Application of a User-Centered Design Approach to the Definition of a Knowledge Base Development Tool

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ABSTRACT

Knowledge Bases (KB) are used to store structured and unstructured information about a specific subject. KB are a key element of Expert Systems, a type of Computer-Based Information Systems designed to analyze and offer recommendations and explanations about a specific problem domain, providing support when human experts are not available or helping experts dealing with very demanding and critical problems, usually because of the problem's complexity, the volume of information processed, and the pressure for short time answers. Developing KB is a quite difficult task, since there is the need to figure out and map, among others, the knowledge elements, organization, context of use, composition and representation, relations, importance and the reasoning processes used to feed the inference process, combining the inputs coming from real world data with such knowledge in order to present the desired outputs. In this paper we propose to address the context and issues involved in defining the requirements for designing a KB development tool, which supports cooperative and participatory processes of knowledge elicitation, which, despite the eventual complexity of the problem at hand, are intuitive and easy to implement. This calls for an approach that carefully considers the principles and methodologies proposed by User-Centered Design.

Keywords: User-centred Design, Knowledge Bases, Expert Systems, Development Tools

INTRODUCTION

Decision Support System (DSS) is often used as a generic term to refer computer-based tools used to provide support to decision-making or problem solving processes. Such tools are particularly relevant when the decision

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factors are complex or the timeliness of the decision is critical, making the decision-makers' task difficult, for instance due to the amount of information to process, because of the uncertainty and vagueness involved, or because of the stressful pressure resulting from the environment or the impact of the decision. Human experts are a high value and costly asset which is not always available, and even the experts may feel the need to have aids to support their decision-making process. Therefore there is an ongoing effort to make available tools that replicate experts reasoning process offering support to human experts or, in the case of lack of experts, becoming an alternative means to ensure the access to the expertise required to deal with specific problems. Expert systems (ES) are a particular type of DSS which, as (Turban and Aronson, 1998) note, through the use of applied artificial intelligence techniques, aim to reach a level of performance comparable to a human expert. ES not only engage on complex inference processes, necessary for evaluating alternative options and offering good quality conclusions and advise, but also offer explanation about the rational that led to such conclusions.

The process of transferring the expertise of the humans into computers can be quite complex and challenging when the type of decision-making problems is unstructured or semi-structured, since they are often based on human intuition. The Knowledge Base is a key component of any ES, since this is where the knowledge elements about a specific subject are stored.

Developing Knowledge Bases for this type of applications is a quite difficult task, since there is the need to figure out and map, among others, the knowledge elements, organization, context of use, composition and representation, relations, importance and the reasoning processes used to feed the inference process, combining the inputs coming from real world data with such knowledge in order to present the desired outputs, ranging from structured (e.g., models) to unstructured (e.g., heuristics),

In this paper we propose to address the issues involved in defining the requirements for designing a Knowledge Base development tool (KBDT), which supports, cooperative and participatory processes of knowledge elicitation, which are, despite the eventual complexity of the problem at hand, intuitive and easy to implement. This calls for an approach that carefully considers the principles and methodologies proposed by User-Centered Design.

The present work builds on the experience in the fields of knowledge engineering and knowledge management that the authors gathered in the development of three independent Expert Systems in the areas of Ergonomic assessment of work places, occupational risk assessment and emergency management.

The structure of the paper includes the present Introduction, which sets the general context, followed by three sections characterizing: (i) concepts related with Knowledge, (ii) Expert Systems architecture and development issues, and (iii) User-centered design. In the next chapter we will elaborate on some issues related with developing a KBDT from a user-centered design standpoint. We will end this paper presenting some conclusions.

Knowledge

For this work it is important to characterize the concept of Knowledge in the context of ES. A common and useful approach is the one of the Data-Information-Knowledge-Wisdom hierarchy (DIKW), since this is a central model in the domain of knowledge management, contributing to define the nature and the relationships among each of these entities (Rowley, 2007). As Rowley notes, there is some debate on the authorship of the concepts underlying the model, however Ackoff's paper "From data to wisdom" (Ackoff, 1989) is often cited when DIKW hierarchy is referred. Ackoff's definitions for the entities of the hierarchy are:

- Data are defined as symbols that represent properties of objects, events and their environment. They are the products of *observation*. But are of no use until they are in a useable (i.e. relevant) form. The difference between data and information is functional, not structural.
- Information is contained in descriptions, answers to questions that begin with such words as who, what, when and how many. Information systems generate, store, retrieve and process data. Information is inferred from data.

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- Knowledge is know-how, and is what makes possible the transformation of information into instructions. Knowledge can be obtained either by transmission from another who has it, by instruction, or by extracting it from experience.
- Wisdom is the ability to increase effectiveness. Wisdom adds value, which requires the mental function that we call judgment. The ethical and aesthetic values that this implies are inherent to the actor and are unique and personal.

