ONTOLOGY-AIDED FMEA FOR CONSTRUCTION PRODUCTS

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ABSTRACT: The goal of improving the quality and the maintenance of building products, and the will to integrate the sustainable development objectives led us to propose an original method based on the use and adaptation of the Failure Modes Effects and Criticality Analysis (FMEA). This method relies among others on ontology use. It facilitates the FMEA proceeding.

This paper aims to introduce innovative software specifically developed to perform more easily FMEA on building components. This software takes advantages of a structured knowledge base and an inference rule engine that allow a complete and formal description of the product to be analysed and an exhaustive analysis of all failures (degradations) that may occur.

KEYWORDS: FMEA, ontological approach, knowledge capitalisation, degradation analysis, construction product.

1 INTRODUCTION

In France, the deficiencies in building construction annually cost 7 billion euros. However, this context is not pushing to the use of innovative solutions. It is in the energy field that innovative products and systems are designed as they allow to reach the objectives of reduced energy consumption in building.

Moreover, the failure of a product is caused by a succession of degradations generated by different causes. This can explain the difficulty to forecast this pathology at the earliest stage of the design (AQC 2005).

A more secured innovation is possible when an analysis such as the FMEA method is integrated in the early design stage. In fact, other scientific domains such as car industry and aeronautics are good proofs, but the criticality is not the same in building. The FMEA is a method for improving quality. It should be conducted mostly in early phases of product development. It is a formalized, analytical method (Stockinger, 1989). Thus, it allows reducing the initial investment (in time and money) for building.

In this paper, we introduce a tool aiming to improve the reliability and quality of innovative products by developing preventive actions of risk analysis and quality management at design and installation stages.

The paper is organised as follows:

- section 2 presents the adaptation of the FMEA method to a building product;
- section 3 introduces the computer-assisted FMEA method in building product-based ontology;
- section 4 presents software architecture to assist the FMEA method.

2 THE FMEA METHOD FOR A BUILDING PRODUCT: EXAMPLE OF THE SOLAR PANEL

The FMEA method is well-known and used in the industry. It is a methodological tool which allows identifying and describing the failures scenarios for a given product or service. At the same time, this methodology identifies the causes of the failures and also allows evaluating their consequences.

The FMEA method is applied to all phases of the considered product or service life cycle (e.g. from the design stage to the realisation, the exploitation or the use, the improvement or the validation).

The implementation of the FMEA method is structured in three main phases:

- A functional analysis phase formalising how the system is running;
- An analysis of the failure modes. This phase is subdivided into three subtasks:
  - An analysis of the modes (Is the failure possible? Why has the failure appeared? What are the consequences of this failure?);
  - An evaluation of the corresponding criticality;
  - A determination of the critical points for which correction actions must be performed;
- An exploitation phase leading to develop preventive measures.

The adaptation of the FMEA method to the characteristics of construction products requires some complements in the method, particularly by introducing one stage dedicated to the implementation and one stage dedicated to the maintenance. Several studies have shown that it is possible to formalize a part of the expert knowledge (Lair & al 2002). This formalized knowledge can then be exploited thereafter by FMEA specialists. This formalisation has also shown that a greater exhaustiveness in the forecast of the failures is possible and can be performed more easily and rapidly.

Hence, in the specific case of construction products, FMEA is performed according to the main following stages:

Stage 1: structural analysis

In this stage, the structure of the considered product is described in its operating/production environment. It leads to the listing of the sub elements (components) that constitute the product, the interactions (interfaces) which can exist among these components, the materials that constitute these components as well as the environmental elements which are in contact with the components. These elements, designated by Environmental Agents (AE), range from air and temperature to moisture or rodents… Some of these AE can be gathered into different sets which represent different typical environments. Each set is called "Environment".

The figure 1 wraps up this stage in the context of Solar Panel. The structural view of the solar panel (considered as the product) corresponds to the description of the assembly of the different components it is made of. For instance, the component n°1 is in liaison (interface) with the component n°7 and in contact with AE contained both in the external and internal environment.

