A Review of Traceability Research at the Requirements Engineering Conference[RE@21]

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***Abstract*—Traceability between development artefacts and mainly from and to requirements plays a major role in system lifecycle, supporting activities such as system validation, change impact analysis, and regulation compliance. Many researchers have been working on this topic and have published their work throughout the editions of the Requirements Engineering Conference. This paper aims to analyse the research on traceability published in the past 20 years of this conference and to provide insights into its contribution to the traceability area. We have selected and reviewed 70 papers in the proceedings of the conference and summarised several aspects of traceability that have been addressed and by whom. The paper also discusses the evolution of the topic at the conference, compares the results with those reported in other publications, and proposes aspects on which further research should be conducted.**

***Index Terms*—Traceability, artefact, artefact relationship, tool support, empirical validation, RE@21.**

I. Introduction

Traceability can be defined as the degree to which a relationship can be established between two or more products of the development process (aka artefacts), especially products having a predecessor-successor or master-subordinate relationship to one another [11]. Tracing in system development can be targeted at different aspects [24][26], such as system verification and validation (V&V), change management, and regulatory compliance. The importance of traceability has been widely recognised, and it is a practice prescribed in many development standards [4].

Traceability research has greatly focused on requirements traceability, aiming at studying how to describe and follow the life of a requirement, in both forward and backward directions [PS21]. Many researchers have contributed to the area for the last two decades [26][27][PS25], providing solutions in the form of methods, tools, and a better understanding of traceability needs and challenges. Traceability has been an important topic at the Requirements Engineering (RE) conference since its inception.

The purpose of this paper is to provide insights into traceability research at the RE conference and how it has contributed to the area. To this end, we performed a review on the traceability literature published during the past 20 years in the proceedings of the main conference.

From a set of 70 papers, we have determined (1) the traceability topics studied, (2) the challenges addressed, (3) the contributions made, (4) the tools features developed to support traceability, (5) the types of systems considered, (6) the types of artefacts traced, (7) the empirical methods used for evaluation, and (8) the researchers and institutions that have led research production. This information has also allowed us to analyse how traceability research has evolved and progressed throughout the conference editions.

Related work mainly corresponds to other secondary studies on traceability (i.e., studies that have reviewed others in depth [14], such as [27]) and papers discussing challenges for traceability (e.g., [PS25]). What differentiates this paper is its focus on the RE conference. To our knowledge, it is also the most recent literature review on traceability, and the one with the highest number of primary studies. Consequently, we consider that the results presented correspond to the widest and most accurate analysis of traceability research that has been provided up to date.

As shown below, we have used related work as input for discussion in relation to (1) comparison of the research at the RE conference with that conducted in general within the area of traceability, and (2) determination of challenges that have not been addressed yet. This analysis has allowed us to argue why and how traceability research at the RE conference has contributed to the progress of the area, as well as what aspects should be studied in the future.

The rest of the paper is organized as follows. Section II describes the research method applied. Section III shows the results from the review, whereas Section IV discusses them. Finally, Section V presents our conclusions.

II. Research Method

The following subsections present the research questions formulated and outline the research process for our study.

A. Research Questions

Our overall goal is to evaluate how traceability research at the RE conference has contributed to the area. We formulate the following research questions (RQs).

RQ1) What topics within the traceability area have been studied?

RQ2) What specific challenges have been addressed?

RQ3) What contributions have been made to address the challenges?

RQ4) What tool features have been developed to support traceability?
RQ5) What types of systems have been considered?
RQ6) What types of artefacts have been traced?
RQ7) What empirical methods have been applied?
RQ8) What authors and institutions have conducted the research?

These or similar RQs have been studied in other related secondary studies. This enables to compare their results with this literature review, and to analyse and discuss how papers at the RE conference have contributed to the traceability area.

B. Publication Selection, Data Extraction and Synthesis

We closely followed the guidelines presented in [14] for literature reviews. We performed an automatic search of the proceedings of the RE main conference (ieeexplore.ieee.org), searching for paper that contained the word "traceability" in the title, abstract, or keywords. We found 76 papers.

