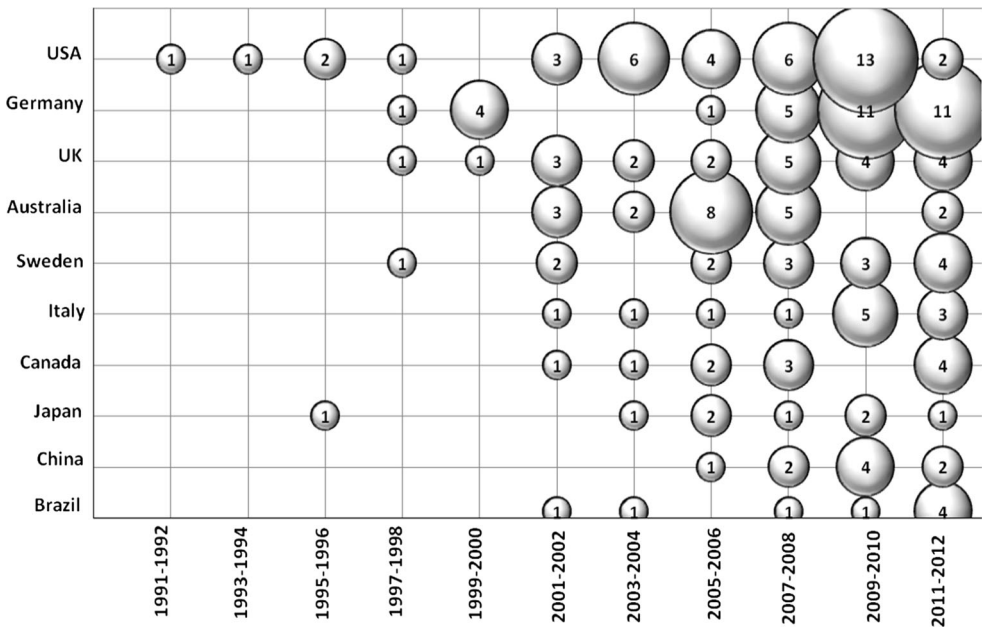

Fig. 4 Yearly distribution of studies in top 10 countries

Germany (38 studies), UK (22 studies) and Australia (20 studies) are also significantly involved in empirical RE research. Sweden, Italy and Canada also reported a considerable number of empirical studies in RE. The empirical work reported in other countries is very little, so they have not been shown in the above figure. The status of 39 studies is unclear for the country to which they belong.

To investigate the second part of sub-question: "in which era a country showed maximum progress?" we mapped the top 10 countries in terms of frequency of studies against per year reporting of studies in these countries as shown in Fig. 4. The earliest empirical RE study is reported in the USA in the year 1991, which indicates that the USA was the first country reporting the empirical work related to RE. The frequency of empirical studies in the top 10 countries is minimal before the year 2000, except for the USA, Germany and UK, that were involved in empirical research work of RE before the year 2000.

4.1.3 In which context, these empirical studies of RE have been carried out over the period of RE research?

The primary studies included in this SMS belong to various domains as shown in Appendix 4. The most significant domains are embedded (13 %), telecom (7 %), MIS

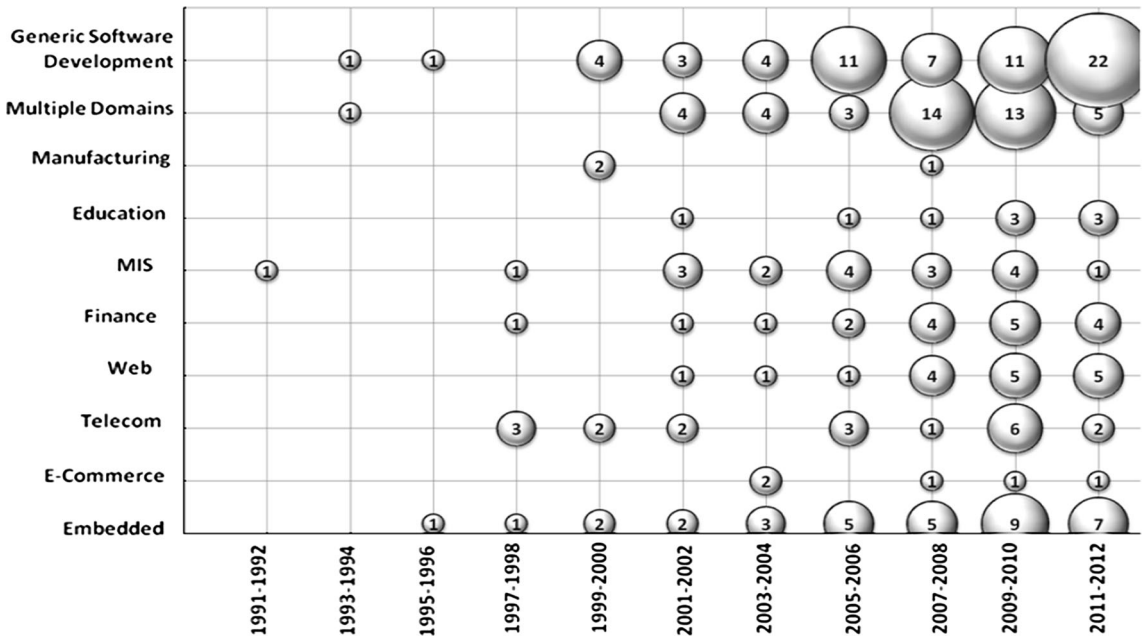

Fig. 5 Yearly distribution of empirical RE studies in various domains

Table 2 Core RE areas

Core areas of RE	No. of empirical studies	Percentage
Requirements engineering fundamentals	9	3
Requirements engineering process	46	17
Requirements elicitation	59	22
Requirements analysis	50	19
Requirements specification	28	10
Requirements verification, validation and evaluation	13	5
Requirements planning and management	36	13
Practical considerations of requirements engineering	29	11

(management information systems) (7 %), finance (7 %) and web (6 %), whereas a small percentage of studies belong to education (3 %), e-commerce (2 %, and manufacturing (1 %) domains. 16 % of studies belong to multiple domains, while 24 % of studies belong to the generic software development domain. There are 14 % of studies that belong to some other domains.

We also tried to investigate the most active domains of RE research recently. So, Fig. 5 shows the yearly distribution of empirical RE studies in various domains. From Fig. 5, it can be seen that MIS is the oldest domain where empirical work of RE appeared, and then, in late 1990s the work in other domains like telecom and finance started. However, embedded domain showed a progressive increase in empirical studies from 1995 to 2012. Also, it is the most active domain of empirical RE work recently. The embedded domain in turn contains other various domains in it, like avionics, medical and automotive [44], and we also categorized electronics and control systems under the embedded domain. In the last decade, some empirical work in education and e-commerce domains can also be seen in Fig. 5. However, in the recent era, the most active domains of RE empirical research are embedded, telecom, web and finance.

4.1.4 How empirical research in various RE knowledge areas has evolved over the years?

To check knowledge areas of RE where research has been conducted, we first had to decide what are the various knowledge areas of RE? So, we consulted SWEBOK [40] and REBOK [41]. The terminologies and concepts of these knowledge areas are, however, finally adopted from REBOK [41].

Table 2 shows the quantification of empirical research done so far in each RE core area. It can be seen that major work is done in requirements elicitation (22 %), requirements analysis (19 %) and RE process (17 %) core areas.

Table 3 Sub-areas of RE

Sub-areas of RE	No. of empirical studies	Percentage
Requirements negotiation	13	5
Requirements prioritization	12	5
Requirements traceability	10	4
Requirements modeling	10	4
Requirements risk analysis	4	2
Requirements trade-off analysis	3	1
Requirements impact analysis	2	1
Enterprise analysis	2	1

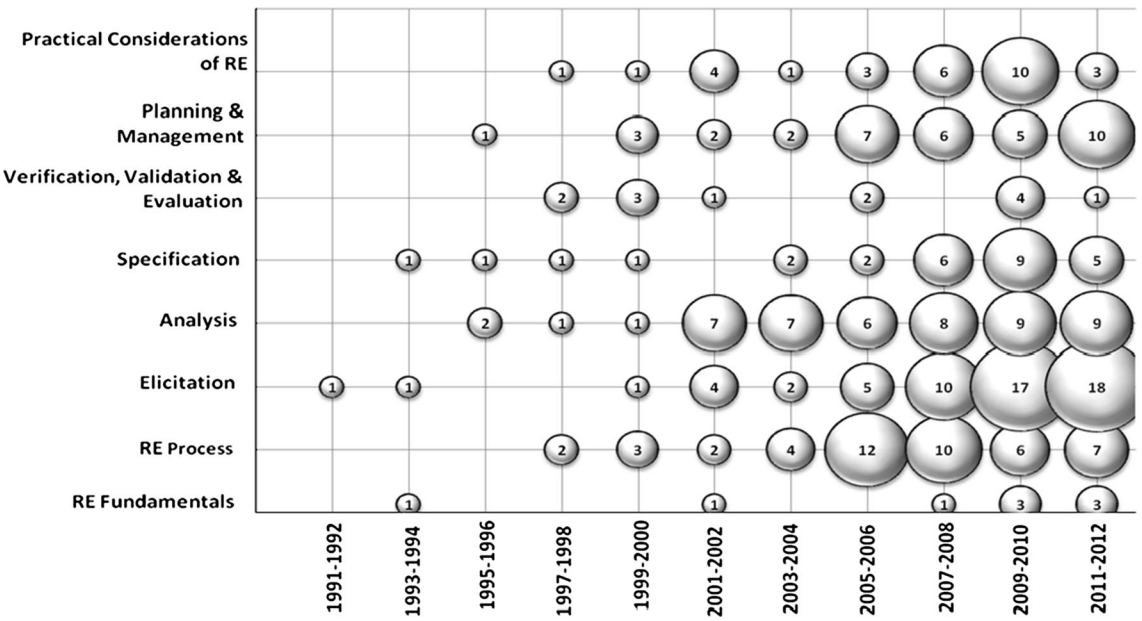

Fig. 6 Yearly distribution of studies in core areas of RE

A significant number of primary studies have reported research in the area of requirements planning and management (13 %). A considerable number of studies have reported research in requirements specification (10 %) and practical considerations of RE (11 %). The studies dealing with the practical consideration of RE have mostly presented research interventions in terms of some lessons learned, so these research interventions have been categorized as "guidelines" during data extraction. Only 5 % of studies deal with requirements verification, validation or evaluation, and only 3 % deal with fundamental aspects of requirements engineering.

