Eliciting Requirements for Industrial Design Using the Knowledge Management Strategy for Requirements Engineering

Karla Olmos-Sánchez
Universidad Autónoma de Ciudad Juárez
Av. del Charro 450
Chihuahua, MX
kolmos@uacj.mx

Jorge Rodas-Osollo
Universidad Autónoma de Ciudad Juárez
Av. del Charro 450
Chihuahua, MX
jorge.rodas@uacj.mx

Alberto Ochoa
Universidad Autónoma de Ciudad Juárez
Av. Del Charro 450
Chihuahua, MX
alberto.ochoa@uacj.mx

ABSTRACT

Eliciting sufficient high-quality knowledge from individuals to design a new product or solution is a very time-consuming and expensive activity, especially in domains where the knowledge is informally stated, partially complete, implicitly assumed, tacit and unstructured. The KMoS-RE strategy has the aim of acquiring and structuring the most quantity of knowledge, either tacit or explicit, in order to incorporate it into a specification that cover the needs and expectations of clients and users. The goal of this paper is to present the application of the KMoS-RE strategy in an industrial design real case. The case study showed that the strategy is effective eliciting and structuring knowledge of an informally structured and complex domain, that the artifacts proposed by the strategy act as an effective means of communication among the involved, and that the strategy evolves the knowledge of all involved in any application domain in a short time, which leads to better design decisions.

Keywords

Informally Structured Domains; Requirements Elicitation Strategy, Industrial Design; Knowledge Management

1. INTRODUCTION

Developing new products or solutions that required specialized technical knowledge is a complex task, especially when application domain knowledge has to be incorporated in their specifications (This work considers that the application domain is the domain where the product or solution will be deployment). This complexity increases when the product developers or solution-solver are not immerse in the application domain. In these situation, the efficient and effective functionality of new products or solutions depends on eliciting, discovering, specifying, verifying and validating their requirements [4][9]. However, this task presents serious and inherent difficulties in the process of eliciting and discovering the correct and appropriate requirements due to the complexity of the requirement task, the intricate interaction between solution-solvers and the intended users, and the limits of human information processing [5]. Usually, clients and users do not have a clear idea of the product or solution they require; even when they have it, they generally are unable to describe it. In most cases, they are so immersed in the application domain that takes important information for granted.

In order to attend this problematic, Requirements Engineering (RE) emerges as a research area that proposes theories, techniques, tools and processes with the aim of eliciting, analyzing, evaluating, consolidating and managing the requirements of a product or solution. Through time there have been various successful proposals that have helped to understand the requirements engineering area and facilitated the different tasks involved in it. However, the interest of this work is on some kind of situation with a higher level of complexity, named Informally Structured Domains (ISD) [17]. In this kind of domains, besides the characteristics mentioned above, the products or solutions are designed according to specific demands of clients, namely they are designed *ad hoc*. Thus, they must be developed according the experience and knowledge of domain specialists. This knowledge depends on the role and experience of domain specialists; therefore it is partial, informal, no homogeneous, unstructured, implicit and tacit. In addition, the product or solution requires of high quantities of specialized knowledge that cannot be possibly for a person to have; thus, a specialized team with distributed knowledge is necessary. In general, in ISD not all concepts and their relationships are formally defined, the solutions are diverse, consensual and unverifiable and domain specialists use large amounts of tacit knowledge in order to attend the everyday situations. Tacit knowledge is personal and context-specific knowledge, generated by experience and therefore, difficult to communicate and formalize [20] and could cause that critical expectations, knowledge and needs of the stakeholders remain hidden [6]. All of these ISD characteristics difficult the RE's tasks causing that the set of requirements and in consequence the product or solution developed would result inadequate and/or increase the cost and development time.