A data extraction template was created in a spreadsheet with respect to the RQs formulated. Apart from the bibliographic information (title, authors, and year), we extracted data related to the RQs from each study. For example, we extracted the authors' institutions for RQ8.

The papers were then reviewed, dividing the workload among the three authors. Since the aim of our review was to evaluate how the publications had contributed to traceability research, we decided to exclude the papers for which we could not answer RQ3. We performed reviews concurrently, and had to meet several times to discuss and agree upon possible exclusions. Six papers were finally excluded, and we obtained a final set of 70 primary studies (i.e., the studies reviewed in a secondary study [14]; PS).

Once all the authors finished their review, we revised the data extracted by each author in order to harmonize details. We defined categories for RQs1-6 (see Section III) and grouped the PSs according to them. Some PSs addressed more than one aspect for some RQs. The authors discussed and agreed upon the categorisation to avoid conflicts. Full details about the data extracted can be found in [18].

In relation to the limitations of our review process, we might have missed some papers and thus some contribution to traceability. However, we consider this to be unlikely as the search term "traceability" is broad to include all the possible relevant studies. We also believe that this was a suitable criterion, and think that the relevant RE papers must include the term in some of the fields for the search.

Identifying the empirical method used in some papers was difficult because of the lack of details about the validation. Different authors can also have a different understanding about, for instance, what a case study is. We mitigated this threat by agreeing upon the definition of the empirical methods to distinguish (see Section III.G).

Finally, it is always possible to miss some information in the papers reviewed, especially for novices in literature reviews or in the area under study. In our case, the first two authors have experience in systematic literature reviews [19], and the three authors have researched on RE and traceability.

III. RESULTS

This section presents the results of the review. We provide only an overview due to page limitations. All the papers matching each aspect analysed cannot be referred to for the same reason. Nonetheless, examples are provided. More details about each PS can be found in [18].

A. RQ1: Traceability Topics Studied

We analysed the various overall topics researched in the conference within the theme of traceability and classified them into 10 groups (Fig. 1). Some papers noted more than one group. The groups are as follows.

Post-requirement traceability (50% of the papers): tracking of requirements from their specification through their lifecycle (e.g., for V&V purposes [PS28]).

Traceability automation (18.6%): automated traceability activities such as trace creation (e.g., [PS44]).

Pre-requirement traceability (17.1%): tracking of requirements from their specification to their origin (e.g., to the human source [PS23][PS61]).

Traceability in practice (12.9%): traceability management in real industrial settings (e.g., a company's approach for traceability [PS47]).

Change management (12.9%): management of artefact changes and their traces, and impact analysis (e.g., [PS66]).

Model traceability (11.4%): traces in and between models (e.g., between requirements models [PS20][PS57]).

Regulatory compliance (5.7%): traceability for demonstrating compliance with some regulation (e.g., with RTCA DO-178B [PS53]).

New approaches for maintaining traceability (4.3%): proposal of new approaches for recording traceability (e.g., through video recordings [PS63]).

Trade-off analysis (2.9%): traceability management during and for decision-making (e.g., [PS9]).

Traceability in new development contexts (1.4%): e.g., for chemical engineering in the automotive industry [PS32].