We also categorized some sub-areas of RE shown in Table 3. However, the studies related to sub-areas do not exist independently, rather all of these studies also fall in any of the core areas too. The sub-areas shown in Table 3 present significant work in requirements negotiation (5 %), requirements prioritization (5 %), requirements traceability (4 %) and requirements modeling (4 %). However, only a small amount of empirical RE work is discovered in requirements risk analysis (2 %), requirements impact analysis (1 %) and enterprise analysis (1 %).

Figure 6 shows the yearly distribution of studies in RE core areas to visualize research trends in these areas. The results show a consistent trend across almost all core areas, highlighting the fact that the interest in empirical research in RE has been on the rise after year 2000. The quantity of empirical research in all RE core areas has progressed well from year 2005 onwards.

During the data extraction and analysis stages of this SMS, we observed few interesting trends. Some new areas of research have been emerging in various RE core areas. Figure 7 presents some areas that have emerged in empirical RE research. Non-functional requirements are by far the most active among these emerging research areas.

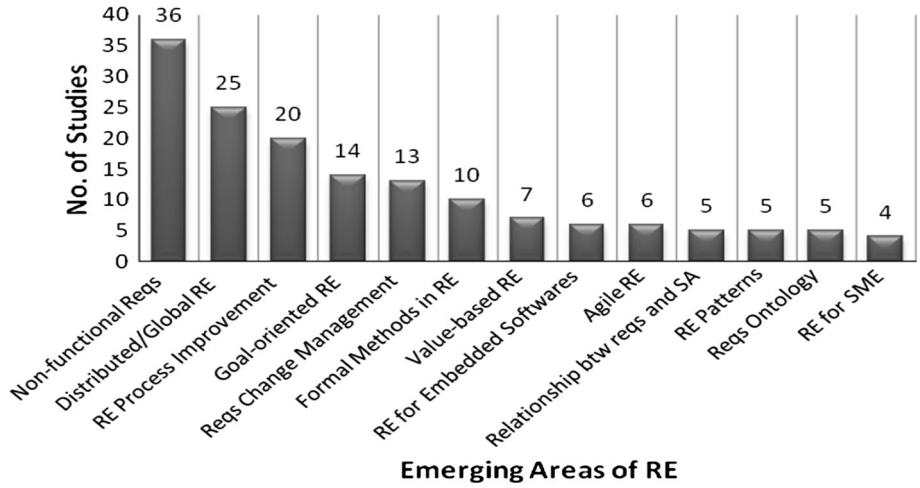

Fig. 7 Emerging areas of RE

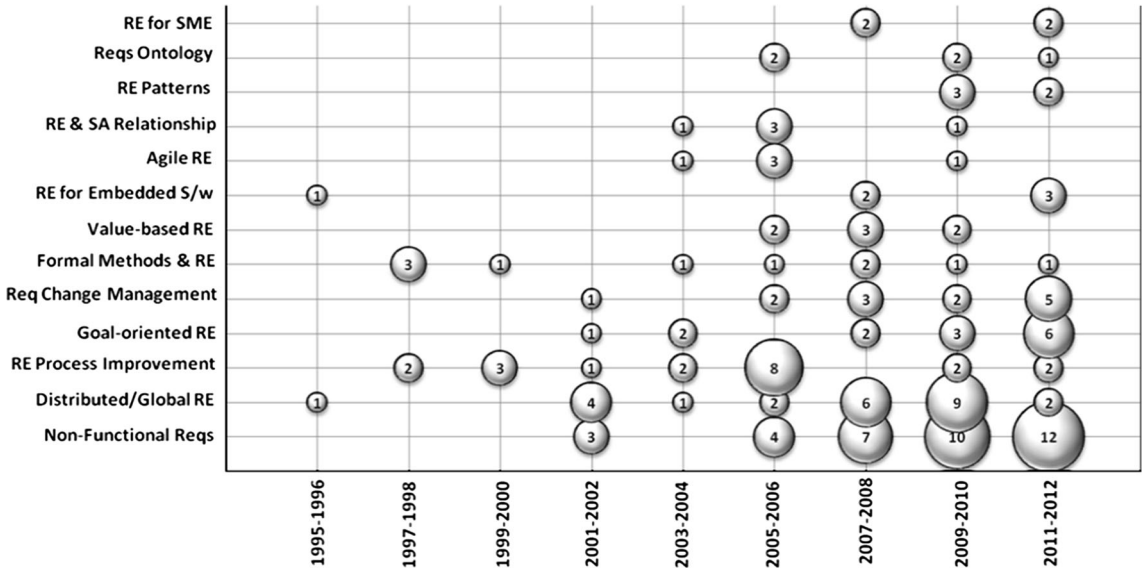

Fig. 8 Yearly distribution of emerging areas of RE

Some of these areas, such as formal methods and process improvement in RE, have been under investigation since 1990s. However, empirical research in the lead emerging areas increased considerably after the year 2005, see non-functional requirements and global RE in Fig. 8, for example. Some areas, on the other hand, have only emerged in twenty-first century and have not been investigated very extensively so far. These include: goal-oriented RE, requirements change management, agile RE, value-based RE, etc.

4.1.5 What type of interventions have been proposed or investigated in RE research?

Figure 9 shows various types of interventions that have been investigated over the years in RE research. These

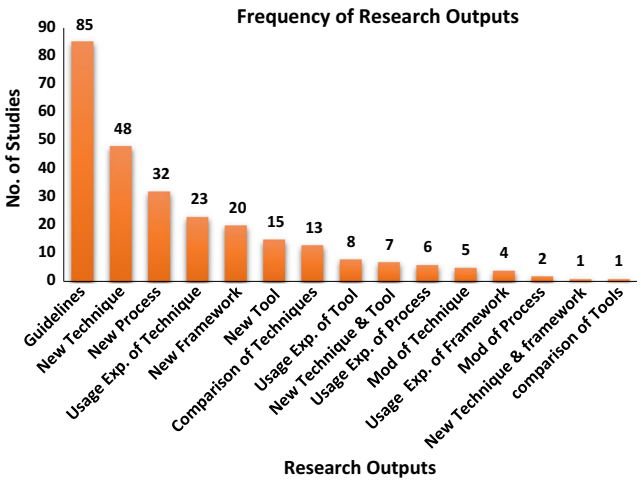

Fig. 9 Research outputs in RE studies

results indicate that guidelines, techniques and processes are highly investigated intervention types in RE empirical research. 31 % (85) of studies proposed guidelines in various RE areas. New techniques and processes have been proposed in 18 % (48) and 12 % (32) studies in our SMS. It was also interesting to note that there is more interest in proposing new interventions (guidelines, technique, processes, etc.) in empirical RE research, while relatively little attention is paid to use and evaluate existing interventions.

To analyze the investigated interventions with respect to each RE core area, we mapped them to each area in Appendix 5. RE area-wise classification of interventions in Appendix 5 can be used by RE researchers and practitioners to identify relevant types of interventions that are proposed and/or validated empirically in their area of interest. The research output "guidelines" is missing in Appendix 5, as we could not represent guidelines with a short name/label as such, but in the future we plan to summarize these guidelines too.

Most of the names of these interventions in Appendix 5 are used as reported by authors in the primary studies of the SMS. However, if we could not find any proper name of the research output mentioned in the paper, we named it by using keywords from the paper. The complete list of primary studies reporting these interventions is available in [43].

4.1.6 *In which channels the empirical studies of RE are published?*

Publication channels for primary studies include conference (62 %), journals (36 %) and peer-reviewed workshops (2 %) as shown in Fig. 10. The International Requirements Engineering Conference (ICRE), with 21 % of the studies, is the top publication channel of primary studies. The Requirements Engineering journal with 16 % is the second in the list. These results confirm the results of the study reported in [5].

Other significant journal publication channels, shown in Fig. 11, include Journal of Information and Software Technology, Journal of Empirical Software Engineering, IEEE Transactions on Software Engineering and Journal of System and Software. Conference channels include REFSQ (International Conference on Requirements Engineering: Foundation for Software Quality), APSEC (Asia–Pacific Software Engineering Conference), ICGSE (International Conference on Global Software Engineering) and ICSE (International Conference on Software Engineering). There are also many other conferences and journals whose percentage of studies was not that significant to be presented here. These sources of RE studies can be helpful for RE researchers to hunt for the desired empirical work of RE and for seeking a chance to publish new RE research papers.

