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A Requirements Engineering Methodology for Technological Innovations Assessment

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Abstract. The constant development of technology connected to the growing of Internet, contributes to promote collaborations between companies, leading them to new business opportunities. This acts as a lever able to make entrepreneurs or investors, namely the ones that can be defined as "risk lovers", to contribute with new ideas, which through an effective implementation would result in new profitable products. Thus, these entrepreneurships initiatives would result in the creation of technological innovations, which are widely recognized as having an important role in the world economies. It is fundamental to support these technological innovations development through effective requirements engineering. This paper presents a requirement engineering methodology composed by five phases able to access the requirements with the purpose of improving industrial scenarios applications implementation resulted from research projects. Its main objective is to support the development, adaptation, and validation of technologic innovations to facilitate further exploitation.

Keywords. Technological Innovation; Technology Assessment; Requirements; Methodology.

Introduction

Entrepreneurs must be one step ahead in relation to their competitors to be successful. They need to be in a constant development of ideas and products at their companies, which may require Research, Technology, and Development (RTD) projects for such ideas applications or prototypes development. It leads to Technological Innovation (TI) creations, which could include solution as processes or tools used to produce products or render services related to the basic work activity of an organization [1][2].

As in any kind of a new product, a TI requires an effective assessment process to validate its quality and reliability. Technology Assessment (TA) is defined as a scientific, interactive and communicative process, which aims to contribute to the formation of public and political opinion on societal aspects of science and technology [3]. Thus, TA is fundamental to generate new reliable ideas and consequently new technological products. In line with this, the authors propose a requirements engineering methodology to support technological innovations assessment. Consequently, to introduce such methodology, the paper first presents Requirement

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Engineering (RE) concepts followed by the proposed Methodology description. Afterwards, a demonstration of its use in OSMOSE project is described. Finally some conclusion with future steps on this research work is presented.

1. Requirement Engineering

A requirement is defined by IEEE (Institute of Electrical and Electronics Engineers) [4] as: 1) a condition or capability needed by a user (person or system) to solve a problem or achieve a goal; 2) a condition or capability, which has to be provided by a system or part of a system, to fulfil a contract, a standard, a specification or any other formal documents; 3) a documented representation of a condition or capability, as in points 1 or 2.

The definition of the IEEE is widely used and underlines the differentiation between requirement and documented requirement. This emphasizes the importance of having a good, requirement documentation, which is normally one of the biggest problems of Requirements Engineering [5]. A "good requirement" demands certain quality criteria parameters, that can be found for instance, in the IEEE-Standard 830 [4], where some examples are: Unambiguity; Understandability; Completeness; Consistency; Verifiability; Traceability; Relevancy; and Feasibility. If requirements are documented following these quality parameters, an efficient choice of the most appropriate/relevant type(s) of requirements can be made more efficiently, hence reducing the risks of misunderstandings and erroneous implementations during a specific project.

These statements underpins the following RE definition. RE is the science and discipline concerned with analysing and documenting requirements [6], and follows a process that leads to a set of well-formulated requirements. RE acts as the bridge between the real-world needs of users, customers, and other constituencies affected by a system, and the capabilities and opportunities afforded by technologies [7]. Being concerned with the identification and communication of the purpose of a specific system, RE helps determining user expectations for a new or modified product/system. It describes the process, in which the needs of one or many stakeholders and their environment are determined to find the solution for a specific problem [8] [9].

In fact, systematic RE and management is a prerequisite for successful projects and products. Despite that more than half of all projects tend to fail or run into difficulties due to inadequate RE [10], its importance tends to be sometimes underestimated; which can lead to errors or omissions in requirements specification. Hence, this paper should derive an pervasive methodology that applies proven practices, methods and tools for helping engineers and others, driving the RE process. In line with this, it was defined the most common phases of a RE process [5]: the requirements elicitation; analysis; specification and validation (Figure 1).

