A FRAMEWORK FOR ECODESIGN: AN INTERFACE BETWEEN LCA AND DESIGN PROCESS

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Abstract

Integrating environmental aspects in the design process is getting more and more covered by the actual scientific research. Based on various fields such as "eco-design", "Design for sustainability", "eco-innovation", several specific software and methods have been developed to tackle this issue. Our work focuses on product designer software and eco-designer software that already exist. This research analyses product design and eco-design—considering their respective complexity—in order to determine the main difficulties to systematically integrate environmental aspects in the design process. Our observations have led us to work on three elements: information, software, and collaboration between designers and LCA expert. The principal objective is to facilitate the interface between product design and eco-design by linking the requirements and performances of both domains. It seems therefore necessary to help the collaboration between various experts and thus to develop a digital interface enabling designers to exchange data and to use their appropriate related software.

The aim of this paper is to argue the need of a digital tool interfacing the actual tools of the design process and of eco-design (among the related software such as CAD, CAx, PLM, and LCA). This "digital interface" is presented at the end of the paper and will be created next year.

1. INTRODUCTION AND INDUSTRIAL CONTEXT OF ECO-DESIGN

1.1 Introduction of the research context

The concept of eco-design was born in the seventies in the industrial society [1]. Today, as asserted by Johan Rockström et al. "largely because of a rapidly growing reliance on fossil fuels and industrialized forms of agriculture, human activities have reached a level that could damage the systems that keep Earth in the desirable Holocene state"–which was the stable state for the past 10,000 years–"the result could be irreversible and, in some cases, abrupt environmental change, leading to a state less conducive to human development" [2]. This assertion entails quite evidently a growing necessity to reduce the impacts generated by our society. Several authors have stated that in order to be sustainable, the product system has to be re-structured at every scale: governments and international institutions (political issues, international laws), the industrial system (industrial metabolism optimization), the services (transition towards a product-service system), the products (eco-design strategies), and the functions (focus on functionality rather than on marketability) [3,4, 5,6]. Since the seventies, eco-design has thus been implemented progressively.

1.2 Overview of the paper breakthrough

Considering this context, this article focuses on eco-design as a approach that might help reducing the damages of the industrial activities. Three consecutive levels of eco-design integration have been identified so far. Firstly, the approach of eco-design can be *partially* implemented (Design for: Recycling (DFR), Disassembly (DFD), Remanufacturing, Product Retirement, Low Energy consumption). Secondly, eco-design integration processes can be seen as *classical* (Design for Environment (DFE), Eco-Efficiency, Environmentally conscious Design & Manufacture), or, thirdly, as *innovative* (Design for life cycle, Design for Eco-effectiveness, Eco-Efficient Services, Design for Sustainability) [7,8]. The objective of our research work is to contribute to help reaching the third level, which goes together with modifying the whole industrial eco-system.

The following part of the paper presents the objectives of the research work. This part includes the definitions of the life cycle, the design process and how they relate to each other. Numerous software have been developed in order to assist engineers to reduce the environmental impacts of their products throughout their entire life cycle [6]. However, the integration of environment into the design process is complex and often fuzzy for the product designer [9,10,7]. Consequently, the third part of the paper based on literature results aims to create a non exhaustive map of available design and eco-design software and then to crosscheck (*i.e. interface*) the information that should be exchanged. This map supports the relevant observation of the eco-designer's communities that argue how difficult it can be to establish an effective and fruitful collaboration with the design core team. It shows that specific knowledge are needed by the product designers to exchange information about the same product or project in order to use the appropriate software of eco-design. A wide range of possibilities are offered to the designer to manage, learn and integrate environment in the design process. Considering this, the fourth part suggests a framework to create a digital interface between eco-design tools and product design tools. This "interface" enables data exchange and refers the designer to the specific tools that will support his activity.

2. OBECTIVES OF THE RESEARCH WORK

2.1 Objectives of the research

This research is a technical approach devoted to technically assist designers to integrate environment in the design process so as to contribute to *innovative eco-design* at a higher scale. To have a better understanding of the subject, the first step in the following section is to define "life cycle assessment" and "design process", and how they relate to each other.

