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FMEA Software for Building Products

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ABSTRACT

Risk analysis, and particularly Failure Mode and Effect Analysis (FMEA), has proved to be an interesting approach for durability assessment of building products. On the one hand FMEA allows identification of the potential failure modes of a product; on the other hand this method is known to be difficult to carry out, especially in the building and construction context. This paper describes the second version of a software developed by CSTB to support FMEA of building products with emphasis on automation and knowledge sharing. The purpose of the tool is to help product experts to lead FMEA on building products using information from previous cases. It relies on an ad hoc product model based upon functional modelling. This model, through fine-grained descriptions of structure and functions, allows representing faulty as well as normal behaviour of products based on a common set of functions and environmental agents. Functional and structural descriptions of products and product's components are made reusable. Cases studies have been conducted in order to assess both model and tool capacity to represent the wide range of building products and degradations phenomenon as well as the tool main functionalities.

KEYWORDS

Durability, FMEA, Product model.

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1 INTRODUCTION

Failure Mode and Effect Analysis (FMEA) is a reliability method that aims to identify the combination of events that might lead to the failure of a product or process. It is now widely used in the manufacturing industries and several quality related standards require FMEA to be conducted in different steps of a product's life cycle. Previous works have shown that this approach is of interest for the durability assessment of building systems [Talon, 2006]. According to Hans *et al.* [2007a], the fact that FMEA is based on knowledge at the material and component scale rather than knowledge at the product scale makes it usable for durability assessment of innovative products. However the common FMEA workflow shows several drawbacks that restrain its widespread use. Among the different drawbacks is often mentioned the fact that it is a time consuming task to complete. Furthermore, product experts involved in assessing durability usually do not tend to render explicit their knowledge on a products' failure modes, thus making the results derived from the implementation of FMEA difficult to reuse.

To date, several attempts to ease the use or even automate FMEA have been successfully completed in different product domains and even some have even been integrated into commercial tools [Bell *et al.* 2007]. Whereas, similar tools that have been developed for building components lack functionalities with respect to automation and knowledge sharing. The purpose of this work is to develop a product modelling framework to automate the FMEA process and that would serve as a basis for future software development.

2 BRIEF REVIEW

2.1 FMECA Automation

Most of the research related to FMEA automation has focused on developing tools and methods to help designers detect potential failure modes of and their effects on products. According to Bell *et al.* [2007] complete automation involves two main steps:

- Simulation of the system behaviour;
- Interpretation the simulation results.

Thus, identifying a proper modelling framework is the first step this work is focused on. Several modelling paradigms have been evaluated for FMEA automation. Even though reviewing these models may be beyond the scope of this paper, it is worth noting that several authors already indicated that qualitative models are suitable for FMEA [Struss, 2008] [Bell, 2006]. Among qualitative models, those derived from qualitative physics or functional modelling are usually preferred as they both allow product representation without numerical details. For example, in the field of building sciences, the use of a model based on qualitative physics for simulating degradation mechanisms has been addressed by Lair [2000]. From results it was apparent that developing a modelling framework based on qualitative physics and able to encompass a range of products, behaviours and degradation phenomena related to the building and construction field was not realistic. According to Teoh and Case [2004], in the field of functional modelling, a common approach is to see systems as a "black box" and their functions as relations between input and outputs of flows of material, energy and information. Function can be further broke down into sub-functions as shown in Figure 1.
Several sets of functions and flows already exist such as the "Functional Basis", which is a reconciliation of the main functions and flow sets used in conceptual design [Hirtz *et al.*, 2002]. The different types of flows and functions are usually organised as a classification of concepts by a supertype-subtype relationships (also known as parent-child relationships). For instance, in the case of flows, *liquid* is a subtype of material, *Energy* is a supertype of *thermal Energy* and *Mechanical energy* and so one. This type of classification of concepts is usually referred to as taxonomy.

