How to find non-functional requirements in system developments

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Abstract: The current complexity of systems requires a full understanding of stakeholder needs in system design. Later, these needs will become requirements of the system: functional requirements are quite easy to describe for the customer, but finding the non-functional requirements is an actual challenge; however, they are essential to design the system. The objective of this research work is to provide support when defining non-functional requirements. The proposal consists in a requirement classification and a questionnaire that progressively guides the elicitation of stakeholder needs. This method is applied to three case studies, demonstrating its interest and indicating opportunities for improvement.

Keywords: Systems engineering, requirements, non-functional requirements, requirement taxonomy.

1. INTRODUCTION

Engineering Science aims at improving people's life quality through problem solution (Faisandier, 2012). However problems do not generally have an easy nor a unique solution. This is where Systems Engineering is valuable, because of its wide vision of the problem in a systemic approach (Kossiakoff et al., 2011). It guides the development processes with a systemic point of view: identifying all the stakeholders and their needs, deriving them into system requirements, designing and evaluating several possible technical options to meet the requirements, till the selection of one solution (Faisandier, 2012). Authors like Hickey and Davis (2003) Faisandier (2012), Blanchard and Fabrycky (2011) and SEBoK (2017) recommend to consider several methods and techniques during elicitation and identification of stakeholder needs, expectations, and requirements, this is to better accommodate the diversity of the sources and situations. However, when analyzing the industrial practices and the causes of projects failures (Oehmen, 2012), it is realized that the actual stakeholder needs and the quality characteristics that the stakeholders want to meet are too often pre-assumed or misunderstood (Faisandier, 2015). Several authors (Blanchard and Fabrycky, 2011; Kiritani and Ohashi, 2015) stress the importance to make additional efforts on the system requirement definition stage, in order to ensure the effectiveness of decision making in the design process. Kritani and Ohashi (2015), specify that "*the quality of requirements definition directly leads to the final success or failure of system development project*". In accordance to Oehmen (2012) the issue of unstable, unclear and incomplete requirements stands second in the themes of challenges in managing engineering programs, because it seriously affects the program efficiency and effectiveness.

Thus, a first conclusion is that precisely and completely identifying the needs is a tricky issue, but a crucial step that has a fantastic impact on the whole development process and the project success. This issue must be methodologically addressed and the requirement elicitation process must be thoroughly guided. Requirements are generally classified in two distinct groups: functional and non-functional (Glinz, 2005; Badreau et al., 2014; Mabrok et al., 2015). This paper thus focuses on non-functional requirements in priority. The objective is to provide help to the analysis and design teams to determine non-functional requirements. To reach this goal, are established a requirement taxonomy and a questionnaire, in order to guide the elicitation of needs and the requirements identification process. The method is applied to three case studies from which some conclusions and perspectives are derived. Section 2 presents the literature review. Section 3 proposes a classification of requirements and the questionnaire. Section 4 illustrates the method applied on case studies. Section 5 concludes on the interest of the proposal and gives future perspectives.

2. LITERATURE REVIEW

In order to be clear, it is necessary to start with some definitions that will help the reader to understand Systems Engineering philosophy, on which this research work has been carried out.

2.1 Systems Engineering & Requirements

Systems Engineering (SE) can be described as an "*interdisciplinary approach governing the total technical and managerial effort required to transform a set of stakeholder needs, expectations, and constraints into a solution and to* *support that solution throughout its life*." (ISO/IEC/IEEE, 2017, p. 457). The SE holistic vision suggest studying problems through a contextual analysis of the situation, exhaustively gathering the needs and later translating them into technical requirements, which will define the possible characteristics of a future system. In that way, the SEBoK (2017) defines SE as "*a pragmatic approach, inherently interdisciplinary, yet specialized*". According to Faisandier (2012), Requirements Engineering (RE) can be considered as a part of SE activities. RE *"is concerned with discovering, eliciting, developing, analyzing, determining verification methods, validating, communicating, documenting and managing requirements"*. (ISO/IEC/IEEE, 2017, p. 381). This paper focuses on Requirements Engineering. Its contribution consists in the proposal of a requirements taxonomy and a questionnaire to provide support during the identification of stakeholder needs and requirements.

