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CONNECTING CAD AND PLM SYSTEMS WITH ECODESIGN SOFTWARE: CURRENT EXPERIENCES AND FUTURE OPPORTUNITIES

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ABSTRACT

Stronger legislation and higher environmental expectations from customers are turning ecodesign into an increasingly attractive approach in industry. Many publications, including standardization, recall the necessity to integrate environmental aspects at every step of a product design process and as early as possible. However, ecodesign is not widely deployed in the industry mainly because few ecodesign methods and their support software tools are today adapted to designers' requirements and activities. Therefore, instead of developing new methods and tools, some first benefits might be reached when connecting existing design software tools, i.e. product design tools and product environmental assessment tools.

The paper reports recent research work aiming at exploring opportunities and limitations of connecting CAD software (Computer Aided Design) and PLM systems (Product Life Cycle Management) with ecodesign software tools. Technical results, e.g. computer languages used for this connection, as well as more general results, i.e. real benefits and limitation of the connection, and potential use in industry, are reported.

Based on this research, a design framework for systematic integration of environmental aspects into product design and development is suggested. In particular, the need to share experts' information and knowledge, the product environmental view that is currently emerging is discussed using concrete environmental constraints, e.g. legislation concerning recycling and substances management. The previously presented interoperability mechanisms between ecodesign and traditional design tools is then re-discussed and further research perspectives are then drawn-up.

Keywords: ecodesign, CAD, PLM, LCA, XML interoperability.

1 INTRODUCTION

Today, with stronger competition on quality, performances and prices, more and more expertises should be considered during the development of industrial products. During the last decade, integrated design has focused on integrating expertises such as quality, manufacturing or mechanical optimisation. In recent years, an emerging issue such as the environment, i.e. the environmental impact of a product during its whole life cycle, has been gaining in importance due to alarming pollution problems. Although secondary today, this issue will surely be crucial for design activities in the next years. It is therefore time to study in detail the potential ways of integrating environmental aspects in current integrated design, through for example connecting ecodesign software tool with traditional design tools, such as CAD and PLM systems. This is the aim of the research reported in this paper. Next section will present some conceptual basis of product ecodesign. In Section 3, a design framework and a way to consider environmental aspects will be presented. Section 4 will report results of connecting existing CAD and PLM systems with ecodesign software, while Section 5 will discuss those results. Final conclusions and research recommendations will then be enounced.

2 PRODUCT ECODESIGN: AN INCREASINGLY ATTRACTIVE APPROACH IN INDUSTRY

2.1 Trends of ecodesign

The protection of the environment has been an increasing concern of manufacturing industries since the seventies, due in particular to resources crisis, acute pollution events, or wider political strategies, like the sustainable development principles expressed in the Brundtland report. From an industrial perspective, the traditional "end-of-pipe approach" of the seventies aiming at treating liquid, solid and gaseous effluents, has expended during the nineties into a more preventative approach, called "middle-of-pipe", that consists for example of waste and energy consumption minimisation. During the nineties, this manufacturing-centred pollution prevention approach has been enlarged to the whole life cycle of products (extraction of resources, manufacturing, distribution, use, and end-of-life recovery) through the development of ecodesign, that is a front-of-pipe approach [1]. Ecodesign aims at integrating environmental aspects during the design of products, as any other criterion [2].

2.2 Some key drivers of product ecodesign development

Based on [3], the authors present below two key drivers of product ecodesign development in the industry.

2.2.1 Legislation

Legislation is an important driver for ecodesign development as many product categories are today targeted by EU (European Union) regulations. For example, packaging products [4], end-of-life motor vehicles [5] and electric and electronic equipments [6-8] are today covered by EU directives.

In general, EU directives define common rules concerning technical issues (e.g. end-of-life treatment of equipment; recycling rate to be achieved), financial issues (e.g. who pays for end-of-life treatment) as well as responsibility issues. EU directives also include essential prevention dispositions that encourage ecodesign: for example in the Waste Electric and Electronic Equipment EU Directive, "the design and production of equipment […] which take into account and facilitate dismantling and recovery, in particular the reuse and recycling is encouraged" (article 4 of [7]).