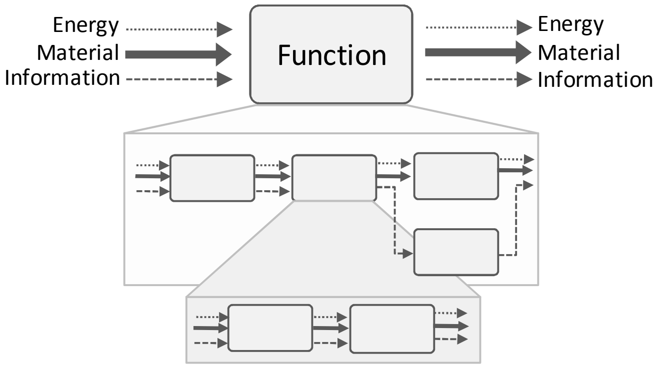


Figure 1. Relation between functions and sub-functions.

2.2 FMECA for Building Products

In literature is offered several approaches in which are presented guidelines for FMEA integration to the building sector as well as a number of related case studies [Talon *et al.*, 2006]. From a practical point of view Hans *et al.* [2007b] describe both method and results obtained from a common FMEA workflow involving products and FMEA experts on several building systems.

Talon *et al.* [2008] developed a prototype tool based on an ontological model that served as a basis for the development of software referred to as CPAO[1] (unpublished work). The objective of this work was to allow product experts to undertake a FMEA without the guidance of FMEA experts as well as permit a certain degree of reusability of knowledge derived in the process of conducting the FMEA. Cases studies revealed that the underlying product model could be further improved on several aspects including its capacity to take into account a wide range of products and degradation phenomena. This leads to the conclusion that a modelling framework based on more generic functional representation, as for example, the one described by Hirtz *et al.* [2002], could indeed be developed.

3 DEVELOPMENT OF A MODELLING FRAMEWORK

3.1 Main Concepts

The main purpose of this modelling framework is to derive the possible failure modes from a simple description of a product, failures modes being described in a generic fashion at the material and component scale. As pointed out before, a representation of the product behaviour is necessary. One particular aspects of our problem is that it should encompass a wide range of systems, behaviour and failure modes.

As a starting point this work used a modified version of the "Functional Basis" flow taxonomy as well as a limited set of functions to describe the product (see Fig. 2a). Our goal is not only to represent the functional structure, but also to detect potential degradation modes from a products' description. A common approach is to consider that most product degradations are caused to some extent by environmental agents, such as those described in ISO 6241 [ISO, 1984]. Each environmental agent has been classified into the proper class of the flow taxonomy (e.g. *water* as a subtype of *liquid*).

Products are modelled as network of interconnected components that represent physical parts of the system – some of them being in contact with sets of flows representing environmental constraints. Each component has a number of specific interfaces, called ports, through which it is brought into

[1] CPAO is a French acronym for "Computer Assisted Durable Design".

contact with another system's components (see Fig. 2b). Within a component, functions define the behaviour from one port to another with respect to flows. The flow and function formalism is designed to enable a simplified and qualitative description of a wide range of physical (e.g. mechanical, thermal, electrical) phenomena. Furthermore, components have additional properties, such as one or more constituent materials.

The system behaviour with respect to flows can be deduced from the behaviour of its components. A flow from outside the system will be processed by a succession of components based on their functions. Processing of all flows through a system can be seen as a *functional simulation*. As environmental agents are related to flows (e.g. *high temperature* is related to the flow type *thermal energy*) it is thus possible to compare component properties (e.g. constitutive materials) to the set of flows in contact with them in order to detect potential failure modes. Additional information regarding this approach can be found in [Bazzana *et al*, 2010].