According to Hansen *et al* [8] this situation is present in several areas such as software design, industrial design, graphical design, instructional design, and business process design. We consider that it is also present in other areas such as developing intelligent systems or intelligent data analysis [17]. In general, every problem that requires a complex, highly creative solution, in which the problem solver is not part of the application domain, and that needs eliciting sufficient high-quality knowledge through a cognitive dialogue to understand the clients' need and expectations faces this challenge

Although all of these areas share the challenges of RE, the major source of RE research comes from software engineering. In this area the critical role of requirements has been recognized for decades because software systems are always embedded in an application domain and their usefulness depends on the problems they can solve and on the objectives they can achieve in those domains [3]. Therefore, the research of this work started analyzing software engineering proposal in order to select the most suitable, and integrating them in a strategy that can be applied to elicit requirements in ISD. In order to reach this goal a perspective that embraces the elicitation requirements problems of all areas mentioned above is necessary. We assume that a Knowledge Management (KM) perspective of RE that emphasizes the importance of knowledge is a useful approach for addressing certain RE inherent problems, due to the characteristics of ISD. This idea is not new [19][23][11], but only few efforts provide a full KM perspective of RE [22]. This perspective involves 1) seeing RE as a KM process where the knowledge is transferred and transformed in a spiral of knowledge evolution, 2) distinguishing between explicit and tacit knowledge 3) emphasizing the application domain knowledge, and 4) facilitating the knowledge exchange among all involved in the project, either domain specialists or solution-solvers.

The KMoS-RE strategy [16] has been developed as a pattern in a stream of decisions, oriented to the transfer or transformation of knowledge, specially designed to be applied in the context of ISD, with the aim of acquiring and structuring the most quantity of knowledge, either tacit or explicit, and incorporate it into a specification that cover the needs and expectations of clients and users. As we mentioned above, the strategy is based in software requirements research, but it is designed for using in ISD, either software system development or industrial design, among others.

The goal of this paper is to present the application of the KMoS-RE strategy in an industrial design real case. The strategy was evaluated to be used as the requirement process of HVAC (Heating Ventilation and Air Conditioning) modules design with the aim of obtaining a product specification the closest to the clients' needs and expectations. HVAC module design is a complex task because it includes a lot of cognitive activities, such as establishing the basic specifications for the provided application, analyzing the building characteristics, selecting the appropriate air conditioning system and its components, and analyzing the control system, among others. The remainder of this document is as follows: Section 2 provides a formalization of ISD. Section 3 explains the KMoS-RE strategy. Section 4 describes the real case study. Finally, in section 5, conclusions and future work are provided.

2. ISD Formalization

ISD are located in the field of *Knowledge Engineering* and *Requirements Engineering* and has the following characteristics [17]:

- Presence of multiple *Domain Specialists* (DS) who have different experience, point of view, interests and expectations, and whose knowledge of the application domain varies depending on their role and function in the domain. Domain specialists generally have a vague idea about the product or solution.
- Presence of a group of *Solution Solvers* (SS) who generally are unfamiliar with the application domain. They have technical knowledge about the solution and must know the solution requirements.
- The *Solution* (S) has a unique design and solves or addresses a particular situation. The Solution (S) could be a product or a solution and must be developed according to a *Solution Requirements Specification* (SlRS).
- The SlRS is a document that contains the greatest possible amount of correct, appropriate and unambiguous requirements.
- The SlRS development will require great quantities of *domain and technical knowledge* about the solution.
- In order to develop the SlRS, a *cognitive dialogue* is necessary among all involved in the project, either solution-solvers or domain specialists.

Based on the previous characteristics, the problem can be formulated as follows.