Ackoff's paper considers Understanding as a fifth entity. However this entity is not considered as a separate level of the hierarchy, but rather as a requirement for the transition from lower to upper levels of the hierarchy.

It is common to present the DIKW hierarchy graphically as a pyramid, as illustrated in Figure 1.

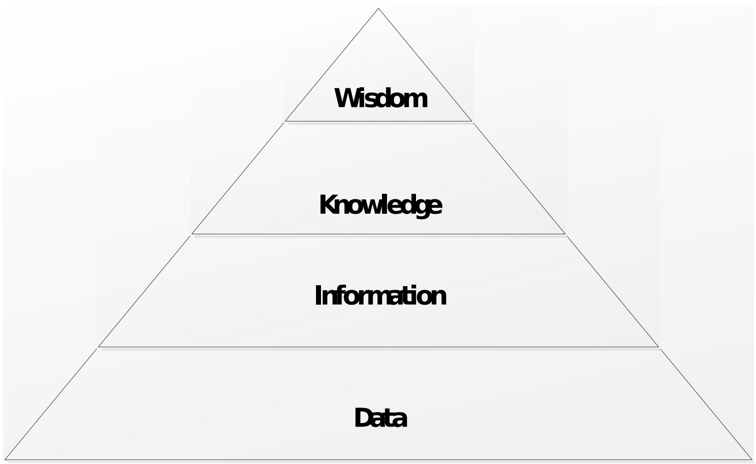

Figure 1. The DIKW hierarchy (Ackoff, 1989)

The European Committee for Standardization issued, in March 2004, the document "European Guide to good Practice in Knowledge Management - Part 1: Knowledge Management Framework" which states as a working definition of knowledge (CEN, 2004):

> "Knowledge is the combination of data and information, to which is added expert opinion, skills and experience, to result in a valuable asset which can be used to aid decision making. Knowledge may be explicit and/or tacit, individual and/or collective."

This definition brings together not only the concepts related with the DIKW hierarchy, but also the ones presented in 1995 by Nonaka and Takeuchi in the book "The Knowledge-Creating Company" (Nonaka and Takeuchi, 1995), where these authors argue that knowledge is initially created by individuals and latter becomes organizational knowledge through a process illustrated in Figure 2. The authors consider two dimensions of organizational knowledge creation: the epistemological, where two types of knowledge tacit and explicit are identified; and the ontological, considering individuals as the lower level, and teams, groups and organizations as increasingly higher levels. Explicit knowledge is the knowledge that can be expressed in words and numbers and readily shared (for instance in as data, scientific formulae, specifications, manuals) between individuals in a formal and systematic way (Nonaka and Konno, 1998). Tacit knowledge is the one which is more difficult to transfer since is highly personal and hard to formalize, often resulting from experience. Nonaka and Takeuchi state that "A spiral emerges when the interaction between tacit and explicit knowledge is elevated dynamically from a lower ontological level to higher levels". This spiral is translated in the SECI model (illustrated in the Figure 2) that addresses the four modes of knowledge conversion (Nonaka and Konno, 1998):

- socialization (from tacit to tacit knowledge) — tacit knowledge is exchanged through joint activities-such as being together, spending time, living in the same environment- rather than through written or verbal instructions;

- externalization (from tacit to explicit knowledge) — the articulation of tacit knowledge - that is, the conversion of tacit into explicit knowledge-involving: (i) techniques to express one's ideas or images as words, concepts, figurative language (such as metaphors, analogies, or narratives), and visuals; (ii) translating the tacit knowledge of customers or experts into readily understandable forms;

- combination (from explicit to explicit knowledge) — conversion of explicit knowledge into more complex sets of explicit knowledge. The key issues are communication and diffusion processes and the systemization of knowledge, relying on three processes: (i) capturing and integrating new explicit knowledge (e.g., public data); (ii) dissemination of knowledge directly by using presentations or meetings; and (iii) editing or processing explicit knowledge to make it more usable (e.g., documents such as plans, reports, market data); and

- internalization (from explicit to tacit knowledge) — conversion of explicit knowledge (embodied in action and practice, or using virtual situations) into tacit knowledge, for instance through learning-by-doing, training, and exercises.