2.2 What is life cycle assessment?

Eco-design is about integrating environmental concerns into the design criteria of products or services to reduce significantly their negative impacts. Eco-design is characterized by the *life cycle thinking*. Indeed, in our research, we decide to help designers to perform Life Cycle Assessment (LCA) because it is one of the most suitable scientific way to analyse the entire life cycle of the product based on a multi-criterion calculation. Concretely the related ISO standard defines LCA as the "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle"[12]. This approach has its own limits but LCA is the only systematic and global approach, the goal of which is to avoid pollution transfers from one life stage to the other [11]. So, this research aims at supporting LCA in the design process, which means that the definition of life cycle from the "LCA standard" must be shared by all designers.

Zwolinski and Brissaud explain the two main ways to understand the product life cycle [13]. The first one makes sense for marketers and is used for strategic approaches. It is decomposed in five phases, which are i*ntroduction, expansion, maturity, saturation and decline*. The second one is more closely associated to the functionality of the product and is thus (or at least should be) shared by all designers working in the design process. But there are three levels of analysis associated with this second definition of life cycle: *the firm level, the team level* and *the expert level*. Considering the **team level**, Niemann et al. [14] define the life cycle as the succession of the following steps: *design (conceptual, detailed)-production (procurement, manufacturing, assembly)-logistics (distribution)-use-maintenance (service)– collection - remanufacturing (disassembly, refurbishment, reassembly) - reuse – recycling – disposal*. But the **eco-design expert** has a slightly different definition: his holistic approach takes into account the environmental aspects and the potential environmental impacts along the successive steps of the product's lifecycle, from *raw material extraction*, production, use, end of life treatment, to the final elimination [15] (the reference standard ISO/TR 14062 gives the definition of the life cycle as "the successive and linked phases of a product system from the acquisition of the raw material to their final elimination" [17]).

2.3 What is the design process?

The design or product development process is a collaborative process that appeals to multiple competencies. It impacts all the activities of a company which aim at bringing a new product to the market. It normally involves design, marketing and manufacturing departments in the company [17]. Pahl and Beitz describe the design process as a succession of four main phases: *clarification requirements – conceptual design – embodiment design – detail design,* to go from a functional space to a physical one [18, 19].

2.4 Life cycle assessment in the design process, what are the issues?

As seen previously, the definition of life cycle varies from a level to another and design is seen as a collective process in which multiple competencies are involved. Designers have to integrate transverse constraints such as environment (it is the same for cost or quality), a task that can be quite complex in most cases. Succeed in this task is the objective of numerous research programs and embrace a wide range of field such as DFE, DFR or DFD [20, 21]. Management support tools are developed to organise and coordinate the process with teams, tools and data. Product Lifecycle Management (PLM) provides solutions such as giving the access to model various product BOM (as-is, as-manufactured, etc.) linked to document lifecycle (creation, modification, validation, etc.) and according to the project organisation modelling (tasks, access rights,...).

Based on the assumption that all eco-design approaches are complementary, the general idea of the paper resides in the *technical* appropriation of those approaches by product designers. Indeed, the experts that have no understanding of the involvements of the eco-design concept have nowadays to take that information into account during the design process and the digital design chain. Since there are enough tools–individual and collective–(part 3), the data circulation between eco-design tools and design tools can be optimized. An interface could help this appropriation at a very technical level.

3. SOFTWARE-SUPPORTED PRODUCT DESIGN AND ECO-DESIGN

3.1 Global approach: software-supported product design and eco-design

Ilgin and Gupta have classified 540 published references from the last decade into four major categories: environmentally conscious product design, reverse and closed-loop supply chains, remanufacturing, and disassembly [22]. The task consisting in adding the environmental requirement to the simultaneous consideration of economic, functional and manufacturable criteria is supported by several techniques and methodologies, such as DFX, LCA and material selection. An overview of the main tools used in DFE, DFR and DFD shows the large possibilities offered by the actual research. In addition, new software in LCA and material selection complete the previous list. As far as PLM systems are concerned, current solutions provide various concepts and technologies to manage the entire lifecycle information while managing heterogeneous files coming from external software applications (e.g. CAD and CAx solutions...).

The aim of the figure 1 is to show an organisation of possible software tools along the design process. This list of tools is not exhaustive and does not pretend to be the best combination of software tools, but is one possibility. This figure 1 introduces a global approach that must link:

- **Local design activities** based on specific requirements and objectives (requirements analysis, structure breakdown definition, manufacturing processes selection...) and supported by **specific software** (also located on figure 1);
- **Global assessment** of the design solution regarding the entire product life cycle.

Information has then to be exchanged horizontally (concurrent and integrated design concept) and also vertically (LCA concepts).