Elicitation is the act to determine or obtain the relevant requirements for the development of a solution, which should bring the greatest possible benefit concerning the goals and motivations of the involved stakeholders, assuming they are correctly understood [9].

Requirements analysis in a broad sense is related to the first step in the system design process, where a user's requirements should be clarified, categorized and documented to generate the corresponding specifications [11]. However, inside a RE

overall process, requirement analysis is also about reviewing, and to analyse them in detail, negotiating with stakeholders on which requirements are to be considered [12].

Figure 1. Requirement Engineering phases

Requirements specification describes the phase, where the requirements are brought into a suitable and unambiguous form [5]. The idea in this phase is to make the requirements document readable and understandable by anyone that has not been involved in the elicitation and/or analysis processes.

Requirement Validation is to review or validate requirements for clarity, consistency and completeness [12]. Requirements validation phase is used to identify the faults in the determined requirements, as the specified requirements have to accurately express the stakeholder's needs [5].

2. Requirements Engineering Methodology

The proposed methodology follows the main RE described phases, namely the requirements elicitation, analysis, specification and validation. In addition, and to prepare information required for the process, a previous phase is considered at the beginning of the proposed methodology. As a result, it is defined a five phase procedure for the RE process (Figure 2), which is thoroughly explained in the following subsections. The bottom part of the figure illustrates the feedback loop among the different stages.

2.1. First Phase – Preparation

At the Preparation Phase there are three steps envisaged. The first is related to the scenarios modelling and meta-modelling. In this step a "Template for collection of user scenarios" should be defined. The aim is to distribute a form among the various actors so they can perform their contributions to the industry scenarios identification. Based on this input information, formal modelling can be achieved (but not mandatory) through the use of languages such as UML (http://www.uml.org). This step intends to provide the foundations and guidelines for the representation of enterprise activities, so that the current process may be analysed and improved. This is what will be accomplished through the execution of the following steps.

The industrial scenarios step represents the act of gathering and understanding the both the AS-IS and the TO-BE scenarios to be addressed in a project. Modelling or representing the current (AS-IS) situation is the basis for identifying shortcomings and potential improvements, in particular as it gives an overview of the current situation for new and external participants in the reorganization intention. This promotes the understanding of relevant relationships and existing problems of the company, and forms the basis for the design of adequate TO-BE models. Sufficient knowledge of the current status is a prerequisite for developing a migration strategy to the new processes. An AS-IS model can be used as a checklist in the TO-BE modelling stage in order to prevent relevant issues from being overlooked, which would result in a reduction in the

efforts for TO-BE modelling [13]. As a conclusion of this second step, two results are expected, i.e. the AS-IS model which represents the current situation as it is, and the TO-BE model, resulting from incorporating the desired improvements [14].

