

An Empirical Study of Software Requirements Verification and Validation Techniques along their Mitigation Strategies

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ABSTRACT— *Requirements engineering is very crucial phase of software development cycle. Different sub activities are performed during requirements engineering. Previous research shows that there are various techniques regarding requirements verification and validation. These techniques can have different relative importance in different situation. Typically the requirements engineers don't have proper knowledge regarding nature of each technique. Existing requirements validation & verification techniques differ in their ability to effectively cover the system requirements. It is highly desirable to conduct an empirical study on requirements verification and validation techniques to know their relative importance in opinion of different experts. In this study we developed a questionnaire based on requirements verification and validation techniques and their relative importance. Analysis of the results indicates that according to experts point of view (based on their experiences and judgments) ambiguous requirements are the biggest reason behind requirements verification and validation issues. Experts do believe that review and inspection are the best mitigation strategies to remove or minimize requirements verification and validation challenges.*

Keywords— software engineering, requirements verification and validation, mitigation strategies, expert judgment

1. INTRODUCTION

According to IEEE Computer Society's Software Engineering Body of Knowledge (SWEBOK) Requirements Engineering (RE) is defined as “RE is an area of software engineering concerned with the acquisition, analysis, specification, validation, and management of software requirements” [16]. Qadir et al. highlights that if RE activities are correctly carried out and managed, then it can result into shorter development time and serve as foundation towards such products which will satisfy market needs [1].

Requirements engineering is a comprehensive process and it's an important part of software development lifecycle. The RE process can play a crucial role in enhancing overall software product quality [2]. The inherently complex nature of software project motivates the requirements engineer to select suitable technique for different phases of the project at hand. There is lack of information and knowledge about attributes of RE techniques and to what extent different techniques fulfil these attributes. Currently, there are number of techniques that cover RE process and system development from different angles [3]. There is rich literature about different techniques and models which are being used software development [19, 20].

It is apparent that each technique offers some unique advantages, some of the techniques are quite mature as compared to others, some techniques offer similar functionality but possess different complexity levels and some techniques are opposite to each other functionality wise. Hence choosing best RE techniques will help smoothening the RE process and will eventually result into quality requirements specifications [17, 18].

Verification activity is performed to ensure that software is being developed in correct manner while validation activity is performed to ensure that software is being developed according to customer requirements [4]. The Verification and Validation (V&V) process verify that products of a development activity are according to requirements of that

specific activity or not, as well as it confirms that the resultant software product achieves its planned purpose and whether that product meet user requirements or not [5].

The core issue in requirements validation activity is that there is very little against which we can validate the requirements. The requirements validation process will enhance the confidence that requirements specification signify a system that should fulfill the actual needs of the stakeholders of that system [21]. The main issue in industry regarding requirements validation is that here are only few validation practices available. Furthermore there are very few experts of requirements validation, so companies have to use ad-hoc validation practices. Typically testing phase receives more attention, even though testing is frequently put in place while integrating different modules of some product.

The remaining part of the paper is structured as: section 2 describes literature review, section 3 presents requirements verification and validation techniques, section 4 focuses on research method used in the study, section 5 describes results with detailed discussion, and section 6 presents conclusion of the study and some future research directions.

2. LITERATURE REVIEW

Requirements engineering is very crucial phase of software development lifecycle. There are various sub activities which are performed during requirements engineering. The requirements engineer should have knowledge of all the activities so that requirement engineering process can be carried out smoothly. Review of literature shows that requirements V&V practices and techniques are receiving much more importance from software engineering community as compared to few years back, when studies on requirements V&V practices and techniques were very few.

Li Jiang et al. presented a “Methodology for RE Techniques Selection (MRETS)”. MRETS is an approach which facilitates Requirements engineers to pick appropriate RE techniques for a project at hand. The MRETS offers three features. 1- It supports requirements engineers for establishing a relationship between different attributes of a project and attributes of different RE techniques. 2- MRETS provides a prospect of using clustering concepts for analyzing details of RE techniques. 3- The objective function offers an efficient decision support instrument for selecting RE techniques [2].

In another study, Li Jiang et al. proposed a “Knowledge-based Approach for the Selection of Requirements Engineering Techniques (KASRET)”. KASRET consists of three main features. 1- A collection of requirements techniques was developed providing brief facts about RE techniques. 2- KASERT combines positive features of various knowledge representation schemata and reasoning mechanisms. 3- The objective function which acts as a main decision support mechanism, assess the overall capacity and the cost of different RE techniques, which is supportive for the RE techniques selection [6].