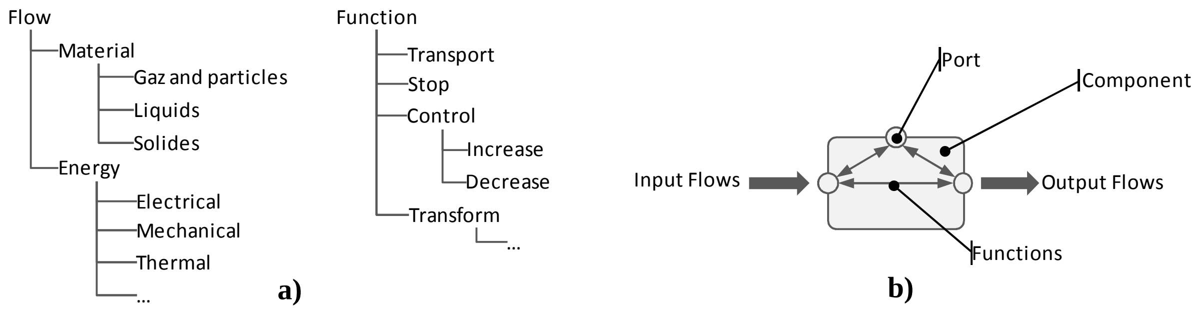


Figure 2. a) Extract from the functions and flows taxonomies and **b)** graphical representation of a component model.

3.2 Nominal and Faulty Behaviour of Products

The "correct" behaviour of a product model is assessed though flow propagation. This step may require modification of the model and of the set of flows involved in the propagation. The goal being to achieve a representation of the nominal behaviour of the system, i.e. the reference operating mode to which the effects of degradation will be compared.

The number of flows involved in a study may be important. Thus identifying those related to the product's main functions is necessary to ensure that critical failure modes will be easily identified. This can be simply done by marking the main functions of critical components. This is a way of identifying the main functions of a system and to alert a user if a change of the model behaviour with respect to the function occurs. It then remains to consider the evolution of the product model as a result of degradation modes. Three different types of degradation modes can be distinguished, according to their causes:

- Degradation caused by one or more flow types;
- Degradation caused by an incompatibility between constitutive materials of two adjacent components;
- Degradation caused by a process or design default described at a component or material scale.

The effects of degradation are expressed in terms of modification of a component's functions. In other words, when a degradation mode is applied to a component model, the new function replaces one or more of the component current functions.

The effects of degradation can then be reflected at the system level by propagating the flows according to the new function; the flow may then further spread into the system and eventually trigger new degradations.

3.3 State Graph and Fault Tree Construction

Degradation modes traditionally revealed by FMEA are usually presented as a spreadsheet or graphs, the latter making it easier to exploit results. In our approach, generic and specific failure modes are taken from a database and each applied failure mode modifies the system model. Furthermore, combinations of degradations are systematically taken into account, which is not usually the case when implementing traditional FMEA. This results in series of degradation sequences that can be seen as a state graph, nodes representing a system state and edges representing degradation modes. The first node represents the system in its nominal state and final nodes are either caused by degradations affecting a marked function or a steady state, i.e. failure modes derived from the available databases or user’s knowledge can no longer be applied to the current product model. The construction of the state graph can be described by an algorithm, or more conveniently as a scheme (see Figure 3a).