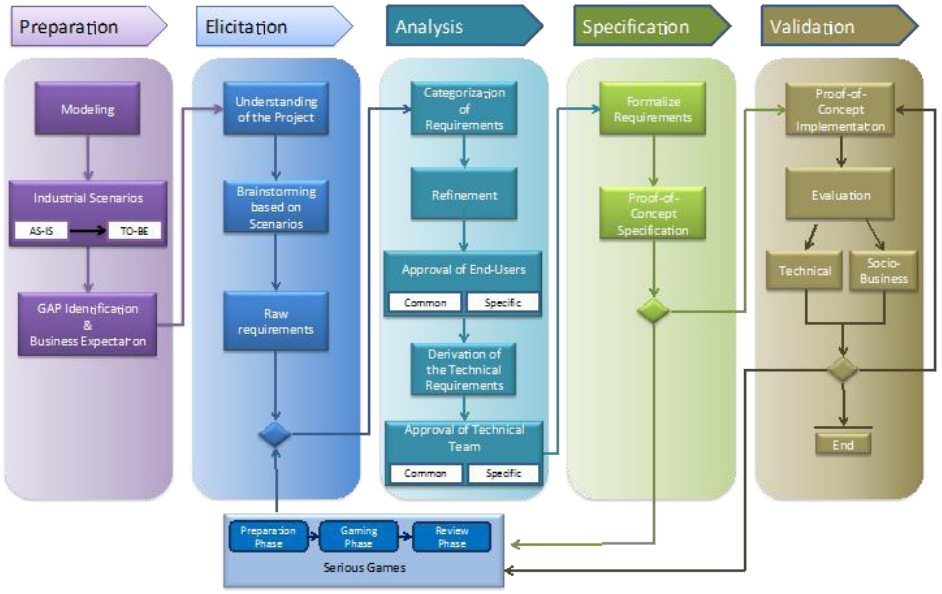

Figure 2. Requirements Engineering Methodology

Some of the most traditional internal expectations are: increase in profits; cost savings; streamlining of processes; reduction of planning times; shortening of processing times; information that is more up-to-date; better communication between company units via defined interfaces; minimization of idle times. On the other hand, some of the common external customer and/or market-oriented socio-business expectations are: higher process quality and resulting product quality; closer proximity to customers and better customer commitment; faster communication with market partners; higher process transparency for the customers; larger market shares; for example, through a faster response to market developments.

These expectations extracted from the TO-BE modelling need to be discussed with all actors involved in the project, so as to avoid project members adopting false or negative expectations. A transparent presentation of the relationship between the different expectations, and the relationship between the different users and the targets of TO-BE scenario, is an important factor to be rendered by the project members during TO-BE modelling [15]. Nevertheless, these socio-business indicators need to be clearly defined to be later used for progress measurement.

2.2. Second Phase – Elicitation

The requirements elicitation phase represents all the actions performed to acquire raw requirements related to what is intended to develop in the project. To perform these actions, it is needed to understand the knowledge related to the involved stakeholders (industries), their scenarios as described in the previous phase, as well as their vision of the project concept. After reaching such understanding, a first formalization approach

of the knowledge handled is accomplished through a set of raw requirements (i.e. they don't need yet to follow all the parameters identified in the IEEE-Standard 830 [4]).

The first step of this phase intends to clarify the project concept, building a common understanding among its stakeholders, as an example, it could be related to the understanding of the project architecture and its hypothetical required multiple views of information representation and management. This will give the knowledge skills needed for making the scenarios processes categorization and its adequacy evaluation to contribute for the project research objective.

In the second step, a brainstorming based on scenarios to discuss and present ideas about the tools/solutions necessary to be developed/implemented to accomplish the TO-BE scenarios needs to be carried out. Requirements elicitation is an iterative activity, where several complementary techniques may (and should) be used as part of this step. Some of the best candidate techniques to support this process are: brainstorming, brainwriting, requirements workshops, and focused groups interviews. At this stage, despite the technique(s) followed, a specific template form to be completely filled out during the requirements definition process should be defined.

The next step (raw requirements) represents the collection of the results from this elicitation stage. The ultimate goal is to end up with a commonly agreed collection of raw requirements. All activities conducted in the elicitation should be carefully documented. The results should be published in a selected requirements management system, in order to obtain the necessary feedback from the actors, for an effective analysis and improvement. This phase also includes a serious games stage which represents an additional requirements elicitation process. It will be executed after further phases to accomplish "hidden" requirements finding in a kind of loops to improve the results associated to the methodology.

The Serious Games strategy can be used to simulate how a project's stakeholders would interact between them, and with the prototypes result of the project. It is commonly acknowledged that a traditional way/approach of elicitation requirements works quite well. However, if complemented with serious gaming interactions better results would be obtained, mainly because of this being focused in extra requirements elicitation iterations' cycles, for specific tuning purposes.