Given:

$ISD = (DS, SS, KT, KH, K, Nc)$ a well-defined area represented as a sextuplet, where:

- $DS = \{ds_1 \dots ds_m\}$ is a set of domain specialists ds, where ds_m represents the value taken by the variable ds in the $m-th$ unit.
- $SS = \{ss_1 \dots ss_n\}$ is a set of solution-solvers ss, where ss_n represents the value taken by the variable ss in the $n-th$ unit. A solution-solver is an individual, generally not involved in the domain, with knowledge and experience to propose a suitable solution S to the necessity Nc. The SS members must know the features of the necessity Nc.
- $KT = C \cup R$ is the union set of concepts and relationships, namely the *knowledge that* where:
  - $C = \{c_1 \dots c_q\}$ is a set of concepts c, where c_q represents the value taken by the variable c in the $q-th$ unit. A concept is knowledge about objects sharing similar properties.
  - $Rdf= \{rdf_1 (c_1 \dots c_k) \dots rdf_r (c_1 \dots c_k)\}$ is a set of relationships rdf defined formally, where rdf_r represents the value taken by the variable rd_f in the $r-th$ unit.
  - $Rdc = \{rdc_1 (c_1 \dots c_k) \dots rdc_s (c_1 \dots c_k)\}$ is a set of relationships rdc defined by consensus, where rdc_s represents the value taken by the variable rdc in the $s-th$ unit.
  - $R = Rd_f \cup Rd_c$ is the union set of Rdf and Rdc being a relationship a representation of the k concepts in a relationship in the domain, with $k >= 2$.
- $KH = Bs \cup Bns$ is the union set of Bs and Bns, namely knowing how, where:
  - $Bs = \{bs_1 \dots bs_u\}$ is a set of situated behaviors bs, where bsu represents the value taken by the variable bs in the $u-th$ unit. A behavior is a set of observable and measurable interactions; a situated behavior depends on the context and does not have solution algorithms, so depends on the knowledge of the domain specialists to be accomplished.
  - $Bns = \{bns_1 \dots bns_v\}$ is a set of non-situated behaviors bns, where bns_v represents the value taken by the variable bns in the $v–th$ unit. A non-situated behavior has at least one algorithmic solution.
- $K = [k_{ij}^{\omega}](m+n)_t$ a matrix, $i = \{1 \dots m + n\}, j =\{1 \dots t\}$, where $m + n$ is the sum of domain specialists plus the solution solvers and t is the sum of the number of concepts, relationships defined formally, relationships defined by consensus, situated behaviors and non-situated behaviors, i.e. $t = q + r + s + u + v$ where:
  - k_{ij}^{ω} is the degree of tacitness of the domain specialist ds_i or the solution-solver ss_i about the concept c_j, the relationship r_j or the behavior b_j.
  - ω a membership degree, with $\omega = f (p, pk)$, where

$$f : (DS \cup SS) \times (C \cup R \cup B) \rightarrow [-1, 0, 1]$$

is an intuitionistic membership function of the tacitness of p_i about the piece of knowledge pk_j, being p a domain specialist or a solution solver and pk the knowledge about a concept, a relationship or a behavior, and

$\forall(p)\ \forall(pk)[\omega(p, pk) = 0 \rightarrow pk \in \text{ tacit } \wedge\ pk \in p]$,

$\forall(p)\ \forall(pk)[\omega(p, pk) = 1 \rightarrow pk \in \text{ explicit } \wedge pk \in\ p]$ and

$\forall(p)\ \forall(pk)[\omega(p, pk) = -1 \rightarrow pk \in p]$

- $Nc \subset (B \cup C \cup R)$ and Nc represents a necessity of the clients and users. Sometimes the necessity corresponds to a problem in the domain, but not always. In both cases, the necessity or problem demands a suitable solution S.
- *S* is defined as a suitable solution. It means an any-time solution that satisfies the clients and users' necessities or expectations. An any-time solution is the best current solution that generates a process at the time it stops.
- $SlRS = \{sr1 \ldots sr_w\}$ is a set of solution requirements sr where srw represents the value taken by variable srw in the w−th unit. A solution requirement is a natural language statement to be enforced by the solution, possibly in cooperation with other system components, and formulated in terms of the application domain.
- *ANP* is informally defined as an *Arduous Negotiation Process* by which domain specialists and solution-solvers settle the features of the S while avoiding arguments.