There is today a trend for manufacturers to set-up efficient prevention measures. For example, in the EuP (Energy using Products) directive, in order to demonstrate the conformity of his products, a manufacturer can use an internal design control. This control process aims at "providing information on products environmental assessment studies, and/or references to (…) literature or case studies, which are used by the manufacturer in evaluating, documenting and determining product design solutions" (Annex 4 of [8]). Traceability of design choices needs indeed to be improved from an environmental perspective.

2.2.2 Customer expectations

Fulfilment of customer requirements is often seen as a driver for the development of ecodesign: this is in particular true for business to business products. It is also more and more true for consumer products as ecodesign is a way to highlight the company environmental policy [3].

Several strategies can be adopted for companies to demonstrate environmental performances of its products. It can either apply to obtain a recognized ecolabel (see e.g. [9]), or develop and diffuse to its customers an environmental profile of its products following a recognised process like e.g. ISO/TR 14025. Such Environmental Product Declarations (EPD) already exist for many product categories, such as LCD monitors [10] or trucks [11].

2.3 Current development of ecodesign in the industry

Ecodesign was in the past mainly developed in sectors targeted by strict environmental regulations, i.e. packaging, automotive and electr(on)ic industry. However, ecodesign is being generalised in many -if not all- other industrial sectors such as building, aeronautic, food and drink or textile.

Until recently, ecodesign was mainly conducted through pilot projects where environmentalists, i.e. ecodesign experts, were leaders [3]. Therefore, such projects have been led with limited interaction with the rest of the design team. In general, ecodesign is indeed little routinely integrated into the product development [12]. This is however slowly changing and environmental experts are today more and more involved in the design team.

Nevertheless, it should be recalled that ecodesign is defined by the ISO 14062 as integrating environmental aspects into product design and development, as any other design criterion [2], and not as developing green products. Environmental issues are currently more and more acting as constraints on the product development process. For example, legislation such as [6] limits the use of some substances (e.g. lead, cadmium) and therefore reduces the design space. However, for other issues such as the recyclability of the product, constraints cannot be expressed as clearly as for substances and the design space is not reduced a priori. Although environmental issues should be considered as soon as possible during the design process, it is not clear yet how they should be considered in the conceptual design and the detailed design phases.
Due to current ecodesign generalisation, there is indeed a real need today to explore further the role of environmental experts in the design team and product development process. This paper reports recent tentative to narrow environmentalists and product designers. That can be done through the analysis of the coherency of their respective vocabularies and approaches and of the interoperability of their software tools. This approach is based on DfX concepts for which the environmental expert works with its own tools and pro-actively negotiates with the rest of the design team to find an acceptable solution. The connexion of expert tools presented below should be seen as a pretext to study possible of interactions of experts, not as technical solutions that will always allow the integration of environmental aspects into the design.

3 DESIGN FRAMEWORK

3.1 Integrated design

Nowadays, product development process[1] is considered as a collaborative process. Indeed, that process tends to take into account a maximum of information related to the entire product life cycle [13-17]. That concurrent and collaborative approach tackles the problem of sequential ("over the wall") process that used to be practiced by designers to develop products without any consideration of manufacturing information, and even less of environmental information.

3.1.1 Modelling framework

In such integrated design approach, interactions mechanisms have to be set among every expert modelling and their respective software applications. As current mechanisms, the authors propose a framework based on [18] (cf. figure 1):

- Several expert models based on usual design expert activities that represent in this paper DfX activity (eg. DfM, DfA, etc.);
- A reference (or shared model) to set relationships among models and to support interoperability capacity.

Based on a DfX analysis and synthesis approach, each design actor:

- Gets the current design state out of the shared model;
- Assesses (i.e. analysis step) the product behaviour respect to its expert domain (mechanical analysis, manufacturing, environment, etc.). This assessment is based on specific expert modelling and on knowledge base (guidelines, rules, algorithms, etc.) as detailed in section 3.1.2;
- Returns (i.e. synthesis step) new information on the product solution in the shared model.

That design approach "by least commitments" then provides a solution "right the first time" versus a "redo until right" process [19].