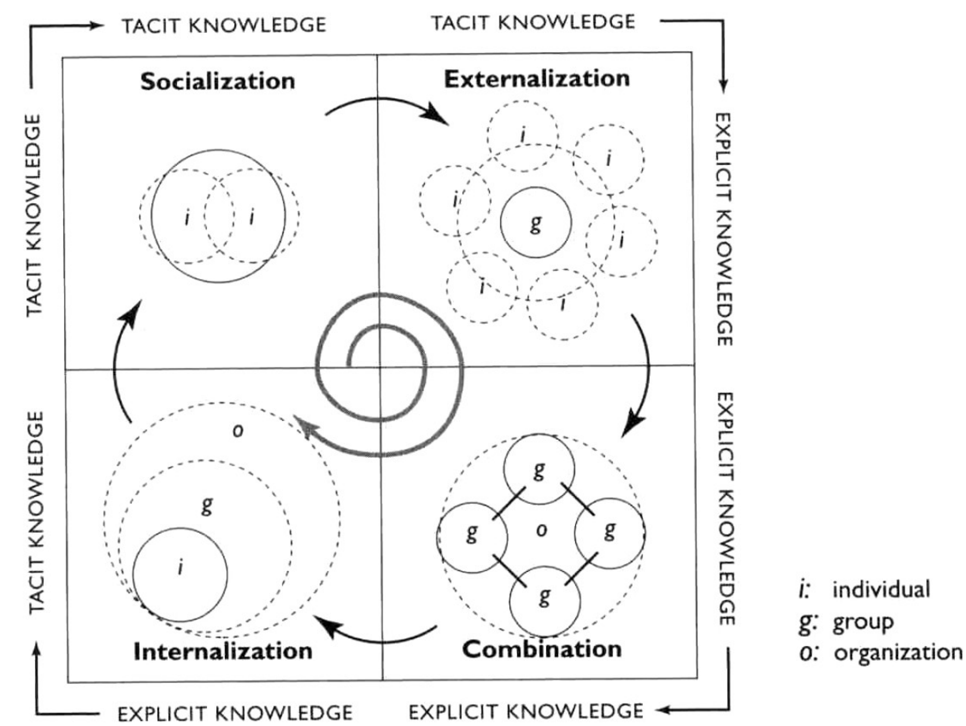

Figure 2. The SECI model (Nonaka and Konno, 1998)

When considering the characteristics of computerized support systems it is possible to map the levels of the DIKW hierarchy with typical categories of computer-based information systems. The first level (Data) maps with Transactions Processing Systems; the second (Information) with Management Information Systems; and, the third with Decision Support Systems (Turban and Aronson, 1998). Rowley recognized that wisdom is a topic that is omitted from information systems and knowledge management literature, and challenges the readers asking if it is believable that information systems have a role at all four levels, therefore if Expert Systems could map to Wisdom, the fourth level of the hierarchy (Rowley, 2007). We will not try to answer this conundrum; nevertheless, we may recall that ES are expected to make complex decisions, to perform inferencing based on symbolic manipulations, and to provide advice and explanations (Turban and Aronson, 1998).

Figure 3 represents the DIKW hierarchy, and SECI model within it, with regard to decision-making and programming complexity. In fact, computer systems designed to manipulate data are the simplest to program but are the ones that add less value in terms of decision making. The complexity increases as the focus of the manipulation evolves to information and to knowledge.

In the following sessions we will address the issues of representing and manipulating knowledge in computer-based information systems, and particularly in ES.

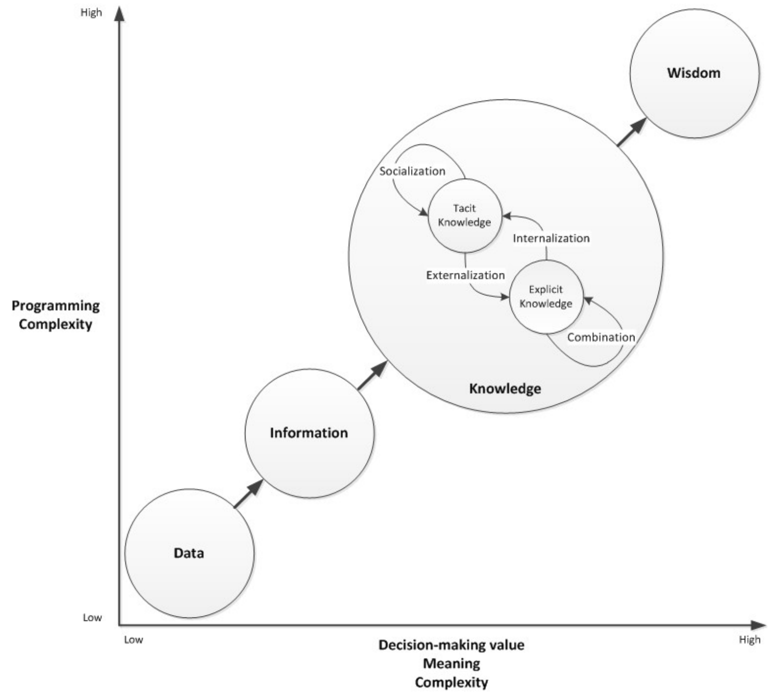

Figure 3. DIKW hierarchy and SECI model representation with regard to decision-making and programming complexity

Expert Systems

As mentioned in the introduction an expert system is a particular type of DSS which tries to replicate the reasoning of a human expert. An ES is expected to perform fast, providing replies to users' needs in a specific domain, extending their level of expertise in an easy, intuitive and controllable way.