3. KMoS-RE Strategy

The KMoS-RE strategy is designed to provide a systematic way to elicit structure and create knowledge that can be incorporated into a product or solution specification [16]. Following to [21], the strategy is composed by three sequential phases: Domain Modeling, System Modeling and Specification Developing. Below, a brief explanation of each phase is provided:

Domain Modeling Phase (DM). The first phase of the strategy aims to formalize the domain properties. It means to describe concepts, attributes, relationships between concepts, and basic integrity restrictions. The *Language of Extended Lexicon* (LEL) [10] is used to identify, classify and define the terms of the domain. Once the LEL is developed, it is used to build a graphical entity-relationship conceptual model. The externalization of this knowledge will enable achievement a consensus about the domain among all involved in the process; hence to minimize the asymmetry of knowledge. The concepts and relationships identified in this phase will generate the first version of the *Piece of Knowledge* (PoK) matrix.

System Modeling Phase (SM). Requirements engineers should model two versions of the system: the system as it exists before deployment a solution (current system), and the system as it should be when the solution will be operated in it (future system). The aim of this phase is to formalize the current and future system processes. The *Use Cases Model* [7] is used to model the system, both current and future. The information used to develop this model is derived from the LEL and the conceptual model. The behaviors identified in this phase will transform the PoK matrix.

Specification Development Phase (SD). In this phase, the requirements engineers derive the set of requirements from the *Uses Cases* of the future system. These requirements will be used to build the Solution Requirements Specification (SlRS) document.

The strategy is supported by the *Knowledge Evolution Model for Requirements Engineering* (KEM- RE) (section 3.1) and includes transversal activities to make explicit the tacit knowledge, such as 1) recording the wrong beliefs and 2) keeping track in the PoK (Piece of Knowledge) matrix, the tacitness level of concepts, relationships and behaviors by every involved in the project. The goal of the matrix is showing what pieces of knowledge should be made explicit.

Fig. 1 shows a structural perspective of the KMoS-RE strategy, phases are represented by redounded rectangles and artifacts are represented by square rectangles. The labeled arrow shows that the activities of tacit knowledge identification must be done transversely.

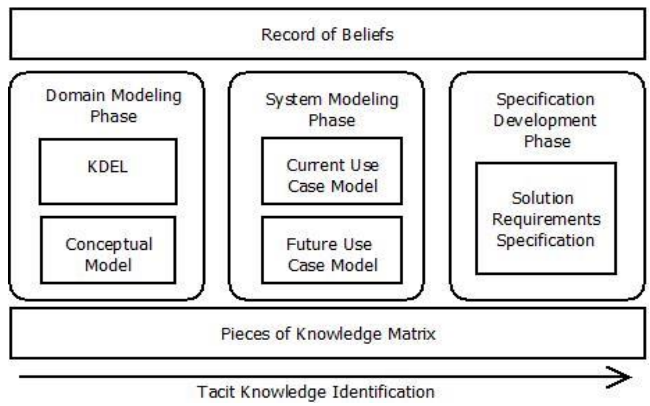

Fig. 1. Structural Perspective of the KMoS-RE Strategy

3.1 Knowledge Evolution Model for Requirements Engineering

In ISD, understanding the problem and the structure of the solution are intertwined [13]; the solution-solvers must explore different areas of the problem to find a solution; they should dialogue with the diverse domain specialists, who have their own domain knowledge, and possibly, their own perspective of the possible solution. By performing this task, the knowledge of the solution-solvers about the application domain increases. If necessary, they can return to previous states of the project but with additional knowledge that allows them to explore new possibilities of solution. In summary, the knowledge of the problem and its solution gradually evolves as requirements engineers gain more knowledge of the domain due to social interaction and their involvement with the business processes.