The process of RE with Serious Games can be divided into three steps [9]: the Preparation; the Gaming and the Review steps. The preparation step deals as the name indicates with the preparation and implementation of the games to be used in the next step. The gaming step comprises the workshop, where the gaming sessions happen. Depending in the advance stage of the prototypes' developments, two types of gaming can be used: the role and gaming approaches as further explained in this paper. The review step consists of the analysis and documentation of the requirements defined from the conducted Serious Gaming. This intends to prepare them for a new RE cycle, specifically to the analysis phase where these "new" found requirements should be categorized as the others in the previous cycle.

2.3. Third Phase - Analysis

The third phase of the methodology concerns the analysis of the requirements previously elicited. In their "raw" stage, requirements are typically unorganized and difficult to communicate to technical teams, sometimes even lacking some detail. For this reason the analysis phase is quite important in the RE process.

The first step consists in the categorization of requirements, an organizational activity to group requirements by types (e.g., functional, business), by processes (e.g., virtualization, digitalization, etc.), or even domain identifying if they are specific to a scenario or generic/common to any industrial situation. Other categories may apply if needed. After having them categorized, requirements are still in their raw nature, thus a refinement activity helps to avoid repetition. This step also enables to readjust them, clarifying sentences and making them well formed according to the parameters of the definition applied for the project, i.e., unambiguous, complete, consistent, verifiable, traceable, relevant and feasible.

During the previous 2 steps, the requirements manager might have changed the meaning of some requirements unintentionally, thus it is important to have an approval of end-users step before proceeding. Typically, refined requirements are communicated back, either directly or using the requirements management system, to the different stakeholders so that they can pronounce themselves about the validity.

From this stage of the project RE methodology onwards, it is important to keep the notion that there will be some application specific requirements, while others are generalized so that the project solutions can be applied to different industrial domains. For each of them, the following step, the derivation of the technical requirements, is responsible for bridging with the technical teams of the project, deriving technical-driven requirements based on the existent user-oriented ones.

Finally, to conclude the analysis stage, it is necessary to have an approval request process of the requirements by the technical team. The approved requirements proceed to the next phases.

2.4. Fourth Phase - Specification

Two steps compose the specification phase. The “Formalize Requirements” step intends to establish an explicit knowledge base of the requirements defined. Its main objective is to have requirements available for both human and computer processing. The idea is to have them in a web-based solution for human consulting purposes and in parallel, on an ontology-based formal representation for specific machine reasoning and traceability. However, the methodology contemplates a number of subsequent steps (presented next) that are equally important.

The Proof-of-Concept Specification step uses the knowledge formalized in the step before to design (specify) the necessary implementations and develop & integrate the existing systems to match the defined requirements (representing the expectations of the To-Be scenarios). The Proof-of-Concept intends to describe essential processes with different objectives and participant roles, to demonstrate identified concepts or ideas implementation feasibility, and to verify its appliance potential. It will educate stakeholders on the formalized requirements, which would solidify the requirements, enabling best practices and set the tone for a successful implementation [16].

At this stage, if discrepancies are identified on the requirements in relation to the planed ideas or concepts, a new requirements reformulation is conducted. Thus, a loop back to Elicitation and Analysis requirements phases would be executed through a Serious Games methodology. In this particular case, since at the time of the first iteration of this phase no implementations are accomplished yet, the Role Playing approach should be the most appropriated. Its aim is to surrogate roles around project stakeholders to inspire a different perspective analysis of the scenarios to facilitate the elicitation of new (hidden) requirements. Additionally, it should be used to verify if the

previous identified requirements are the most appropriate, and if not, these requirements will be conducted (again) to the RE analysis phase to a new refinement.

2.5. Fifth Phase - Validation

In the last phase of the RE methodology, it is intended to validate the obtained requirements. At the Proof-of-concept Implementation step it is implemented the solution(s) accordingly to the defined specifications and requirements. Subsequently to the implementation an evaluation step it is accomplished. It identifies if the implementation correctly addresses the identified requirements both at technical and socio-business perspectives, and if accurately responds to the stakeholder's needs. If both evaluation results are positive, this means that all the developments are valid and have reached its end.