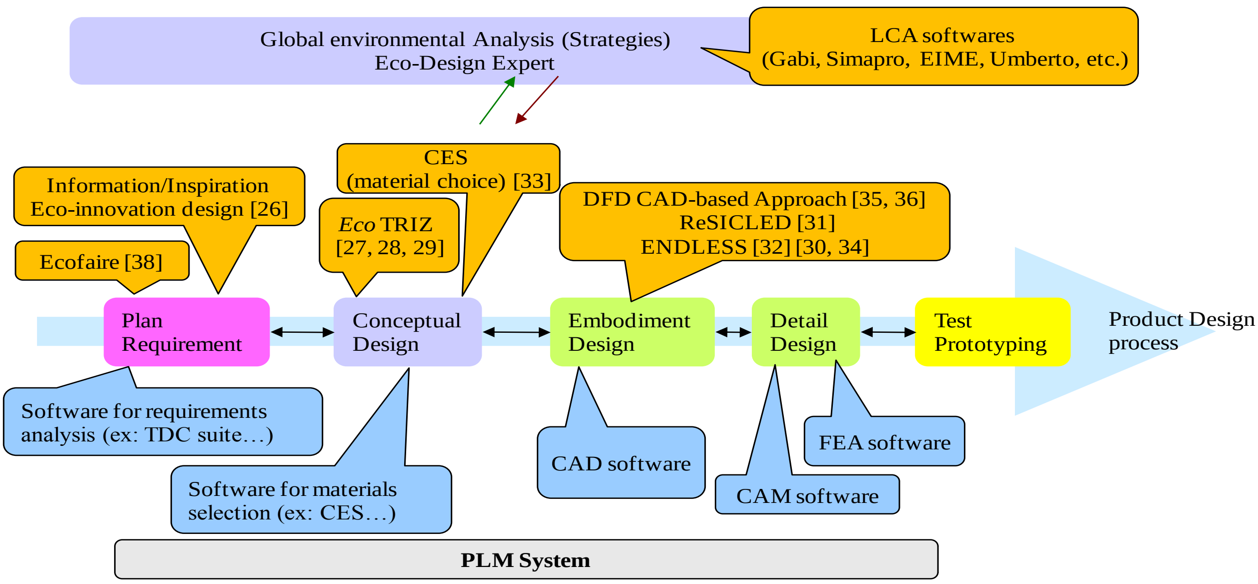

Figure 1 - An example of product design and eco-design software tools

3. 2 Are those methodologies really used?

As stated above, it is clear that methodologies and software are existing from both sides: design and eco-design. The eco-design tools can be classified depending on their characteristics and their functionalities: impact assessment (environment and cost), performance improvement, creativity, hybrid (integration of the environmental criteria in the classical design tools), strategy, etc. However, from a general point of view, product designers have a partial understanding of the integration of environment in the design process. This may be due firstly because some eco-design tools present lacks of practical value. They require a lot of information or time to use and bring out uncertainties. Secondly, the environmental field introduces to new concepts linked with biology or chemistry for instance (eutrophication, acidification) and requires a global vision concerning the whole product life cycle (material flows, energy flows and pollutions from raw material to the end of life). Consequently, most of the eco-design tools are not used in industry [36, 37] and their integration and appropriation by designers are usually mostly inefficient [9, 38, 39, 40, 42, 43]. Becoming familiar to a guide or to new software for instance requires time and motivation, in other words, financial resources and acceptation by the rest of the team. Their use does not necessary give quick and visible improvements, but rather brings changes. For the designer there is a lack of criteria to choose the tools and methodologies within the design process and the coordination between them [43, 44, 45]. For instance, it is rare to find suitable indicators to evaluate the tools in a given context: organization of the company, expertises, type of products [36, 6, 44]. To use the suitable tool, product designers have to be educated to environment. As stated by Ilgin and Gupta, "firms must educate their employees in environmental aspects of manufacturing to increase their competitive edge. Moreover, ECM (Environmentally Conscious Manufacturing) principles should be incorporated into engineering curriculums at universities" [22]. This statement raises the question of knowledge management, which is obviously linked to the project of transferring data from an expert to another to perform a LCA.