In this paper, the shared model is supported by CAD and/or PLM solutions. Noël et al. nevertheless presents what could be future software architectures to support that modelling concepts [20]. Further information on the entire shared model can be found in the literature: for example, Roucoules et al. details a specific design-manufacturing interface model based on this shared model to illustrate the progressive definition of the product (and of CAD model) "by least commitment".

[1] Recent papers have been talking about "virtual product development" to go further regarding digital management of the whole product life cycle information [13].

3.1.2 Expert activity and information modelling

Figure 1 presents how can be detailed expert product modelling in the proposed integrated design framework to support analysis-synthesis process:

- Simplified models support data to allow rapid analyses of the expert activity (DfX concept) in order to propose a large number of alternative solutions as soon as possible in the design process;
- Advanced models are available for product accurate analyses and to find the "best" solutions among alternative ones. They usually need more time and information than the simplified ones. They are therefore used later in the design process;
- The knowledge base represents any kind of knowledge (ex: books, computer database, own experience, etc.) used by design experts to find and assess solutions respect to specific requirements. In respect to this last issue and depending on the industrial design context, two approaches have so far been identified:
  - In the case expert "A" is fully involved in the design group (cf. 3.2.1) and can support the specific product analysis, he uses a large and complete expert knowledge database to provide an accurate assessment. The expert is indeed able to understand and appreciate the details of the analysis;
  - In the case expert "A" is not involved in the design group (cf. 3.2.2), a "light" database could however be provided to expert "B" in order to nevertheless integrate "A" expert information during the product development. "Light" means that the database has to be sufficiently understandable by expert "B". It is, therefore, not worthwhile to be as detailed as a complete database.

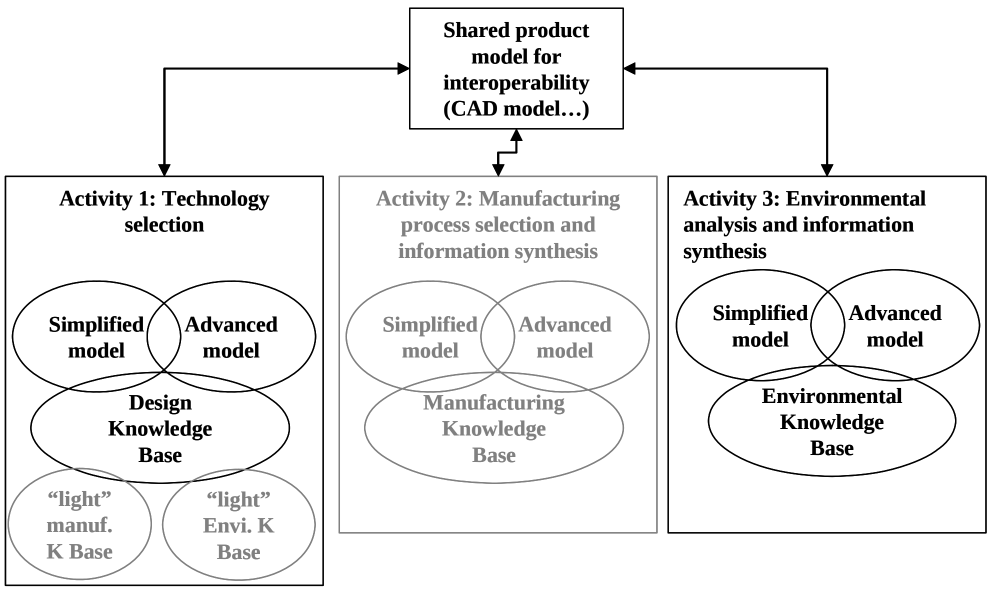

Figure 1. Modeling framework.

3.2 Integration of environmental aspects in this framework

The paper now details how could be integrated the environmental expertise within the modelling framework presented in section 3.1. After analysing in the past many industrial design contexts, the authors argue that the environment is indeed an expertise among others and that integrating environmental aspect into product design seems similar to integrating manufacturing or any other expertise.

