TOWARD PROACTIVE ECO-DESIGN BASED ON ENGINEER AND ECO-DESIGNER'S SOFTWARE INTERFACE MODELING

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ABSTRACT
Integrating environmental concerns as well as other constrains (cost, quality, etc.) in the design process, requires to organize the process as a system. Specific software for each design expertise are created to embrace new demands and are supporting the design activity in such complexity that the interoperability between software is crucial.
The approach presented in this paper proposes a specific organization of the design process composed of *local* and *global* activities. The article focuses on the importance of modeling the data input and output exchanged between activities. It points out the necessity to define rules of transformation that are needed to link models together. The system modeled allows an infinite number of interactions and notably the integration of environmental concerns.
This paper illustrates the method by studying a part of the design process of a simple product in a DTE approach. This case study involves software of material choice, CAD, LCA and focuses on transformation rules needed to give interoperable models. The results of the case study finally bring designers to adopt a new design of the product, which reduces initial environmental impacts.

Keywords: eco-design, UML modeling, design process, software interoperability, LCA, Design To Environment (DTE)

1 INTRODUCTION
Our contribution in this article is to illustrate that proactivity can arise from a specific systemic organisation that integrates environmental impacts of the life cycle of the product into the design process. A proactive system differs from a reactive process for two reasons. The first one is that a proactive process allows dynamic and bilateral exchanges between actors. The second one is that those exchanges occur as early as possible in the design process. To support an effective eco-design process our proposal is to work on interfaces between models of usual designer's software (eg. Computer Aided Design (CAD) or material selection software) and global environmental assessment tools such as Life Cycle Analysis (LCA). Our research uses Unified Modeling Language (UML) to describe:
1/ the Inputs and Outputs (I/O) of activities that occur during the design process;
2/ the transformations needed to connect I/O together.

The structure of this paper is as follows. Section 2 introduces to the engineering process and its complexity, where collaborations and data sharing are important issues to conduct a Design To Environment (DTE) study. Section 3 describes our method, which focuses on the I/O data modeling of each activity involved in the design process of a product. Section 4 presents a case study which illustrates the transformations needed to link I/O between local and global activities and software. The last section concludes and proposes directions for further work.

2 CONTEXT OF THE RESEARCH WORK

2.1 Tools and methods in the complexity of the design process

2.1.1The rapid growth of eco-design tools and methods
Due to relatively new environmental concerns and customers pressure, environmental legislation raised on the market place (WEEE, RoHS, REACH, EuP, IPP, etc.). They have been the starting point for many industries to search for new strategies in order to match those legislations and answer

customer's demand. Cost, quality, security, environment are familiar examples to illustrate the transversality and multi-disciplinarity needed by companies to remain competitive. Collaboration is necessary between engineers, commercials, suppliers, etc., during the design process.
Consequently there has recently been an influx of new collaborative methods and software for DTE [1], based on team management programs and technical supports (example of tools and software: [2,3], methods [4,5,6], check-lists [7]). Despite the evidence that design needs methodology [8], when Baumann et al. studied hundreds of articles in 2002 about green product development, they showed the high amounts of tools that were developing and they claimed the necessity to adopt a systemic approach to reach effective eco-design in industry [1]. As noted by Robert and colleagues in 2002 'despite the evidence that the number of tools and approaches to develop sustainability is growing rapidly, they are complementary and can be used in parallel for strategic sustainable development' [9]. Eight years after Collado-Ruiz shows that the effort for developing methods and tools to integrate environmental concerns might not have been as strong as the one for testing them in industry [10]. W*hat kind of complexity makes the integration of environmental tools and methods so difficult for designers during the design process?*

2.1.2 The complexity

During engineering design the complexity of the product is numerical, relational, structural and variational, and the complexity of the process is disciplinary and organizational [11]. In a DTE approach the validation of the design solution for instance is related to environmental criterion such as environmental impacts, which require the exploration of unusual domains such as biology or climatology to be understood properly. Researchers in complexity shows that a complex system has complex effects and cannot be resolved by a complex equation [12]. It is possible to describe the diversity of engineering process contexts to bring a product to the market (involving various tools, stakeholders, etc.). But it is not possible to propose a general rule to optimize the design process in a DTE approach.