3.3 From global to specific environmental knowledge

The product designer (e.g. working in the preliminary design phase) has his own bundle of knowledge and know-how (material properties etc.). In addition, he also has a basic understanding of other specific domains, such as environment (life cycle thinking, LCA, etc.). In order to use specific software, which will help him to integrate the impacts of the environment in his activity; he will however need additional knowledge. Indeed, a general lack of environmental skills is noted at each stage of the industrial design process [8], especially concerning the eco-design vocabulary [43, 34, 46]. Consequently, it is difficult to use the appropriate software and to share a global understanding about the way the environment should be integrated in the design process. The lack

of coherence between the environmental stakes as understood by the firm departments and by its providers [47], raises the question of the environmental management strategy, which is most of the time linear and positioned on a short term vision [36,9].
In reaction to this, researchers are working on methodologies to choose the suitable software. The Design Society for instance covers all issues of the environmental integration in the design process (http://www/ecodesignsociety.org/). Some other design and eco-design communities, such as MCE (Méthodologies de Conception et d'Eco-conception) aim at developing, test and help the emergence of eco-design tools and methodologies in the design process. To illustrate some "macro tools", Ny has developed a Framework for Strategic Sustainable Development (FSSD) the goal of which is to unify methods and tools and to identify how they can be used strategically (proposition of a "toolbox" for Sustainable Product Innovation (SPI))[10]. Some guides have also been created to manage the design team along the design process, bringing environmental knowledge and referring to numerous tools [48].

4. PROPOSITION OF A RESEARCH PROGRAM: AN INTERFACE BETWEEN DESIGN AND SUSTAINABLE DESIGN

4.1 Proposition of a research program

Resulting from the literature results the figure 2 shows the global frame of a design process that would integrate the suitable already-existing software tools. The data interface that will be created will be compatible with the majority of tools that are developed by the actual scientific community. In this framework various experts are working at each stage of the design process.

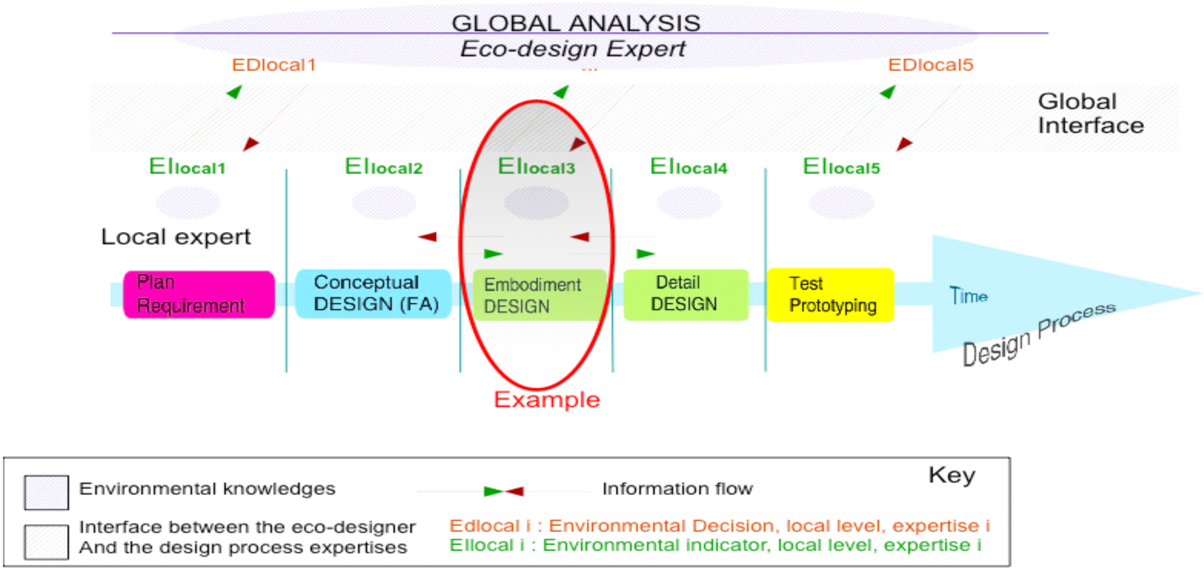

Figure 2 - Proposition of a general interface framework along the design process

As shown by the literature, these experts are using specific software systems that have access to local environmental tool, depending on their particular domain of expertise. Resulting from this, they would exchange the related local environmental information (material choice, origin of production, transformation process, etc.) with the "global eco-design expert" via an appropriate digital *interface* and specific environmental indicators. This support (*i.e. interface*) is a "channel" for data transfer. But, this interface is also a "linking support" to provide a *common understanding*, (i.e. a *minimum of environmental knowledge* from the expert and a *minimum of expert knowledge* from the eco-design expert). It is a "junction" in which the expert has access to the data he is related to and to his suitable support (tool, guide, database, etc.) that will help him change his data. The eco-design expert receives all pieces of information from each stage of the design process (at it is shown on figure 2), which confer a global understanding avoiding pollution transfer to his environmental assessment. In other words, this global framework guarantees the transversality of the environmental assessment during the design process, without obliging all designers to have a global understanding of the project.