2.2 Needs and requirements

Literature offers several definitions of needs and requirements. According to Ryan et al. (2015) *"needs are typically considered to be expectations stated in the language of those at the business management level or of stakeholders at the business operations level. Requirements are considered to be formal statements that are structured and can be verified and validated"*. The purpose of translating needs is to transform a natural language expression into a more formal one, as clearly as possible, and without introducing any bias. The set of requirements will be useful to assess if the system meets the requirements, and to validate that the system meets the needs. Requirements have been classified through time and in different ways; but, which is the purpose of classifying requirements?

2.3 Requirement classifications

According to Palmer et al. (1990), requirement classifications are helpful as an approach for problem solving and requirement analysis, and to detect conflict among requirements. They may be applied to complex tasks as verification and validation. Sommerville et al. (1998) propose an approach to organize system requirements to provide a support for requirement elicitation; their approach identify the concerns (goals) which affect the system, derive a set of questions to assure that the information required will satisfy the concerns (essential information and constraints), and finally elicit and negotiate the requirements which ensure that the system will satisfy the identified concerns. Ryan et al. (2015), Faisandier (2015), and SEBoK (2017) highlight that the importance of these requirement classifications lies in that they allow taking all kinds of requirements in consideration. Authors like Glinz (2005), Badreau et al. (2014) and Mabrok et al. (2015) classify system requirements in two groups:

1) Functional requirements (FRs): they describe the expected services, what a system is supposed to or should do (Faisandier, 2012).

2) Non-functional requirements (NFRs): they are essential in the design process because they determine the technical specifications of the product that will be delivered; they impose constraints and capture the properties to operate the system; they also describe the non-behavioral aspect of the system (Mabrok et al., 2015). According to SEBoK (2017) they are the quality characteristics or attributes that define how is supposed to be a desired system.

Both, FRs and NFRs are needed in the design process: the first ones to satisfy the need in functionality, the seconds to make the system possible and to satisfy the non-functional user expectations. FRs often are considered as the most important requirements, because they define the systems functionalities, and less attention is paid to NFRs. However, researchers have recently argued that there is no underlying theory to answer "*why we ought to consider function as the most fundamental aspect of engineering design*" (Mabrok et al., 2015). Considering FRs and NFRs with the same importance will allow the analysis and design team to make sure that the selected design satisfy (or not) both type of requirements. Beyond this distinction between functional and non-functional requirements, several sub-classifications of NFRs themselves can be found in literature. However, they can differ. Indeed, Glinz (2005) expresses that there is no consensus of *"what a non-functional requirement really is"*, and the author adds that there are divergent concepts for sub-classifying NFRs.

2.4 Non-functional requirement classifications

Among the sub-classifications of NFRs, Glinz (2005) proposes a requirement classification based on four facets: kind, satisfaction, representation, and role. Faisandier (2012) and SEBoK (2017) proposes to classify the requirements by "type", that means "*the nature of the requirement itself"* (SEBoK, 2017). Lately, some authors have done interesting propositions, considering new kinds of non-functional requirements:

a) Grispos et al. (2017) mention that in the past few years, researchers have proposed to integrate what they call "forensic requirements" during system development, related to the detection, investigation, eradication and recovery of incidents. However, the authors express that techniques for eliciting and analyzing these forensic requirements have not actually been proposed in the literature.

b) Ryan (2014) talks about the "end of life" versus the "end of life cycle" of a system; the author proposes that the system design should focus on the system retirement stage to include requirements related to the transition between the different life cycles of the system. The author suggests considering several elements during the system concept stage: a) the reasons for system retirement, b) the potential retirement methods available, and c) the design issues that will be present from the consideration of each retirement method.

c) De Weck et al. (2012) talk about the "ilities" like desired properties of the system that are not the primarily system functional requirements, but the "ilities" should be considered due to their direct impact in those primarily functional requirements. The authors affirm that more recently the number of "ilities" has considerably increased because of the growing complexity of systems.