In order to model that behavioral, the *Knowledge Evolution Model for Requirements Engineering* (KEM-RE) was developed based on the SECI model proposed by Nonaka [14][15]. The author proposes a model of knowledge conversion in organizations based on Polany's theory about tacit knowledge [20]. For him, knowledge creation in an organization is the result of social interactions that involves tacit and explicit knowledge. The SECI model postulates four iterative conversion modes: 1) *Socialization*, the process of transferring tacit knowledge between individuals by sharing mental models and technical skills; 2) *Externalization*, the process of converting tacit knowledge to explicit through the development of models, protocols and guidelines; 3) *Combination*, the process of recombining or reconfiguring existing bodies of explicit knowledge to create new explicit knowledge; and 4) *Internalization*, the process of learning by task repetition. Some of these tasks could have been defined by explicit knowledge. Whatever the case, individuals will absorb the knowledge as tacit knowledge again.

The KEM-RE is an iterative cycle (Fig. 2) composed by four stages that include the four kinds of knowledge processes in the innovation of complex problem solving [12]:

- *Knowledge Elicitation and Creation (KE&C) Stage.* The requirements engineers (filled circles) elicit knowledge from domain specialists (empty circles) and vice versa. The socialization mode (empty bar) predominates.
- *Knowledge Integration and Application (KI&A) Stage.* The requirements engineers integrate the acquired knowledge and their own experience into models. This is a complex activity in which combination and externalization modes are presented. In addition, as the requirement engineers develop models they internalize (clouds) the domain knowledge.
- *Knowledge Sharing and Exchange (KS&E) Stage.* The models developed by requirements engineers will be shared with the domain specialists. This phase takes place through socialization.
- *Knowledge Validation (KV) Stage.* The domain specialists validate the models. In order to develop this activity, an arduous negotiation process is necessary since they must internalize the knowledge behind the models. This process leads to the elicitation of new knowledge. Then the cycle starts again.

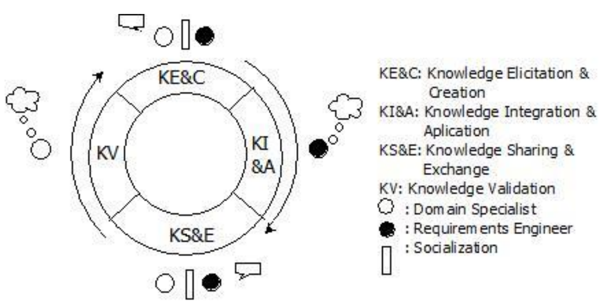

Fig. 2. Knowledge Evolution Flow for Requirements Engineering

3.2 KMoS-RE Activity Flow

The Fig. 3 depicts the activity flow of the KMoS- RE strategy at a global level in UML notation. Every activity of the strategy corresponds to one state of the KEM-RE: *Model Validations (MV*) is related *to Knowledge Validation (KV), Knowledge Elicitation (KE)* is related *with Knowledge Elicitation and Creation (KE&C), Model Discussion (MD)* corresponds to *Knowledge Sharing and Exchange (KS&E), and Domain Modeling (DM), System Modeling (SM) and Specification Development (SD)* corresponds to *Knowledge Integration and Application (KI&A).* The swim lanes in the figure represent the activities developed by each type of actor.

The KMoS-RE strategy begins with an *Initialization Activity (IA)* in which an initial interview is conducted. This information can be completed with formal documents such as user manuals, policies, business processes, and even legacy systems. After the interview, the requirements engineers initialize the PoK matrix by identifying domain specialists, concepts, relationships and behaviors. Finally, the values of the PoK matrix are recorded according the knowledge tacitness level.