The Technical evaluation verifies if the entire functionalities implemented meet the requirements defined. However, if there is any issue, a specific (technical) feedback is provided to developers, which would accomplish reformulations as adequate. If this occurs, it is carried out a new evaluation cycle.

The Socio-business evaluation verifies if the solution(s) implemented are able to accomplish the To-Be scenarios, and especially if they are able to realize the business expectations and indicators defined. In the case of failure, a loop back to requirements Elicitation and Analysis is necessary. As before, the loop back would be executed through a Serious Games methodology. However, in this particular case, since at this phase there are already some tools accomplished, the Game Playing approach should be the most appropriated. Its aim is to replicate the experiences of stakeholders but already using the new working systems to mimic, as much as possible, the real life situations that the To-Be scenarios implementations would bring. This would provide new insights that would result in the elicitation of new requirements and in the update of existing ones. These requirements will be conducted (again) to a new cycle of the RE methodology to accomplish suitable new refinements [15].

3. Requirements Engineering Methodology in OSMOSE project

The OSMOsis applications for the Sensing Enterprise (OSMOSE) project has the main objective of developing a reference architecture, a middleware and some prototypal applications for the Sensing-Liquid Enterprise, by interconnecting Real, Digital, and Virtual Worlds (RW, DW, and VW) in the same way as a semi-permeable membrane permits the flow of liquid particles through itself [17]. The worlds represent three types of data management environments: RW is related to data that comes directly from devices that handles with physical components (e.g. sensors, actuators etc.); DW is related to data management available in data and knowledge bases or in Internet (big data); VW is related to specific management of data with the support of artificial intelligence related programs for specific simulations and predictions. A semi-permeable membrane (like in biology) means that the worlds are not really independent and that the "liquid particles" could pass through them and influences the neighbouring world. This means that what is handled in the RW could be represented in the DW, which then could be used for specific predictions in the VW. It intends to illustrate the use of Internet of Things technologies for managing physical elements of an enterprise, at RW, through the support of querying (online) digital data and reasoning explicit

knowledge, from DW, for taking decisions. It also addresses predictions characteristics that are handled through simulations, at VW, to avoid failures during the life cycle of the materials.

In Figure 3, a triangular diagram is represented. It represents the interaction between the three mentioned worlds, liquid stargate and the osmotic processes (e.g., virtualization, actuation). The osmotic processes interconnect the mentioned worlds and represent the activities that result in data flow between such worlds' actors. Liquid stargate is an abstract element that represents the interfaces, which allow users to browse the relevant real-digital-virtual assets in an integrated multi world representation view, to configure the behaviour of their RW actors (e.g. humans), DW agents, and VW avatars and to support knowledge sharing and experiences/emotions exchange, by crossing seamlessly the three worlds' gates[17].

The OSMOSE project has been experimented in two industrial scenario domains, assessing not just the technology but also the socio-technical implications, including privacy and security issues. Agusta Westland SPA participate with two scenarios in the aviation industry and Engine Power Components, Group Europe, S.L. with one scenario in the automotive industry.