ICRE: International Conference on Requirements Engineering.
REFSQ: Requirements Engineering Foundation for Software Quality.
APSEC: Asia Pacific Software Engineering Conference.
COMPSAC: International Computers, Software & Applications Conference.
ICSE: International Conference on Software Engineering.
PROFES: International Conference on Product-Focused Software Process Improvement.
HICSS: Hawaii International Conference on System Sciences.
ER: International Conference on Conceptual Modeling.
SAC: Symposium on Applied Computing

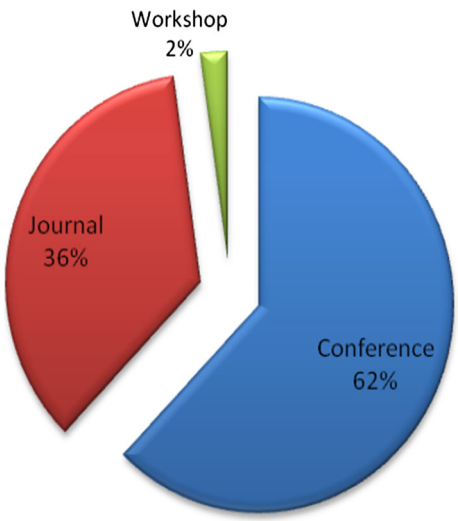

Fig. 10 Types of publication channel

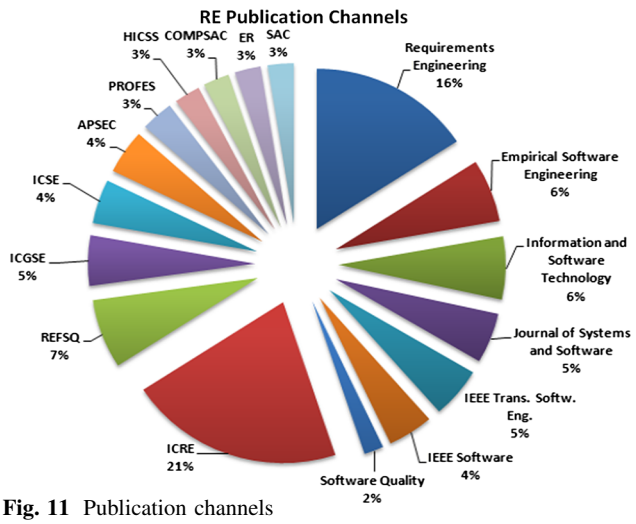

Fig. 11 Publication channels

4.1.7 How the research method, type, intervention and domain are related to RE core areas?

This research question aims to characterize the research conducted in different RE core areas with respect to the research method, type, output and domain of the studied projects/products. Figure 12 classifies the primary studies with respect to the RE core areas and research types. The results show that most of the research in RE is of "evaluation" and/or "validation" type. This pattern is consistent across almost all RE core areas. The fact that research is evaluated in laboratory settings (validation) or implemented and/or evaluated in practice (evaluation) is positive in terms of rigor. However, relatively fewer experience papers in different RE core areas (e.g., Analysis, Planning & Management) point to the need for encouraging practitioners, to share their firsthand experiences more frequently at academic venues.

Figure 13 classifies research in RE core areas with respect to the type of interventions proposed or investigated. The results indicate that the dominant trend, across almost all RE core areas, is that of proposing new interventions. These intervention types are new guidelines, new techniques, new processes and frameworks. "Guidelines" by far is the leading intervention for "Practical Considerations of RE" and "RE Fundamentals" core areas. Various types of interventions have been proposed in "Elicitation" and "Planning & Management" core areas including guidelines, techniques, processes and frameworks. Technique-oriented research dominates "Analysis," while "RE Process" core area has high number of studies proposing new processes, guidelines and frameworks. These results can be used by researchers in initiating efforts to organize and classify knowledge in different core areas of RE. There are relatively fewer studies that report results of using or modifying existing interventions in new contexts. It is important for the maturity of RE discipline that more studies are conducted to further validate and enhance existing interventions. The interventions that have been validated in number of

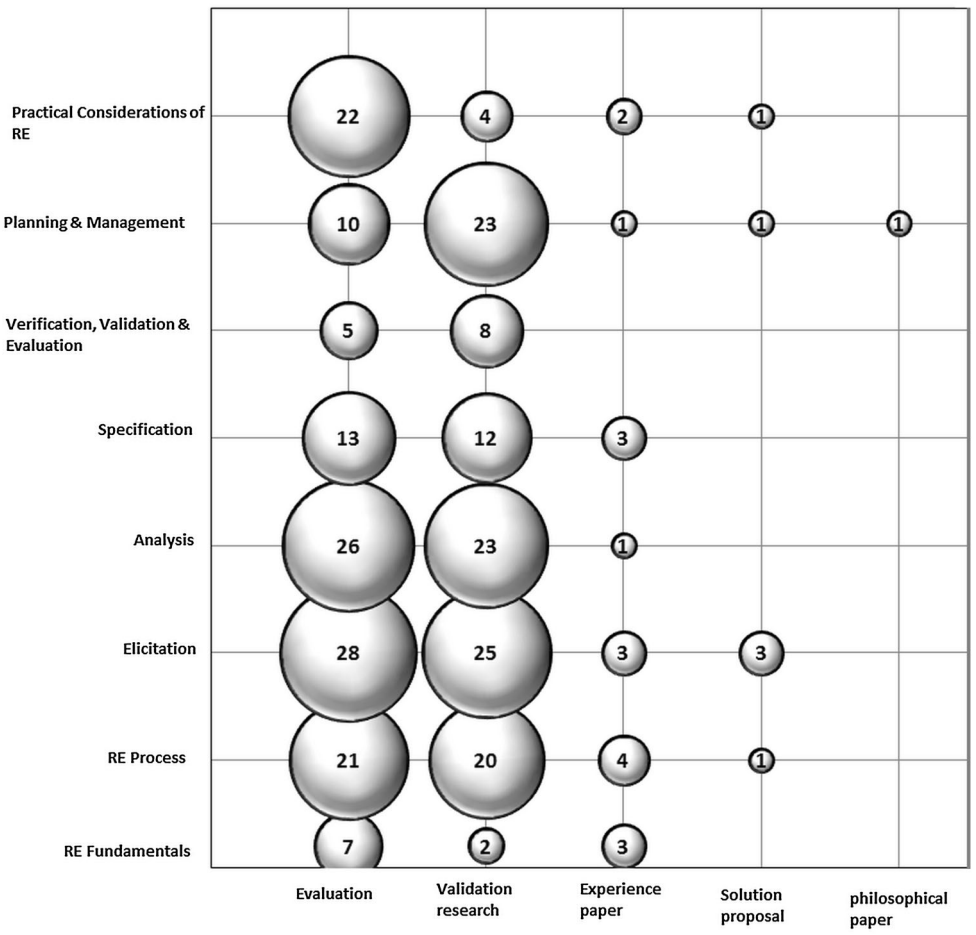

Fig. 12 Research types versus RE core areas

contexts would be more acceptable for software companies and practitioners.

Figure 14 presents classification of primary studies with respect to the domain of the studied project or product or organization for all RE core areas. General software development and embedded systems development are the leading domains across all core areas. The results show that research in "RE Process," "Elicitation" and "Analysis" core areas has been conducted in variety of domains. However, it is not the case for core areas like "Specification," "Planning & Management" and "verification, Validation and Evaluation" wherein the most research efforts are limited to relatively fewer domains. We also tried to investigate which RE areas are investigated by which research methods, see Fig. 15.

From Fig. 15, it can be seen that surveys have mostly been conducted for investigation of practical consideration of RE, for investigation of requirements elicitation and for exploring fundamental aspects of RE, while a large number of case studies have been conducted for investigating issues related to requirements engineering process, requirements elicitation, requirements specification and requirements planning and requirements management areas of RE. The experimentation methodology has mostly been employed to explore requirements elicitation and analysis areas of RE. However, for investigation of issues related to requirements analysis, an equal amount of case studies and experiments have been conducted in the empirical studies. The maximum number of experience reports has been reported related to RE process area. It can be seen that the case study is the most popular research method for almost all the areas of RE except, RE fundamentals and verification, validation and evaluation area of RE.

4.2 Strength of empirical evidence of RE (RQ2)

The aim of the second question of this SMS was to find out the strength of empirical studies by finding the source of empirical studies along with the research methods and data collection methods employed in the studies. Following section deals with various question used to explore the strength of empirical studies of RE.