2.1.3 Integrated engineering as the key success to complexity

Nevertheless, concurrent engineering has given a parallel organization of the design process, in which data push the process forward [13]. Accordingly all elements of the life-cycle of a product have to be considered in the early design phases and the design stages must occur concurrently. Therefore, various companies have adopted this relatively new design management system [14]. To materialize such systemic organization in the case of a DTE approach data must be able to circulate with as much freedom as possible.

2.2 Supporting collaboration between actors: DFX *versus* DTX, local *versus* global interface modeling

The integration of environmental concerns into the complexity of the design process thus requires to focus on collaboration and data transfer between software. Our research focusses on the interface between activities involving different software and distinct knowledge in a DTE process (eg. CAD-LCA or material selection software-LCA).

2.2.1 Data interfacing modeling between software: the example of CAD and LCA

When observing the market of environmental assessment in engineering design, it can be seen that editors are nowadays integrating Life Cycle Analysis and Computer Aided Design software together. The work being done with *Dassault System* and *PE International* is a current example of integration of environmental assessment–simplified LCA in CAD[15]. Databases as well as product information are gathered in the main software and shared, avoiding interoperability problems between LCA and CAD. But this has two main effects that we consider to be dangerous:
1/ the extension of the product designer expertise to the eco-designer's skills and knowledge is ambitious. Even if in some small companies most of the product designers are experts in various domains, environmental assessment is too much transversal to be in the hand of a unique engineer;
2/ it tends to reduce eco-design to a simplified LCA. There is indeed an important gap between performing eco-design and using a LCA software.
If we extend this example to other DTX approaches, similar problems might occur if all expert software are gathered in one single global software and if product designers are reduced into one

multi-skills person. It is better to have the possibility to connect heterogeneous knowledge and separate software rather than all of them into one. Therefore we propose to deal with the complexity of the design process by creating interactive interfaces between distinct activities involving specific engineers using their proper knowledge and software. This method answers to the real context of heterogeneity of knowledge, models and software, by allowing any new tool to be added in the design process and support any design to X approach (DTC, DTE, etc.).

2.2.2 Dissociating DTX from DFX approach as well as local from global exchanges: a new organization

In a previous paper authors proposed an organization of the design process dissociating the *local* level from the *global* level [16] (figure 1). The *local* level (individuals and asynchronous activities) matches with local experts such as designers, material engineers or mechanical engineers. They respectively use their own software and interact together horizontally during the design process: exchanging data, sharing models, etc. On the *global* level the expertise is transverse to manage collateral impacts: cost, quality, manufacturing, environment (DTE, DTC, DTX) and interacts vertically with the local level. In accordance with the eco-designer's community, designers need the life-cycle thinking and a global understanding of the system to support eco-design and use environmental assessment tools. In this paper eco-design tools such as LCA are thus considerate as global software. An eco-design expert will control the environmental assessments, analyze the results and direct expert's research and development on specific solutions and tools, in order to optimize the whole process. However, he needs data from every local expertise. That is why, we argue the need of dynamic data exchange between local and global scales within the design process. From this organization, we think that proactivity can arise from **vertical** and horizontal exchange in the design process.

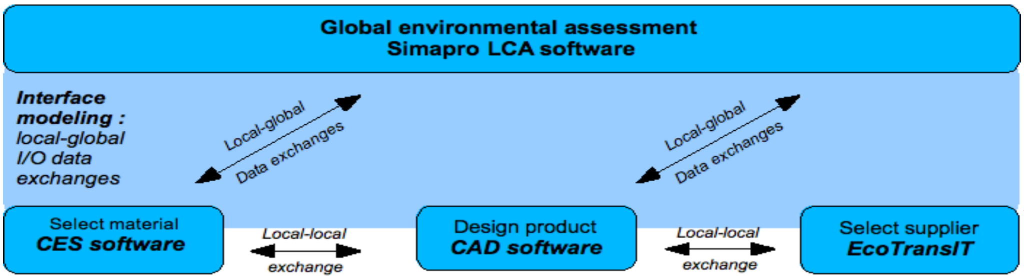

Figure 1. Scheme of a part of the design process (case study) : horizontal and vertical exchanges.