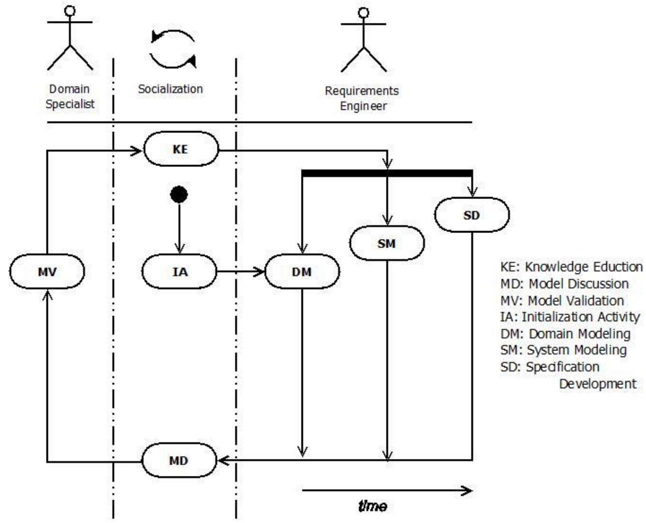

Fig. 3. UML Activity Flow Diagram of the KMoS-RE Strategy

Once the *IA* is concluded, the requirements engineers begin to develop the artifacts to model the domain. Then, the requirements engineers discuss the models with the domain specialist in order to validate them. By doing this process, more domain knowledge is elicited, and the requirements engineers can decide to improve the previous models or to continue with the artifacts of the next phase, that is, the requirements engineers can work in parallel with several models but it is necessary to start in the established order. The above is represented in Fig. 3 with a bold line. These activities will be repeated until those involved in the project reach a consensus about the set of requirements for the solution. Each phase is composed by a set of tasks that will guide the requirements engineers to the development of the artifacts; the details of the KMoS-RE strategy can be consulted in [18].

4. INDUSTRIAL DESIGN CASE STUDY

FLUTEC Design + Build Company is a manufacturing company located in the city of Juarez, Chihuahua, on the US-Mexican Border. This company designs and builds Heating Ventilation and Air Conditioning (HVAC) modules specifically designed to meet the demands of its clients on a case-by-case basis. In other words, FLUTEC offers a customized build for every single project they undertake.

HVAC module design is a complex task [2] because it includes a lot of cognitive activities, such as 1) establishing the basic specifications for the provided application, 2) analyzing the building characteristics, 3) selecting the appropriate air conditioning system and its components, and 4) analyzing the control system, among others. HVAC design becomes even more difficult because there is a lot of information and restrictions about the domain where the HVAC will be installed and this knowledge belongs to the domain specialists, a group of specialists from different fields, such as mechanical engineers, control engineers, electrical engineers and architects; therefore it is incomplete and vague. Moreover, there could be multiple and controversial solutions, so that the criteria to determine the goal are complex and imprecise.

To deal with the challenges of eliciting requirements to design HVAC modules, the company has developed an artifact in which the basic necessary information of every project is included. They have called "DNA" to this document, as a metaphor for the *deoxyribonucleic acid*. To facilitate the DNA document building process, the company developed a generic DNA; a guideline composed of general attributes. For each project, a person is assigned to elicit requirements and assign values to these attributes. The DNA document is used in two ways: as a guide to elicit requirements and, once it is completed, as a guide to design the HVAC module. It is a bridge between the domain requirements and the HVAC design. Since a requirements engineering perspective, the DNA acts as a specification document.

Although the DNA document had given some structure and order to the requirement process, there are still some associated problems that cause delays, reworks and elevated costs. Therefore, FLUTEC needs to improve its elicitation process in order to facilitate the negotiation between the requirements engineers and the domain specialists and to obtain a specification document closest to the needs of clients.