Figure 4 illustrates the generic architecture of an ES, showing the four core building blocks - Knowledge Base, Working Memory, Inference Engine and User Interface. The functions of each block are:

- Knowledge Base - stores the knowledge required for the specific problem solving application;
- Working Memory - stores data about the particular problem context to analyze;
- Inference Engine - runs the knowledge against the data, assessing the concrete situation and generating the conclusions and advise, as well as any explanations required by the user;
- User Interface - offers the human-computer interaction means necessary to input data, insert requests and

obtain system outputs.

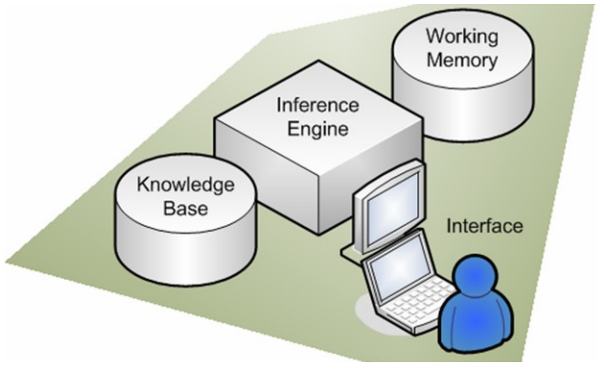

Figure 4. Generic architecture of expert systems

The growing innovation of technological solutions conducted to an explosive offer of different alternative devices with high computational and communication capabilities that offers the basis for cooperative work and collaborative decision-making. Naturally this is a field that offers a lot of opportunities for the application of ES. Figure 5 presents an example of such applications, illustrating the use of a distributed expert to support inter-agency cooperation in the context of Emergency Management (Simões-Marques and Nunes, 2014). As the authors note, in the response to critical situations (for instance in Disaster Relief operations) it is normal to involve several entities that should cooperate to improve the effectiveness and efficiency of their collective effort. This calls for common tools (like the one illustrated in the figure) for generating and sharing a common operational picture that ensures situational awareness, and that offer common evaluation criteria and advice which help anticipating the courses of action of other stakeholders involved in the process, while also helping to break cultural and procedural barriers, contributing to strengthen the maturity of the interaction among groups of responders and to elevate the level of global preparedness and response. This is a particularly relevant goal since Emergency Management is a complex process that requires the coordination of different actors, with different cultures, aims and views of the world.

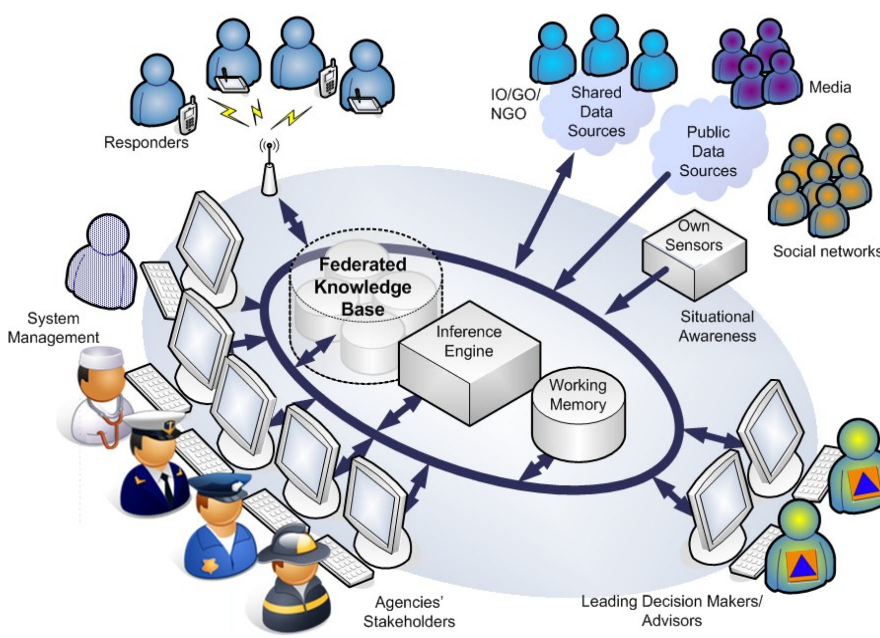

Figure 5. Example of a complex distributed expert system to support inter-agency cooperation in the context of
Emergency Management (Simões-Marques and Nunes, 2014)

The structure and contents of all these blocks have to be designed according to the type and specificities of the decision support required. Naturally designing an ES for complex broad scope decision-making problems is more challenging than designing one for dealing with more narrow problems. An example of an ES designed using the basic architecture for stand-alone application is FAST ERGO_X (Nunes, 2009), which is an ES that performs ergonomic assessment of workplaces and offers advice on potential lines of action to correct the identified inadequacies. An example of a more complex ES, designed to be used as a collaborative decision-making platform is SINGRAR (Simões-Marques and Pires, 2003), which is a system developed to support crisis management activities on navy ships.