2.3 Local – global activities: application to the case study

To conduct the case study (section 4) we have selected several software: CES for material selection, Catia as a general 3D CAD modeling, EcoTransIT for transport modeling and Simapro to perform LCA. The reason of those choices are explained below.

2.3.1 Global assessment tool in a case DTE study, why choosing LCA software?

LCA is a standardized approach to quantify the environmental impacts of the products. It is a multi-criteria and systematic procedure for compiling material and energy flows of a product or service and evaluate the environmental impacts potentially generated throughout its life cycle [17]. Finnveden and colleagues when presenting recents developments in Life Cycle Assessment in 2009, stated that 'although the method is still under development, there are several ongoing international initiatives to help build consensus and provide recommendations, including the Life Cycle Initiative of the United Nations Environment Program (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC), the European Platform for LCA of the European Commission [18], and the emerging International Reference Life Cycle Data System (ILCD)' [19]. However, despite the fact that LCA is one of the most widespread environmental evaluation tools, its integration in industry presents remarkable gaps. Due to the complex modeling involved, the eco-design community outlines the necessity to be specially trained to conduct a correct LCA. They also point out the time consuming and the important amount of information that is required by this task [20]. Although, the aggregation of flows coming from different databases presents various level of uncertainty and the apparent exactness of the results can be a source of over-confidence. In addition, such impact assessment does not always fits into the product development process [10].

Nevertheless, LCA is a scientific based assessment, unmissable when studying the integration of environmental concerns in designing a product [21]. Considering the difficulties encountered to integrate LCA in the industrial design process, our research aims at developing solutions to reduce the time consuming, by optimizing and facilitating the research and compilation of data, without reducing the complexity required to perform a scientific approved LCA and without excluding the human impact factor. We considerate that the results of the LCA are analyzed by an eco-designer, trained and capable of measure the uncertainties (Monte-Carlo analysis in Simapro software for instance).
To support the LCA in the case study, designers have used SimaPro software, developed by PreConsultant [22]. It is a general and world-recognized LCA tool covering various fields. It uses the most furnished international databases, such as Ecoinvent (on material and process), which presents several feedbacks since a couple of year, and proposes a set of calculation methods with their related impact indicators [23]. We have used exclusively the Ecoinvent database and the ReCiepe calculation method. To help the understanding of the LCA results and distribute the different recommendation to the local experts, in this case study, the eco-designer has extracted six relevant impact indicators.

2.3.2 Local activity : material selection, computer aided design and transport mode

Material selection software and databases have permitted to integrate several environmental parameters in product design. Ramalhete et al have listed more than three hundreds software, databases, and internet websites of material selection. They have studied eighty-seven of them, and according to the paper, the selection methods of Michael Ashby is the one with a highly praised applicability [24]. It proposes indeed an original and effective method, a wide database and numerous material properties. The Cambridge Engineering Selector (CES) software package developed by Granta Design and Cambridge University by Ashby and colleagues is a material and process selection software using a systemic procedure based on design constrains. This software uses a significant number of mechanical, thermal, optical, electric, environmental and other properties to select over a wide database (of around 160,000 materials) [25]. The aim is to identify on which constrains (properties) the material depends. Once the function of constrains (called *performance*) is built, we use the logarithmic scales charts (by substitution, comparison, (etc.) operations) to identify the material families and eventually converge to suitable materials. With this method material designers can deal with a vast set of choices (various constrains and materials) and make them rational, which means that they are not obliged to lean on a previous experience.
The case study involves CES software for the local material engineer because of the quality of the method which allows to deal with effective environmental properties when choosing material and process.

To assist **mechanical engineering**, we have chosen *Catia*, a *Dassault System Computer Aided Design software*, which is a commonly used tool by industries (available on http://www.3ds.com/).

EcoTransIT-World, *Ecological Transport Information Tool Worldwide*, is an easy to handle web based software tool for assessing the environmental impact of transporting freight by various transport modes worldwide (available online on www.ecotransit.org). It supports decision making by helping to optimize the logistical chains and networks of a company's distribution activity (in terms of environmental impacts: energy consumption, carbon dioxide, polluting emissions) and in our case study it is used by engineers to calculate and compare the distances and the differing transport solutions for the needed components (referring to suppliers), and also to explore alternative routes. It takes into account influencing factors such as transport mode, vehicle type, transport network (etc.).

