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A Framework for Capturing and Applying Design Knowledge in Complex Systems

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Abstract. The large amount of available design information from different areas has become common in most organizations. Under these conditions, there are difficulties in sharing and reusing knowledge, especially by the fact that this knowledge is available within the company in different formats and locations. Due to this, design engineers often fail to use such information. To ensure a better use, it is important to organize and integrate the available knowledge in a collaborative manner. In this context, the Knowledge-based Engineering (KBE) approach can be associated. Through KBE concepts, the current study aims to develop a set of tools for assisting decision making, by storing and providing useful information in a timely manner. Such solution should meet the needs of its users (i.e. designers), as well as improve the quality of design activities along the Product Development Process (PDP). For this study, still under development, the following steps have been adopted: (a) delimitation of action scope (i.e. steps of PDP to be focused); (b) knowledge capture; (c) knowledge structuring through ontologies; (d) standardization; (e) development of rules; (f) creation of application solutions; and (g) performance evaluation of solutions. The application of the present proposal is expected to facilitate the access to information, significantly reduce the number of Engineering Change Requests (ECR's), as well as allow acquired knowledge to be used in subsequent projects (e.g. lessons learned).

Keywords. KBE, Knowledge Capture, Ontology, PDP.

Introduction

It is a common practice, not only in the automotive industry, but also in other segments, that good design practices of complex systems are available in the form of standards or other records of technical expertise. At various locations and formats, these are not always applied by project teams. Due to difficulty of access, time restrictions or the way information is made available, many products flaws (i.e. non-conformities) end up occurring due to valuable analyses that are skipped or information that cease to be supplied to subsequent project activities. These issues were confirmed during an evaluation of the development process of a company, which was the basis for the present study.

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Neglecting information at the beginning of the product development process (PDP) and the subsequent appearance of flaws causes increasing rework, which, in turn, makes design development longer.

In this context, the present research for technologies and methodologies for capturing and reusing knowledge, also referred as Knowledge Based Engineering (KBE), has been considered. Therefore, the focus of the present research is to develop a solution, in the form of an expert system based on an ontology model, that meets the needs of its users (i.e. designers), as well as improves the quality of design activities along the Product Development Process (PDP). Based on a diagnosis a group of critical components was set, i.e. hydraulic hoses, which will serve as the basis for the study.

To this end, some steps have been adopted: (a) delimitation of action scope (i.e. steps of the PDP to be focused); (b) knowledge capture; (c) knowledge structuring through ontologies; (d) normalization; (e) development of rules; (f) creation of application solutions; and (g) performance evaluation of solutions.

This article is structured as follows: Section 1 presents some of the important concepts for this study and related studies, Section 2 presents methodological aspects, Section 3 shows part of the activities necessary for the development of the solution, Section 4, discussion and Section 5, final considerations.

1. Theoretical Background

Faced with the problem previously elicited, most organizations have been concerned with the availability and management of knowledge. The main reasons for this increasing concern are given by globalization of business, need to quickly develop products, frequent changes in organizations and increasing technological advancements [1]. In this scenario, it is important to introduce some concepts to develop the solution proposed in this study. Among them are the flow of information in the PDP, KBE, knowledge capture, ontologies and expert systems, which are presented as follows.

Along the PDP, there are several flows of information that involve different areas. According to the PDP proposed by [2], much of this information accumulates in embodiment and detailed design phases [10]. In addition, Product Life-cycle Management (PLM) tools are not able to manipulate all the information involved. Thus, it is necessary to conceptualize the knowledge that should be generated and applied in each phase of the PDP [3]. Figure 1 presents a representation of the information flow with some examples of associated knowledge (i.e. needed or developed) at every step of the PDP.

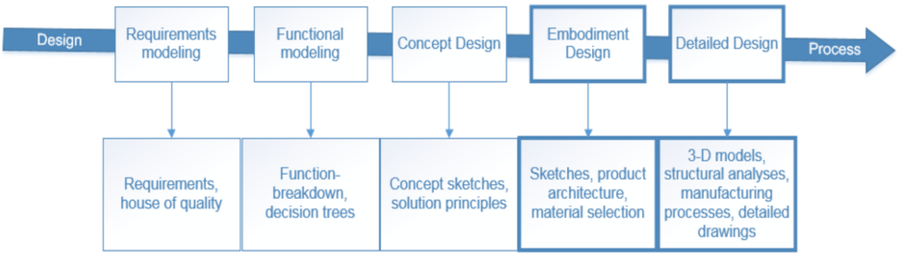

Figure 1. PDP steps associated with types of knowledge representation

Source: adapted from [10]

Given this large amount of information and the need to develop resources to assist organizations for sharing this knowledge, the investigation of KBE approaches is fully justifiable.