Independently of the scope and complexity of the application, developing an ES requires performing Knowledge Management (KM) activities. KM supports the process of transferring expertise from human experts to computers and back to humans. (Turban and Aronson, 1998) identify four activities in such process: knowledge acquisition (from experts to other sources), knowledge representation (in the computer), knowledge inferencing, and knowledge transfer (to the user).

Knowledge acquisition activity relate with the Externalization and Combination phases of the SECI model, since in this stage it is required to make explicit knowledge that eventually is still tacit or to combine knowledge which is already explicit.

Knowledge representation requires dealing with abstract concepts (e.g., events, time, physical objects, beliefs) and their relations, which constitute the content of the knowledge base, involving a new scientific field called ontological engineering (Russel and Norvig, 2010). A concurrent topic is the one of knowledge visualization which is defined as “the use of complementary visual representations to transfer and create knowledge between at least two persons (Burkhard, 2005). Knowledge visualization exploits new ways of graphically representing insights, experiences, gathered evidence, and know-how in order to share knowledge, create new knowledge, or apply knowledge to decision making (e.g., lists, trees, semantic networks, schemas translating the know what/ where/how/what/why), making use of the whole spectrum of graphic representations, ranging from simple hand-drawn sketches to immersive virtual 3D worlds (Eppler and Pfister, 2013). Figure 6 illustrates some alternative standardized representations used in the depiction of elements of information and their relation which can help conveying knowledge.

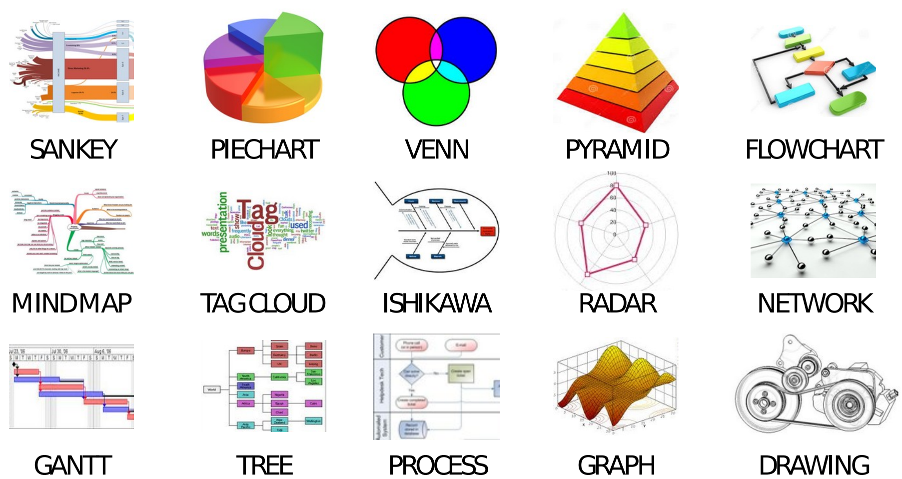

Figure 6. Example of standardized representations used in the depiction of elements of information and their relation

In (Nunes, 2007) and (Simões-Marques and Pires, 2003) the authors described the knowledge acquisition (or elicitation) and knowledge representation activities, respectively, for FAST ERGO_X and SINGRAR expert systems previously referred.

Developing an expert system KB is a quite challenging task, since there is the need to figure out and map, among others, the knowledge elements, organization, context of use, composition and representation, relations, importance and the reasoning processes used to feed the inference process, combining the inputs coming from real world data with such knowledge in order to present the desired outputs. Furthermore, the acceptance of an ES depends greatly on the quality of the outcome of these developing activities, making it a critical success factor. This was observed by (Hecht et al., 2011), which analyzed the factors influencing the adoption, acceptance and assimilation of Knowledge Management Systems' design. These authors argue that some factors cannot be directly influenced by design (e.g., environment, technological infrastructure, resources, organizational characteristics, social influence, attitude towards technology use, management characteristics, institutional characteristics), while others can be directly influenced by design (e.g., innovation characteristics, fit, expected results, communication characteristics, effort expectancy, performance expectancy, social system characteristics, process characteristics). Among the factors that can be influenced by design, the ones classified as effort and performance expectancy, are intimately related with usability (e.g., Complexity, Ease of Use, Usefulness, Results Demonstrability, Job-Fit).

Eliciting the contents of KB is a big task on its own; therefore it is desirable to have an ES shell available which avoids the burden from developers of designing the entire ES for each application. This is particularly true for the KB component. In fact, having knowledge base development tools available which are "user friendly" help reducing the application implementation effort to a minimum. This assertion implies the adoption of a user-centered design approach in the project and creation of KBDT. We will proceed reviewing some basic concepts related with the topic user-centered design.