Thus, it can be concluded that non-functional requirements are as important as functional requirements, and that the quantity of non-functional requirements is directly related to system complexity.

2.5 Current industrial practices to elicit stakeholder needs

Authors like Hickey and Davis (2003) Faisandier (2012), Blanchard and Fabrycky (2011) and SEBoK (2017) converge in saying that current industrial practices to elicit stakeholder needs are techniques or methods like structured brainstorms workshops, interviews, questionnaires, simulation, models, prototypes, and quality function deployment among others. Each method or technique has advantages and disadvantages. For example, brainstorming has the advantage of generating an enormous number of ideas; but many of them are not "quality" ideas since they are not screened, tested or evaluated; or brainwriting, that produces even more ideas that brainstorming, but that not allow verbal interaction among participants (Brahm & Kleiner, 1996). Table 1 compares the advantages and disadvantages between interviews and questionnaires (Akbayrak, 2000); here, it is interesting to observe that, if these techniques are conducted simultaneously in a wise way, they would complement each other resulting in obtaining all the possible advantages.

Table 1. A summary of advantages and disadvantages of interviews and questionnaires. (Akbayrak, 2000)

Criteria	Interviews		Questionnaires	
	Advantages	Disadvantages	Advantages	Disadvantages
Access to information	✔			✗
Anonymity		✗	✔	
Application Skill		✗	✔	
Bias		✗	✔	
Confidentiality		✗	✔	
Cost		✗	✔	
Data Analysis		✗	✔	
Flexibility	✔			✗
Reliability	✔			✗
Response Rate	✔			✗
Sample size and Sampling		✗	✔	
Time		✗	✔	
Validity	✔			✗

Meaning of symbols: ✔ Advantage ✗ Disadvantage

3. TAXONOMY AND QUESTIONNAIRE

This section presents a taxonomy of requirements and a questionnaire whose objective is to guide the analysis and design team in identifying non-functional requirements.

3.1 Taxonomy of requirements

The taxonomy we propose results from a compilation of several complementary contributions found in literature. Primarily based on the requirements classification proposed