Y.Ayalew et al. proposed a support technique selection process for requirements elicitation on the basis of factors which affect this process. The Analytic Hierarchy Process (AHP) gives a formal model which specifies the relative importance of the selection factors and the applicability of technique with respect to each factor. AHP can deal with subjectivity and improve the reliability of the results [7].

According to C. Ponsard et al. verification and validation practices must be started earlier during development process for achieving high level of assurance. The results of their study shows that higher assurance level can be gained through a goal oriented RE framework [8].

Another study suggests that ambiguous requirements are very critical issue during software development, as most of the stakeholders do not know about presence of ambiguity in requirements [9]. The objective of software verification and validation is to identify and resolve problems in the earlier stages of the software development life cycle. The initial phase of any software product, is elaborating requirements. Therefore, verification and validation of requirements may be considered the single most essential element of the software testing cycle [10].

Several formal and informal methods and techniques for verification and validation of software requirement specifications exist, but it may not be clear to a software team what types of methods could be used. Depending on the size of a software project, requirements specifications are developed only in natural language and therefore become less formal.

Requirements validation techniques are used to make sure that software requirements specifications are complete. These techniques range from prototyping, view point oriented techniques, use case based modeling, requirements reviews etc. [14].

The requirements validation techniques focused in current this study are: reviews and inspections, user manual writing, tracing approaches, requirements testing, prototyping and formal validation.

The aim of this work is to get knowledge about requirements validation & verification techniques and how these can be selected on the basis of their attributes. In order to achieve the above mentioned aim we set following objectives:

- To facilitate decision making in case of requirements V&V selection.
- To facilitate requirement engineer in changing their policy.
- To enhance project manager's performance.

In order to achieve above objective this study investigates the following research questions.

- Q1. Which attribute of requirements validation & verification have more relative intensity in software development industry?
- Q2. Which requirements V&V technique is more favorable on each requirements V&V attribute?

3. REQUIREMENTS VERIFICATION AND VALIDATION TECHNIQUES

Requirements validation is a concept where requirements documents are checked for ambiguity, consistency, completeness and accuracy. Some stakeholder related problems discovered during requirements validation which needs to be corrected are, lack of conformance to quality standards, requirements ambiguities, errors in model of the system, requirements conflicts which were not detected during the analysis process. The inputs and outputs to the validation process are as follows:

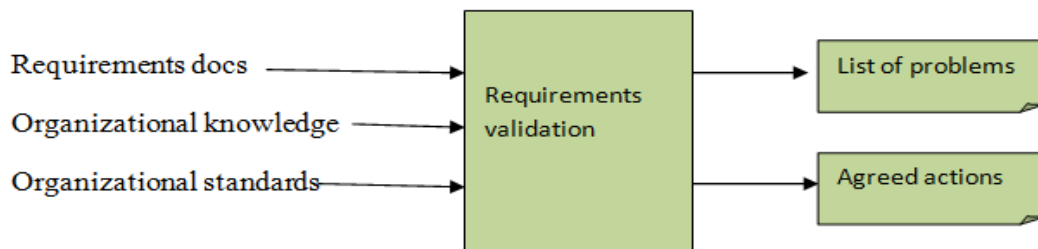


Figure 1: The Inputs and Outputs to the Validation Process

There are different verification & validation techniques, where each has some advantages and disadvantages. Following are most important software requirements V&V technique surveyed from literature:

3.1 Tracing approaches

Tracing approaches help to ensure the coverage of all elicitation notes by examining goals against requirements, tasks and features. Furthermore these approaches make assure that everything in the specification is justified.

3.2 Prototyping

Prototypes are excellent way of demonstrating the requirements in the form of scenarios to help stakeholders discover problems; negotiate problems and validate requirements.

3.3 Requirements Testing

Each requirement should be testable and formulating requirements tests is a useful requirements validation technique. Test cases based on requirements should be written, so that these can be traced to requirements.

3.4 User Manual Writing

User manuals forces to have detailed look at requirements especially related to usability. Typically user manuals include information related to system functionality, implementation, installation and getting started with it.