3.2.1 High level of expertise and integration

If environmental experts are to be involved in design teams, exhaustive, scientific and therefore complex environmental aspects should be considered. Nowadays, environmental aspects are strongly led by EU compulsory norms, customer requirements or companies own environmental policies (cf. Section 2). Therefore, several environmental sub-criteria are usually considered in a global product's life cycle perspective, for example:

- Environmental impact categories:

- Ecological damages, for example: global warming; ozone depletion; acid rain; water eutrophication; eco-toxicity; land use;
    - Human health damage, for example: smog and air pollution; health damaging substances; carcinogenic substances;
    - Resources depletion, for example: depletion of fossil fuels, of fresh water, of minerals;
- Content of hazardous substances;
- Recyclability of the product.

So far, these criteria have been implemented as indicators in expert ecodesign software tools to assess the environmental impacts of already defined design solutions. Such indicators represent a good mean to analyse and compare several design alternatives and to select the “best one” from an environmental point of view. As an illustration, the input and output information of the ecodesign software EIME is presented in the Table 1 below. However, such indicators have been rarely considered during product design process.

Table 1. Input and output information of the EIME ecodesign software tool (after [21]).

Input information		Output information	
Product’s architecture:	Part name and level; physical links between parts	Life Cycle Assessment indicators:	Global warming potential; ozone depletion potential; acidification potential; air toxicity potential; eutrophication potential; etc.
Parts details:	Material, weight, manufacturing process		
Electronic components details:	Type and reference	Design indicators:	Weight ratio of special handling components; Weight ratio of recyclable components; Number of extractible reusable components; etc.
Energy details:	Quantity of energy consumed during use		
Packaging details:	Type and quantity of packaging		

3.2.2 Low level of expertise and integration
In the case that no expert on environmental aspects is involved in the design group it would be however interesting to give some guidelines to designers in order to reach a “good” solution from an environmental point of view “the first time”.

In that objective, environmental knowledge has first to be formalised in order to be used by non expert and has to be provided via the right means to designers. For example for the end-of-life issue, a list of a limited number of simple and understandable design guidelines (e.g. “allow easy dismantling of hazardous substances”; “prefer easily dismantlable links”; etc.) could be provided. However, from our perspective, ecodesign guidelines are today not mature enough to be considered by designers without the environmental expert. This low level of expertise is therefore not explored further in this paper.

4 CONNECTING TRADITIONAL CAD AND PLM SYSTEMS WITH ECODESIGN SOFTWARE
For computing implementation of the interoperability mechanisms presented above, several tries have been done on specific CAD and PLM systems that are here supposed to support the shared model. According to the design approach and based on the modelling concepts, two software data exchanges have then been studied to get out CAD and PLM systems current design state and bring it to ecodesign software;

4.1 Identifying relevant design tools
Although scientific results presents original software solutions for supporting the shared model (e.g. [19]), a recent study on industrial practices realised by M. Lindhal through interview shows that current CAD (Computer-Aided Design) solutions and geometric model are still considered today as the data reference by industry ; they are also the most utilised tools during the design [12]. Another recent –unpublished- survey lead by IKP Fraunhofer among German small and medium size enterprises shows that CAD, CAE, CAM and PLM/PDM (Product Life cycle Management / Product Data Management) software tools are the most utilised tools in the industry [22]. Considering this, the

authors conclude that ecodesign tools should in priority be connected to two main design tools: CAD and PLM/PDM systems. PLM[2] tools are currently gaining in importance in industry. This paragraph presents results of the tentative for connecting CAD and PLM systems with ecodesign software. Our aim to explore this connexion was in particular to assess:

- Potential improvement for time effectiveness and flexibility of the connexion;
- Potential opportunities for assessing environmental performances of product early in the design process;
- Potential opportunities for facilitating the cooperation within the design team.

The connexion of CAD and ecodesign software has already been explored by several researchers. For example, Cappelli et al. gives an initial introduction to their EcoDesign Helper, a software application that allows the designer to assess the environmental implications of design choices based on the CAD structure [23]. Recently, some preliminary attempts to connect PLM system with ecodesign tools have been reported: for example Park et al. present a framework where an approximate Life Cycle Assessment system is integrated into a collaborative design environment implemented by engineering solution CO™ [24]. However, from our perspectives, none of these attempts was done with the aim of exploring the interactions between environmental experts and the rest of the design team. This is the particular aim of the research work presented below.