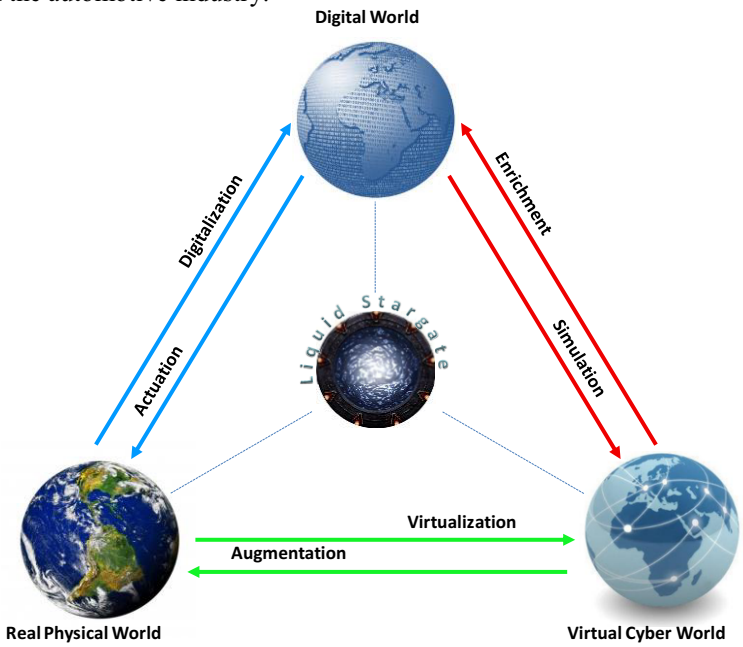

Figure 3. Osmosis Process Identification

The presented RE methodology has been tested in OSMOSE project to effectively accomplish its prototypes implementation. In the first phase (Preparation) two templates were defined and distributed through the various scenarios stakeholders. With such templates they could contribute for the identification of their AS-IS and TO-BE industrial scenarios. Afterwards an analysis over the defined AS-IS and TO-BE scenarios was made. The socio-business expectations of the involved companies were derived from the TO-BE scenarios analysis. Additionally, such exercise helped to identify the real gaps between the AS-IS and the TO-BE scenarios.

At the second phase (Elicitation), it was accomplished an understanding of the project through discussions, about the project concept and its adequacy to

handle/represent the identified scenarios. Then, techniques as brainstorming, brainwriting, and focus groups interviews were used in the requirements workshops. Thus, a set of raw requirements was obtained. During the same workshops were also conducted a first categorization of the requirements, which already represents the first step output of the RE methodology analysis phase. This categorization was accomplished through writing the requirements in coloured post-its accordingly to: (Pink) - Business Requirements - "higher-level" statements of the goals, objectives, or needs of the enterprise; (Green) - Functional Requirements - required behaviour of the system to be built; (Orange) - Non-Functional Requirements - additional properties such as interfaces, performance, etc.; and (Yellow): Other Requirement types. Additionally, in these same workshops the requirements were also categorized accordingly to the project concept worlds and the osmotic processes. As an example, in the following, it is presented a set of automotive requirements categorized accordingly to the three worlds:

- Virtual World: *To have a customized (3D) viewer to guide an overview to customer (information about a piece)*
- Digital World: *To have the information distributed in a cloud system; to have a database to integrate all data about camshaft manufacturing process for further traceability.*
- Real Physical World: *Reduce manufacturing errors; Improve company image in front of the customers.*

Afterwards, the requirements were refined and introduced in an adapted WIKI system, to share them among the industrial end-users. Through this WIKI they could check/complete and give their approval on the identified requirements. Then, specific technical requirements were derived from the set of approved requirements. This means that from a general one could result in smaller but focused ones, which could mention specific modules or elements of an existent platform (e.g. a specific database) to which they are related to. Finally, a set of common requirements was identified for both industries to support further analysis, which goal is to help the project concept implementation in other industries.

Since these last steps were defined using a WIKI platform, the formalization of requirements in the specification phase was accomplished through the transfer of its contents to a similar structure ontology. Through this last step, simple queries or advanced reasoning over the requirements can be done. The next steps are intended to be accomplished in OSMOSE in the near future.

4. Conclusions

Nowadays, the creation of methodologies in companies or in specific projects is fundamental to have a method to follow/to use in the implementation of an idea or product. In this paper, the authors created a RE methodology for TI assessment in companies. This methodology can be used in different project types that intend to use to develop new TI, contributing by this way to increase company entrepreneurships initiatives acceptance and consequently, promoting the collaboration between enterprises generating new business opportunities.

For the future, the authors would like to follow the implementation to the fourth and fifth phases of the methodology as well as the implementation of the serious games in the OSMOSE project to verify if the expected results would be achieved.

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