4.1 Case Study Design

The case study was an explorative research and had the objective of providing evidence that the KMoS-RE strategy could be implemented as the requirements elicitation process of FLUTEC. Therefore, the research question was formulated as follow: Is it feasible to implement the KMoS-RE strategy to elicit requirements of an HVAC module in order to obtain a specification as close as possible to the client's needs? To answer the research question, the following steps were performed:

1. Verify is the problem is an ISD according the formulation given in section 2.
2. Analyze the current requirements elicitation process with the domain modeling phase of the KMoS-RE strategy.
3. Empower the FLUTEC requirements engineers with the theoretical foundations about the KMoS-RE strategy.
4. Determine, in collaboration with FLUTEC engineers, the feasibility of implementing the strategy in the company

4.2 Case Study Development

The first step of the case study was to determinate if the problem is an ISD. According section 2 the problem belongs to ISD because the next characteristics:

- Presence of multiple domain specialists. FLUTEC offers a custom build for each project they undertake. Thus, it is necessary to elicit the requirements from the domain specialists; that is, everyone with knowledge about the domain. In this case, the domain is the building in which the HVAC module will be installed. The group of domain specialists will be formed by the technical team responsible for designing and constructing the building.
- Presence of a group of solver-solutions responsible for eliciting the requirements. In order to build a HVAC module, a multidisciplinary team composed by electrical, mechanical, electronic and control engineers work together and share their knowledge to arrive at a solution. Therefore, the solution-solvers will be all the specialists involved in the project.
- The product or solution has a unique design and solves or addresses a particular situation. As it was said above, FLUTEC offers a build-to-suit approach for every project.
- The product or solution must be deployed according to a Solution Requirements Specification (SlRS).
- The SlRS development significantly requires great quantities of domain knowledge and technical knowledge about the building and the solution.
- In order to develop the SlRS, an arduous negotiation process between the requirements engineers and the domain specialists, and even among the domain specialists is required.

The second step of the case study was to analyze the current requirements elicitation process. As explained before, the HVAC design activity is a complex process; thus, it was decided to use the *Domain Modeling Phase* of the KMoS-RE strategy to structure and make explicit the HVAC domain. At the end of the domain modeling phase the research team generated the LEL and the entity-relationship conceptual model, both validated by the domain specialists.

The LEL and the conceptual model were used to analyze the generic DNA document. After the analysis, it was confirmed that the generic DNA document was disorganized, incomplete, and incorrect. Moreover, it had ambiguous information.

The third step in the case study aimed to empower the FLUTEC requirements engineers with the theoretical foundations about the KMoS-RE strategy, such as requirements engineering process, knowledge transference process, symmetry of ignorance and tacit knowledge. The observations of every concept and their application in the FLUTEC environment are explained below:

- *Requirements Engineering Process.* The FLUTEC engineers empirically understood the importance of the requirements elicitation and the problems caused by it. This was the reason they created the DNA guide document. However, they did not have the knowledge that this activity could be viewed as a systematic process. Thus, the application of the DNA guide was conditional on the personal judgment of the FLUTEC project personnel.
- *Knowledge Transference Process.* It was explained to the FLUTEC engineers that the requirements engineering could be viewed as a knowledge transference process. This was a new concept for FLUTEC engineers. Also, it was explained that one of the main implications of this view is to be aware of the human limitation of information transference. So, the FLUTEC engineers realized that they could minimize the ambiguous and incomplete requirements by being aware of this phenomenon.
- *Tacit Knowledge.* The goal of the explanation about tacit knowledge was to sensitize and raise awareness of the problems caused by this phenomenon. It was observed that it is a very confusing term. However, once it was explained with examples, it was fully understood. As an example, FLUTEC engineers said that once a module was designed without the external ladder, because nobody asked the client if it was required. The mistake was evident only when they delivered the product and the product had to be redesigned.
- *Symmetry of Ignorance.* The concept of symmetry of ignorance and the consequences of not being aware of it was explained. FLUTEC engineers realized that when they did not know the building environment

(application domain), it was more difficult to design the HVAC module.