3.5 Formal Verification and Validation

It is a useful way to verify whether a formal specification contains needed characteristics like consistency, mutual exclusion and completeness etc.

3.6 Reviews and Inspections

It is a widely used requirements validation technique. Reviews and inspections are conducted by a group of people by reading and analyzing the requirements, searching for issues, meeting and discussing those issues and developing a consensus on corrective actions to be used for addressing those issues.

4. RESEARCH METHOD

The data for the current study is gathered from experts working in software industry. As the target population is dispersed, so we used survey (online questionnaire) based approach to gather data. Survey research method is a recommended for situations where self-reported data from large population is to be elicited [11]. The online questionnaire is based on Multiple-Criteria Decision-Making (MCDM) approach. MCDM is a decision aiding method having the goal of prioritizing the associated techniques and their attributes on the basis of the judgments of the decision makers. The experts have to choose their preference on the basis of their judgments. A number is assigned on a scale to each of these judgments, adapted from Saaty [27].

TABLE 1: The Saaty Rating Scale [27]

Intensity of Importance	Definition	Explanation
1	Equal preference	Two factors have same relative importance
3	Moderate preference	One is slightly preferred over other
5	Strong preference	One is strongly preferred over other
7	Very strong preference	One has very strong liking over other
9	Extreme preference	Highest possible significance of one over other
2,4,6,8	Intermediate values	When compromise is needed

The questionnaire developed for this study is based on requirements V&V techniques and their relative importance. The questionnaire can be accessed at the following link.

<https://docs.google.com/file/d/0B7kcEnZ3IYUBMFFWY2FRMmoxN0k/edit?usp=sharing>. Data is gathered from experts working in software industry for years. Target population includes different job role, company sector, gender and level of experience for more reliable results. Questionnaire is designed taking into account scale balancing, validity and reliability [12].

According to Pakistan Software Export Board (PSEB) most of the software houses are working in cities like Islamabad, Rawalpindi, Karachi and Lahore, so our targeted population is mostly from these cities. We used web based survey as it is an appropriate and fast method of data collection [13, 15]. We also emailed to CEO's/project managers and requested them to participate in this survey.

The Questionnaire used in the survey is designed according to the needs of the study and the questions are based on requirements V&V techniques and their relative importance.

The questionnaire is divided into two sections. Questions in section 1 of the questionnaire are related to respondents' demographic/organizational profile, while there are many questions in section 2 of the questionnaire which are related to requirements V&V techniques and their relative importance [15].

After getting data, results are gathered using statistical tool named Expert Choice. This study presents experts point of view on main causes behind requirement V&V issues and corresponding best mitigation strategies to remove or minimize requirements V&V challenges.

5. DISCUSSION ON RESULTS

The questionnaire was posted online and requests were sent to different individuals and companies. Total 74 experts filled the survey. We received 55 complete responses and 19 incomplete responses. The results are based on 55 complete responses.

5.1 Results from Section 1

The respondents are from both segments of society with male representation of (83%) and female representation of (17%). Survey is filled form different experts working in software industry for the validity of results. The roles representations are: The Requirements Engineer representation in the survey is 20 (37%). The System Analyst representation in the survey is 14 (25%). The Team Lead representation is 4 (7%). The Project Manager representation is 8 (15%). There are also 9 (16%) responses from the professionals under the heading "Other". Gender results shows that the male representation is 43 (78%), while the female representation is 12 (22%). Their working experience in software industry ranges 2 years to 15 years. The respondents with work experience between 2 to 5 years are 30 (55%). The

respondents with work experience between 6 years to 10 years are 17 (31%). The number of respondents having experience greater than 10 years is 8 (14%). The respondents having experience of working at different organizations ranges between 1 to 3 organizations is 32 (59%), 4 to 6 organizations is 15 (27%) and more than 6 organizations is 8 (14%).

There are 7 (13%) responses from the professionals having undergraduate level education, 35 (64%) respondents have graduate level qualification, while 13(23%) respondents have masters level qualification. There was also an optional question asked from respondents to provide the name of the organization where they work. The representation of professionals providing their organizational names are 46 (84%), while 9 (16%) respondents didn't mentioned the name of the organization where they work. The representation from professionals working in Local Companies is 19 (35%), Multinational Companies is 22 (40%), respondents under the heading "Others" were 5 (9%) and 9 (16%) respondents gave no answer to this question. There is maximum participation by private sector with 43 (79%) participants, the participation from semi Government Sector are 3 (5%), from Public Sector are 6 (11%), while 3 (5%) participants are under the heading "Other".