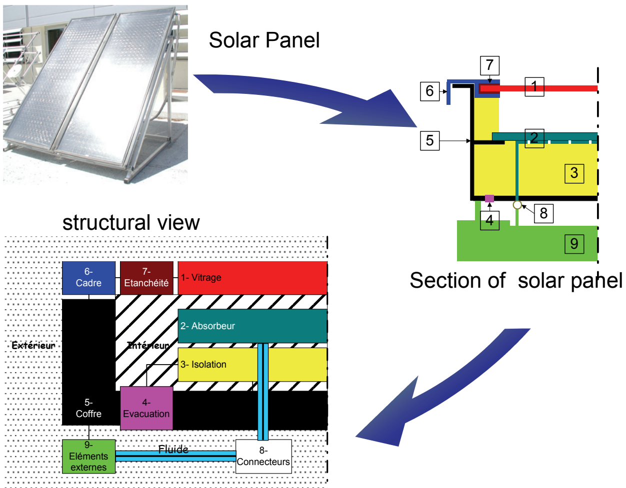

Figure 1. From real product to semi structural view.

Stage 2: functional analysis

This stage is an exhaustive description of the functions that must be provided by the product. It consists in assigning to each component the main and secondary functions it ensures. For instance, the primary function of a window could be "to be tight with the air" and the secondary function could be "to rigidify the structure".

Stage 3: migration of the environmental agents

This stage consists in "placing the product in its real environment". The AE are applied to the component which they are in contact with. According to the permeability of these components and their fitting, these AE will be more or less able to migrate. They will go through some components and be in contact with others. This stage requires the knowledge of the behaviour of each component or material for each considered AE. When no more migration of AE is possible, this stage is considered as finished. The product is then in a stable state. It is possible to know, for each component the list of AE which are in contact with it.

Stage 4: searching for degradations

According to the potentialities (possible degradation of a component pursuant to the possibilities of degradation: presence of an AE degrading a component/a product, incompatible contact of two components, etc), a list of possible degradations is drawn up. This stage strongly relies on expert knowledge for the considered product. It is indeed, necessary to know, for each component/materials, what are their physicochemical behaviours according to the influences they can be confronted by.

Also, degradations can be caused by the combination of sources coming from the Environment of the product, the errors of Process, or Incompatibilities. Degradations related to the Process are obtained after analysis of constitutive materials and/or the type of the component. Those related to the Environment are obtained after the algorithm of migration of AE. Finally degradations caused by the Incompatibilities are obtained after the analysis of materials in contact with AE.

Stage 5: selection and application of degradations

One degradation is selected among the list obtained at the previous stage and applied to the considered components. The system is not any more under its initial conditions. The selected degraded component behaves now according to permeability rules (for the AE) and is no more ensuring its initial functions.

The application of the degradation consists in migrating the AE according to the new capacities of the degraded component. It returns to stage 4.

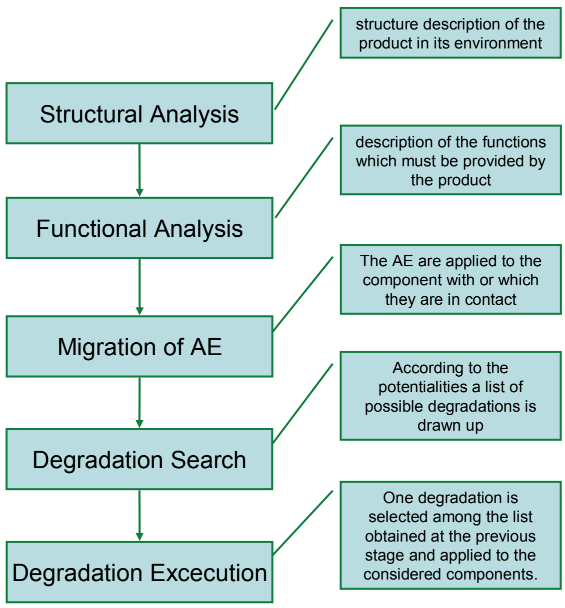

Figure 2. Steps for FMEA applied to the construction products.