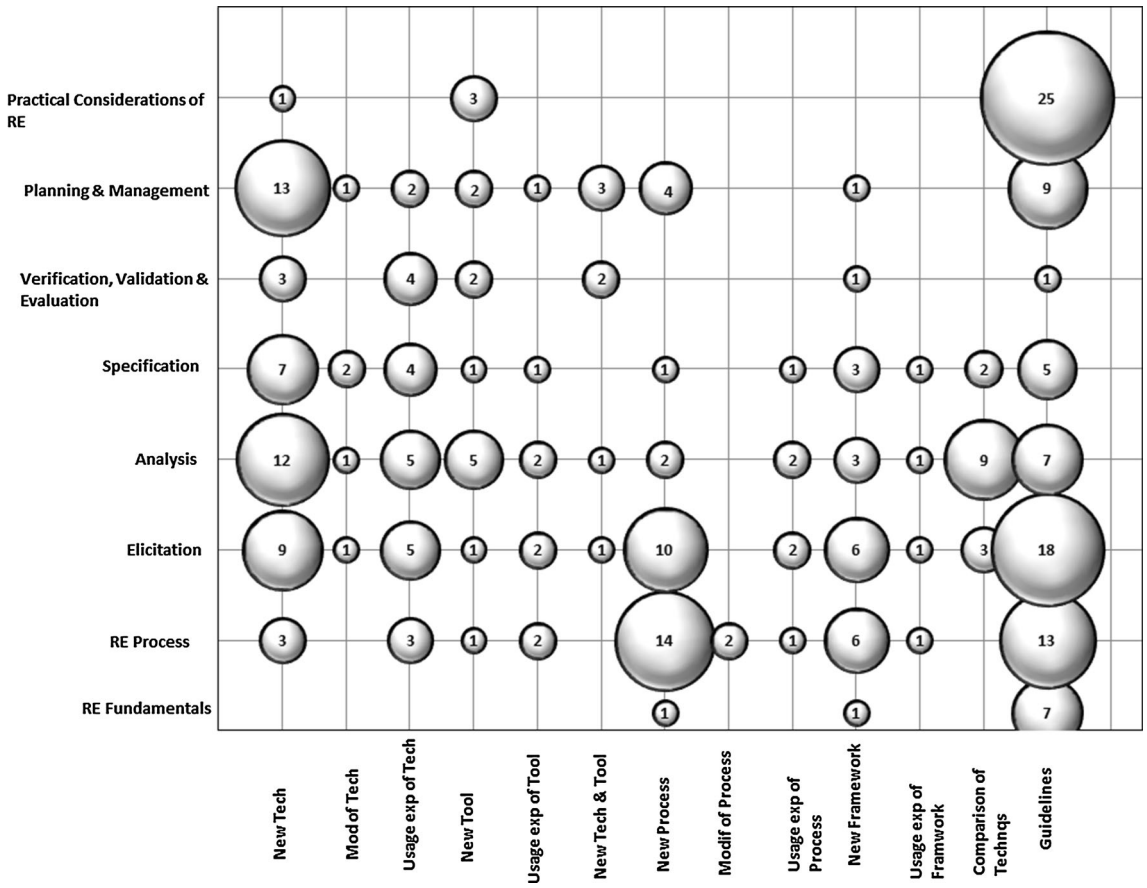

Fig. 13 Research interventions versus RE core areas

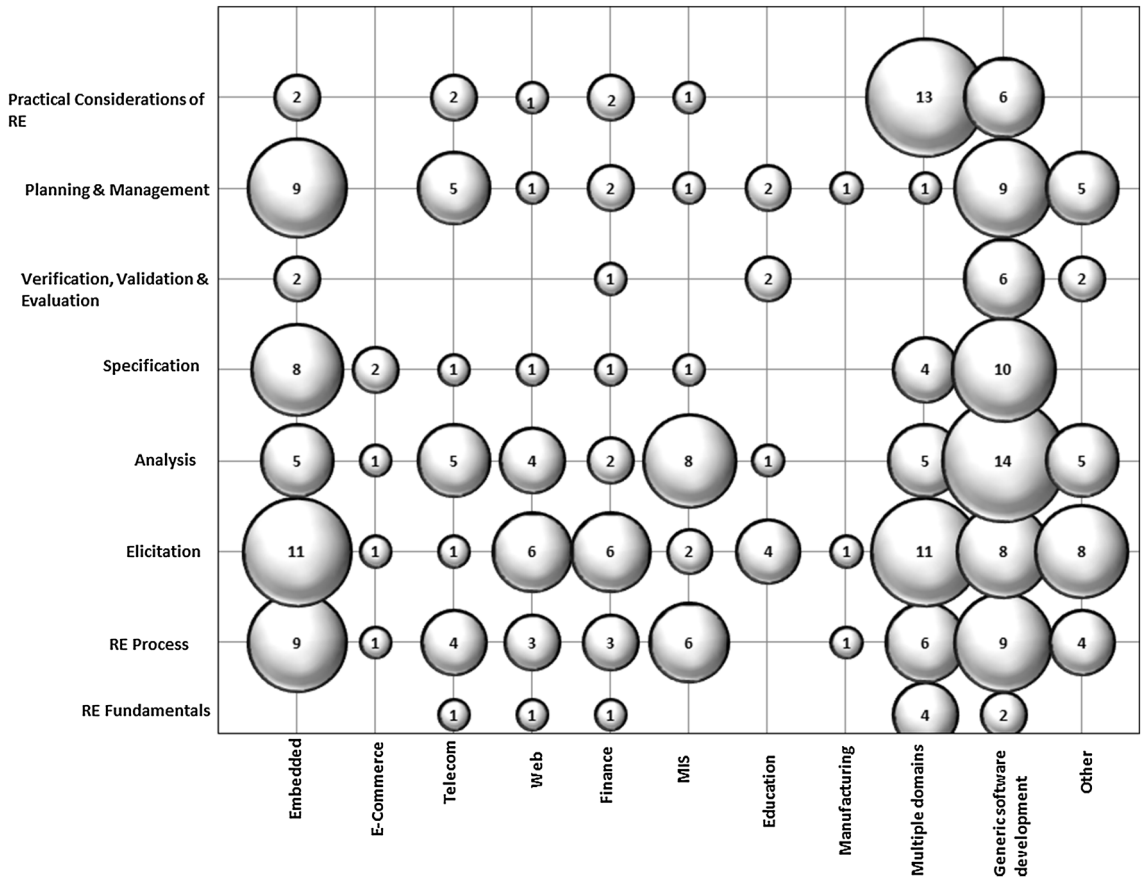

Fig. 14 Domains versus RE area-wise studies

4.2.1 *Which research method is frequently used in primary studies?*

The results show that the half of the primary studies used case study as the research method (see Fig. 16). The experiments have been used in 28 % of primary studies, surveys in 16 % of primary studies, whereas only 6 % of the studies reported the experience reports as an evidence type. It points out the need for more experience reports to let RE researchers and practitioner gain benefit from these experiences. Also, a large number of case studies and experiments offer opportunities for replication of the studies.

We used the quality assessment criteria, given at the Appendix 2, to assess the quality of the primary studies. The quality scores for half of the primary studies using case study was 50 % or less. The quality score for 37 % of the primary studies using the experiment as research method was more than 75 %. Figure 17 shows the research methodology-wise quality scores segments of the primary studies.

4.2.2 *What kind of research participants are frequently involved in primary studies?*

From Fig. 18, it can be seen that 59 % of the studies involved practitioners as subjects, while 27 % of the studies used students as subjects. There are only 4 % of studies where subjects both from industry and academia participated, indicating a collaborative research. The type of subjects of investigation in 10 % of the studies is not mentioned in the primary studies. These results indicate that RE research is more practice-oriented as it involved more practitioners and professionals from the industry.

It is interesting to note that 66 % of studies using case studies as research method have been investigated in an industrial setting, as shown in Table 4. Only 16 % of case studies have been investigated in an academic setting. Similarly, surveys have also been investigated largely in an industrial setting (76 %) and comparatively less in an academic setting (7 %). This trend is reversed for experimentation as 59 % experiments have been investigated

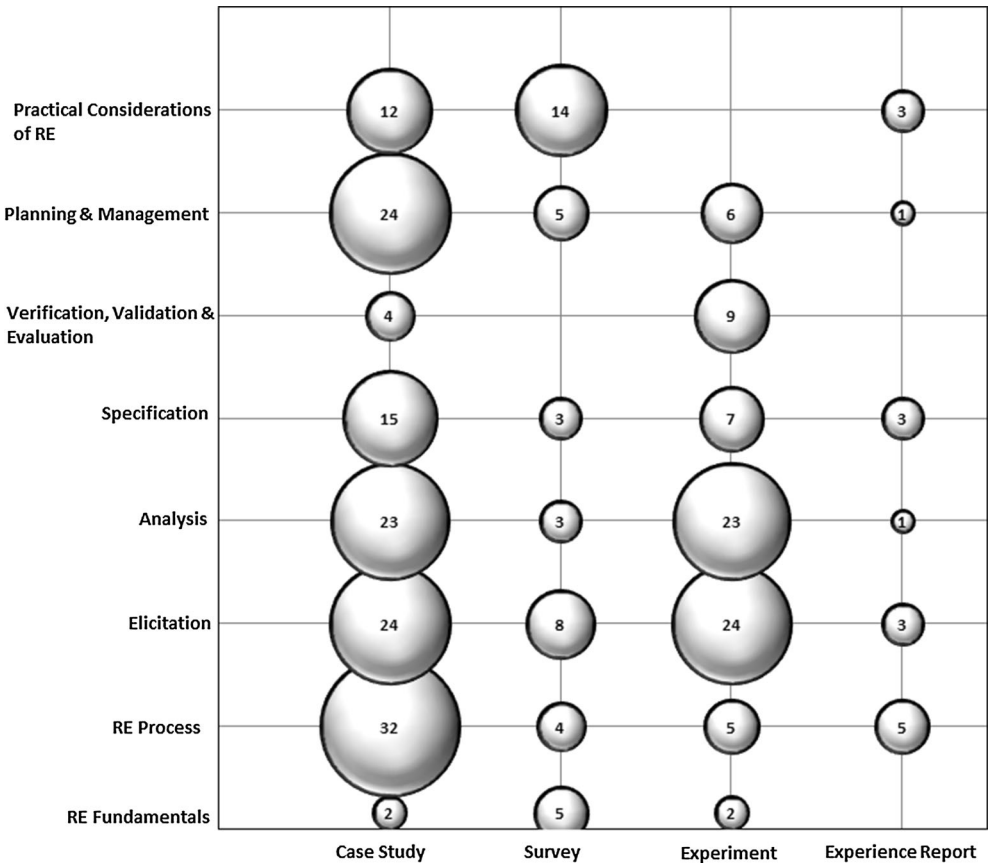

Fig. 15 Research method versus RE area-wise studies

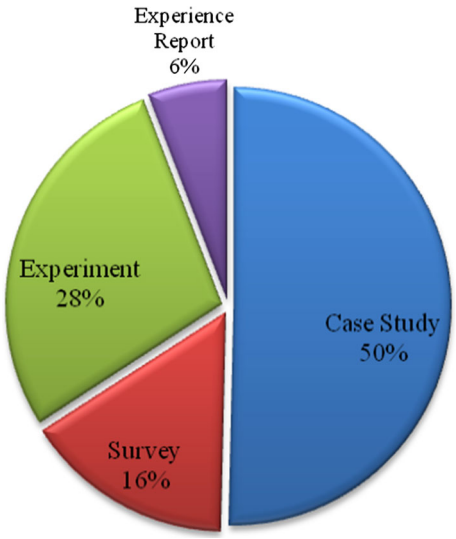

Fig. 16 Types of research methods

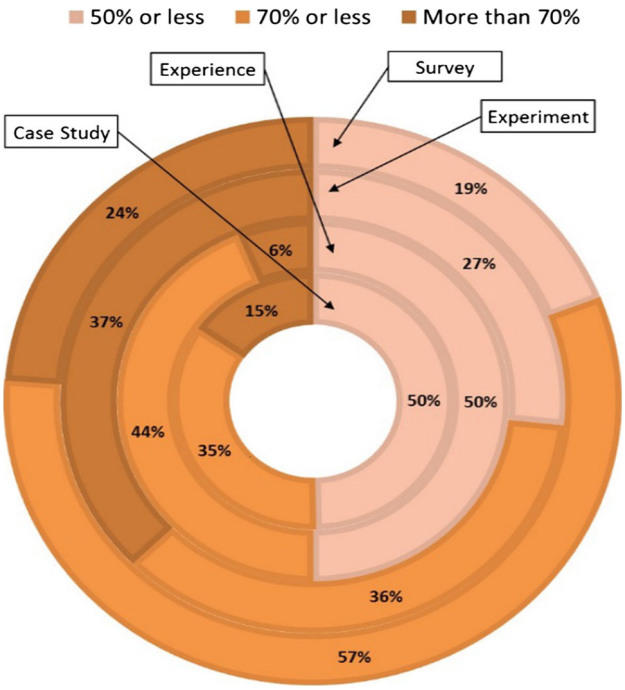

Fig. 17 Quality scores of primary studies (research methods-wise)

using subjects from academia, i.e., students and 32 % from industry. This result may be due to the factors of cost and effort, as it is more expensive and difficult to conduct the

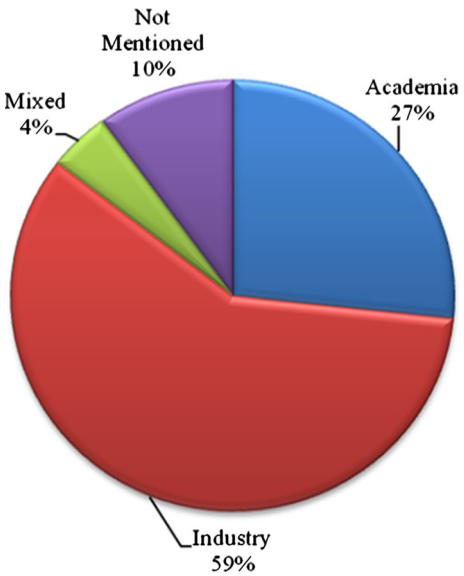

Fig. 18 Subjects of investigation

experiments in the industrial setting. However, the credibility of the results using students as subjects is debatable. We see an opportunity for repeating these experiments using subjects from the industry to improve the credibility of results from these experiments.