User-Centered design

User-centered design is a structured development methodology to attain software usability, focused on the needs and characteristics of users, which should be applied from the beginning of the development process in order to make applications more useful and easy to use (Averboukh, 2001; Nunes, 2006).

Different authors and organizations offer their perspective about the principles that developers should adopted when designing a product to achieve an appropriate usability. For instance, European Union's Council Directive, 90/270/EEC, of 29 May, lists usability principles that should be taken into account when designing, selecting, commissioning and modifying software. Jordan identified a list of ten general principles to observe: consistency, compatibility, consideration of user resources, feedback, error prevention and recovery, user control, visual clarity, prioritization of functionality and information, appropriate transfer of technology, and explicitness (Jordan, 1998). Reiss presents usability techniques that help improve product design regarding functionality, responsiveness, and clarity (including its visibility, understandability, logicalness, consistency, and predictability) making it ergonomic and foolproof (Reiss, 2012). Despite the breadth, depth and terminology may vary, the core principles are equivalent.

Gerhardt-Powals identified a set of heuristics to improve performance, which includes automating unwanted load, reducing uncertainty, condense data, present new information with meaningful ways to support their interpretation, use names that are conceptually related to functions, limit data-oriented tasks, include only information on the screens that the user needs at any given time, provide multiple coding of data (where appropriate), and practice a judicious redundancy (Gerhardt-Powals, 1996).

ISO 13407 identifies four key activities related with user-centered design approach (see Figure 7), which should be planned and implemented in order to incorporate the requirements of usability in the process of software development: understand and specify context of use; specify the user and organizational requirements; produce design solutions; evaluate design against requirements (ISO 13407, 1999). These activities are performed iteratively, with the cycle being repeated until the usability goals have been achieved.

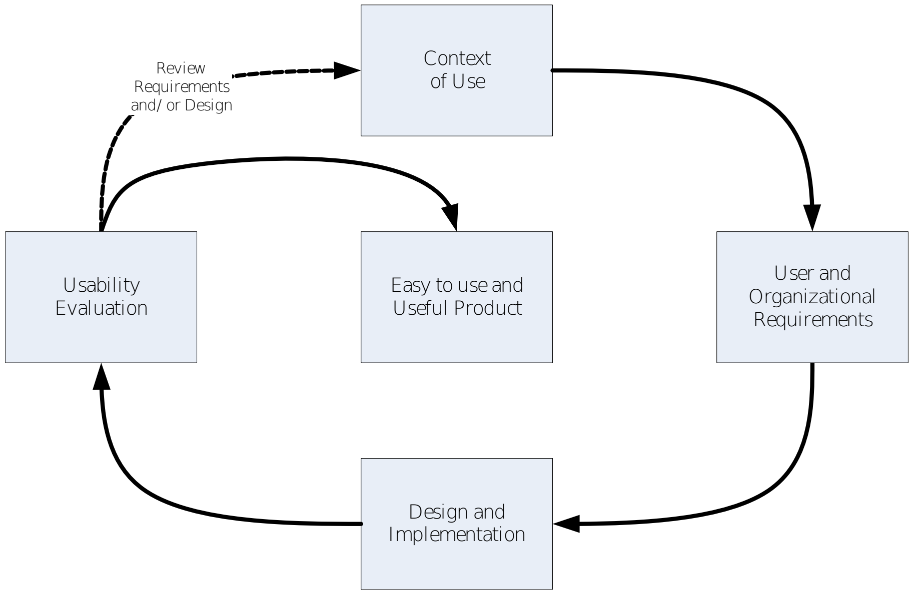

Figure 7. Activities of user-centered design, adapted from ISO 13407 (ISO 13407, 1999)

USER-CENTERED KNOWLEDGE BASE DEVELOPMENT TOOL

A KBDT is an environment designed to support the knowledge management activities, adapted to the ES context of use and to the application requirements. Regarding the knowledge acquisition phase it must support the elicitation of knowledge from experts (e.g., through structured and unstructured interviews) and the import of or link to explicit knowledge from different sources (e.g., other KB, multimedia, web-based). Regarding representation the KBDT has to support alternative ways (e.g., graphical, tabular, tree) of presenting and relating the knowledge (e.g., ontologies, models, heuristic rules, semantic networks, description logics). The knowledge has to be coded in formats that can be used during the knowledge inferencing and knowledge transfer phases.