In these stages, the efficiency of the method strongly relies on the degree of precision of the information given by the user. Precision is also the most tedious side of the method. Consequently, we propose to lighten this tiresome work by automating it.

3 COMPUTER-AIDED, FMEA-BASED ONTOLOGY

The FMEA automation will provide guidance for the user when describing the structure of the product description. Product description will be based on an ontology providing predefined objects. The objectives of a "computer-aided FMEA" are:

- to achieve a better formalization/re-use of the generic products and phenomena;
- to build and maintain a knowledge base on the various notions previously mentioned (AE, components, functions, degradations, materials…)…

For this purpose, we propose a guided framework which major concepts (from components to degradation) are predefined in a structured knowledge base. This leads to elaborate an ontology, as a model of our knowledge base. The knowledge base is therefore modelled as an ontology.

3.1 *Contribution of ontology*

An ontology is a formal model which allows to express assertions in a structured manner and then make them "computable". It is also a representation of a system from a certain point of view. This representation is details concepts from this system and the interactions or relations that may exist between these concepts (Gruber 1993).

The first "exercise" consists in "conceptualising" a construction product. This process leads to the definition of the following abstract "concepts" that could be reused for all construction products:

- Product: The Product is the considered Construction product which will be analysed. It is a mechanic-physico-chemical and geometrical fitting of Components linked between them via Interfaces.
- Component: A Component is a sub-element of the Product.
- Interface: An Interface is an abstraction of the existing physical liaison between two Components. The interfaces are defined by their connection mode (stuck, screwed, embedded…).
- Material: This notion indicates the chemical composition of the component (e.g. What is it made of)
- AE (Environmental Agent): The Environmental Agents represent the "aggressions" that may come from the environment of the product and which may influence its behaviour, by degrading one or more of its components during its life cycle. The contacts between components and AE can be direct (coming directly from the description of the contact component-medium) or indirect (coming from the migration of the AE in the product).
- Environment: The environment gathers a set of AE which may influence on its behaviour during the product life cycle.
- Function: The primary functions represent the essential characteristics for which the product or component has been chosen. For each couple (primary component-function) of the product, the component supports also secondary functions which help the component to perform primary functions.
- Degradation: Degradations can be separated into two categories: degradations related to the process and those related to the exploitation. The second category can be broken down into two subcategories: degradations related to the environment and those related to the other components (incompatibilities).
  - (Degradation) Process: Degradations related to the process are all degradations that may occur since the design phase until the beginning of the exploitation of the considered product.
  - (Degradation) Environment: Degradations related to the environment are caused by the climatic (e.g. water, radiation…), biologic (e.g. bacteria, mushrooms…) factors and are forced (forced action of the wind, seism…).
  - (Degradation) Incompatibility: Degradations related to the incompatibilities are caused by the contacts between components. They can be of mechanical (e.g. dilation, wrenching, thermal shock…), chemical (e.g. chemical attacks, efflorescence…) or physical (e.g. overheating…) types. The incompatibilities are defined by the conditions and materials of incompatibilities.

For instance, we can study a low emissive double glazing unit in its environment, from the point of view of its thermal properties or its efficiency. As soon as a model is set up, it is then possible to capitalize knowledge as instances of this model, and this knowledge is completely structured.

The examples of these instances are as follows:

My **component** Frame *is composed of* **material** Aluminium. My **component** Frame has for **function** *to be watertight*. My **Environment** External *is containing* the **environmental agent** Humidity, Gas, UV, rain, … The **Environment** External *is in contact with* the **component** Frame…

A set of instances is allowing the description of a product on which we want to perform the FMEA. (In the example shown before, the words in bold are concepts of the ontology, the ones in italic are the relations between these concepts and the ones underlined are the instances of the ontology). Figure 3 also displays the structure of the ontology.