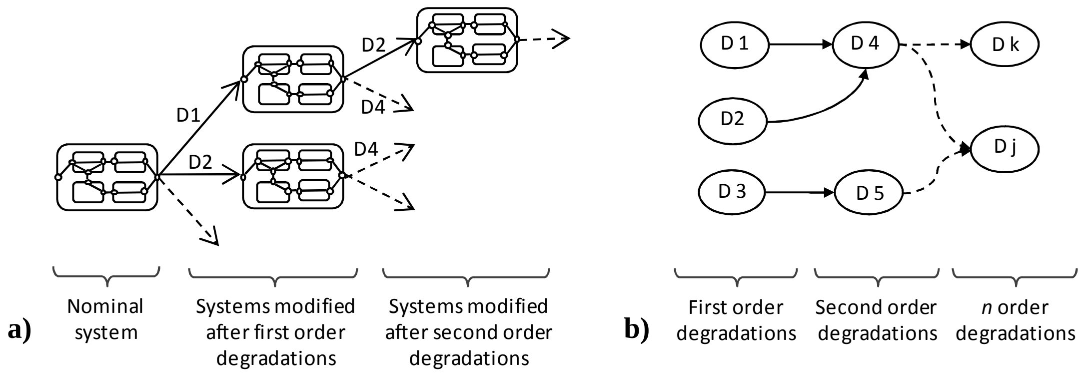
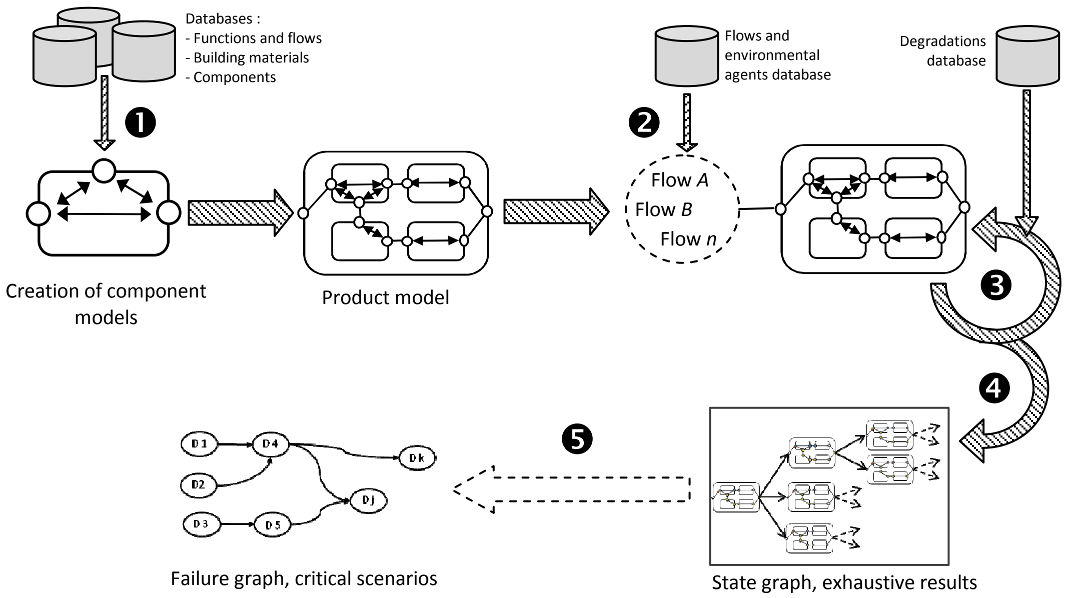


Figure 3. a) State graph and **b)** corresponding failure graph after criticality ranking.

State graphs represent an exhaustive representation of all combination of possible degradation modes. These should be further processed in order to highlight the most critical combination of events that affect the system (see Figure 3b). This process is usually carried out through criticality analysis. For building products, Talon [2006] and Lair [2000] have shown that temporal data of degradation modes (e.g. the duration of degradation phenomena or occurrence probability) play an important role in criticality ranking. It appears that exploitation of such an approach can only be achieved through the use of a computer tool. The prototype of such a tool has been developed and its functionalities are discussed in the next section.

4 PROTOTYPE TOOL

The primary modelling framework concepts have been implemented under Teexma®, a technical knowledge management platform [Teexma, 2010]. Functionalities of the resulting prototype are summarised in Figure 4. The databases within the prototype tool have been enriched with data taken from previous tools developed by CSTB [HANS *et al.* 2007a], as well as literature and literature [Offenstein, 1988] [Wright 2001] [Addleson & Rice, 1991] . To date, results are presented as text logs describing sequences of product model states and degradation phenomenon leading to them.



❶ Product modelling using existing knowledge: materials and components databases, functions and flows lists. Creation of new component models if needed.

❷ Description of environmental conditions as a set of flows (environmental agents).

❸ Automated search for relevant degradation types, modification of product model according to effects of degradation and flow propagation through the system.

This process is iterative and ends when labeled functions (main product functions) are affected by degradation types, or until no more degradation types are identified.

❹ Exhaustive results overview represented as a state graph: nodes represent system configurations and edges degradation phenomena.

❺ Most relevant results: Identification of critical degradation modes from the state graph and construction of a failure graph. *This step is not implemented yet.*

Figure 4. Current Prototype Tool (steps 1 to 4) and expected features (step 5).

5 CASE STUDIES AND INITIAL RESULTS

Case studies have been conducted in order to assess both the tool and the ability of the modelling framework to represent and simulate a product's nominal and faulty behaviour as well as suggest relevant failure modes from the degradation database. The very first step involved modelling a known product, namely a photovoltaic panel. Previous FMEA reports [HANS *et al.* 2007b] of this specific product served as a guideline for model description as well as benchmark for an analysis of the results. As well, a more systematic testing and evaluation procedure has been set up.