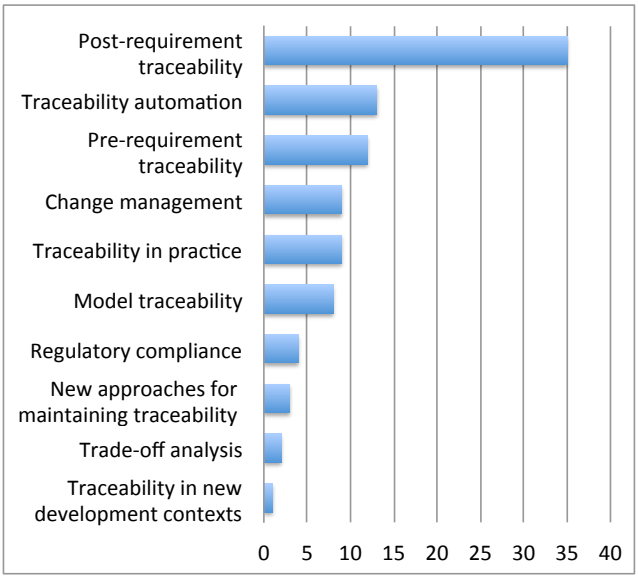

Fig. 1. Number of papers that have studied each topic

B. RQ2: Traceability Challenges Addressed

We identified eight types of challenges and needs specific to one or more topics from RQ1 (Fig. 2). Some papers did not address any specific challenges. We classified the challenges as follows.

Lack of knowledge and understanding about traceability (17.1% of the papers): the general lack of sufficient knowledge when dealing with traceability both in practice and research (e.g., [PS2]).

Maintaining traceability when requirements evolve (12.9%): the challenge of maintaining traceability for evolving requirements (e.g., [PS45][PS6]).

Showing satisfaction of requirements (12.9%): the need for assessing if requirements are met in successor artefacts such as a design specification (e.g., [PS9]).

Impact of human factors and judgment (8.6%): the challenges faced when incorporating human judgment for traceability, and related factors (e.g., [PS13]).

Reducing the cost related to requirements traceability (8.6%): the challenge of cost-effectively maintaining traceability among, from, or to requirements (e.g., [PS35]).

Effective representation of traceability information (8.6%): the need for presenting the traceability information in a clear and concise fashion (e.g., [PS57]).

Challenges in practice (5.7%): the various problems that practitioners face in industrial project settings (e.g., [PS4]).

Assessing the traceability maintained (1.4%): the importance of evaluating the traces captured (e.g., [PS14]).

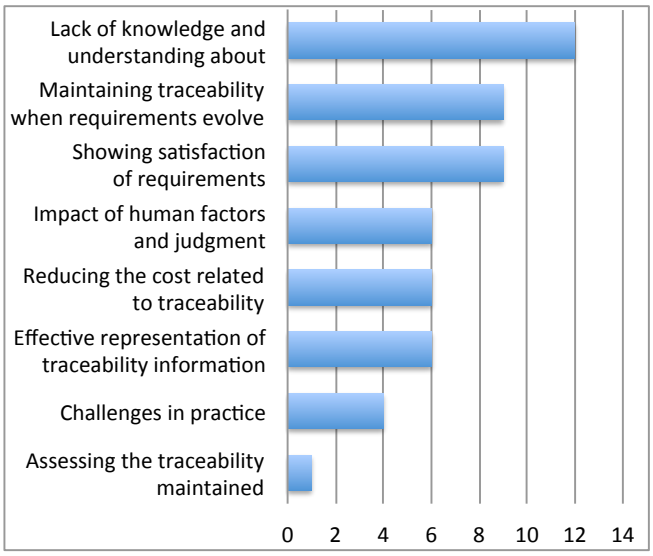

Fig. 2. Number of papers that have addressed each challenge

C. RQ3: Contributions to Traceability

We classified the contributions made by the papers to address the challenges identified in RQ2 into three broad categories. Some papers made more than one contribution.

Technical contributions (50% of the papers): provision of solutions by means of technical approaches or methodologies with tool support (e.g., a tool with explicit user defined links through the use of a matrix [PS9] or a web-based tool [PS59]).

Methodological contributions (31.4%): provision of solutions by means of new methods and approaches without tool support (e.g., a traceability information model [PS37] or traceability means for aspect-oriented requirements [PS70]).

Insights into practice and experience reports (21.4%): provision of details about real world traceability (e.g., a case study about the traceability practices in a company [PS33]).

It must be noted that, from a general perspective, the contributions made map to the challenges addressed (RQ2) and the tool features developed (RQ4).

D. RQ4: Tool Features for Traceability

Some traceability tool was presented in 35 papers. We extracted their key features and categorised them. The percentage of the features is the ratio in these 35 papers. Some tools provided several features.