KBE can be characterized as a set of solutions capable of assisting the development of engineering activities in different steps of the product development process, in the form of knowledge-based systems. According to the definitions proposed by [3] and [4] it is possible to highlight the ability of KBE on providing development solutions that enable the automation and customization of design activities, by the union of object-oriented programming (OOP), artificial intelligence (AI) techniques and CAD technologies. Moreover, object-oriented KBE systems technologies allow the construction of object classes that contain several useful representations related to the product (e.g. geometry definitions, costs) [5], which make knowledge explicit. Another characteristic of KBE, more recently suggested, is the ability to create frameworks to capture, store and reuse the knowledge acquired [4].

In this sense, KBE solutions can contribute both with traceability, reuse and search for knowledge, which ensures a collaborative environment and the possibility of reduction in design time, by the automation aspect associated. However, to develop a KBE application, one of the first challenges is the elicitation of knowledge [6].

There are several ways presented in the literature that assist in the elicitation of knowledge. According to [7], it is possible to categorize the capture or elicitation of knowledge in direct and indirect methods. Direct methods (e.g. interviews, case studies, simulation) involve direct questioning the experts of a particular domain on how their activities are carried out. Indirect methods (e.g. role-playing, document analysis, laddering) are those used when information is difficult to express. Another study [8] points out that, among the most appropriate ways to capture tacit and explicit knowledge (both groups and individuals) are questionnaires, interviews, storytelling, brainstorming and round-table method. The purpose of questionnaires and interviews can be related to explicit knowledge, i.e. previously verbalized/formalized. Other mentioned ways make it possible to capture tacit knowledge, that is, knowledge a given expert has acquired over time. The acquired knowledge should be structured to enable subsequent reuse and traceability.

Among various ways of representing and structuring knowledge, one is the use of ontologies. A literature review indicates the use of ontologies for structuring knowledge, as pointed out by [9], [10], [11], [12] and [13], stands out. According to [14], ontologies are an explicit specification of conceptualization and any knowledge base or knowledge-based system is linked with some conceptualization, implicitly or explicitly. Also, [15] refers to ontology as a special type of object information or computational artifact. Computational ontologies are a way to formally model the structure of a system (entities and relationships that emerge from these observations) and which can be used for a specific purpose.

A formal language is needed to build an ontology. Based on RDF (Resource Description Framework), OWL (Web Ontology Language) has a well-defined syntax, which is a basic condition to allow machine-processing [15]. The purpose of this language is to meet two main requirements: support effective reasoning and provide a more complete logical expression. However, these two requirements are contradictory, which led to a subdivision of the language in OWL Full, OWL DL and OWL Lite [15]. Among them, OWL DL (short for Description Logic) would be the intermediate language to meet these two requirements; it restricts some constructions while ensuring greater efficiency in terms of reasoning support.

The study presented by [16] highlights the main benefits of ontologies: the principle of sharing by the semantic expressiveness of ontologies, possibility of creating complex models and the possibility of increasing the community share for providing a wide range of applications. In addition, [16] emphasize that a resulting conceptual model must be transformed into an executable scheme before it can be implemented and applied in a system.

One way to implement ontological models is through expert systems. Expert systems are AI applications whose goal is to represent the knowledge of an expert and thus help in decision-making activities. Generally associated with knowledge-based systems (KBS), AI allows both computers and humans to understand the knowledge expressed through them [17] and their problem solving capability makes the realization of useful inferences for its users possible [18]. By creating rules, it is feasible to evaluate the data contained in a domain to achieve a particular goal [19].

Given these fundamental concepts and the issue raised in the introduction, some studies found in the literature, related to the study, are presented as follows.