3 RESEARCH APPROACH

3.1 Focusing on interfaces between activities: input and output data exchange between software

Our method is part of a global research program aiming at testing if proactivity can occur during the design process when the models of local software and global software are interfaced. Interface modeling is thus the core of this approach. By *interface* we especially mean the I/O data transfer of

each activity. Those data transfer differ from a simple data exchange. They involve information as well as some knowledge that is associated to the engineer in charge of the activity.
Our method is composed of three distinct tasks. In the first one we select and understand the global and the local activities involved in the chosen design process as well as the knowledge and software associated to them. In the second task we define the I/O of each activity and each software. In the third task we specify in detail the evolution of the I/O: within an activity and between two activities. We consequently associate the data and the knowledge.

The precise understanding of the evolution of the data within the interacting network of activities and software gives us the capacity to optimize the design process paths and facilitate new connections.

3.2 Using UML to build the interface

To support the previous three steps of the method we have chosen the UML, a standard of the Object Management Group (OMG). Class diagram allows to precisely describe the data by the means of concepts and how they are related. Activity diagrams allows to describe the design process itself, which explicitly links the I/O of each activity and software (first issue).
However in most of the case, the Output data of one software are not equivalent to the Input of another. Several transformations are needed to connect I/O between software. As previously introduced, building those transformation models (involving knowledge) is the second issue of our research.

4 CASE STUDY

This section illustrates the three steps method through a case study and gives a pragmatic example of transformations that occur at the interface between activities and between software.

4.1 Presentation of the case study

4.1.1 Levels of complexity of the case study product

This case study is an example of what might be a part of the design process in the (re-)designing of a toothbrush in a DTE approach.
We are currently working with industries–such as Airbus, on a part of the design process of the airplane structure. The purpose of those collaborations is to apply our methodology on distinct levels of complexity of the design process.
We have chosen the toothbrush in this case study for various reasons. Obviously the product complexity of a mass produced toothbrush is less than the one of an airplane. However the complexity of the design process of the toothbrush can be similar or more complex, depending on the internal organization of the company. Three levels of complexity can be identified:
1/ the complexity of the product;
2/ the complexity of the design process of the product;
3/ the complexity of the effects of the product during its life cycle (from the extraction of raw materials until its end of life).
A simple mass production product has a non negligible impact during its life cycle (it will be bought and thrown away dozen of times during a customer's life). The design process of such products are much more shorter than the ones of an plane, which means that improvements can be done more rapidly. Because of those three levels of complexity, we think that a toothbrush can be a relevant application case to test our methodology.

4.1.2 Studied product set up

The case study presented in this paper is a toothbrush: a simple object involving general knowledge on material, manufacturing and design. In some case, global information such as LCA results from a previous and similar product can be available in the beginning of the process, in the creative stage. We have simplified the product and some stages of its life cycle to limit the data involved during the design process. Thus, we have performed a simplified LCA rather than a detailed one. We have not taken into account neither the packaging, the flows during the use phase (water and toothpaste), nor the transport at the end of life. The table 1 describes the toothbrush parameters before and after our three steps method and therefore the iteration between local and global levels. That shows the benefits of our research as an eco-design approach.

Table 1. Initial and new parameters of the toothbrush

Expertise (software)	**Initial toothbrush**	**Final toothbrush**
Material (CES)	- The handle: 12.3g of PP and 6g of TPE elastomer (EPDM-PP) by bi-injection; - The brush: 0.7g of nylon bristles thermoformed to the bi-injected handle.	- Wood handle (*density:* 800, at 20% of humidity on rought/crude wood (bois brut)); *process:* turning; 100% biodegradable; reusable 10 UF. - PP teeth-brush head (*density:* 900) ; *process:* injection moulding; - Nylon brush (*process:* thermoforming to the handle).
Design (Catia)	- bi-injection of PP and TPE elastomer	- a serie of holes in the head to ameliorate the toothpaste rinsing (total volume of the part: $5.6\ 10^{-6}\ m^{3}$); - reusable handle (*volume:* $3.6.\ 10^{-5}\ m^{3}$).
Transport (ecoTransIT)	- Produced in Franckfurt (Germany); packed in Compiègne (France) - distance: 525.42km by road (32t, EURO III standards, 100% of load factor)	- alternative route by rail (distance: 585.33 km, 1000t, electrified, 100% load factor).
LCA (SimaPro)	- Functional Unit (UF): « Brushing teeth 3 times a day, 3 minutes long, for 6 months (equals to 1647minutes), satisfying the sanitary standards »; - Aim: simplified LCA in order to highlight I/O - EcoInvent databases and with ReCiPe midpoint (E) calculation method. - Not taken into account : packaging, flows during use; - End of life: 50% landfill and 50% incineration avoided (France's average).	