Traces lifecycle (34.3%): features for creating, maintaining, and updating traces between various artefacts (e.g., Ecolabor is a tool for using hypermedia to maintain traceability between different artefacts [PS63]).

Maintaining traceability between artefacts specific to requirements specification (28.5%): features for maintaining traces between requirements and managing them (e.g., TOOR is a tool for recording traces between requirements [PS48]).

Automated traceability (20%): features for creating and maintaining traceability information (semi) automatically (e.g., Poirot [PS38] implements a probabilistic approach to dynamically generate traceability links; work is still being performed for its extension and improvement [PS40]).

Change management (11.4%): features for managing and updating changes in artefacts and hence their traceability information (e.g., a tool that extends on DOORS for change management [PS36]).

Requirements validation with traceability support (8.6%): features for assessing and validating requirements with other artefacts and hence maintaining their traces (e.g., RESAT [PS30] allows users to automatically assess if a design description meets its requirements).

Model management with traceability support (8.6%): features for creating and maintaining traces between and in models used in the development process (e.g., a tool for model merging and verification [PS55]).

Support for regulatory compliance (2.9%): features for maintaining traceability towards compliance purposes (e.g., for compliance with DOD-STD-2176A [PS58]).

Project management (2.9%): features for controlling and monitoring a project (e.g., charts generation [PS52]).

Traceability visualization (2.9%): features for visualizing the traces maintained between artefacts (e.g., CREWS-EVE [PS26] offers multimedia support and animation to visualize traceability to test cases).

E. RQ5: Types of Systems Subject to Traceability

Out of 70 papers, 27 (38.7%) did not mention any specific type of system. For the rest, these types were distinguished.

Information systems (32.9% of the papers; e.g., [PS37]), which store, process, and show data for their users.

Safety-critical systems (17.1%; e.g., [PS53]), whose failure may cause harm to people or to the environment.

Real-time embedded system (7.1%; e.g., [PS51]), which are subject to real-time constraints.

Non-software system (4.2%; e.g., [PS32]), such as the physical documents managed in an organization.

F. RQ6: Types of Artefacts Traced

For analysis of the types of artefacts traced, we extracted information about the source and target of a trace.

Traces between requirements specification artefacts (60% of the papers): high-level and low-level requirements (24.3%; e.g., [PS1][PS24][PS56]), requirements and source (17.1%; e.g., [PS49][PS68]), requirements and rationale (8.6%; e.g.; [PS12][PS65]), requirements versions (7.1%; e.g., [PS58]) requirements and person responsible (5.7%, e.g., [PS11][PS31]), requirements and creator (4.3%; e.g., [PS22]), requirements and contributor (4.3%; e.g., [PS54]), non-functional and functional requirements (2.9%; e.g., [PS8]), and requirements and conflicts (1.4%; [PS33]).

Traces between requirements specification artefacts and other types of artefacts (58.6%): design (27.1%; e.g., [PS19][PS39]), testing artefacts (27.1%; e.g., [PS3][PS5]), code (25.7%; e.g., [PS41][PS69]), development standards (4.3%; e.g., [PS29]), formal verification (2.9%; e.g., [PS55]), and testers (1.4%; [PS64]).

Traces between other types of artefacts (14.3%): design and code (5.7%; e.g., [PS10][PS27]), design and testing (2.9%; e.g., [PS43]), design components (1.4%; [PS51]), design and responsible (1.4%; [PS51]), design and creator (1.4%; [PS48]), design and development standard (1.4%; [PS2]), testing and development standard (1.4%; [PS2]), and code and development standard (1.4%; [PS2]).

As shown above, the most frequent traces are between requirements and testing, requirements and design, requirements and code, high-level and low-level requirements, and requirements and source. This is in line with RQ1, which shows that post-requirements traceability has been the most frequently studied topic.

G. RQ7: Empirical Methods

The methods considered are: experiment (validation based on different treatments applied to or by different subjects); survey (validation based on practitioners' opinion and perspectives); field study (validation with data from real projects, but not during the execution of the project); case study (validation in real projects by practitioners different to the authors), and; action research (validation in real projects by the authors themselves).