There are solutions associated with CAD tools that enable the insertion of knowledge for design automation and other applications. In the studies presented by [20] and [21], commercial CAD systems are used to drive design activities in order to automate the geometric definition of products. [22] presents a solution to convert information from geometric and simulations models (i.e. CAD, CAE) into a centralized and structured knowledge model through a tool, which ensures knowledge acquisition and consistency of parameters and constraints. These proposals, however, do not meet the need to use other forms of knowledge other than those from geometry and simulations, which are also important to the design.

In other studies, the use of formal ontologies to represent knowledge from design activities are proposed. [9] and [10] point the use of formal ontologies to represent assembly information mainly for knowledge sharing, by establishing concept semantics in this domain. [11] use a formal ontology to represent knowledge in the form of standards which, associated to computational meaning, brings greater expectations for more meaningful use of such information. The study conducted by [23] presents a method to capture potential relationships in a large set of data through the use of an ontology, which allows storage and reuse of knowledge. A graphical tool provides a user-friendly interface and the method based on ontologies described in the article helps the integration of heterogeneous data sources.

However, it has been observed that none of these works presents a friendly solution to the user, able to cover the various knowledge sources and formats (e.g. manufacturing requirements, standards, good engineering practices) necessary for designing components and subsystems. Therefore, the solution proposed in this paper is a suitable answer to this research opportunity. Its methodological aspects used are presented next.

2. Methodological aspects

The present research work was carried out with reference to the approach called DSR (Design Science Research) [24]. This approach has been developed facing the need to differentiate studies related to the natural sciences from those related to project science. In the first case, the studies are related to how and why things happen. In the latter, they are related to how things should be to meet certain objective. Thus, DSR's main function is the development and design of artifacts, that is, means by which it is possible to achieve a goal.

In this sense, this work presents an ontological model as the artifact to be designed. Models represent situations as problem and solution, to describe tasks, situations, or, in this case, artifacts.

The DSR approach provides a set of work phases, which lead to the proposal of a consolidated and approved model for use. They are: (i) Problem Identification and Motivation; (ii) Definition of Goals and Solution; (iii) Design and Development; (iv) Demonstration; and (v) Evaluation. Each of these steps is detailed as follows. The present research work is currently in the Design and Development phase.

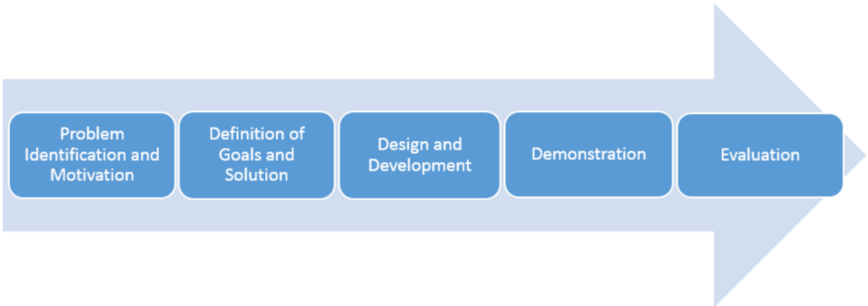

Figure 2. Methodological structure framework based on DSR approach

According this approach, the creation of an ontological model happens through a sequence of steps and activities in each phase. In step 'Problem Identification and Motivation' a strategy based on the analysis of Engineering Change Orders (ECOs) was adopted. For this analysis, a product was initially set as a reference, chosen for it provided a large number of change requests associated. Then all ECOs related to this product have been raised. A classification was subsequently carried out in order to identify and organize the number of ECOs with respect to the product systems and components, resulting in a list. After that, an assessment based on all listed components enabled the definition of which were the most critical ones. Consequently, among the most critical components, it was possible to highlight flexible elements (i.e. hydraulic hoses and electrical harnesses). Careful analysis of the information submitted by design engineers related to the development of their activities revealed that many of the ECOs resulted from neglecting or inappropriate use of design information during the detailed design phase.

In step 'Definition of Goals and Solution', it was decided that the designers could benefit from this work through an expert system based on ontological models, which could contain the knowledge necessary for the design of flexible elements such as hydraulic hoses and electrical harnesses. Currently, designers are pressured to quickly develop projects directly in CAD tools, so that they often fail for not implementing many important aspects related to good design practices. Such information is usually available in standards and recommendations, or even tacitly, from the experience gained in past projects. An expert system could work not only as a repository of this knowledge, but also as driver element for proper work of designers. Ontological models, in turn, allow the knowledge of a particular domain to be registered, debugged and propagated for future use.