4.2 Application of the three-steps method on the toothbrush

The case study presents successive steps taken by the design team–composed of a material engineer, a product designer, an engineer in charge of choosing suppliers and an eco-designer–in designing the toothbrush. Some examples of vertical data exchanges between local and global activities are presented, as well as transformation rules to link software I/O.

4.2.1 Modelling the design process

The UML activity diagram (figure 2) describes a part of the design process involved in the case study. Referring to the metamodel of UML the lines represent the paths through which the data is exchanged. *Horizontal* data exchanges (*local-local* : between material choice, design choice and transport choice activities) can be seen as *Design for X* approaches (DFX). Whereas *vertical* data exchanges (*local–global* : between local activities and LCA) are a typical representation of *Design to Environment* Approach (DTE). The *I/O* (in a square) are defined before and after an *action* (in a round corners square) and refer to *class diagrams*, which are presented in the next section.

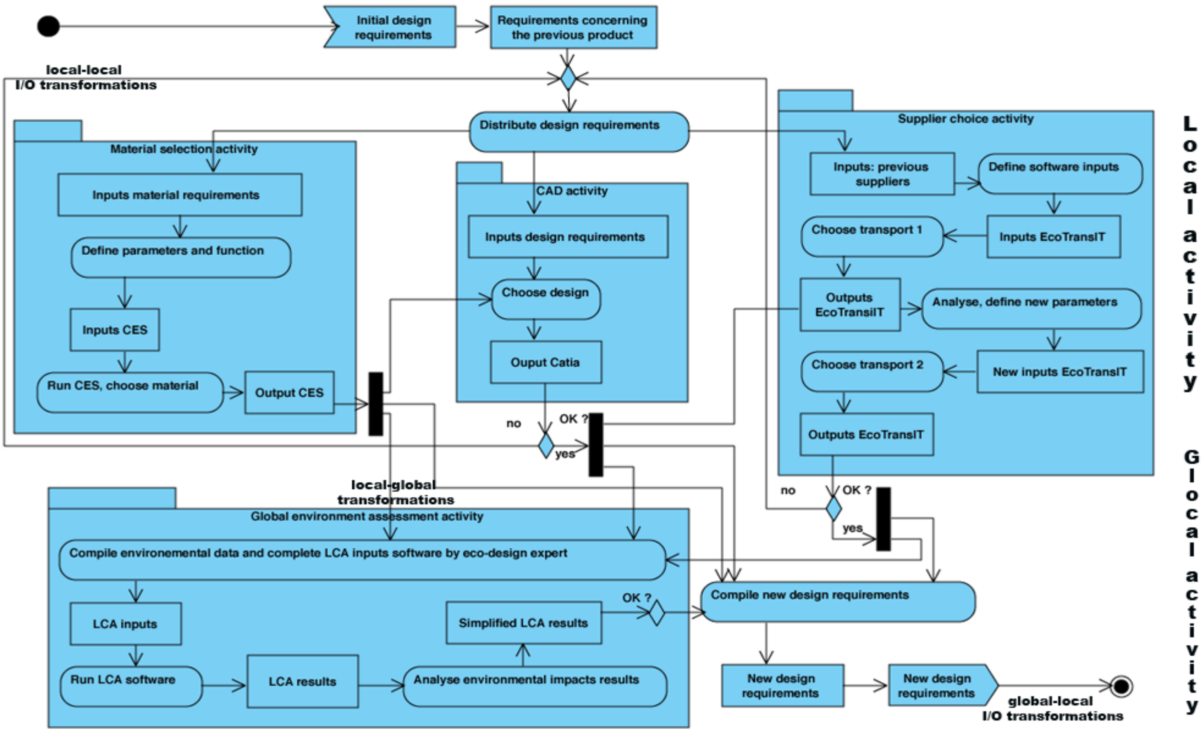

Figure 2. Activity diagram of the case study

4.2.2 Modelling local and global I/O

The class diagrams of each I/O data have been deduced from the observations of the activity inherent to each expert and the use of his software during the experimentation. The metamodel defined by UML gives the frame to describe for each class of data, their attributes. The material choice activity, for instance, starts when the material expert has the list of material requirements for the re-design of the toothbrush. Using his own skills he will deduce the *performance* as a function of *n* parameters (material properties) that are defined by a *name* (eg. : density) and a *unit* ($kg.m^{-3}$). Once the Inputs are fulfilled (figure 3), the material product designers makes his choice by using charts and limits of CES software. The outputs of CES can be described in a class diagram (see below). To each *part* (*ie.