The instances describing the product make up a static base on which we have to identify the degradations according to the information to be extracted (see explanation on AE migration for example…). The study of the consequences of those degradations comes after.

A computer aided FMEA allows, starting from this knowledge base, to build a specific instance corresponding to the studied product. Then, the degradations mechanisms/algorithms can be automatically applied, followed by the automatic propagation of the degradations.

This reveals the necessity to develop an engine coupled with the static representation of the product, to be able to apply degradations and to propagate their effects on the product. It could be considered by taking into account the rules of propagation, the structure, and the composition of the product.

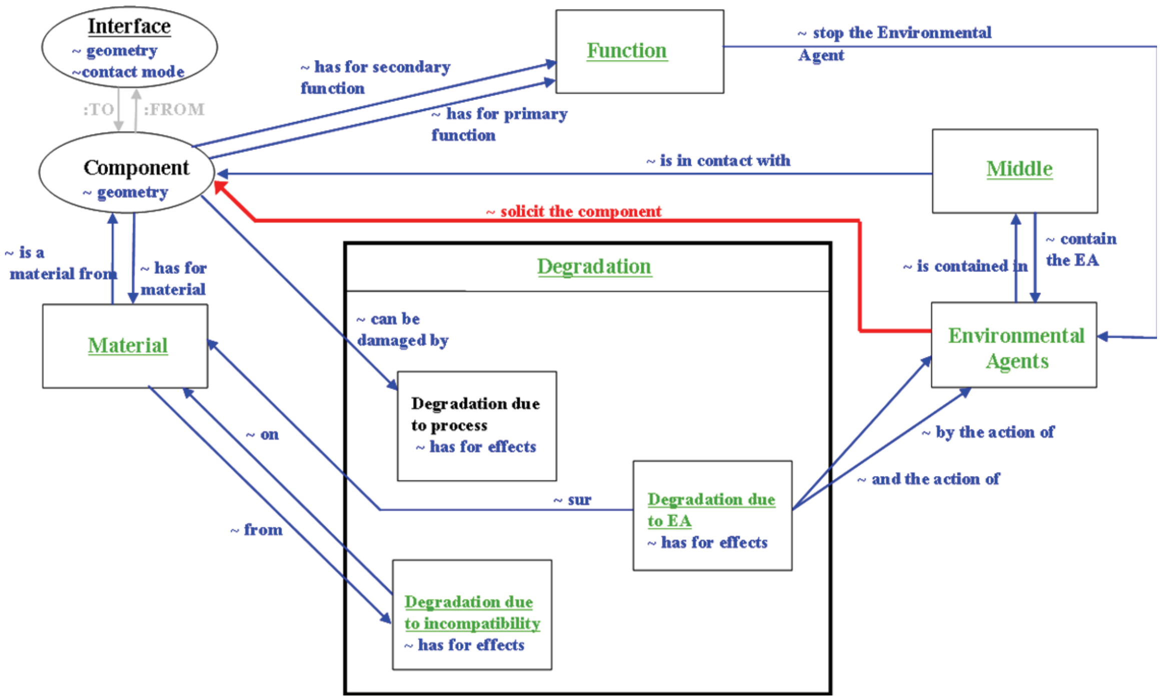

Figure 3. FMEA of building products ontology (Talon 2006).