5.1 Product Modelling and Nominal Behaviour

The product has been modelled according to an existing FMEA report [HANS *et al.* 2007b] and the resulting structural decomposition has been implemented under the prototype tool (see Figure 5a). Each component model has then been further defined with respect to the function and flow taxonomies. Three environments, namely *external environment*, *fastening system* and *domestic electric network*, allow the representation of external constraints (model inputs flows) and system behaviour (model output flows).

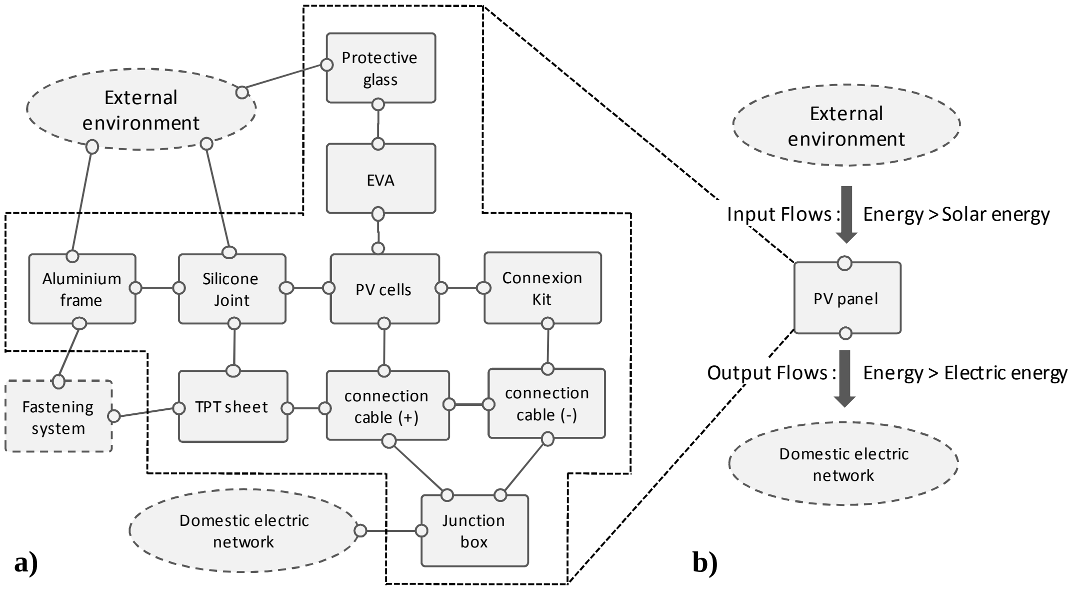


Figure 5. a) Simplified representation of a product model of a photovoltaic panel and **b)** representation of the expected behaviour of the entire product.

Flow propagations shown that the product model behaves according to expectations for most of the flow types, including *solar* and *electrical energy* which are related to the product's primary function as shown in Figure 5b. In some cases, however, results were inconsistent thus leading to a modification of the product model or revealing limitations of the modelling framework. These latter issues are briefly discussed in section 5.3.

5.2 Faulty Behaviour

The known failure modes of the photovoltaic component as well as the generic degradation modes (such as corrosion or photo-oxidation of polymers) have been implemented in the degradation database. Due to technical limitations, the study was discontinued after third order degradations were identified thus preventing the building of an exhaustive state graph. In this first step, thirty one distinct degradations modes have been identified, from mechanical deformation of the entire panel to process errors occurring during the fabrication process of the photovoltaic cells.

The model revealed that several of these degradations phenomena already affect main product functions, ether by limiting the flow of solar energy reaching the cell or by creating short circuits. In addition, several generic degradation modes related to constitutive materials of the product components are taken into account. The comparison of these results with the previous FMEA report [HANS *et al.* 2007b] also shows that the prototype automatically identified relevant degradation modes but sometimes fails to take their effects into account.