4.2 Connecting CAD system with ecodesign software

The connexion of a CAD system, CATIA V5, and an ecodesign software, EIME, was realised and has already been presented elsewhere [25]. Only conclusions of this connection are presented here.

4.2.1 Benefits of the connection:

It was shown through the demonstrator that a number of relevant information can be extracted from CAD system to be automatically exported to ecodesign software, in particular:

- The product architecture, i.e. part name and level;
- Part material and weight.

It should be noted that specific connections have been developed instead of using standards for data exchange (e.g. STEP AP203) because the long term research work will largely be based on features that are not currently supported in STEP (ex: hazardous substances, recyclability performance).

Benefits in term of time efficiency and product structure reliability (all member of the team share the same part name) have been therefore demonstrated and quantified [25].

4.2.2 Limitations of the connexion

However, it was also shown that the connexion was not fully operational:

- First, CAD models do not contain all information necessary for environmental evaluation: for example, characteristics such as energy consumption of product during the use phase, life span of the product, or exact reference of an electronic component, are not described in CAD models, although they are absolutely crucial for environmental assessment. This type of data will need to be found elsewhere (e.g. in Electronic Design Automation tools for electronic components) and input into the ecodesign software manually;
- CAD models contain relevant information only if they are correctly customised and used: for example, if the CAD user does not define the materials, as it is often the case in companies, the demonstrator will obviously not be able to extract them. This is the same problem for the manufacturing process, as CAD users generally do not define it in CAD models, and above all often ignore it;
- Although export of results from ecodesign software to CAD system was possible, it was judged too early to do so due to the lack of pertinence of expert results for the CAD user: indeed, questions such as “which of the eleven environmental indicators should be reported to the designer?” or “to which part allocating the environmental impact of the product’s life cycle?” did not find any answer yet. This might be explored in the future.

It was shown that CAD models were not fully efficient to automatically collect relevant and sufficient data to be imported into an ecodesign software. It was therefore decided to explore the connexion of

[2] “PLM/PDM” will be referred by only “PLM” in the rest of the paper. The authors indeed argue that PLM and PDM are referring to the same concepts. PLM is the software editors naming evolution of PDM one.

ecodesign software with PLM system. In particular, the potentialities of metadata for identifying information relevant for ecodesign software should be highlighted.

4.3 Connecting PLM system and ecodesign software

4.3.1 Software tools considered

The PLM software tool studied was SmarTeam distributed by Dassault Systems [26]. Two main reasons explained this choice:

- SmarTeam is more and more used in the industry, in particular by some of our industrial partners;
- More pragmatically, the education version of the software available at our university allows us to access SmarTeam functionalities from external applications using Visual Basic API (Application Programming Interface)

The ecodesign software used was EIME, developed by CODDE [21], and supported by the French Federation of Electric and Electronic Industry (FIEEC). Again, several reasons explain this choice:

- EIME is very much used by many of our industrial partners from several sectors, mainly from the electr(on)ic sector but also from mechanical, automotive and aeronautic industry;
- In EIME modelling, a product is defined by material type, mass, and production process of the parts, but also by the physical links between parts and the product’s architecture; also, EIME allows not only LCA-based environmental impact indicators calculation, but also calculation on other physical criteria, such as recycling indicators (cf. Table 1); EIME can also include a basis of ecodesign rules for designers; therefore, to our perspective, EIME is more an ecodesign software than a typical LCA software;
- Pragmatically again, a cooperation with CODDE allowed us to access to input/output computer codes from/to the software.

Whatever the software used, it should be always reminded that a generic approach was adopted and any result reported in this paper is not only true for these software tools, but also for any other software tool of the same type.

A first analysis of the connexion aimed at defining compatible and incompatible aspects of the input/output formats of both software tools. This is summarised in Table 1.

Table 2. Summary of I/O data needed in EIME and SmarTeam software tools.