The following figure synthesizes our approach of computer aided FMEA:

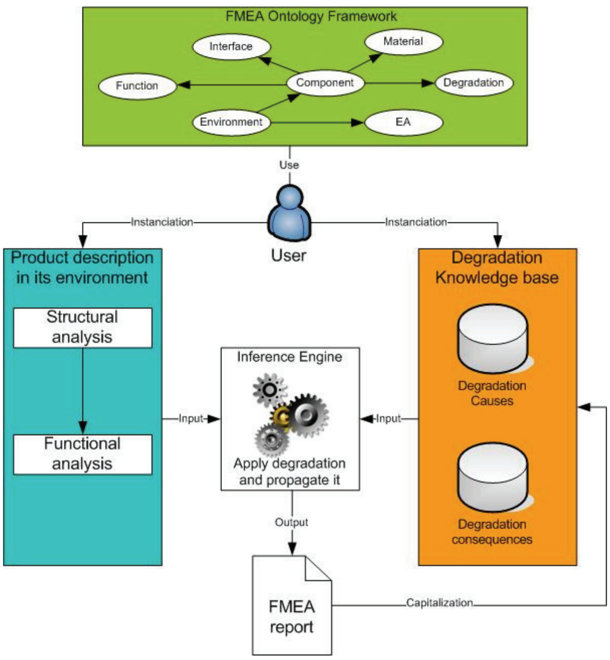

Figure 4. Suggested principal architecture for computer-aided FMEA.

3.2 *Management of the knowledge base and its enrichment by an expert knowledge*

The ontology presented in the previous paragraph represents the formal model of an expert knowledge base containing suitable elements to carry out FMEA on a construction product. This knowledge base could be enriched by various experts.

To this purpose a dedicated interface has been developed (figure 5). This form allows an expert to describe the degradation phenomena, in a user-friendly way. Behind the form, the description is translated into a formal assertion.

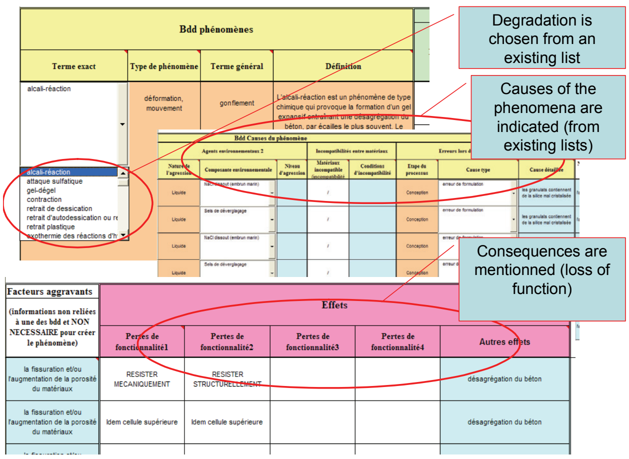

Figure 5. Dedicated form to enrich the knowledge base.

From a technical point of view, the ontology and the knowledge base have been initially written using the freeware Protégé editor (Genari et al 2002). The chosen language is OWL and the assertions concerning the degradations are expressed in Description Logic (DL).

On the other hand the ontology and the knowledge base are specifically designed to perform FMEA. With this intention we associate to the ontology an FMEA software in order to accumulate information on material and components.

4 MODEL DRIVEN APPROACH AS A WAY OF STRUCTURING FMEA SOFTWARE DEVELOPMENT

The FMEA software allows the FMEA user to perform a structural and functional analysis and thus to describe the analysed product in its environment with a graphical interface. Thus, we could, for instance, specify the type of a component (e.g. frame, beam, film, joint…), its functions, (e.g. water tightness, mechanical resistance…), constitutive materials, relations and interfaces between components (e.g. glued, screwed…), environmental agents constitutive of the environment etc.

Hence, we propose a FMEA software implementation according to three tiers architecture in order to distinguish presentation, business and data layers. This also provides a good flexibility for further enhancements and allows a maximum maintainability of the code (figure 6).