6 DISCUSSION AND CONCLUSIONS

A new functional modelling framework for FMEA of building products has been developed and has been implemented into a prototype software tool. An initial case study on a photovoltaic panel has shown that most of the relevant failure modes can be automatically identified using this tool as well as some of the failure mode combinations. As some of the degradation effects were not taken into account in a relevant way, the automatic construction of a state graph was only partially satisfactory.

This study also revealed some limitations that are inherent to the modelling framework. In some cases the function and flow formalism is limited with respect to the representation of some physical phenomena, such as heat transfer or mechanical deformation. This is due to the qualitative nature of this formalism and the nature of studied systems. It does not necessarily prevent identifying relevant degradation modes but this particular aspect should be further explored. Further development is required in order to assess the impact of these limitations on the results. To date, the results are displayed as a state graph, in which an exhaustive representation of degradation combinations is provided. However the simplification of results as a failure tree remains to be done through the process of criticality ranking.

REFERENCES

Addleson, L. & Rice, C. 1991, ‘Performance of Materials in Buildings: A Study of the Principles and Agencies of Change’, First edition. Butterworth-Heinemann Ltd.

Bazzana, M., Sauce, G., Hans, J., Laé, L., & Mehl, C. 2010, ‘Development of a product model for FMEA support of building products’, Proc. CIB2010 Building a Better World Congress.

Bell, J. 2006, ‘Interpretation of simulation for model-based design analysis of engineered systems’, Thesis (PhD), University of Wales, Aberystwyth.

Bell, J., Snooke, N. & Price, C. 2007, ‘A language for functional interpretation of model based simulation’, *Advanced Engineering Informatics*, vol. 21.

Hans, J., Chorier, J., Morlot, R., Boddaert, S. Proisy B, & Boulanger, B. 2007b, ‘Durabilité des équipements énergétiques et de composants d’enveloppe du bâtiment’, CSTB – Internal report.

Hans, J., Joffre C., Boilève C. & Fies B., 2007a, ‘FMEA Software to enhance innovation in building’, Proc. of the 2007 CIB Construction Research Congress.

Hirtz, J., Stone, R.B., Mcadams, D.A., Szykman, S. & Wood, K.L., 2002 , ‘A Functional Basis for Engineering Design: Reconciling and Evolving Previous Effort’, *Research in Engineering Design*, Vol. 13, No. 2., pp. 65-82.

ISO – International Standard Organization, 1984, ‘Performance standards in building. Principles for their preparation and factors to be considered’, ISO 6241:1984.

Lair, J. 2000, ‘Évaluation de la durabilité des systèmes constructifs du bâtiment’, 2000. Thesis (PhD), University Blaise Pascal Clermont II.

Offenstein, F. 1988, ‘Compatibles, incompatibles: ou comment associer les matériaux de construction’, Edition du Moniteur. Paris.

Price, C.J. & Taylor, N.S. 2002, ‘Automated multiple failure FMEA’, in *Reliability Engineering & System Safety*, vol. 76. No. 1, pp. 1-10.

Struss, P. 2008, ‘Model-based Problem Solving’, in *Handbook of Knowledge Representation*, vol. 3, eds. van Harmelen, F., Vladimir Lifschitz, Bruce Porter, Elsevier p. 395-465.
Talon, A., 2006, ‘Évaluation des scénarii de dégradation des produits de construction’, Thesis (PhD), University Blaise Pascal Clermont II.

Talon, A., Boissier, D., Hans, J., Lacasse, M. A., Chorier, C., 2008, ‘FMECA and management of building components’, 11DBMC International Conference on Durability of Building Materials and Components Istanbul, Turkey.

Talon, A., Chevalier J.L., Hans J. 2006, 'Failure Modes Effects and Criticality Analysis Research for and Application to the Building Domain', Publication CIB n° 310. Working commission 80, 246 p.
Teexma® 2010, BASSETTI, [online] Software description available at <http://www.bassetti.fr/> last accessed on 01-31-2011.

Teoh, P.C. & Case, K. 2004, 'Modelling and reasoning for failure modes and effects analysis generation', Journal of Engineering Manufacture, vol. 218. No. 3., pp. 289-300.

Wright, D. 2001, 'Failure of plastics and rubber products: causes, effects, and case studies involving degradation'. Ed. William Andrew, 416p.