4.2.3 Which data collection method is frequently used in investigation of research in primary studies?

Figure 19 shows the frequency of various data collection methods used in the empirical studies of RE. There are four distinct data collection methods that have been used overall during the investigation of the primary studies, including questionnaire, interview, archive analysis and observations. 27 % (74) of studies, however, employed a combination of data collection methods, marked as "Mixed" in Fig. 19. Observation (21 %, 57), questionnaire (17 %, 45), archive analysis (14 %, 39) and interviews (13 %, 36) have also been used frequently in empirical studies. The data collection method of 19 primary studies was not mentioned in primary studies of the SMS.

4.2.4 What is the frequency of various research types of primary studies?

The types of research reported in empirical studies shown in Fig. 20 have been decided by consulting the research types provided in [42]. Validation research type covers empirical studies used to present new research outputs of RE (new techniques, new tools, etc.), "Evaluation" research type has been assigned to empirical studies where usage experience, modification or comparison of existing research outputs of RE has been done, while solution proposal" research type has been assigned to the empirical studies, where some new research output has only been proposed without a full validation. The research type "experience paper" represents all the studies based on experience reports. The "philosophical paper" represents the study where some whole new philosophy has been presented, and there is only one such empirical study that we categorized in this type.

Table 4 % of subjects of investigation in research methods

Type of research method	Subjects of investigation		
Case study	Academia: 16 %	Industry: 66 %	Mixed: 3 %
Experiment	Academia: 59 %	Industry: 32 %	Mixed: 5 %
Survey	Academia: 7 %	Industry: 76 %	Mixed: 7 %

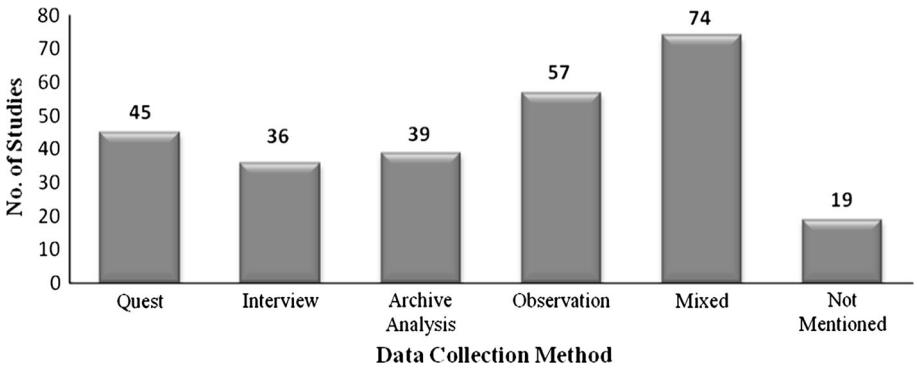

Fig. 19 Data collection methods

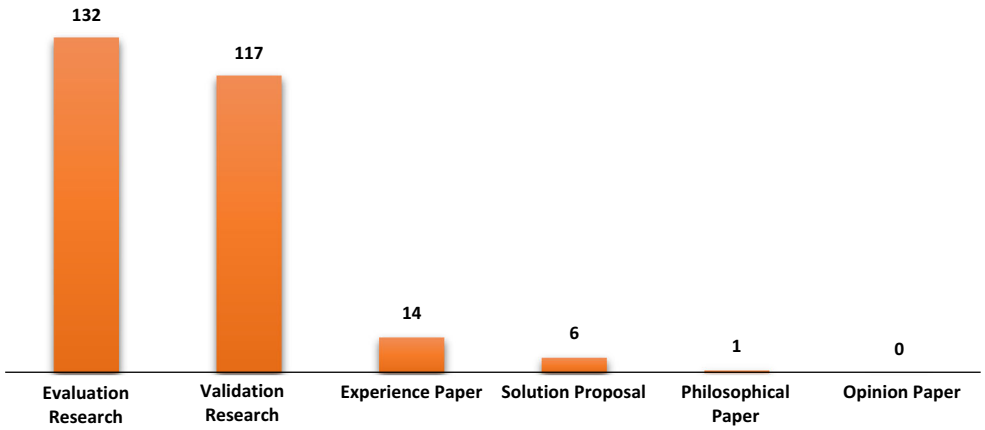

Fig. 20 Types of research in RE studies

From Fig. 20, it can be seen that 49 % (132) of studies belong to evaluation research type, while 43 % (117) deal with validation research. Only a handful of studies are categorized as experience papers and solution proposals. There is only one paper that is of philosophical research type, while opinion papers, understandably, were not represented in our study due to the absence of empirical evidence in them.

4.2.5 How rigorous is the reported research in different RE core areas?

This research question aims to assess the quality of reported research in all RE core areas. Figure 21 presents the classification of primary studies with respect to the quality scores for all RE core areas. The quality assessment instrument presented in Appendix 2 was used to assign a quality score to all the primary studies.

The minimum and maximum quality scores were in the range of 6–26, respectively. We divided the quality score range from 6 to 26 in four groups as depicted in Fig. 21 and assigned all studies to the relevant groups based on their scores. The results show a similar pattern across all core areas, i.e., most of the studies have quality scores falling in two middle groups, i.e., 11–15 and 16–20. "Elicitation" is one core area that has relatively higher percentage of studies in high-quality-score group (21–26), as compared to low-quality-score group (6–10). Other RE core areas, such as RE process, analysis and planning & management, have almost same number of studies both in low-quality-score (6–10) and high-quality-score (21–26) groups. The future studies in these core areas need to properly address questions related to rigor and relevance of the research.

5 Discussion

This section presents discussion on major findings of the mapping study to highlight trends and opportunities for future research.

5.1 Findings for RQ1

The empirical research in RE mainly started in 1990s and is on the rise since the year 2000. This has also been observed in a recent editorial [45]. A number of publication venues emerged during this time line that might have contributed in this trend, e.g., in the year 1991, the systems engineering symposia of the International Council on Systems Engineering (INCOSE) started working, then in 1993, IEEE International Symposium on RE started, later in the year 1994, IEEE International Conference on RE and International Conference on Requirements Engineering: Foundation for Software Quality (REFSQ) started and Springer's Journal for RE started in 1996 [5]. The emergence of evidence-based software engineering (EBSE) paradigm around the year 2004 also resulted in the increased awareness and interest in performing empirical studies in all the fields of software engineering, including RE. The rise in the number of studies after 2005 (see Fig. 2) coincides with the emergence of EBSE paradigm [45]. The emergence of new areas in software engineering, such as global software development or value-based software engineering, also contributed in this rising trend by giving rise to the need for re-investigation of existing RE practices.

Requirements elicitation is the leading empirically researched RE core area, and the interest in investigating it further is still on the rise (see Fig. 6). Does this mean

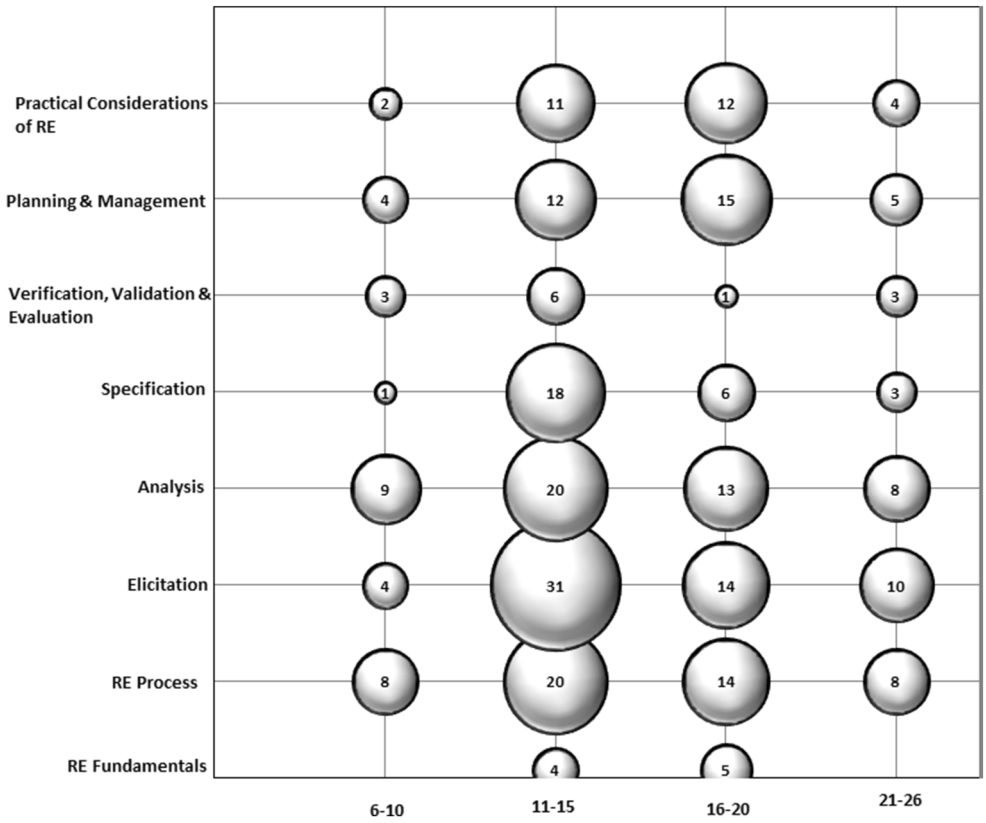

Fig. 21 Quality score versus studies of RE core areas

that we have failed to solve the problems in the requirements elicitation area or we are facing new problems? The later seems plausible as empirical studies in RE have been conducted for a variety of domains (see Fig. 5). The extensive body of knowledge in requirements elicitation needs to be organized in such a way that it is readily available to software practitioners. Requirements analysis, which is very closely linked with elicitation, has also been an active area of research. A large number of studies have also been performed to investigate RE processes. These leading topics have been investigated in variety of domains (see Fig. 6) such as embedded, finance, information systems, etc. Some domains, such as embedded or information systems, have relatively high number of empirical studies. It could be interesting to initiate efforts to organize existing RE knowledge in such domains. What interventions, for instance, have been proposed and evaluated in information systems domain?