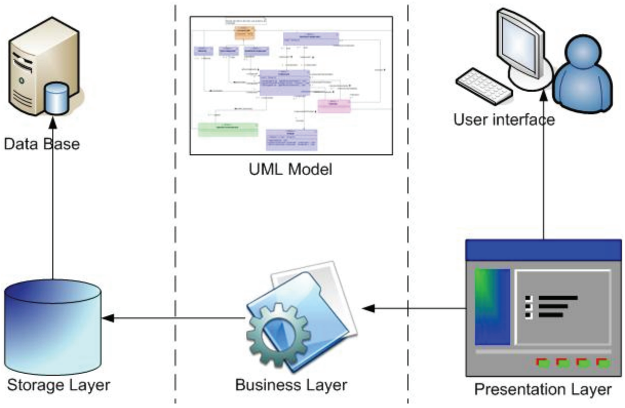

Figure 6. Three Tier architecture.

With this intention, we adopt a model driven approach (Blanc 2005). It allows centralizing maximum of information in UML model (Figure 7) and generating a business and persistence layers. For this purpose, we use AndroMDA framework, for back-end and Graphic User Interface generating from the model. This GUI is developed with Spring RCP framework (figure 8).

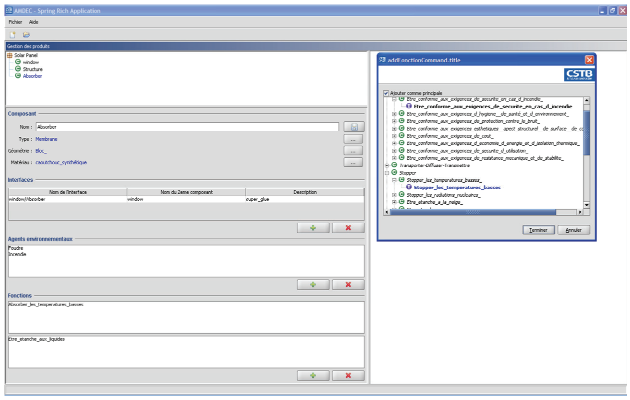

Figure 7. GUI for FMEA software.

On the other hand, and in order to assist the FMEA users in information impound, we link the FMEA software to FMEA ontology framework via the Application Programme Interface JENA.

Data access is achieved with the help of the Hibernate Framework. The data are stored in a MySQL database for further reuse (Figure 9).