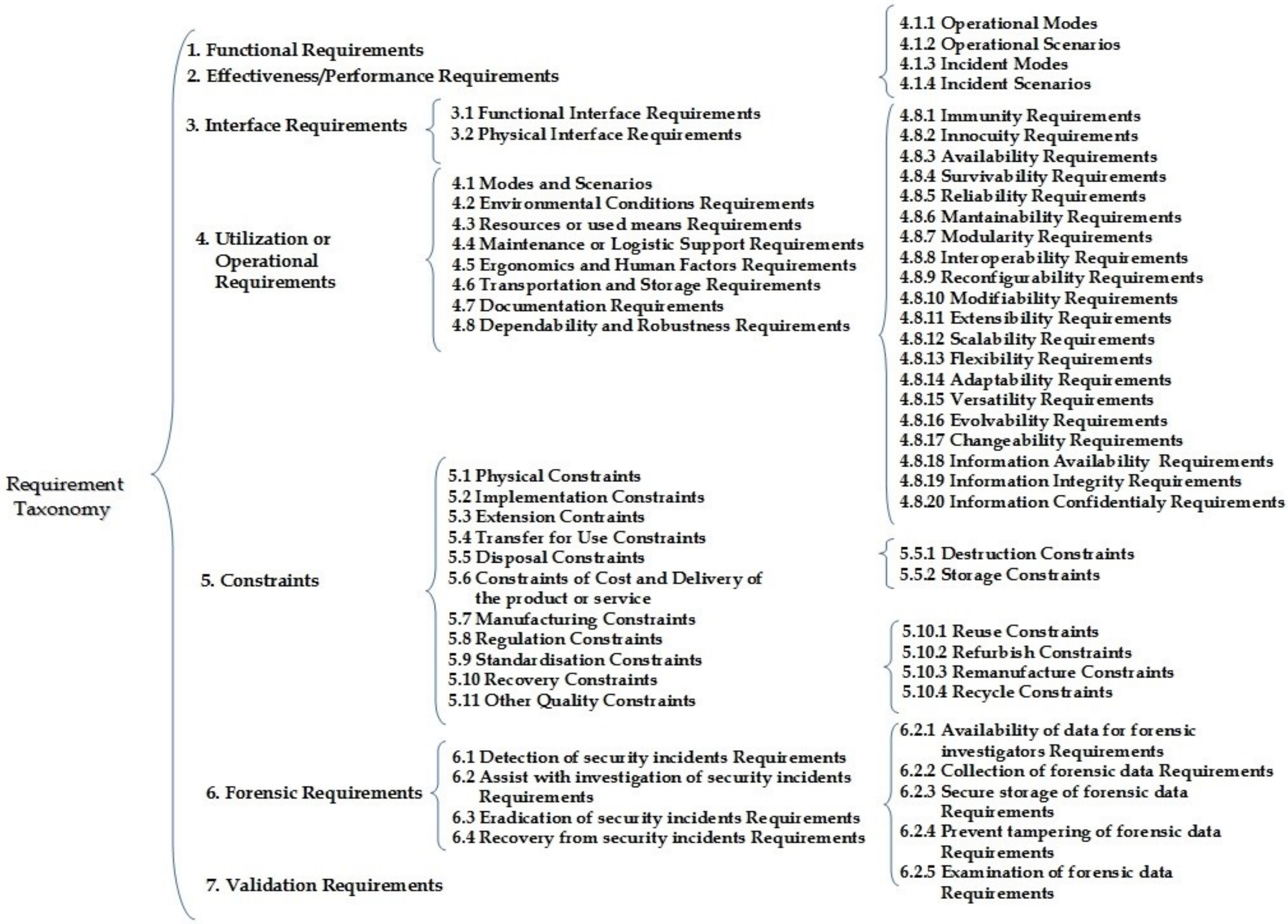

Fig. 1 Proposed Requirement Taxonomy

by Faisandier (2012), considered here as the most complete one, it also integrates the propositions of Grispos et al. (2017), Ryan (2014), and De Weck et al. (2012). The taxonomy includes both functional (expected services) and non-functional (all others) requirements (Fig. 1). The proposed requirement taxonomy should be read from the left to the right side; it shows seven main categories: six of requirements (number 1: functional requirements; numbers 2, 3, 4, 6 and 7: non-functional requirements) and one of constraints (number 5). When available, there are shown subcategories and sub-subcategories of requirements and constraints.

3.2 Questionnaire

Once the taxonomy was elaborated, each requirement definition statement was transformed into question(s); in this way, the different types of requirements are considered when stakeholder need elicitation is conducted. For example, the definition of *functional requirements* is "main operational activities or the highest-level of functions that the system of interest has to achieve", then, the derived question is "what are the main operational activities or the highest-level functions that the system of interest has to achieve?" Here below is presented the questionnaire, directly related to the taxonomy (Table 2).