* the toothbrush components) defined by a *name*, *is* associated *a process* and a *material*. Each material has its list of *properties (eg. : density, recyclability faction, etc.).*

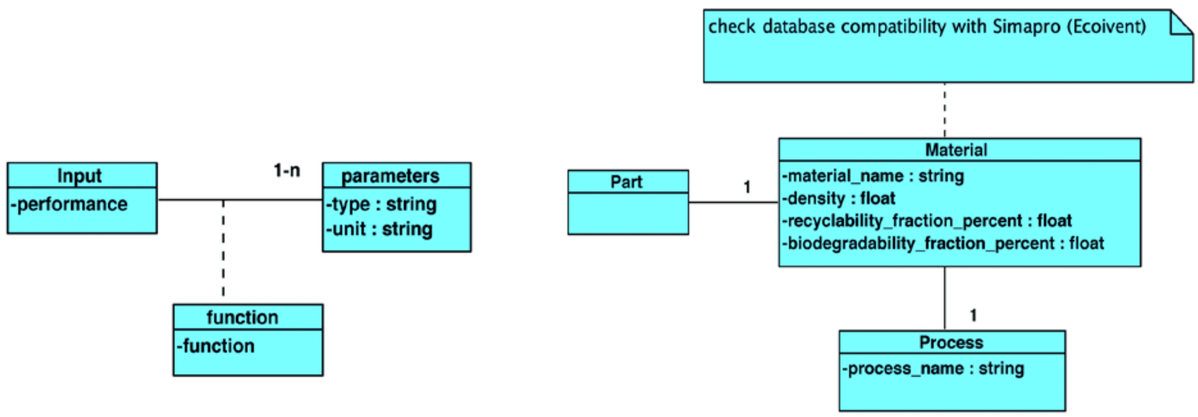

Figure 3: Class diagram of CES Inputs (left) and Outputs (right)

The design and the transport activities models have been created using the same scheme. Once the Outputs coming from the different *local* activities are all completed they have to follow some transformations to become suitable LCA Inputs:
1/ databases compatibilities (eg.: CES databases - Ecoinvent databases);
2/ simple operations of calculation between Outputs (eg. : volume from CAD activity multiplied by the density from CES gives the mass needed in LCA Inputs);
3/ complex operations involving knowledge inference for dynamic interfacing (for example, automatic questions if data are required, rule of order, iterations, etc.);
4/ selection of suitable tools to support the transformations (guidelines, database for concept mapping).

During the local-global transformation activities, additional I/O data are fulfilled by experts if they are not given by any software (via transformations). In this case study, an eco-designer has completed manually the end-of-life scenario of the product. The class diagram (figure 4) shows the Inputs needed to perform an LCA. Before running the calculation with SimaPro, the eco-designer has chosen the calculation method and checked that all parameters intervening in the life cycle of the toothbrush have been completed.