These very generic statements unveil the need for an edition and visualization environment which is quite complex, since there is a great variety of alternative ways and formats of collecting and representing knowledge that must be made compatible as much and possible and, whenever possible, presented in multiple formats. In fact, it is long recognized that, according to their level of proficiency and personal likings, whenever there are different ways of doing the same task, users tend to choose the alternative that performs best in a way that the user can control. An obvious example is the use of keyboard shortcuts to perform functions that otherwise would force the user to take the hands out of the keyboard, use a pointing device to make multiple clicks to navigate on menus or on button panes. Naturally the option of using shortcuts is only controlled by individuals that are proficient on the use of the application and when the environment offers such functionality. Of course if you don't know a software you can always try to use the commonly used shortcuts (e.g., CTRL+C, CTRL+V) and hope the developers of such application adhere to the "standard". If you are well succeeded this means that the development of such software followed the some basic usability principles, making its use predictable. A new challenge imposed by the overwhelming progress of technology and the increasing number of computer device types, is finding the corresponding interaction alternatives when you use different devices (e.g., desktop or portable computer, tablets, smartphones). Note that the interaction with touch and multitouch devices follows paradigms that don't match many of the standards established for conventional human-computer interaction.

Resuming our previous discussion about proficiency and preference, the scope is much wider than just the issue of shortcuts. For instance, there are many ways of creating, accessing and editing databases. "Beginners" tend to prefer environment where they visually interact with objects that represent the structure and the relations of a particular instance of a database, hiding the cryptic language of scripts and queries. "Intermediate" level users probably risk switching to the DBMS text editor environment and fine tuning the code automatically generated in the visual environment. “Experts” will probably start using the text editor environment to quickly reutilize code already developed, change it, and eventually at the end switch to the visual environment to check in a glance if everything looks good. The readers can find identical type of examples on their own field of expertise. In fact, experts (e.g., engineers and scientists) usually fill the need to adopt formats for dealing with the details of a particular domain of knowledge that are not well suited to be the media of interfacing with non-experts (e.g., clients, workers, students).

Therefore, a KBDT has to offer means to make possible editing and visualizing knowledge in different formats. A self-sustained tool that contains all types the required functionalities might be a desirable solution to offer coherent and uniform environment. However, developing and keeping updated such a product seems almost impossible. Another fact to consider is that there are already many products available that partially solve the problem.

A pragmatic approach might be the KBDT to act as mediator between a KB (or a federation of KB) that stores the knowledge elements and different applications (e.g., open-source, commercial) that offer the required functionalities for edition and visualization. Such approach would allow a modular growing of the solution and would require minimum effort for keeping the KBDT up with new interaction and technological standards. Finally, it would also make possible to build the KBDT as a collaborative endeavor.

From a user-centered design standpoint, an advantage of this approach would be the opportunity to build the KBDT based on solutions that comply with usability standards. According to (Nielsen, 1993) the characteristics that influence the usability of a system are:

- Ease to learn - the system must be intuitive, allowing even an inexperienced user to be able to work with it satisfactorily;
- Efficiency of use - the system must have an efficient performance, i.e., the resources spent to achieve the goals with accuracy and completeness should be minimal;
- Memorability - the use of the system must be easy to remember, even after a period of interregnum;
- Errors frequency - the system must provide adequate conditions to users for achieving specific objectives with high accuracy and completeness;
- Satisfaction - the attitude of the user towards the system should be positive.

Thus, we advocate that a KBDT should be an environment complying with the following requirements. The KBDT must:

- Provide a User Interface that adheres to the commercial standards, to be easy to learn, intuitive and easy to remember;
- Provide means that support performing collaborative, participatory and distributed knowledge management, allowing the combination of the work of multiple users;
- Provide access to alternative edition environments (e.g., text and graphical) which offer different ways of creating, editing and representing the knowledge, ensuring an efficient performance for users with different skill levels and preferences, making it satisfactory to users;
- Provide means to import knowledge from compatible KB and from standard file formats (e.g., office and multimedia software packages), allowing the reuse and combination of already available knowledge;
- Provide knowledge acquisition support, namely through the use of methodologies for dealing with alternative knowledge sources, namely humans, deterministic, stochastic and heuristic models, and big data (e.g., questionnaires, analytical methods, simulations, fuzzy logics, data mining);
- Provide means to support different ES output types, both for advice and for explanation (e.g., text, tabular, graphical, georeferenced, actionable);

- Provide means to support different inference processes (e.g., deterministic, stochastic, heuristic);
- Provide the necessary help means to support of systems exploitation, as well as the means to recover from errors.

The implementation of the KBDT should be done using a spiral and incremental approach where typical users (i.e., knowledge managers) are involved to validate and refine the requirements, to evaluate design against requirements, and to assess the usability of the solutions. Figure 8 illustrates this user-centered perspective about the development of KBDT.