The interest in three RE core areas (specification, requirements planning and management, and practical considerations of RE) has gone up since year 2005. Practical considerations of RE covers best practices and patterns of RE, gained mostly through research methods of surveys or experience reports. Researchers and practitioners can gain benefit from these experiences in various small- and medium-sized organizations [46, 47], or companies located in some specific countries such as Australia [48], New Zealand [46], China [49, 50], Malaysia [51] and Europe [52].

The empirical research in the requirement validation and verification (V&V) is little and has a decreasing trend. Validation and verification of requirements helps the development team to check whether systems meet its business objectives and stakeholders' needs, and all the documented requirements have been implemented or not. Given its importance, it is surprising to see lack of interest in V&V area. There is a need to investigate these topic further, in future empirical studies.

Non-functional requirements (NFRs) is most extensively researched emerging area. Table 5 presents various NFRs and corresponding number of empirical studies. We identified, like [45], that security requirements are investigated relatively extensively followed by usability requirements,

Table 5 Research on NFRs

Type of NFR	Frequency
Generic NFRs	6
Security requirements	16
Usability	7
Legal/regulatory requirements	3
Performance requirements	2
Sustainability requirements	2

while other NFRs lack empirical research. The need to investigate security requirements has been stressed elsewhere at [4] as well. However, the researchers need to look into the emerging non-functional requirements such as privacy, and regulatory requirements.

Future research efforts should be directed at other NFRs as well such as performance, sustainability requirements. Other emerging areas, where a reasonable amount of RE research has been published (see Fig. 8), include distributed/global requirements engineering, requirements process improvement and goal-oriented RE. Chang and Atlee [4] highlighted globalization as "RE research hotspots" in 2007, since then number of studies have investigated this topic.

Value-based requirements engineering is also an emerging area. However, it has only seven empirical studies. Other interesting emerging areas, where a relatively small amount of empirical research has been conducted so far, include RE for embedded software (6 studies), agile RE (6 studies), RE and software architecture's relationship (5 studies), and RE patterns and requirements ontology (5 studies). The relatively limited empirical work in these emerging areas so far presents opportunities to explore in future research efforts.

Researchers in recent years have also investigated small- and medium-sized enterprises (SME) from various aspects, as these companies are considerably different to large companies. Following this notion, RE researchers have also investigated SMEs for requirements engineering aspects in recent few years in a small number (5 studies) of empirical studies. Some other topics also emerged in the last 5 years with a very few studies (3 or less than 3) including power and politics in RE, requirements inspection, requirement conflicts resolution and requirements information modeling.

Formal methods in RE and requirements change management are two areas that have been around for quite some time. However, these areas lack empirical research. For requirement change management, an SLR conducted in [53] also pointed out the same notion that there are only a handful empirical studies in this area. For formal methods in RE, we found many studies initially. However, later during data extraction, majority of these studies were excluded due to lack of empirical evidence. We did not select such studies wherein only toy examples, illustrations or scenarios are used as empirical work. The interest in requirements process improvement area has been on the decline after year 2006. It needs to be investigated what does it indicate, saturation and/or maturity of the area.

We identified 43 RE topics investigated in our sample of empirical studies. We have categorized them in three categories in Table 6: core areas, sub-areas and emerging areas. Some of the emerging areas are also highlighted in other works [3, 4].

The main interest in RE research is on proposing new interventions in the form of new guidelines, techniques, processes, frameworks, etc. There are a few studies which evaluate and modify existing interventions. The researchers ought to work and solve problems by "standing on the shoulders of giants." However, we do not see this trend in RE field. The researchers in future, besides proposing new guidelines or techniques, should also focus on validation of existing guidelines and techniques in different contexts, and attempt to build and improve on top of existing work. The interventions that have been evaluated in multiple studies in different contexts would be more acceptable for software practitioners.

5.2 Findings for RQ2

A half of empirical studies included in this mapping study have used case study as a research method. Two-thirds of these case studies are conducted in industrial settings, a good sign of involvement of industry participants. Experiments have been conducted in 28 % of the primary studies and mostly student were used as subjects. Therefore, there is a need for replication of these experiments using industrial subjects to improve the credibility of results.

The researchers also need to replicate case studies to validate the credibility of existing results. The researchers reporting case studies and experiments must provide detailed protocols for their studies enabling other researchers to replicate. The purpose behind such replication is to prove the validity of the results from the original study to a larger population [54]. Various authors have pointed out toward the lack of replication and a need of replication of empirical studies in research [55–57]. The lack of replications might be due to the difficulty inherent in the process of replication of studies, because of the involvement of human subjects [58, 59]. The results of this mappings study identified that case study and experiment are the two main research methods used in empirical RE

Table 6 Topics of empirical research of RE

Core areas	Sub-areas	Emerging areas
Requirements engineering fundamentals	Requirements negotiation	Non-functional requirements
Requirements engineering process	Requirements prioritization	Distributed/global RE
Requirements elicitation	Requirements traceability	RE process improvement
Requirements analysis	Requirements modeling	Goal-oriented RE
Requirements specification	Requirements risk analysis	Requirements change management
Requirements verification, validation and evaluation	Requirements trade-off analysis	Formal methods in RE
Requirements planning and management	Requirements impact analysis	Value-based RE
Practical considerations of requirements engineering	Enterprise analysis	RE for embedded software
		Agile RE
		Relationship of requirements and SA
		RE patterns
		Requirements ontology
		RE for SME
		Power and politics in RE
		RE for scientific computing projects
		Requirements inspection
		Requirement conflicts resolution
		Requirements information modeling
		Requirements communication
		Requirements consolidation
		Creativity in RE
		Decisions in RE
		Requirements' analyst skills
		RE for market-driven Software development
		RE for software product lines
		RE for web application
		User management

research; this provides opportunities to replicate these studies in future.

The use of survey research method is not very popular as only 16 % of primary studies presented surveys. However, there is a need for more surveys to collect best practices and patters of RE from a large population. There is only 6 % of studies reporting experiences of RE practitioners. We need to learn from practice. Therefore, practitioners should be encouraged to share their firsthand experiences by publishing industry reports. An alternative approach for researchers is to work more closely with practitioners, not just to evaluate a proposed invention but also to work together during problem identification and solution design phases [4, 33]. The practitioners may benefit from the catalogue of tools/techniques given at the Appendix 5. We encourage practitioners to uses these tools/techniques and share their usage experiences with the RE community for further improvements.

6 Study limitations

The main limitation of this study is the inaccessibility to the full text of some studies as mentioned earlier. Another limitation of this study is that we could only cover four databases, although we had various other options too, but due to time availability, we could not extend the studies search to other databases.

The decision to categorize various emerging areas was a subjective decision as we have decided it solely on the results presented in the primary studies so that it might be subject to criticism. Moreover, there were a number of overlapping topics of the studies that deal with emerging areas of RE, so we selected the topics on our personal judgment. We faced a critical difficulty during execution of this SMS, when the platform of SpringerLink was under construction for modification, and query results used to be changed so frequently, so we might have missed some

studies during that. The threats to validity of our SMS are as follows:

Construct validity describes the correct operational measures of the concepts that are being studied. The key constructs for our study are the concepts related to "software requirements engineering" and the methodology of "systematic mapping review." For the first construct of software requirements engineering, we tried to find the basic concepts and core areas of RE and tried to compared the related work. For the second construct, i.e., systematic mapping study, we properly followed the guidelines of the SMS to formulate our research questions, search strategy and the protocol of our study. For constructing the search string, we tried to use related terms of the various activities involved in the requirements engineering process to get as many results as possible. For targeting the maximum search results, we covered the four major databases to collect as many publications as possible. But still we could not cover many other databases as Scopus, Compendex, Citeseer, etc. So this can be a possible threat to construct validity in our case.

Internal validity determines a causal relationship, where specific conditions lead to other conditions. Regarding internal validity, the key threats might be the primary studies selection and individuals' bias in their assessment. The sources of studies in our case were conferences, journals and peer-reviewed workshops of requirements engineering. We followed an automated search process by properly formulating search strings according to the rules defined for searching each database to find the relevant studies. During hunting the studies from various databases, we have applied queries on titles and abstracts of the papers only. Therefore, we may have missed the paper if it has not mentioned any of the keywords we used, in its title and abstract, but the probability of this is very low. So this can be a threat to internal validity. The other threat originates from the bias introduced by the individual researchers during assessing their assigned primary studies. We handled this threat by defining a proper protocol, pilot testing of the protocol and then solving the problems and issues collaboratively during each and every step.

External validity is about generalization of the results. It involved the areas and domain to which findings of a study can be generalized. For handling external validity, we did not limit the start of the period to which studies belong, and the ending period was set to be 2012, to get a large number of studies. But as we only selected empirical studies in our mapping study, the studies appeared from 1991 till 2012. Due to the empirical nature of the studies, we did not select many types of studies as theses, technical reports and books, etc. But this cannot be a threat to external validity in our case as the nature of our SMS was purely empirical-based. This is the reason we have rejected so many studies based on toy examples and scenarios in the name of case studies in our SMS. Also, our search strategy was based on an automatic search having defined search strings consisting of many related terms to our topic of SMS, to possibly get a large number of primary studies.