Some empirical method for evaluation has been used in 48 papers (68.6%). As show in Fig. 3, the most frequent method has been **experiment** (20% of the papers; e.g., [PS14] [PS15][PS18][PS34]), followed by **field study** (15.7% e.g., [PS42][PS46][PS67]), **action research** (15.7%; e.g., [PS60] [PS62][PS17]), and **case study** (10%; e.g., [PS7][PS16] [PS50]). **Survey** (7.1%; e.g., [PS21][PS43]) has been the least frequent method. Two papers presented evaluations with more than one empirical method [PS30][PS66].

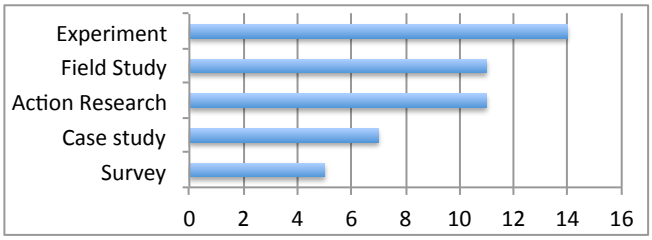

Fig. 3. Number of papers applying each empirical method

H. RQ8: Authors and Institutions

Among all the **institutions** that have published some paper on traceability at the RE conference, the University of Kentucky (9 papers) have the highest number of papers, followed by the University of Toronto (7 papers), DePaul University (6 papers), Johannes Kepler University (4 papers), and City University London (4 papers).

In relation to the **origin** of the authors, the largest number of contributions comes from academia (70%). Practitioners have also published papers at the RE conference on their own (14.2%) and in collaboration with academia (15.8%).

When analysing the **countries**, USA (37 papers), UK (12 papers), Canada (11 papers), and Germany (9 papers) have led production. Other 10 countries have contributed to traceability research at the RE conference.

IV. Discussion

This section discusses how traceability research at the RE conference has evolved, how the results of our study relate to those reported in other secondary studies, and what aspects should be addressed by future research.

Although we would have liked to present a more detailed discussion, this has not been possible due to page limitations.

A. Traceability Research Evolution at the RE Conference

We performed a comparative analysis between all the editions and the last six editions (from 2007) on different aspects in order to understand how traceability research has evolved at the RE conference over its 20 years.

A total of 32 papers were published in the last six editions, which is almost 46% of all the papers published. This indicates that traceability research has gained more attention at the RE conference in the near past. We identified that in the last six years there was no paper at the conference in the context of new approaches for maintaining traceability. This might mean that this topic has lost relevance, or that its associated challenges have already been tackled in previous research. Out of the 13 papers on traceability automation, 10 have been published since 2007. This shows that more and more effort is being spent on the topic.

We discovered that the challenge related to assessing the traceability maintained emerged during the last five years. This might indicate that interest in traceability quality is growing. Tool features specifically targeted at model management were first published in 2007, what suggests an increasing interest in model-driven engineering as a new framework for traceability.

With regards to the empirical validation, 72% of the experiments identified were conducted in the last six years. This indicates a strong focus on provision of evidence about the contributions made, as well as the maturity that traceability research is achieving.

Finally, we identified that seven papers published in the last six years were a result of industry-academia collaboration, whereas five had been published earlier. This suggests that there exists an increasing interest in innovation and technology transfer in the area of traceability.

Table I shows what we have regarded as the main highlights related to traceability in each conference edition ("Ed." column), along with the number of PSs identified at each edition ("PS" column). No PS was identified in the 2001 edition. It is interesting to see the importance of empirical evaluation and tool support since the beginning of the conference, how some editions have strongly focused on some topics, or that the three most productive institutions did not published any paper until 2003. Most of the publications were identified in the recent past (last seven years), showing that traceability is gaining more attention at RE.