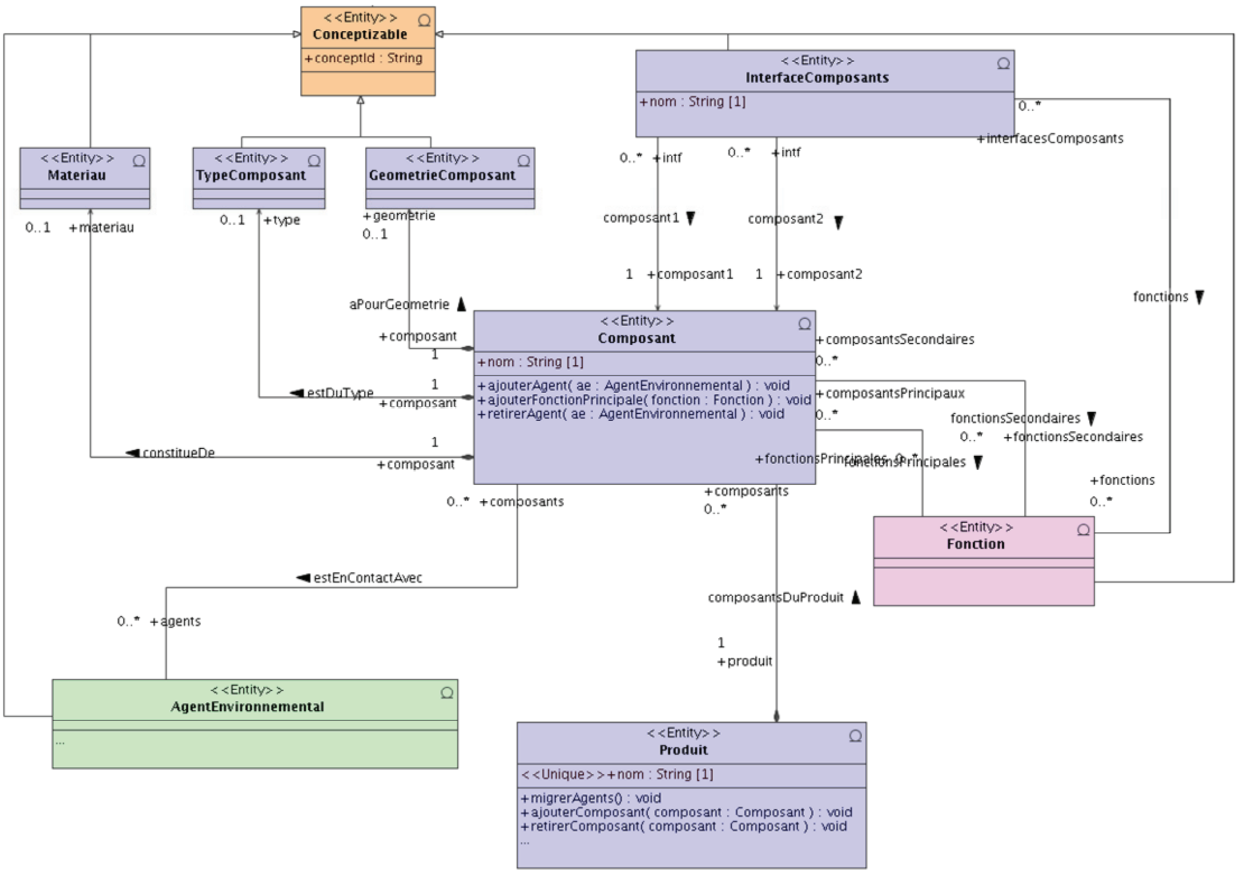

Figure 8. FMEA software model - UML formalism.

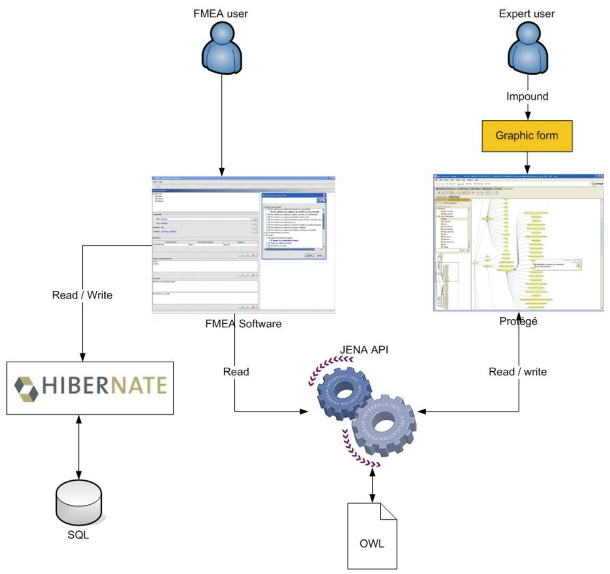

Figure 9. FMEA data access.

5 CONCLUSION

The results obtained with the FMEA software were promising enough to lead us to:

- Start the development of a more elaborate software based on a UML model.
- Start capitalizing degradations information compatible with the format proposed by the model, in order to be able to reuse the information for the study to come. It is the knowledge base of our software and it can be updated before every study according to the information we have on the component or material.

This means that from now on, every study allows the next study to gain efficiency and speed. It is a good reason to continue to use FMEA to design new building products; all the information collected during the analysis will be reused, and will contribute to the enrichment of a knowledge base which is the heart of this tool. But there are still areas that need further research. For instance, we do believe that a bridge should be set up between our tool and the Industrial Foundation Classes (IFC). This will enable the direct reuse of complex product description.

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