Table 2. Questionnaire

1. Functional Requirements
1. What are the main operational activities or the highest-level functions that the system of interest has to achieve?
2. Effectiveness / Performance Requirements
2. What is the expected performance or effectiveness of the system? What is the quality metric of effectiveness?
3. Interface Requirements
3.1. What are the functional interfaces between the system and the components of its operational context?
3.2 What are the physical interfaces that connect the system to the components of its operational context?
4. Utilization or Operational Requirements
4.1.1 What are the Operational Modes (on/off, standby, run, maintenance, etc.)? What is the system expected to do in each mode? What are the trigger events that initiate the transition from one mode to another one?
4.1.2 Describe each Operational Scenario
4.1.3 What are the Incident Modes? What the system is expected to do in each mode? What are the trigger events that initiate the transition from one mode to another one?
4.1.4 Describe each Incident Scenario
4.2 What are the physical conditions to which the system is submitted? Describe.
4.3 What are the consumed resources or produced elements by the system, what do not belong to the system? Is it possible to define the requested autonomy, expected maximum of consumption or rejections, etc.?
4.4 What are the requirements concerned to conditions of maintenance and logistics, duration of maintenance actions, management of spare parts, availability of maintenance equipment, qualification of the maintenance team, possibility or not for having specific tools, marking, identification, etc.? Consider preventive, corrective, and predictive maintenance.
4.5 What are the expected man-system interfaces? What are the expected available commands and information? What are the disturbing elements resulting from the environment that could influence the operator? Describe.
4.6 What are the requirements concern transportation? What are the requirements concern storage? What are the requirements concern handling?
4.7 What are the requirements concerning the user documentation as installation, operating and utilization of the system, preventive, corrective, and predictive maintenance procedures, training handouts, etc.?
4.8.1 What is the expected system ability to resist to natural, accidental or unintentional external threats?
4.8.2 What is the expected system ability to guarantee the protection of the environment (people and goods) against its own actions?
4.8.3 What percentage of time, ratio or average time the system will operate without failure a requested function at any time, under given environmental, maintenance and usage conditions?
4.8.4 What is the aptitude of the system to achieve its mission including occurrence of internal failures, external threats of its environment, taken into account the expected degraded states?
4.8.5 What is the expected ability of the system to achieve a requested function without a failure, during a given period of time, under given environmental and usage conditions? What is the expected mean time to failure (MTTF)? What is the expected mean time between failures (MTBF)? What are the expected failure rate per hour, km, number of cycles, etc.?
4.8.6 What are the needs for maintainability?
4.8.7 In what degree should the system be composed of modules? What modules are necessaries?
4.8.8 How much effectively the system should interact with other systems? What are these systems?
4.8.9 Is it necessary that the system changes its component arrangement and links reversibly? What components?
4.8.10 Is it necessary that the system change the current set of specified system parameters? How much?
4.8.11 Is it necessary that the system accommodates new features after design? What are these new features?
4.8.12 Is it possible that the current level of a specified system parameter may change? What parameters? How much?
4.8.13 Is it necessary that the system may be changed by a system-external change agent with intent? What agent(s)? When? In what circumstances?
4.8.14 Is it necessary that the system may be changed by a system-internal change agent with intent? What agent(s)? When? In what circumstances?
4.8.15 Is necessary to satisfy diverse needs of the system without changing form (measure of latent value)? In what situations?
4.8.16 In what cases the system design is inherited and changed across generations (over time)?
4.8.17 When does the system needs to alter its operations or form, and consequently possibly its function, at an acceptable level of resources? In what situations?
4.8.18 What is the aptitude of the system to prevent a denial of access to a resource or information?
4.8.19 What preventive actions are taken against non-authorized modifications of the information?
4.8.20 What preventive actions are taken against non-authorized disclosure of information?
5. Constraints
5.1 What are the size, weight, color, amount of space, of memory volume, etc.?
5.2 Is there imposed solutions; examples components to reuse, technology to be applied, material to be used or not, etc.? What is the envisaged duration of the system life? Are there processes imposed on the development if no management/development plan is associated to the project?
5.3 Is there a constraint imposed for future evolutions?
5.4 What are the constraints concerning to the transfer for use?
5.5 What are the constraints concerning the disposal actions when the system can-not be recovered by any means?
5.5.1 Does the system has no useful parts or hazardous materials? Should the system be destroyed, disposed as waste or maybe incinerated?
5.5.2 Does the system can-not be recovered but neither destroyed? Is storage it the best solution? What documentation /information associated with the system as historical records, and the compliance with archival regulations must be kept? How long the system and its documents must be kept?
5.6 Is there a constraint of cost and delivery of the product? For example a performance of effectiveness requirement could be decreased to offer a lower cost.
5.7 What are the constraints resulting from the manufacturing actions: reuse of tools/of complete production line, gripping, test outlet, etc.?
5.8 What are the legislations, regulation applicable to the system?
5.9 What are the standard references applicable to the system?
5.10.1 What are the possibilities to use the system on its retirement stage? Is possible that the system may be reused in another life cycle: 1) as a complete system: in its original role, or in a diminish role; 2) as separate system elements, in other words, the complete system can-not be reused as a whole, but are one or more of its elements useful?
5.10.2 Is it possible that at the end of system life it could be renovated, renewed or reconditioned? Is additional work required for continuing operating the system in its original role?
5.10.3 Would the system need significant work to be able to operate in its original role?
5.10.4 Is it possible to recover saw materials from the system in order to recycle and