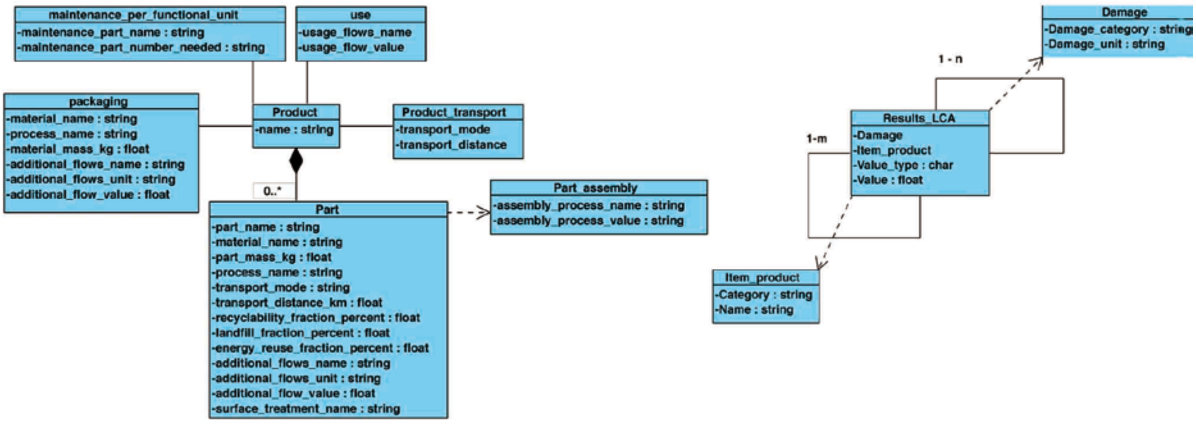

Figure 4: Class diagram of LCA Inputs (left) and Ouputs (right)

As seen on figure 2 informations have to be transformed from global to local. The global-local transformations needed to link the LCA Outputs to the Inputs activities are far more complex than the previous transformations between local Ouputs activities and global environmental assessment Inputs. Essentially because the eco-designer has done:
1/ a pre-extraction of six relevant indicators (from the hight amounts of indicators proposed by the calculation method);
2/ treatments to highlight the links between the environmental consequences and the expertise choices;
3/ a new representation of the results to give simplified informations to local experts.

Here are some examples to illustrate the post-treatment operated by the eco-designer to classify the parameters of the product and its life cycle the local expertise they are related to.
- the extraction of raw material and the production of plastics used to produce the toothbrush are linked to the material expertise/choice (CES software);
- the process of injection and thermoforming are related to the material selection (CES software) and the design chosen by the product designer (CAD software);
- the design of the toothbrush that has for consequence the fact that plastics can not be disassembled, and thus that determines the end of life scenario, are related to the mechanical engineer (CAD software);
- the transport is linked to the route chosen (infrastructures) and the localization of the suppliers (EcoTransIT).

In addition to this global to local data transfer the interface opens links to some specific guidelines (DFX) or tools for each local expertise to re-iterate a new choice and re-create some local Outputs. For instance, the product designer had access to simple guidelines about *design for disassembly*.
Following this iterative process, new material, design and transport mode choices have emerged from the study of the simplified LCA results (*cf.* Table 1).
The compilation of the new local Outputs have lead to a new product life cycle. A comparative LCA between previous and toothbrush has shown the environmental impact of the new choices (figure 5).