The final step of the case study was determine, in conjunction with *FLUTEC* engineers, the feasibility of applying the KMoS-Re strategy as the company requirements elicitation process. An analysis by every phase of the strategy was then performed, as it is explained below:

- *Domain Modeling Phase.* The first phase of the strategy aims to formalize the domain properties. The LEL would be used to identify, classify and define the terms of the application domain. In the HVAC module design, the application domain would be composed of knowledge of the building, its use and the environment. Once the LEL was developed, it would be used to build the conceptual model. The externalization of this knowledge will enable to achieve a consensus among the stakeholders hence minimizing the symmetry of ignorance.
- *System Modeling Phase.* In software development projects, requirements engineers should model two versions of the system: the system as it exists before the deployment of a solution (current system), and the system as it should be when the solution will be operated in it (future system). In the HVAC module design case, it is not possible to develop the current system. Thus, the FLUTEC requirements engineers would proceed to develop the future use cases. The information used to develop this model would be derived from the LEL and the conceptual model. In [1], a case study of a HVAC design using UML is presented. The paper explains how a HVAC system is modeled using use cases; it shows that it is feasible to use the case use model in a HVAC module design.
- *Specification Development Phase.* In this phase, the requirements engineers would derive the set of requirements from the Uses Cases of the future system. These requirements would be used to build the Solution Requirements Specification (SlRS) document.

4.3 Case Study Results

There were several significant results of this case study. The first one is that the KMoS-RE strategy helped to structure the knowledge domain of the HVAC module design. The HVAC domain is very complex: it is composed of a large quantity of concepts and relationships, and it involves several knowledge areas. The domain was structured and done explicated by the LEL and the entity-relationship conceptual model. These models also helped to visualize the domain from a global perspective. It was noticed that every domain specialist knew the information about his or her area, but they ignored information about others. The research team realized that in order to design the DNA guide document, every specialized area proposed the attributes they considered important, but there was no global vision of the document. According to FLUTEC engineers, a global perspective of the module would reduce errors caused by side effects.

The strategy also helped to reduce the symmetry of ignorance between the FLUTEC engineers and the research team in a short time. Reducing the symmetry of ignorance was a key factor in order to improve the communication between the teams and ensure that the analysis of feasibility was effective. Moreover, FLUTEC engineers recognized that the research team's knowledge about the design of HVAC modules evolved in a very short time. Therefore, they consider that the implementation of the strategy as their requirement process would have the advantage of better understanding of the clients' application domain.

Another result was that the FLUTEC engineers obtained awareness about the importance of requirements engineering, and of the problems that tacit knowledge and the symmetry of ignorance can cause. However, the most meaningful result was to validate the feasibility of implementing the KMoS-RE strategy as the requirements engineering process.

5. CONCLUSIONS AND FUTURE WORK

Since the advent of RE as a research area, the view of this discipline has changed from being considered a craft to being considered a critical and influential factor in implementing a solution in any application domain. Although the research work in RE has been good and productive, it has not been enough. Nowadays, there is not a universally accepted methodology or strategy for approaching RE problems. This is even more so if the problem belongs to an Informally Structured Domain (ISD), i.e. domain with a high degree of informality, where the knowledge is informally stated, partially complete, implicitly assumed, tacit and unstructured.

The KMoS-RE strategy confronts the problem of eliciting, structuring and creating knowledge in order to achieve a solution or a product closest to the needs of the clients or users and avoiding incorrect, inappropriate and ambiguous requirements in the context of ISD. The strategy was addressed from the knowledge transference and transformation perspective. This view led us to consider knowledge management theories to make the knowledge transference and transformation process more efficient and to make explicit the largest possible amount of tacit knowledge.

The case study showed that the KMoS-RE strategy is effective eliciting and structuring knowledge of an informally structured and complex domain, such as the HVAC module design, which does not belong to software development. This result shows that the perspective of engineering requirements from the point of view of the characteristics of the domain led to a generic strategy that can be applied in different contexts. The case study also showed that the artifacts proposed by the strategy act as an effective means of communication among the involved. Finally, it shows that the strategy evolves the knowledge of any application domain in a short time, which leads to better design decisions.

As future work, it is necessary to continue applying the KMoS-RE strategy in several contexts in order to get an ever closer generic proposal for requirements engineering, as well as, developing software tools to automate some activities of the strategy.

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