5.2 Results from Section 2

Results from the Section 2 are related to requirements V&V techniques and their relative importance. There are further four subsections in Section 2. These are:

5.2.1 Major Challenge for Requirements V&V

The experts were asked to highlight the most critical cause which results into requirements verification and validation challenges. On the basis of previous research and studies from literature they were given three choices. These choices were: ambiguous requirements, inconsistency and conflicts and incomplete requirements.

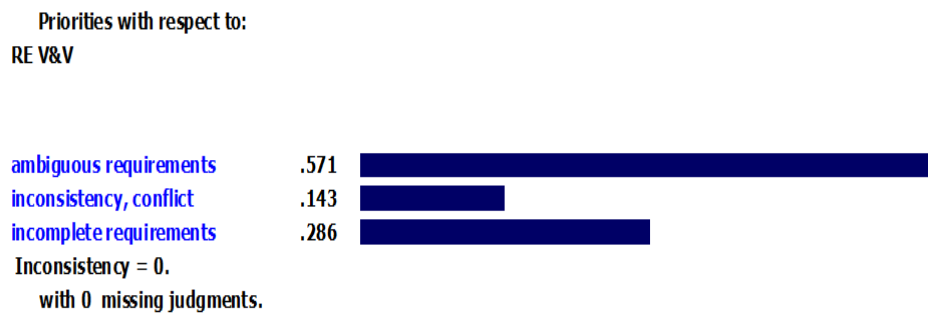


Figure 2: Major Causes of RE V&V Challenges

Figure 2 shows that ambiguous requirement emerges as the main cause of requirements verification and validation issues as it received an overall importance of (.571), compared to inconsistency and conflicts (.143) and incomplete requirements (.286). So it can be assumed from the opinion of the experts for this research study that ambiguous requirements are the major cause of requirements verification and validation challenges. Therefore it must be given due importance so that requirements verification and validation challenges can be minimized or eliminated. The questions under the below headings explain effectiveness of each technique with respect to each criterion.

1) Ability to Identify Ambiguous Requirements

In this question the experts were asked about their preference for identifying ambiguous requirements on the basis of their experience and judgment. They were given the choices as: formal validation, tracing approaches, requirements testing, prototyping, reviews and inspections and user manual writing. They were also given a nine point scale for showing their preference.

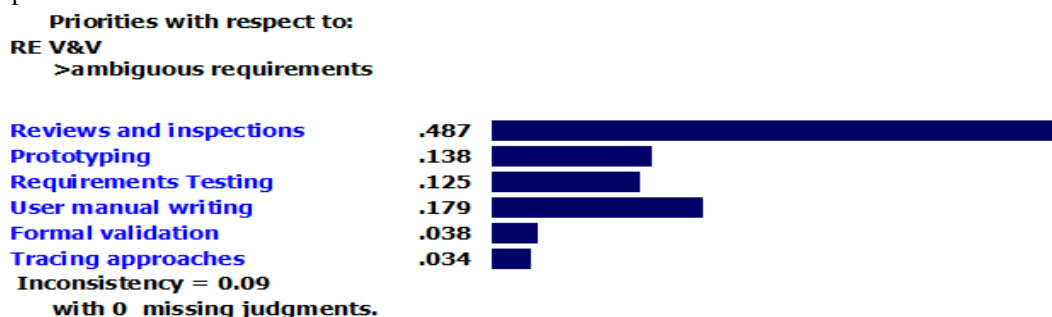


Figure 3: Ability to Identify Ambiguous Requirements

The above Figure 3 shows the overall points weights given by experts to each requirements verification and validation technique regarding its ability to identify ambiguous requirements. Tracing approaches received an overall weight of (.034), prototyping (.138), requirements testing (.125), user manual writing (.179), formal validation (.038) and reviews and inspections received an overall weight of (.487).

So the results show that reviews and inspection with an overall weight of (.487) is the best choice for experts when it comes to the identification of ambiguous requirements.

2) Ability to Identify Conflicts and Inconsistency

In this question the experts were asked about their preference for identifying conflicts and inconsistencies among requirements on the basis of their experience and judgment. They were given the choices as: formal validation, tracing approaches, requirements testing, prototyping, reviews and inspections and user manual writing. They were also given a nine point scale for showing their preference.