For the 'Design and Development' of the artifact, the following activities were carried out: (a) specification; (b) conceptualization; (c) formalization and; (d) implementation [25]. Specification corresponds to identifying relevant information of a specific situation (i.e. domain). Conceptualization is characterized by the development of a conceptual model of the ontology to be built. In Formalization, the conceptual model content is described more formally, i.e. through the assignment of properties and axioms. Implementation is the step in which the ontology, through a knowledge representation language, becomes a formal model and allows querying and inferencing.

During Specification, the artifact application domain has been set, that is, design of hydraulic hoses. Then in Conceptualization, the main classes of the ontology were determined. For that purpose, mind maps were used. In Formalization, the classes that were previously discovered were organized in the form of a taxonomy. In this phase, Protégé ontology editor was used. Finally, in Implementation, axioms that express the key concepts of the model were built, as well as the object properties, datatype properties and individuals.

For the Demonstration phase, a user-friendly interface is to be presented, in which searches for information related to the design domain of hydraulic hoses can be performed. Thus, design engineers can access more easily and quickly information needed to develop such components. For the Evaluation stage, the intention is to use this interface in the corporate environment, to verify that the proposal actually meets the needs of designers, or whether adjustments or implementations need to be made. According to the DSR methodology to evaluate the artifact proposed in this work certain criteria are required. Such criteria correspond to the fidelity of the model with respect to reality, completeness, robustness, consistency and level of detail.

3. Proposed Solution

Following the sequence of activities presented on the methodological aspects to build the artifact, i.e. the ontology model, initially captured knowledge has been structured in the form of mental maps. Figure 3 shows part of an internal standard of the company in the form of mind maps as an example. This standard specifies class types of hydraulic hoses, each of which is associated with classes from SAE J517 and J30 standards.

Furthermore, technical features of each type of hose are defined, as dimensions, materials, work temperature and pressure, among others.

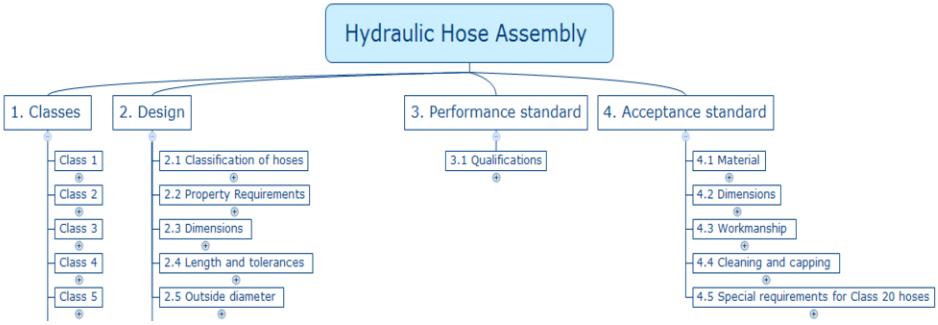

Figure 3. Representation of one of the standards in the form of mind maps

Next, the taxonomy of the ontology model was defined. For the construction of this taxonomy, the following key classes were created: HoseOptions, TechnicalFeatures and SupplierOptions. The representation of this taxonomy with the main classes and its subclasses is illustrated in Figure 4, through the Protégé ontology editor. The TechnicalFeatures class and its subclasses (e.g. ES-B120, TemperatureRange, Atribute, SAE, LengthGroups, Material and PressureRange) are presented in figure 5, in Protégé´s OWLViz plug-in format. It is important to emphasize that the class hierarchy has changed and readapted several times throughout its development to improve the domain representation.