CONCLUSIONS

Knowledge Bases are used to store structured and unstructured information about a specific subject. KB are used by Information Systems to provide support and advice, and can be applied to a variety of application fields. Expert Systems are a particular type of Information Systems, designed to support restrict user communities that have to deal with complex problems. In this context a Knowledge Base is a component of an Expert System, together with the Inference Engine, the Working Memory and the User Interface. Expert Systems are designed to analyze and offer recommendations and explanations about a specific problem domain, providing support when a human expert is not available or helping experts in dealing with very demanding and critical problems, usually because of the complexity of the problem, the volume of information processed, and the pressure for short time answers. Developing Knowledge Bases for this type of applications is a quite difficult task, since there is the need to identify and map, among others, the knowledge elements, organization, context of use, composition and representation, relations, importance and the reasoning processes used to feed the inference process. The inference process combines the inputs coming from real world data with the knowledge stored in the KB in order to present the desired outputs.

In this paper we presented the basic concepts related with Knowledge, Expert Systems and User-Centered design, setting the stage to address the issues involved in defining the requirements for designing a Knowledge Base Development Tool, which follows basic Usability principles. The proposed requirements envisage a KBDT that supports cooperative and participatory processes of knowledge elicitation, which are, despite the eventual complexity of the problem at hand, intuitive and easy to implement.

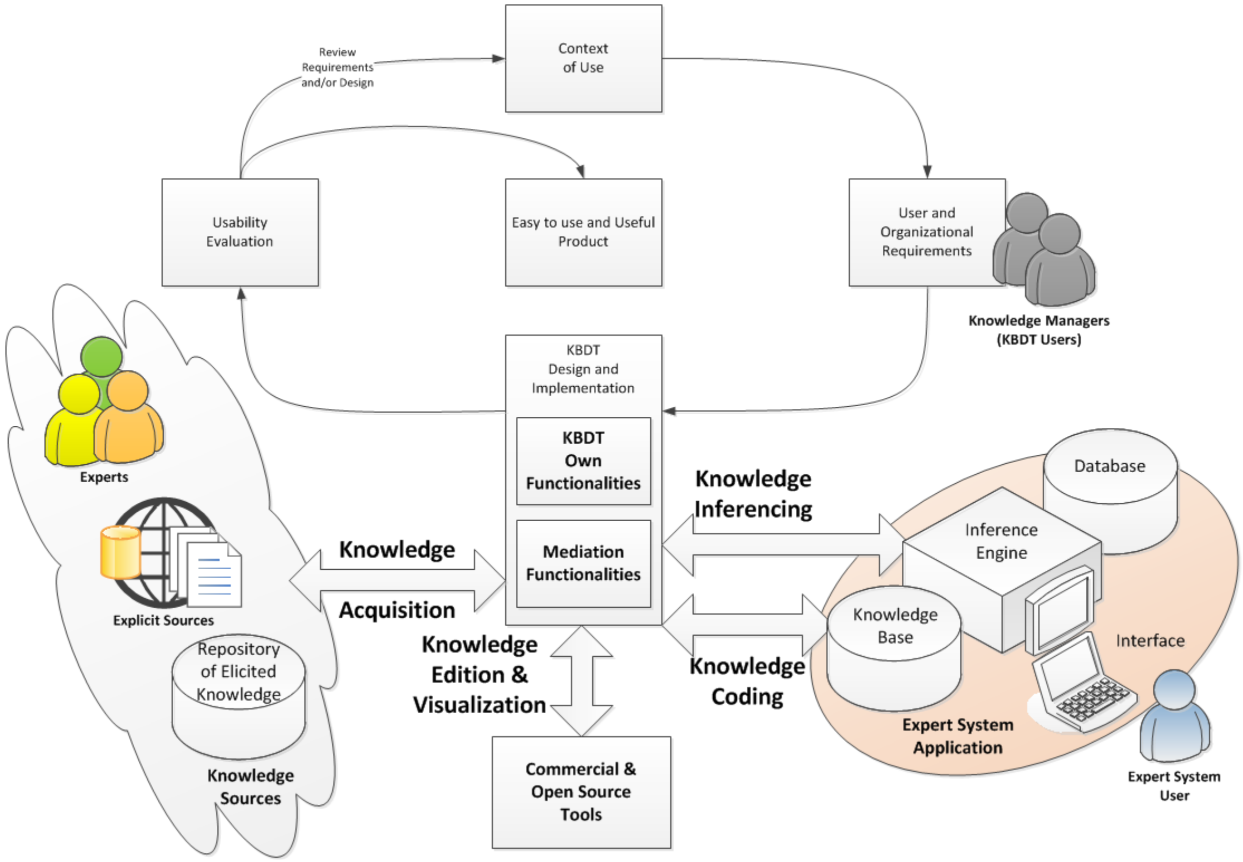

Figure 8. User-centered design perspective of KBDT

This work was build up on the experience in the fields of knowledge engineering and knowledge management that the authors gathered in the development of two independent Expert Systems in the areas of Ergonomic assessment of work places, and emergency management, which were referred to illustrate some of the discussed subjects.

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