Conclusion validity is about getting the same results in case of replication of a study. To handle conclusion validity, we followed the guidelines [11, 35] to conduct the systematic mapping study, with distinct steps of SMS and proper criteria for searching and data extraction. But as during replication of the study, the choice of databases, search string terms and research questions might vary, so results might differ to some extent, but overall trends should remain same.

7 Conclusion

In this paper, we reported results of a mapping study on empirical research in RE. The mapping study is based on 270 empirical studies from four databases ACM, IEEE, SpringerLink and ScienceDirect till the year 2012. The interest in the empirical research in RE is on the rise after year 2000. Requirements elicitation, analysis and management were identified as leading areas with highest number of empirical studies. Despite being an important topic, requirements verification and validation lacks empirical evidence. Non-functional requirements and global RE were identified as the lead emerging areas of research. Lately, topics such as RE patterns, RE for small and medium enterprises and requirements ontologies have also received some attention.

There is limited interest in evaluating and comparing existing interventions, rather the focus is on proposing new ones. Guidelines and techniques are most frequently proposed types of RE interventions. There is need to replicate studies in different contexts wherein existing RE interventions are evaluated and implemented in practice. Although most of the case studies involve practitioners as participants, there is a need to work more closely with practitioners. Practitioners' involvement should not be limited to their role as subjects, wherein they help researchers in just evaluating a proposed intervention. They should also be involved in problem identification and solution formulation stages. Only 6 % of the studies were identified as experience papers. Software requirements practitioners should be encouraged to share their experiences as experience/industry reports.

Appendix 1: List of existing systematic reviews of RE

This appendix describes a summary of existing systematic reviews of RE. These systematic reviews have been discussed in body section of this paper, but their overall summary in terms of year of publication, number of primary studies included, source of primary studies, the range of databases covered and the nature of the primary studies included in the systematic study (empirical/non-empirical) is listed here, to give an overview to readers through a bird's eye view.

Sr#	Year	Title of systematic study	# of studies	Source of primary studies	Covered till the time	Empirical/ non-empirical
Existing systematic reviews of RE						
1	2006	Effectiveness of Requirements Elicitation Techniques [18]	26	SCOPUS, IEEEXPLORE, ACM DL	March 2005	Empirical
2	2008	Requirements Prioritization Based on Benefit and Cost Prediction [24]	240	ACM Digital Library, Compendex, IEEE Xplore, ISI Web of Science, Kluwer Online Science Direct Elsevier, SpringerLink, Wiley InterScience, and manual search	Feb 2008	Empirical and non-empirical
3	2009	RE in the Development of Multi-Agent Systems [32]	58	ACM DL, IEEExplore, Inspect, and Science Direct	1998 to March 2009	Empirical and non-empirical
4	2009	Software Requirements Specifications Techniques [21]	46	Scopus, IEEE Digital Library, ACM Digital Library, and manual search	1987–2008	Empirical
5	2009	Software Requirement Errors [26]	149	Databases:IEEExplore, INSPEC, ACM Digital Library, SCIRUS (Elsevier), Google Scholar, PsychINFO (EBSCO), Science Citation Index	Not mentioned	Empirical and non-empirical
6	2009	Generation of Requirements Specifications from Software Engineering Models [20]	24	IEEE Digital Library,ACM Digital Library,ScienceDirect, MetaPress (Kluwer + springer), Wiley InterScience, Google scholar	Not mentioned	Empirical
7	2009	Risks in RE Process in Global Software Development [30]	36	IEEE Digital Library,ACM Digital Library Metapress, Google Scholar	2000–2009	Empirical and non-empirical
8	2009	Technology transfer decision support in RE [60]	97	RE Journals in Inspec	Start time: not mentioned end time: June, 2008	Empirical and non-empirical
9	2009	Systematic Review of Requirements Reuse [29]	18	IEEE Xplorer digital library, ACM digital library, Springer Link and Science Direct	2004–2009	Empirical and non-empirical
10	2010	Managing Quality Requirements [53]	18	ACM Digital Library, Compendex and Inspec, IEEE Xplore, Wiley Inter Science Journal Finder	2008	Empirical
11	2010	Requirements Engineering for Software Product Lines [33]	49	ACM Digital Library, IEEE Xplore, Science Direct Elsevier, Wiley Inter Science Journal Finder.	1990–2009	Empirical

Sr#	Year	Title of systematic study	# of studies	Source of primary studies	Covered till the time	Empirical/ non-empirical
12	2011	Elicitation Techniques [17]	26	SCOPUS, IEEEXPLORE, ACM DL databases, as well as Google	Start time: unlimited, ending time: March 2005	Empirical
13	2011	User Requirements Notation [22]	281	IEEE Xplore, ACM Digital Library, Google Scholar, SpringerLink, Scopus	Start time: not specified ending time: 2010	Empirical and non-empirical
14	2012	Stakeholder Identification Methods [19]	47	ACM Digital Library, IEEE Xplore, Springer Verlag, Google Scholar, ScienceDirect, Metapress, Wiley InterScience	1984–2011	Empirical and non-empirical
15	2012	Software Requirements Triage and Selection [28]	23	Scopus, INSPEC, EI Compendex, IEEExplore, ISI web of science	Not mentioned	Empirical and non-empirical
16	2012	Requirements Evolution [23]	125	ACM Digital Library, IEEE Xplore, Science Direct, Springerlink, InterScience	1994–2009	Not mentioned
17	2012	DRE-Specific Wikis for Distributed RE [31]	27	ACM portal, Elsevier'sScience Direct, IEEE Xplore, Springer-Verlag's Link;	Start time: unlimited, ending time: 2011	Empirical
18	2012	Causes of Requirement Change [27]	5	Springer link, IEEE Explore, ACM Digital library, Cite Seer library, Science Direct, EI Compendex	December 2008 to March 2009	Empirical
19	2012	Creativity Techniques for Requirements Engineering [61]	25	IEEE Xplore, ACM, Compendex, Inspec, Springerlink, Science Direct	Start time: not mentioned ending time: 2011	Empirical and non-empirical

Appendix 2: Quality assessment checklist

This appendix describes the quality instrument that we used to access the quality of studies. It consisted of 5 sections, a section having general checklist items which was applied to all the studies included in the SMS, while other 4 sections were decided specifically for various research methods used in the study, i.e., experiment, survey, case study and experience report. These criteria were adopted from SLR guidelines [13, 36–39]. The questions included in the checklist were answered either "yes," "no" or "partial" and were given rates as 2, 1 or 0, respectively. The sum of the scores for all of these questions was used for assessing the quality of a primary study.

Quality assessment checklist	
Generic	
Are the aims clearly stated?	Yes/no
Are the study participants or observational units adequately described?	Yes/no/partial
Was the study design appropriate with respect to research aim?	Yes/no/partial
Are the data collection methods adequately described?	Yes/no/partial
Are the statistical methods justified by the author?	Yes/no
Is the statistical methods used to analyze the data properly described and referenced?	Yes/no
Are negative findings presented?	Yes/no/partial
Are all the study questions answered?	Yes/no
Do the researchers explain future implications?	Yes/no
Survey	
Was the denominator (i.e., the population size) reported?	Yes/no
Did the author justified sample size?	Yes/no
Is the sample representative of the population to which the results will generalize?	Yes/no
Have "drop outs" introduced biasness on result limitation?	Yes/no/not applicable

Quality assessment checklist	
Experiment	
Were treatments randomly allocated?	Yes/no
If there is a control group, are participants similar to the treatment group participants in terms of variables that may affect study outcomes?	Yes/no
Could lack of blinding introduce bias?	Yes/no
Are the variables used in the study adequately measured (i.e., are the variables likely to be valid and reliable)?	Yes/no
Case study	Yes/no
Is case study context defined?	Yes/no
Are sufficient raw data presented to provide understanding of the case?	Yes/no
Is the case study based on theory and linked to existing literature?	Yes/no
Are ethical issues addressed properly (personal intentions, integrity issues, consent, review board approval)?	Yes/no
Is a clear chain of evidence established from observations to conclusions?	Yes/no/partial
Experience report	
Is the focus of study reported?	Yes/no
Does the author report personal observation?	Yes/no
Is there a link between data, interpretation and conclusion?	Yes/no/partial
Does the study report multiple experiences?	Yes/no

Appendix 3: Data extraction scheme

This appendix enlists the data extraction items that have been extracted from the primary studies of the SMS. The RE core/main areas and sub-areas in this data extraction scheme were decided by consulting *SWEBOK* [40] and *REBOK* [41], while the type of research in this data extraction scheme was formulated according to the research types provided in [42]. The rest of the items were extracted to carry out a rich analysis and present various themes and trends as advised in [35].

Data extraction items			
1. Study ID	2. Reference type	3. Conference/ Journal	4. Title
5. Authors	6. Publication year	7. Countries involved in research	
8. Conference/Journal name	9. Aim of study	10. Results of study	
11. RE Core Area (RE Fundamentals/RE Process/Reqs Elicitation/Reqs Analysis/Reqs Specification/Reqs Validation, Verification & Evaluation/Reqs Planning & Management/ Reqs Practical Consideration)			
12. RE Sub Area (Reqs Modeling/Enterprise Analysis/Product Analysis/Reqs Prioritization/ Reqs Tradeoff Analysis/Reqs Impact Analysis/Reqs Risk Analysis/Reqs Traceability)			
13. RE Emerging Trends			
14. Technique/Process/Tool/Framework Name			
15. Research Output (New Technique/Tool/Process/Framework, Modification of Technique/ Tool/Process/Framework, Usage experience of Technique/Tool/Process/Framework, Guidelines, Other)			
16. Company Size (Small/Large/Medium/Mixed)	17. Name of Company		
18. Industry/Domain(Telecom/Web/Finance/Automation/Automotive/Medical/Manufacturing/ Governoment/Ecommerce/Education/Generic Software Development)			
19. Type of Evidence (Experiment/Case Study/Survey/Experience Report)			
20. Data Collection Method (Questionnaire/Interview/Archive Analysis/Observation/Mixed)			
21. Type of Research (Evaluation Research/Validation Research/Solution Proposal/ Philosophical Paper/Opinion Paper/Experience Paper)			
22. Subjects of Investigation(Academia/Industry/Mixed)			

Appendix 4: Domains of empirical studies of RE

This appendix describes various domains to which empirical studies of RE belong, along with frequency and percentage of studies for each domain. Some studies belong to software development generally, without mentioning of some specific domain in them, so we have categorized such studies under "generic software development" domain. The studies dealing with the domains of avionics, medical, automotive, electronics and control systems have been categorized under the category of "embedded" domain. Some studies belonged to more than one domain, so we categorized such studies under "multiple" domain category.