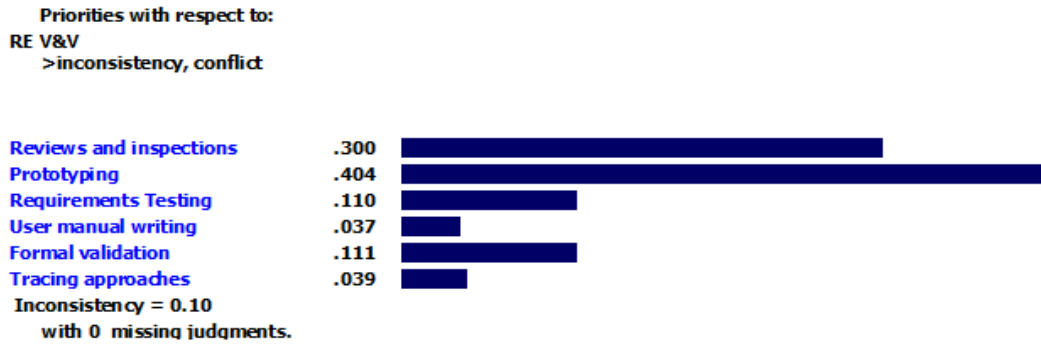


Figure 4: Ability to Identify Conflicts and Inconsistency

The above Figure 4 shows the overall points weights given by experts for each requirements verification and validation technique regarding its ability to identify conflicts and inconsistency. Tracing approaches received an overall weight of (.039), prototyping (.404), requirements testing (.110), user manual writing (.037), formal validation (.111) and reviews and inspections received an overall weight of (.300).

So the above results show that prototyping with an overall weight of (.404) is the best choice for experts when it comes to identify conflicts and inconsistencies among software requirements.

3) Ability to Identify Incomplete Requirements

In this question the experts were asked about their preference for identifying incomplete requirements on the basis of their experience and judgment. They were given the choices as: formal validation, tracing approaches, requirements testing, prototyping, reviews and inspections and user manual writing. They were also given a nine point scale for showing their preference.

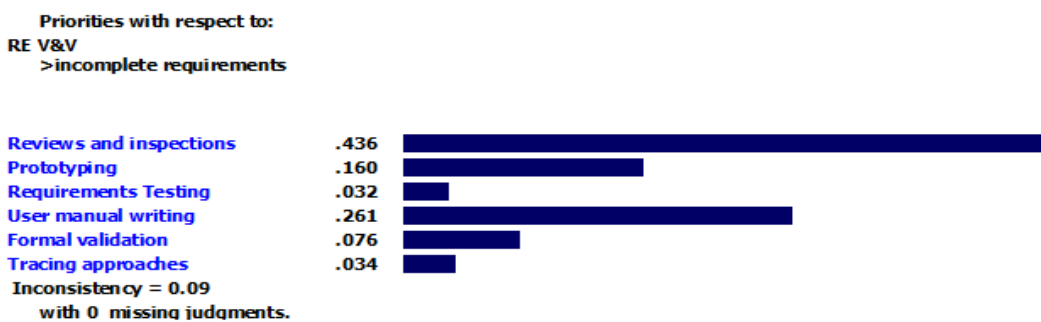


Figure 5: Ability to Identify Incomplete Requirements

The above Figure 5 shows the overall points weights given by experts for each requirements verification and validation technique regarding its ability to identify incomplete requirements. Tracing approaches received an overall weight of (.034), prototyping (.160), requirements testing (.032), user manual writing (.261), formal validation (.076) and reviews and inspections received an overall weight of (.436).

The above mentioned results show that reviews and inspections with an overall weight of (.436) is the best choice for experts when it comes to identify conflicts incomplete requirements. In coming section Dynamic Sensitivity Analysis of the above results are presented.

5.2.2 Dynamic Sensitivity Analysis

The most important part of sensitivity analysis is dynamic sensitivity of the results of the survey. The dynamic sensitivity shows percentage distribution of each criterion and their corresponding mitigation strategies. Figure 6 shows the dynamic sensitivity analysis summary for the current study.