Data Type	Description
Data needed in EIME available from SmarTeam	• Product architecture: part name and level

Data needed in EIME and available from documents embedded in SmarTeam (type of application or file where data is encapsulated)	• Part material, part weight (in CAD)
	• Physical links among parts (in expert application)
	• Manufacturing process (in expert applications)
	• Data on other product life cycle stage, for example:
	  ◦ Information on packaging (in Expert application or Word Document)
	  ◦ Distribution modes and distance (in Word Document)
	  ◦ Energy consumption of the product (in Word Document)
	  ◦ Life duration of the Product (in Word document)
	  ◦ Probable end-of-life treatment (in Word document)

From the preliminary analysis, it can be concluded that if PLM system is properly parameterised, few data needed by EIME are not available from PLM.

4.3.2 Software technology used

A demonstrator aiming at translating output data from Smarteam into input data for EIME has been developed. The computer language chosen for this interface was VisualBasic (VB). VB Application Program Interfaces (API) give the access to any functionality of SmarTeam from external applications. For our demonstrator, API were developed using VB to extract data from SmarTeam, and generate exchanges files based on XML, readable by EIME.

Flows of input/output data between software tools are summarised for the PLM / Ecodesign connection in Figure 4.

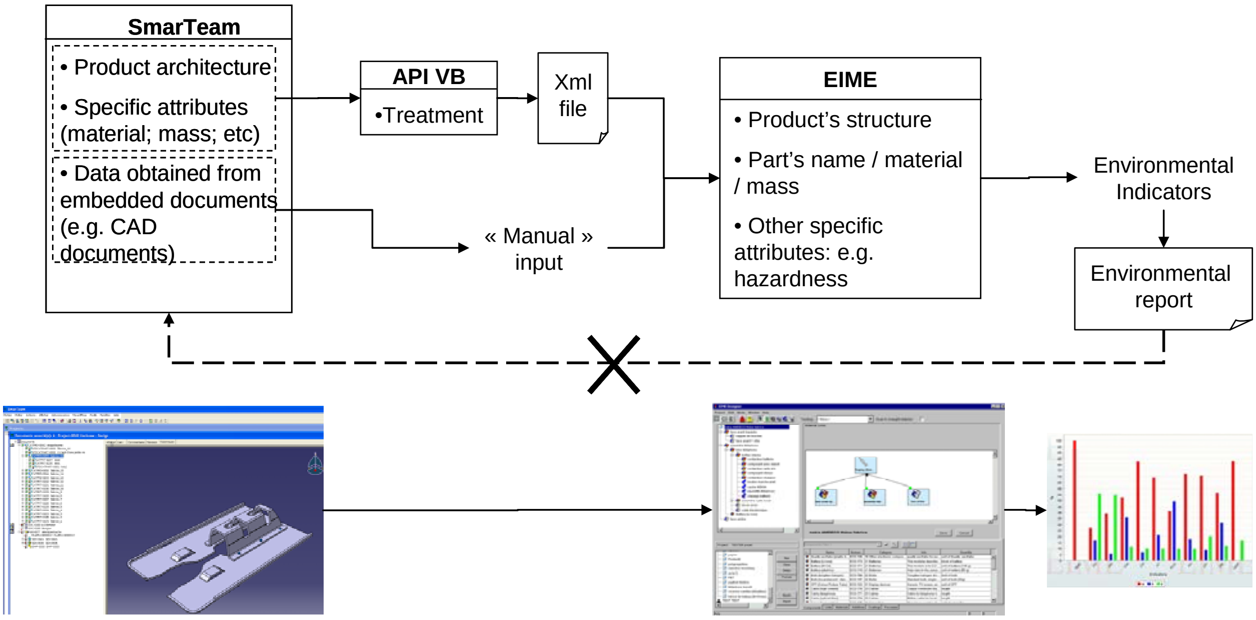

Figure 4. Flow of I/O data in the connection of SmarTeam and EIME.