use it in a different form, or sold as scrap?
5.11 What are another quality constraints to take into consideration?
6. Forensic Requirements
6.1 What may help the system to detect a security incident?
6.2 What data helps to discover why and how a security incident occurred?
6.2.1 What is the aptitude of the system to prevent a denial of access to a resource or information to establish the cause of an incident?
6.2.2 What forensic data is acquired during investigations? How and what logging is done? How is system examined?
6.2.3 How long forensic data must be kept?
6.2.4 What forensic data must be prevented to be tampered?
6.2.5 What forensic data is going to be analyzed in order to know the cause of the incident?
6.3 What requirements may help to avoid and prevent security incidents?
6.4 What requirements may help the system to recover by itself when a security incident has occurred?
7. Validation Requirements
7. What are the justification activities that provide elements or arguments to select the most effective solution among candidate solutions that satisfies the set of needs, expectations and requirements of stakeholders? Describe. What is the validation strategy? What are the necessary documents for validation purpose? List them. Which are the activities or procedure to validate that the system satisfies the set of needs, expectations and requirements? Ex: tests. Which are the metrics and values to accept the system?

This questionnaire was applied in three case studies to help analysis and design teams to identify non-functional requirements. These case studies are described in the following section. Based in the research work of Brahm & Kleiner (1996), Akbayrak (2000) and Bouchereau & Rowlands (2000), we propose to apply this questionnaire in the following environment: a) in a collaborative session, preferably in stakeholder's facilities, with the possibility of being virtual if some stakeholders can-not attend the session, with the availability of chat, video and phone; b) with a facilitator who leads the session. During the development of the session, the facilitator reads the question, every stakeholder express what they want to say -orally or written if they prefer to keep anonymity-, and as needed, the facilitator adds more questions -like developing an interview- in order to clarify the point. This way, the facilitator mix both techniques –questionnaire with interview- to profit the advantages of both of them.

4. CASE STUDIES

The case studies were led in the Instituto Tecnológico de Toluca (ITT) in student projects. Students had to design three different systems and they used the questionnaire to find the non-functional requirements. The goal for us was to evaluate the simplicity of use of the questionnaire, and the gain of performance obtained using it. Case studies are introduced here below.