Domains	Frequency of studies	Percentage
Domains of empirical studies		
Generic software development	64	24
Multiple domain	44	16
Embedded	35	13
Telecom	19	7
Management information systems	19	7
Finance	18	7
Web	17	6
Education	9	3
E commerce	5	2
Manufacturing	3	1
Other	37	14

Appendix 5: Research interventions in empirical studies of RE

This appendix describes various interventions reported in empirical RE research. The type of these interventions has already been discussed in body section of this paper. These interventions in this appendix have been provided per each core area of RE, to let practitioners get a handful of these empirically evaluated interventions while practicing some activities from the RE process. The organization of interventions this way can also be helpful for the RE researchers to get a collection of various existing empirically evaluated interventions in case they are attempting to develop new interventions of RE or want to modify/replicate existing interventions. The research output "guidelines" is missing in this appendix, as guidelines cannot be summarized like this; also we left this part for the future work.

Research interventions in empirical studies of RE	
Requirements elicitation	
New technique	ROADMAP
	QRF (Quality requirements of a software Family)
	Structured digital storytelling
	CREE
	StakeRare
	Agent-based goal elicitation (ATABGE)
	Interview-driven requirements elicitation
	Scenario weaving
	ORE (Ontology-based requirements elicitation)
	Confidentiality requirements elicitation and engineering
New tool	Gaius T
New process	Display-Action-Response Model
	IRIS (Integrating Requirements and Information Security)
	Enterprise Analyzer
	UEProject (Usability Evaluation Project)
	Domain-specific requirements model for scientific computing
	CelLEST
	Cognitive-Driven Requirements Prioritization Process
	Cognitive Psychology Approach for Balancing Elicitation Goals
	SQUARE (Security Quality Requirements Engineering)
	Model describing the relationships between
	Threats, security requirement types and related IT infrastructure components
New framework	RE-GSD (Requirement Elicitation for Global Software Development projects)
	A framework to support alignment of secure software engineering with legal regulations
	RE-GSD
	Strategy-based process for requirements elicitation
	Non Functional Model
	A framework of analysis of group performance in synchronous text-based distributed requirements elicitations and negotiations.
Modification of technique	EasyWinWin modified to WikiWinWin
Usage experience of technique	Group story telling
	Prospect theory
	Scenarios
	Appreciative Inquiry
	Scenario Acting
Usage experience of tool	Cerno
	REE(Requirements Engineering Environment)
Usage experience of process	GORE(Goal Oriented Requirements Engineering)
	SREP(security requirements engineering process)
Usage experience of framework	Nomos
New tech &tool	OREW (domain Ontology Reconstruction Environment by Web search)
Comparison of techniques	Attack trees & Misuse cases
	Full EPMcreate & Power-Only EPMcreate
	Optimization of full EPMcreate &Traditional Brainstorming

Research interventions in empirical studies of RE	
Requirements analysis	
New technique	Human facilitation in computer-mediated requirements meetings
	SIREN (SImple REuse of software requirements)
	heuristic decision making algorithm
	Automated similarity analysis
	μ-Strategy
	Lightweight Semantic Processing
	SBSE (Search-Based Software Engineering)
	Business process modeling method
	Fuzzy QFD (fuzzy quality function deployment)
	RA (Relationship Analysis)
	Security Requirements Analysis and Secure Design Using Patterns and UMLsec
	Scenario transformation method
New tool	IntelliReq
	JSPWikiWinWin
	useystem case retrieval system
	RE Context
	requirements analysis supporting system
New process	Distributed Prioritization Process
	NFR Evaluation Model
New framework	VOP (Value-oriented Prioritization)
	Goals-Skills-Preferences Framework
	Staged Modelling Methodology
Modification of technique	Use Case
Usage experience of technique	Scenarios
	AHP for requirements prioritization
	WinWin
	Prototyping
	Heuristic Critiques
Usage experience of tool	QuARS
	QARCC-1
Usage experience of process	SFMEA(Software Failure Modes and Effects Analysis)
	RAM(Requirements Abstraction Model)
Usage experience of framework	i* Modelling Framework
New tech &tool	Automated requirements classification technique
Comparison of techniques	Use Cases & Tropos
	F2F communication & COFFEE & Second Life
	Lexical similarity & Searching and filtering
	Single-Objective GA & FOOM & OPM (Object-Processes Methodology)
	UML Use Case (UC) model & OODFD Transaction
	Analytic Hierarchy Process method (AHP) & Case-Based Ranking method (CBRank)
	Non-dominated Sorting Genetic Algorithm-II (NSGA-II) & Pareto GA
Comparison of tools	ARENA II(Anytime, Anyplace REquirements Negotiation Aids) & ARENA-M ((Anytime, Anyplace REquirements Negotiation Assistant – Mobile)

Research interventions in empirical studies of RE	
Requirements specification	
New technique	Clone Detection
	SCR(software cost reduction)
	Structuring specification documents by using temporally adjacent topics
	High-level requirements engineering methodology for electronic system-level design
	Information model approach
	CSRML (Collaborative Systems Requirements Modelling Language)
	SOFL(Structured-Object-based-Formal Language)
New tool	LAMPS(Learning Action Model from Plan Samples)
New process	AutoRELAX
New framework	PDS(Problem Decomposition Scheme)
	DAM(domain analysis methodology)
	Theoretical Framework of Requirements Documentation Styles
Modification of technique	TORE(Task and Object Oriented Requirements Engineering)
	Use case
	Z Language
Usage experience of technique	OCL (Object Constraint Language)
	GQM (Goal-Question-Metric)
	FRORL (Frame-and-Rule Oriented Requirements specification Language)
Usage experience of tool	SeCSE's Service Discovery Environment
Usage experience of process	Performance Refinement and Evolution Model
Usage experience of framework	AUTOSAR
Comparison of techniques	Use case & textual Approach
	F2F communication & Think-Pair-Square
Requirements verification, validation and evaluation	
New technique	SQ2E (Scenario Question Query Engine)
	Requirement Error Taxonomy
	ALIGNMENT OF ONTOLOGY AND MODELS
New tool	SRA (System Reliability Analyser)
	MEG
New framework and tool	GRIP (Groupware-supported Inspection Process)
Usage experience of technique	UML Diagrams
	CBR(checklist-based reading) and SBR (scenario-based reading)
	Symbolic Model Checking
	Perspective-Based Reading (PBR)
New tech &tool	CREWSAVRE (Scenarios for Acquisition and Validation of Requirements)
	I VT (Input Validation Testing)
	MICASA (Method for Input Cases and Static Analysis)

Research interventions in empirical studies of RE	
Requirements planning and management	
New technique	ARMOR
	Extended Traceability
	RC Cost Pre-evaluation
	Owner ship based user group model
	Automatically Structuring Textual Requirement Scenarios
	Traceability-Based Notification Strategy
	UMGAR (UML Model Generator from analysis of Requirements)
	Rule-based generation of requirements traceability relations
	PiLGRIM (Propagating i*-Led Goal-Requirement Impacts)
	FoCM (Feature-oriented requirements Change management Method)
	Value-based analysis method for variability evolution
	Business Process-driven Approach for Requirements Dependency Analysis
New tool	RM-Tool
	SPMS(Software Project Management Simulator)
New process	VRRM(Value-Based Requirements' Risk Management)
	VBRT (Value-based Requirements Tracing)
	ReChaP (Requirement Change Propagation)
	Requirements change management for implementing a CMMI level 2 specific practice
New framework	iMORE (information Modeling in Requirements Engineering)
Modification of technique	PLUSS (product line use case modeling for systems and software engineering)
Usage experience of technique	PREM (Performance Refinement and Evolution Model)
	FPA(Function Point Analysis)
Usage experience of tool	ReqSimile
New technique &tool	ILRE (Indirect Traceability Link Recovery Engine)
	ReqAnalyst
Requirements engineering process	
New technique	DWARF(data warehouse requirements definition method)
	Customer-Centered ERP Implementation (C-CEI) method
	RPMAI (Requirements process maturity assessment instrument)
New tool	RQM (Requirements Quality Model)
New process	Requirements Capability Maturity Model (R-CMM)
	VIRE (Value-Innovative Requirements Engineering)
	User-centered requirements engineering
	RE process for Web Service project
	domain requirements development process
	Evolutionary model of RE
	RDMod (Requirements data model)
	SREP (Security Requirements Engineering Process)
	SecuRUP(security requirements engineering conformed to RUP)
	RE process model for projects in emerging markets
	SREPPLine (Security Requirements Engineering Process for software Product Lines)
	Requirements Engineering using Prototyping Projects in Healthcare Diagnostic Software Application

Research interventions in empirical studies of RE	
New framework	Organization modeling-based requirements engineering framework
	Software requirements management (Quality Function Deployment) framework based on QFD
	REPI (Requirements Engineering Process Improvement)
	IterativeC-K requirements engineering process
	FRERE (Framework for requirements engineering process development)
	REF (Requirements engineering framework)
	Iterative requirements engineering process using FCA(Formal concept Analysis)
Modification of process	XP requirements process
	Praxis
Usage experience of Technique	Gilb Style
	SQUARE (Security Quality Requirements Engineering)
	VORD (The Viewpoint-Oriented Requirements Definition method)
Usage experience of tool	PVCS
	Wikis
Usage experience of process	Requirements Process Maturity Model
Usage experience of framework	TORE (task-oriented requirements engineering framework)
Requirements practical considerations	
New technique	Gilb Style
New tool	BBN-based expert system
	Requirements Quality Model
	KASRET (Knowledge-based Approach for the Selection of Requirements Engineering Techniques)
Requirements engineering fundamentals	
New process	Ontology for Requirements Engineering
New framework	Framework of Power & Politics in RE

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