4.3.3 Benefits and limitations

Once the software implementation was achieved[3] and some real case tested, a scientific and technological synthesis has been done. Here are the main conclusions of the analysis:

- The data interoperability between software is possible using XML language;
- Product breakdown can easily be extracted from PLM systems (using Object breakdown and exploring CATPart files). CATProduct exploration algorithms were used for CATIA-EIME connexion.
- If PLM metadata are correctly parameterised and if parameters are correctly valued[4], a greater number of relevant information can be extracted and imported into ecodesign software. For example, parts' weight and material can be described in metadata; moreover, any material or part categorised as "hazardous" by an environmental expert can be set as such in the PLM system (cf. Figure 5), and then be re-exported into the ecodesign software:
    - o Adhoc parameters have to be created in the CATPart construction tree;
    - o Adhoc parameters have to be created in the "profile card" of CATPart objects;
- In case of non customised CAD or PLM, a huge benefit of PLM systems versus CAD software is that any encapsulated information can be sought by the environmental expert in order to collect missing data (e.g. energy consumption; life span; etc.) necessary for the ecodesign modelling. The expert can then "manually" import that data into the ecodesign software (cf. Figure 4);
- Environmental assessment reports, such as standardised EPD (Environmental Product Declaration), based on the results of the EIME calculations on the product under consideration (or of previous product generation) can be stored in PLM and consulted by any member of the design team at any time. This was not realised yet in our demonstrator (cf. cross on the feedback from EIME to SmartTeam on Figure 4) but it is currently being explored., This should not imply major technical problems but rather methodological problems (who and when should consult the reports? for which use? etc.). To our perspective, this nevertheless represents an important asset of PLM systems over CAD systems for better ecodesign integration.

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[3] Authors do not pretend to develop industrial software but are able to implement demonstrators to test technological feasibility and scientific benefits.

[4] Exploration algorithms are indeed based on specific parameters with specific (char*) values that have to be known and well instantiated by the designer.

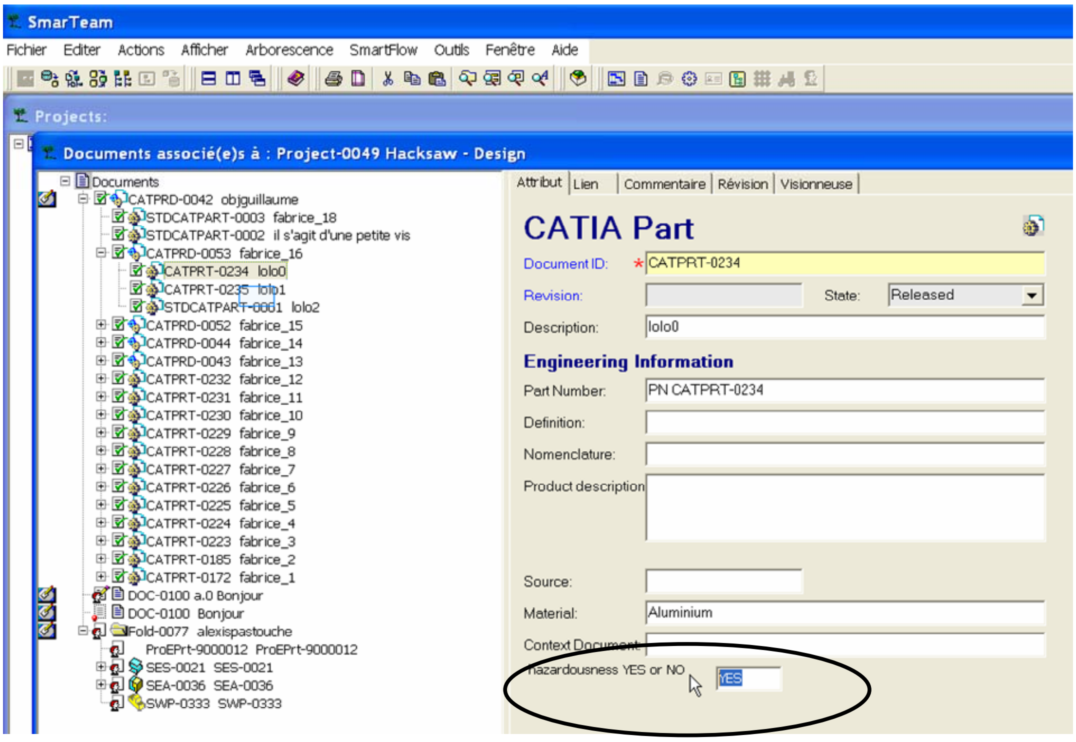

Figure 5. Flexibility of PLM tool allows to define specific attributes needed in an expert (here ecodesign) application: here the hazardousness of a part.