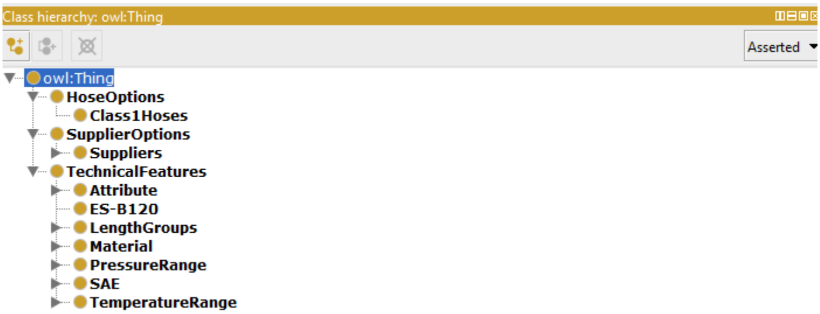

Figure 4. Protégé screen of class hierarchy of the proposed model

In order to correlate the classes, axioms and object properties were created. In addition, datatype properties were created to relate objects to values of data types. As illustrated in Figure 6, it was possible to describe one of these subclasses using object and datatypes properties. In this case, subclass named Class1 is described according to the material, diameter and pressure. Through properties, these features describe what characteristics a hose must present to belong to that class.

To verify possible inconsistencies in the model, one of the Protégé´s reasoners, called Pellet, was used. A reasoner checks if there is any contradiction in the ontology, comparing tested classes with the resulting knowledge base [26]. The results of this check indicated that none inconsistency was found in the proposed model.

Figure 5. Protégé OWLViz plug-in screen with TechnicalFeatures class and its subclasses

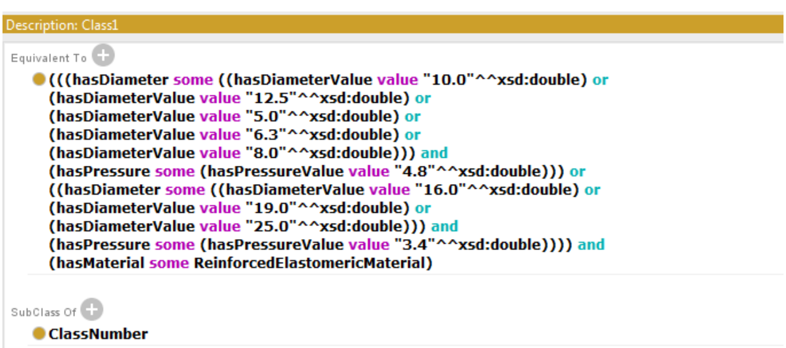

Figure 6. Protégé screen of class description of the proposed model

The ontology model presented in this work should be further implemented. By adding new classes, properties and individuals, the aim is to make it more representative with respect to the proposed domain.

4. Discussion

The research conducted throughout this study showed that there are still many difficulties regarding the issues involving the knowledge generated in organizations. Even with technological advances and availability of new tools, companies encounter problems caused by the unavailability or non-use of design information.

Faced with the activities so far carried out to develop the solution proposed in the study, the structure of the ontology model was the most challenging. The model has been amended several times to represent more adequately the knowledge domain without generating inconsistencies.

As sequence of this study, it is initially intended to increase the ontological model to make it more representative. To do this, information related to manufacturing, costs and lessons learned from previous projects should be introduced. Furthermore, the use of queries in the ontology should be performed to identify individuals created, that is, to obtain inferred information from the domain.

The next step is to develop a user-friendly interface that can be easily used by designers. Through this interface, the user should be capable to access the knowledge represented in the ontology using pre-determined rules. To this end, this study must go through the steps of standardization and creation of those rules.

Some pros and cons of using the solution may already be predicted. On the one hand, the solution can improve the performance of activities associated with hydraulic hose project and allow greater reliability of the final product, i.e. lesser susceptibility to failures. On the other hand, such a solution requires a specialized ontology engineering team to perform the updates that are required over time, such as the introduction of a new supplier or a revision of standards.

5. Final considerations

To meet the demand for provision of knowledge during the detailed design stage, an ontology model was presented. This model ensures the structuring of knowledge in a given domain, here defined as the project context of hydraulic hoses. The knowledge associated with this domain was captured and structured through building the fundamental taxonomy proposed. In addition, object and datatype properties have been created to relate classes with other entities.

This study shows the potential union between ontology models and expert systems to achieve a system that actually is able to meet the needs of design engineers. From this association, it is possible to develop a solution capable of creating a collaborative environment, which contains knowledge from different areas and in different formats.

Such solution should allow the availability and faster use of the knowledge acquired, bringing benefits such as the reuse of knowledge in future projects and the reduction of engineering change requests.

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