To support the local-global environmental data exchange, the authors will obviously base their work on existing models and information technology. As shown on figure 1, Expert software (TDC, CAx solutions), PLM solutions and LCA software will be then customized to manage and dynamically provide the right local information to the global eco-design expert at the right time in the design process. Local and global information models will be enhanced to tackle this issue (e.g. ID card in PLM systems). Data exchange would be based on XML or STEP standards. This idealistic framework is rather *a support* to help the authors focus on the specific links between practices along the design process.

To illustrate the researches, the authors are thus considering more in detail the embodiment phase (surrounded by a circle and presented in figure 3) in order to analyse its specific arrangement of information flows. The data flows are presented by dark harrows on figure 3. One of the solutions given by the PLM support is to edit an ID Card of each component of the product X (for instance). This card can be parameterized to specify the list of requirements needed to perform an LCA (type of material for instance). Ones the card is filled up, the digital interface will transfer the data to the LCA software. The eco-designer will run the LCA software and obtain the detailed results. He will then communicate his analysis to the right designers (indication about material impacts for the material engineer for instance). The interface will transfer the remarks from the eco-design expert to the referring designer and suggest to the latter tools and methodologies to make another choice to his local expertise. The designer changes the parameter (for instance the material choice) and, again, the data is transferred to the LCA software to analyse the new combination that has been made (figure 3).

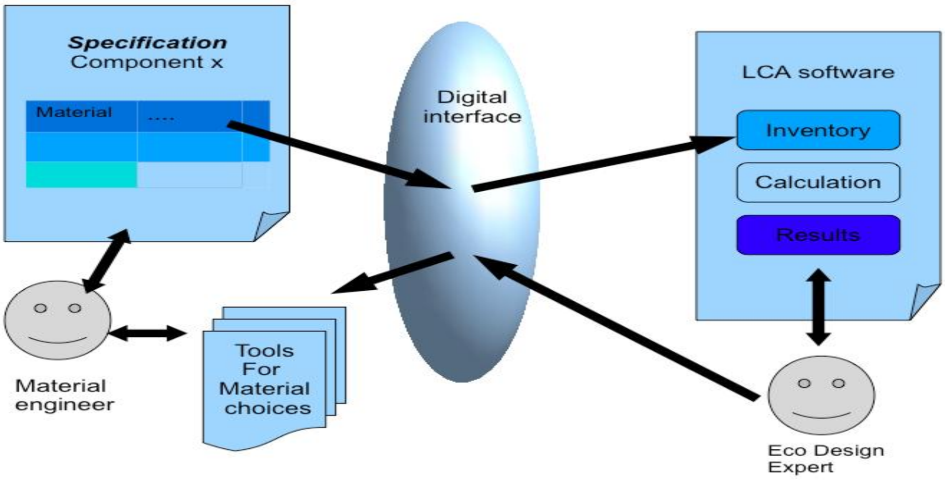

Figure 3: proposition of a digital interface between product designers and eco-designers during the embodiment design stage

To create this interface a methodology in collaboration with industrials has been created. This methodology is based on observation, prospection and analysis, aiming at answering to the following questions:

– Which data have to be exchanged from local to global analysis as soon as possible during the design process?
– What are the data formalism for those exchanges between designers and eco-designers during the design process?
– Which tools are used and what are their possible compatibilities with eco-design tools?

5. CONCLUSION

Despite the number of software at each stage of the product development process, the industrial society is not integrating environment efficiently in its design process yet. Through literature review and research observations, it appears that numerical interfaces between usual design and eco-design software are needed to help the various experts involved in the design process to interact with each other. The paper aimed at presenting a framework that might help resolving some difficulties that are preventing the product designer from systematically integrating environmental considerations in his activities. This framework links expertises more efficiently and enables pro-activity.

In our future research work, a comprehensive model of the interactions and information flows between the designer and the eco-designer will be created. Once the several constraints are identified, a methodology will be developed in order to create the most suitable interface on a given context. The model will be tested through an application case.

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