4.1 Design of an information system to monitor stoppages in production lines

Industry "X" (the company name is not mentioned for confidential reasons) is implanted in six countries in Latin America; it manufactures several kinds of packaging like industrial and food service packaging, disposable medical supplies, and packaging for mass consumption. After conducting a diagnostic in industry "X", students from the ITT Computing Engineering Department realized that one of the reasons for economic losses was the uncontrolled stoppage in production lines. They proposed to design an information system to monitor these stoppages in order to measure, control, and improve the situation. In this case study it was recognized that the questionnaire provided support in finding stakeholder needs that later were translated into non-functional requirements. For example, when identifying man-system interfaces, through question 4.5, the operator answered that the system may advise him through light and sound when the machine is stopped, but that he should be able to turn off this light and sound while he were serving the machine in order to avoid disturbance; he added that the visual aid should be big enough to see it without walking, and placed in an easy visible space. The operator expressed his interest in an "easy system" for him, arguing that if the system would add extra work for him –like walking–, he wouldn't use it.

4.2 Design of a web and mobile device information system for on-line shopping

On-line shopping is a practical way to save time, but it is not always easy to compare the prices of products. Students carried out a market study to find out the opinion of consumers when buying clothes on-line. Their study revealed that 88% of buyers would like to have an application to accede easier to several cloth stores and compare product prices. One example of how the questionnaire helped in this case study was when identifying the operational modes of the system; through question 4.1.1, the analysts identified the needs shown in Table 2.

Table 2 Example of identified needs

Operational Modes	On/off	Operation	Maintenance	Waiting for server connection
The system is expected to	Get fast connection to server	Maintain a fast connection to server	Engineers working on the system	Maintain a stable connection to server

4.3 Design of a wireless loader by magnetic induction through an electrical generator

It is fundamental to have electricity to do daily activities; the diverse electrical devices need an electrical feeding source and conductors to transfer the energy. Students observed that people who use bicycles as mean of transportation could generate the energy to charge their own mobile devices; nevertheless, one present problem to face is that wires make the solution non-practical and unsightly. Students proposed to design a system (electrical generator) that, assembled in the rims of a bicycle, would produce the amount of energy needed to load a mobile device in a wireless way through the application of magnetic fields. To this goal, they designed a module that reacts as a Wi-Fi network, in order to wirelessly transfer the electric power to the mobile device. In this case study, the questionnaire was valuable when identifying for example a) ergonomics and human factors, b) dependability and robustness, like avoiding damage for people; c) environmental conditions, for example the physical conditions in a rainy or sunny day.

4.4 Synthesis on the use-cases

As it can be seen, the three case studies addressed different kind of systems: a production system, a software system, and an electrical system. Using the questionnaire helped the students –who had not any experience in system design– to identify the non-functional requirements and to take them into account in their designs. Non-functional requirements are not easy to find, they are not elicited in a natural way, and the use of the questionnaire made it possible; that is the value added by the proposed taxonomy and related questionnaire. Nevertheless, during the application of the questionnaire some troubles were detected: a) some vocabulary was not familiar for the students, some questions were thus not well understood nor answered; and b) the systems were not very complex, for that reason some kinds of requirements (like some "ilities" and forensic requirements) were not identified as "needed"; one positive point is that the questions were asked, not forgotten, even if the answer of a question did not have a requirement as a result. After the experiments, an evaluation questionnaire was answered by the students and their professors in order to find opportunities for improvement. They are: a) to automatize the questionnaire with a software tool to facilitate its use; b) to give the possibility of consulting a glossary to better understand the definitions; c) in order to save time and have more ideas, every participant could answer the questionnaire by her/himself before the collaborative session is conducted; d) the facilitator of the collaborative session could be external, not an involved stakeholder, to bring impartiality.

5. CONCLUSIONS

In a changing and evolving environment, it is necessary to adapt the way of creating new systems for the emerging needs of the customers. The questionnaire that we propose is a simple but efficient approach to support and initiate correctly the development of complex systems. The questionnaire helps the analysis and design teams to find the requirements that are not naturally easy to identify; moreover, if ever new kinds of requirements would be discovered, they may be added to the taxonomy and the questionnaire may evolve to include very specific system needs. Nevertheless, it is important to remember that "*consensus exists that one elicitation technique can-not work for all situations"* (Hickey and Davis, 2003).

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