The left portion of Figure 6 represents the priorities of the experts when they were asked to give weights to each requirement V&V related issues. According to experts point of view (based on their experience and judgment) 57.1% issues in requirements verification and validation are due to requirements ambiguity. Incomplete requirements received importance from 28.6 % of the total respondents. Inconsistent and conflictive requirements were given an overall weight of 14.3 % as being the issue behind requirements verification and validation related challenges.

The right portion of figure 5.5 represents the overall priorities of the experts when they were asked to give weight to each requirement V&V related mitigation strategies. Expert judgment data results show reviews and inspection as the best mitigation strategy with an overall weight of (44.1%) while other mitigation strategies received weight as prototyping (18.8%), user manual writing (18.1%), requirements testing (9.5%), formal validation (6.1%) and tracing approaches (3.5%).

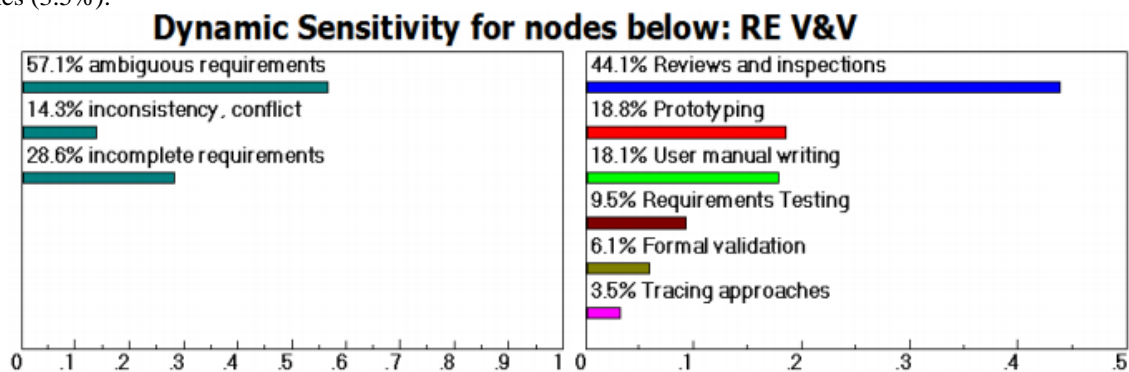


Figure 6: Dynamic Sensitivity Analysis for V&V

The results of the survey indicate that to deal with requirements V&V issues, the management should try to avoid ambiguous requirements earlier in development lifecycle. A proper requirements analysis plan should always be developed for tackling requirements ambiguity. Review and inspection process should be implemented regularly throughout all software projects.

6. CONCLUSION & FUTURE RESEARCH DIRECTIONS

Requirements engineering is very crucial phase of software development cycle. Different sub activities are performed during requirements engineering. Literature shows that there are various techniques regarding requirements verification and validation. These techniques have different relative importance in different situations and different researchers have suggested their usage according to their own expertise. This study performed a survey regarding requirements verification and validation techniques and their relative importance.

Talking about participants, there is participation from experts working in local companies as well as from multinational companies. Participants are from both segments of society male and female. Their education ranges from undergraduate to master level. Participants have variant experience from 2 years to 15 years. Most of the participants are from the area of requirements engineering which is the area of concern for this study.

The survey results received statistical treatment through the use of Expert Choice software. Generated results show that there is variance in choices of experts regarding causes of requirements verification and validation issues and their mitigation strategies. However majority of the experts believe that ambiguous requirements are the root cause behind most of the requirements verification and validation issues. Further analysis shows that experts also believe that reviews and inspections are best mitigation strategies to reduce/minimize requirements verification and validation issues as reviews and inspections are easy to implement as it associate less cost and time as compared to other corresponding mitigation strategies.

In recent times there is huge amount of research going of software requirements engineering related issues. However there is still lack of research dedicated to find mitigation strategies to overcome/minimize requirements verification and validation issues. This research activity was performed to bridge this gap.

However this study is based on responses from experts (based on their experience and judgments). The experts are only from Pakistan software industry. Therefore there is a clear future research direction of performing the same study in other countries as well. Another possible research direction can be to perform a questionnaire based survey from software

engineers (which includes all roles like: (requirements engineer, designer, developer, quality tester etc.) and academia (requirements engineering teachers and researchers) and perform a comparative study to identify similarities and differences between industry and academia regarding the same topic. We are also planned to perform a case study at some software house to measure the impact of results identified in this research activity.

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