TABLE I. HIGHLIGHTS REGARDING TRACEABILITY AT THE CONFERENCE

Ed.	PS	Highlights
1993	2	First RE edition. Traceability research started to be published.
1994	2	All the papers published so far at RE had applied empirical methods. Pre-requirements traceability was acknowledged as essential.
1995	5	Traceability started to be addressed in emerging topics such as goal-oriented RE. City University London published its first paper
1996	3	All the papers presented tool support this year.
1997	1	The first case study was published.
1998	1	A tool for distributed development was presented.
1999	1	Action research was the most frequent empirical method at RE so far.
2000	1	DOORS was extended for better traceability support.
2002	2	Change management was the main topic this year. The first paper applying several empirical methods was presented (survey and case study).
2003	6	The first paper evaluating information retrieval techniques was presented. Practitioners were authors of 66% of the papers of the edition. The University of Kentucky published its first paper.
2004	3	All the papers of the edition presented some tool with features for automated traceability. DePaul University published its first paper.
2005	6	Lack of knowledge and understanding was the most addressed challenge in the edition. The University of Toronto published its first paper.
2006	5	The Poirot tool was presented.
2007	5	Combination of information retrieval techniques and the first model management tool with traceability support were presented. Johannes Kepler University published its first paper.
2008	5	80% of the papers of the edition had authors from different continents. All the papers studied post-requirements traceability.
2009	5	The most recent survey was published. A paper applied action research and experiment.
2010	7	Edition with the highest number of papers. All of them applied some empirical method, and five of them action research or case study.
2011	4	Experiment becomes the most frequent empirical method. It was suggested to analyse traceability practices in other disciplines.
2012	6	A roadmap for future research was proposed.

B. Comparison with other Secondary Studies

As mentioned above, secondary studies related to our study can be found in the literature. We use their results to compare them with those reported in this paper and to evaluate how the RE conference has contributed to the development and progress of the traceability area. Review of other secondary studies also allows us to compare the maturity of traceability research at the RE conference with the maturity of other software engineering fields and RE areas.

In general, the results presented in Section III coincide with those reported in other secondary studies that analysed:

- Traceability motivation (related to RQ1; [22][24][28])
- Traceability challenges (related to RQ2 and RQ3; [17][21] [23][27][28][29])
- Traceability approaches (related to RQ3 and RQ5; [1][9] [27][28][29][PS25])
- Tool features for traceability (related to RQ4; [1][9][15] [25][26][27][28])
- Requirements interdependencies, types of traces, and types of artefacts traced (related to RQ6; [6][8][22][26][28])
- Empirical evaluation in traceability research (related to RQ7; [26][27][28])

Therefore, it can be argued that traceability research at the RE conference provides an excellent overview of the area and that it has significantly contributed to its progress. It is also true that a reason for the coincidence of results could be that traceability research at the RE conference served as input for other secondary studies. Even in this case, this shows the relevance and contribution of traceability research at RE.

One aspect that has not been extensively addressed at the RE conference and that other researchers have started to focus on is model-driven traceability [1][9][25][29]. The minor presence of this aspect at the conference might be a result of its focus on requirements instead of, for instance, model-driven development approaches and tools in general.

The ratio of empirical studies is also higher in the results reported in this paper than in, for instance, [27]. A reason could be that we have considered the most recent traceability research (until 2012), which, as discussed above, has significantly matured in relation to empirical validation in the latest editions of the conference.

The frequency in the use of empirical methods also shows that traceability research at the RE conference is more mature than the overall research in other RE areas (e.g., requirements specification [5]), and much more than other software engineering disciplines (e.g., safety assurance and certification [19]). Nonetheless, we consider that presentation of validation results can be improved. For example, more details should be

provided about the studies design to increase rigour [12]. A reason for this weakness might be the page limitations at RE.

Past studies (published before 2007; [1][3][6][20][26][28][PS21]) discussed challenges and areas for future research, such as pre-requirement traceability, conflict analysis, requirements reuse, automated traceability, trace verification, and tailoring of approaches. We consider that, directly or indirectly, these challenges have been partially or completely tackled at the conference.

Finally, a demographic analysis of RE publications was presented in [7]. When comparing the results with this paper, they are similar. USA, UK, Canada, Germany, the University of Toronto, and City University London are highly ranked in both studies. The study considered publications until 2008. This might be a reason as to why the rest of most productive institutions on traceability at RE do not appear in the study.