4.3.4 Application in the industry

Based on this academic work, a similar work of connecting a PLM system, i.e. Matrix One, and the EIME ecodesign software was recently realised in the industry, and reported in [27]. During this work, the convenience of connecting ecodesign and PLM platform for global companies was demonstrated: this indeed allows dispersed design teams to effectively collaborate on product development efforts. Opportunities for continuously and easily updating the environmental information during the whole product design process were also shown. At last, the industrial application quantified also the reduction of the time for the creation of the product's first architecture.

5. DISCUSSION ON INTEROPERABILITY OF TOOLS

The aim of this paper was to study the coherence and possible links between traditional design methods and expert ecodesign methods through the analysis of the interoperability of their respective tools. The analysis is based on the design framework defined in section 3. Here are our main conclusions:

- Connection of CAD and PLM tools with ecodesign software is indeed possible and seems to bring obvious time efficiency and convenience benefits;
- For CAD, it is possible to export specific useful data such as product's architecture, part's name, material and weight;
- For PLM:
    - Only product's architecture and part's name can be directly extracted;
    - Other specific attributes can easily be extracted if metadata are correctly parameterised such as: part's material and weight; hazardousness of a part;
    - The environmental expert can browse product's information to find necessary information;
    - Therefore, PLM seems more flexible and promising for ecodesign purposes;
- PLM seems also more performing than CAD for the re-exportation of some environmental expert results to be used by the design team;
- However, it should be recalled that to be efficient, the connection of CAD and PLM tool with ecodesign software tools should be always carefully parameterised to the company needs. The

parameterisation should also consider all constraints / requirements of other expertise tools (e.g. manufacturing, calculation, etc.).

Those first conclusions open the discussion toward the general limits of CAD and PLM solutions to manage the whole Product Life Cycle information. CAD is indeed mainly restricted to form feature data and PLM only manage encapsulated object and not really embedded data.

A generic modelling framework and an open software platform could then provide a very good solution. A multiple views product breakdown would really structure environmental information to optimise the product's environmental performance. In term of software application, each computer services could moreover be developed independently and on independent data structure.

6. CONCLUSIONS AND PERSPECTIVES

After a general introduction related to environmental aspects presentation and ecodesign conceptual ideas, the paper presents the theoretical concepts of a design framework based on multiple product breakdowns and an open architecture for software interoperability.

Those concepts are afterwards applied to the integration of environmental aspects into the product development process based on a "right first" and "by least commitment" objective. Basic software interoperability is then tried among CAD and PLM systems and ecodesign software.

The results validate the technological feasibility of the approach: the main assets of the automatic transfer seem to be the time efficiency and the reliability of the product structure. The real benefits of the automatic transfer in industry practices should however be studied in the future. Interested potential benefits of the connexion were also identified;

However, demonstrators need tests with industry to explore the usefulness when used:

- Either disconnected from projects, to assess environmental performances of all products generations and verify that continuous improvement is achieved through ecodesign practices,
- Or during projects, to assess in real-time environmental performances of design alternatives and to be used for decision making.

Nevertheless, conceptual limits are highlighted, in respect to:

- CAD and PLM systems and the current use in a virtual product development process and for life cycle information management;
- The activity of environmental expert which is nowadays quite well-known but which is not formalised enough to really have an analysis-synthesis process during the product development.

The authors are currently working on the proper customization of PLM systems for efficient connexion with ecodesign tool. They are also working on the simulation of a design process of a real product to explore further the interactions between environmental experts and other well-recognized experts, in particular manufacturing experts.

The authors plan to develop such an integration of environmental aspects in a more generic platform that support the proposed modelling approach. That platform could be based on the first results issued from the IPPOP project [28].

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