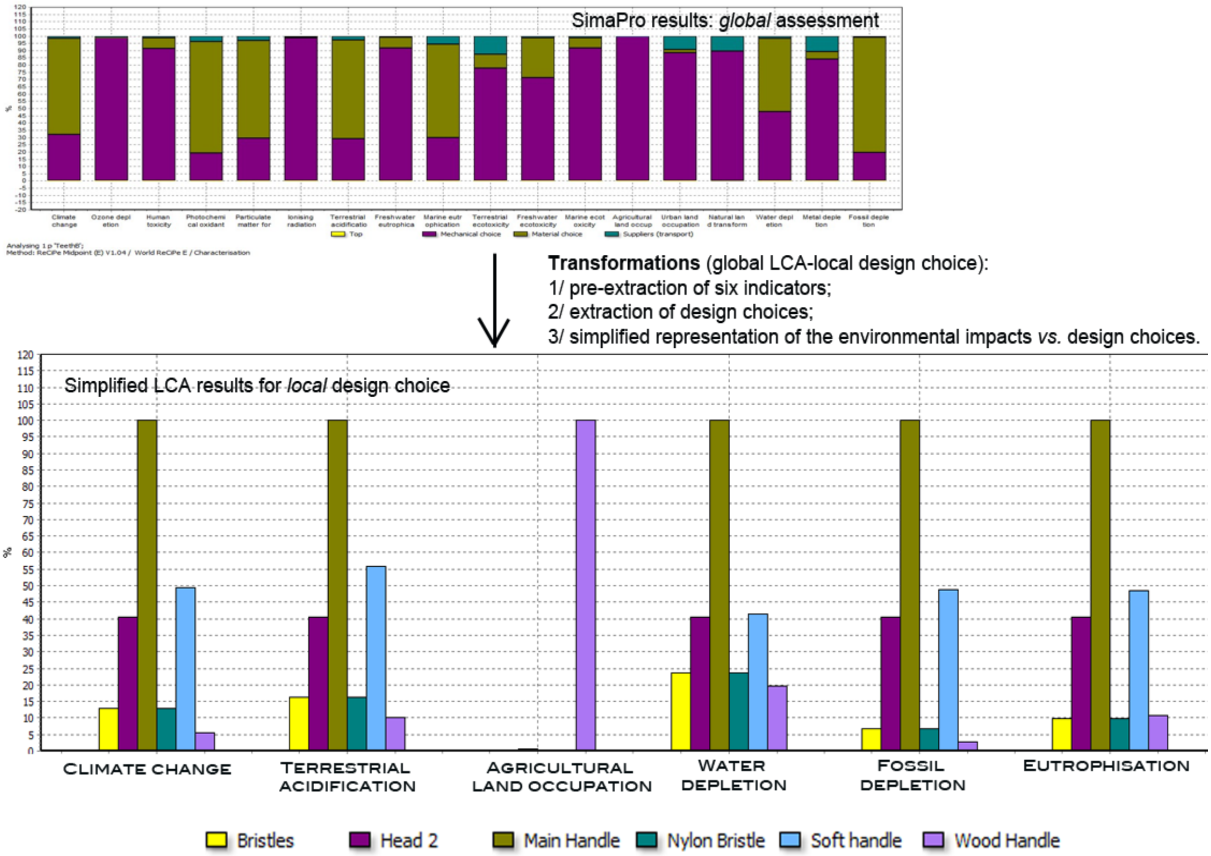

Figure 5: Example of LCA results after eco-designer's post-treatment

The new LCA results have demonstrated that the choices are better in term of environmental impacts and fulfill all initial requirements. The solution is a toothbrush with a wood handle and re-changeable toothbrush head. The product designer has modeled on CAD software the final product (figure 6). The toothbrush head has been drilled by a set of holes, in order to facilitate the evacuation of toothpaste at the end of each utilization, and consequently limit water consumption.

Figure 6. Wood handle toothbrush

4.3 Discussion about the case study

This case study is voluntary simplified in terms of the life cycle stages of the product that were considered (eg. the packaging was neglected), in terms of selected tools (only material choice, CAD, and transportation). Nevertheless, it covers a relevant part of the design process (between preliminary and detailed design) and is not far from what occurs in industry. Despite the remain complexity of

such simplified process, those simplifications have given a pertinent frame to identify the main transformations. Referring to the models of the inner tools, Inputs and Outputs can be given exhaustively.
Currently some work is conducted with other industries (Airbus, Parkeon, Bourgeois) to describe a more generalized method of transformation between local and global.

5. CONCLUSION AND RECOMMENDATIONS FOR FURTHER WORK

The final results of the case study show the great impact of linking what authors introduce as local and global information during the design process. The interface modeling as proposed in this paper therefore support this link in order to ease data exchange among heterogenous designers, knowledge and software. Understanding how and where the Inputs or Outputs of local or global tools are, determines the type of transformations needed for a more appropriate and effective design process integrating environmental concerns as well as cost or quality. This is what we call the interface modeling between *local* and *global* activities involving specific tools.
A short term work is now to develop the modeling framework to support the transformations between I/O diagram according to the dynamic design process. We will use an appropriate model of transformation language (ATL Transformation Language used in model-driven engineering) to build the operations of transformation between models (interoperability).

There are also many questions that arise when looking at the issue of such interface modeling: are all I/O covered, how human actions can be characterized when modeling dynamic interface in order to go further than usual data exchange format, how to specify new functions in software and new links, (etc.).
Despite the apparent complexity of such interface modeling, the real asset of such a system is that it would be dynamic in order to be implemented in accordance to each industrial situation and its temporal evolution. Currently, work has started with three companies to investigate in different context how to apply more widely the three steps of the method.

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