C. Aspects for Further Research

Several recent papers have discussed future research in the traceability area [2][13][25][29][PS25]. We aim to complement them by focusing on a set of selected areas, based on our discussion in the two previous subsections and on our own current research (e.g., [19]). Such research is mainly focused on V&V of business-critical systems (e.g., systems computing taxes) and on safety-critical systems (e.g., systems in the automotive, avionics, and railway domain), and conducted in close collaboration with industry.

Traceability visualization. One interesting area is visualization of how requirements are realized, for instance, by a test case for complex systems maintaining vast amounts of data. A high-level visualization can reveal requirements holes or gaps in a database or a test set in general. New ways of visualization could be feature and classification tree models.

Consideration of more artefacts. Research has strongly focused on requirements traceability, but many other artefacts and traces exist in development projects, especially in the context of safety-critical systems [19]. It has to be studied how requirements traceability research could be adopted or adapted to a wider spectrum of artefact types.

Traces semantics for impact analysis. Related to the previous aspect, we think that more research on trace semantics for impact analysis is necessary. Practitioners will benefit on more guidance about how to deal with changes and what actions to perform, beyond only being aware of the artefacts potentially affected by a change.

Advanced empirical evaluation. Although this area has been recurrently mentioned in the literature, there is some specific issues that we consider not to have been discussed enough. Firstly, it is necessary to perform more dynamic validation [10], especially of automated traceability. Secondly, it will be important to replicate empirical studies in order to create a larger body of evidence. Approaches should also be compared more commonly, but very few studies have addressed comparison (e.g., regarding trace creation [PS14] and visualization [16]). Finally, it has been shown that case study and survey have been the empirical methods least frequently used at the RE conference. Since they allow researchers to analyse industrial perspectives and experiences, we think that more research must apply these two methods.

Advanced tool support. For adoption in industry, automated traceability must be available or integrated with commercial tools. It is also important to study the confidence that can be placed in automated traceability (e.g., how to qualify automated traceability tools for use in the development of safety-critical systems).

V. Conclusion

This paper has presented the results of a literature review on traceability at the RE conference. The review has allowed us to provide new insights into the traceability research published at the conference, its focus, its maturity, its evolution, and its contribution to the traceability area.

The results indicate that traceability research at the conference has greatly focused on post-requirements traceability. The challenges most frequently addressed have been lack of knowledge and understanding about traceability, showing satisfaction of requirements, and maintaining traceability when requirements evolve. Most of the contributions have been technical, including a wide range of tool features and usually in the context of information systems.

Although traceability between requirements and between requirements and other artefacts have been studied, specific traces of the latter type have been most frequently reported. A high percentage of papers have applied empirical methods, and North America has led research production.

Traceability research at the conference has positively evolved. There is an increasing interest in automated traceability, model traceability, traceability quality, experimentation, and academia-industry collaboration. We think that the evolution shows the growth of the area in terms of maturity and interest in technology transfer.

When comparing the results of the review with those reported in other secondary studies, it can be argued that traceability research at the RE conference has provided a very good picture of the advances in the area and has significantly contributed to its progress. It has also shown a high degree of maturity, although need for more rigour might be claimed. Challenges acknowledged in the literature and based on insights from practice have been regularly tackled.

With regard to the areas for further research, we consider that traceability visualization, impact analysis, and tool qualification must be studied in more depth. We also think that it is necessary to focus on the opinion and experiences of practitioners different to the researchers, conduct dynamic validation, replicate studies, and compare approaches. We plan to research on these areas in the future.

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RE@21

This is a RE@21 special track paper for RE'13. The concept of "RE@21: Keeping Requirements on Track" is to gather together a collection of shorter papers that specifically summarize the contribution of twenty years of the RE conference series to the development and evolution of the field of requirements engineering, and to act as a baseline as the field moves forward. All survey and analysis work reported in this paper is therefore (primarily and intentionally) based upon the RE conference publications. The reader should be aware of this restricted scope.