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Design to Environment:

Modelling approaches to support environmental integration in the design process

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Abstract:

The growing demand for environmentally friendly products has been on the list of the main topics in the past decades. Design to Environment (DtE) proposes integrated methods to encourage the development of ecodesigned products during the design process. Several environmental methods have been developed and introduced in the strategies and design processes of industries. However it is still uncertain how effectively their contribution helps to assist in the up-growth of ecodesigned products during product designers' activities. This paper explores some available information systems offering support in environmental integration across and into the activities involved during the design process. Some relevant information models characteristics are highlighted to help integrating the DtE since early stages in the product design process. Such designed product (or service) would bring environmental values into the society as well as some other possible benefits such as cost reduction and quality improvements during the product lifecycle. An industrial case study is under development to formalise and validate a proposition based on linking and relating these characteristics.

Keywords: Integrated Design, Design to Environment (DtE), Information System, Engineering System, Ecodesign

I. INTRODUCTION

Designing to Environment (DtE) is maintained by environmental management international standards (*cf.* ISO14001-14006 including ecodesign practices, and ISO 14040-44 focusing on lifecycle assessment and the implementation of products and processes). DtE methodically takes into consideration the environmental parameters within the product design performance with regards to all aspects included in the product lifecycle (*e.g.* environmental legislation, industrial sectors, society, cost, health and safety [1]).

The design phase is essential to measure and master the product's environmental lifecycle performance, as any changes after this phase can be extremely costly. Design is an evolving process leading to increasing knowledge about the product/process and decreasing freedom in the design solution space (*cf.* figure 1). The more advanced the design solution the harder smaller are the possibilities for changes that may be necessary [2].

An optimised multidisciplinary design activities plan coupled with a sophisticated information system supporting product designers in using adapted tool and exchange information together can significantly help reducing the future environmental impacts of products, *i.e.* to (eco)design them.

The main problem the integration and the implementation of the environmental aspects has been facing in the design process is that the majority of attempts were limited to the use of environmental evaluation tools (*e.g.* lifecycle assessment), and rather in the late stages of the design process for reasons of lifecycle data inventory availability.

This means product designers are considered with very modest and limited options to influence their product's environmental performance. This is mainly due to the fact that environmental experts are not able to intervene since the early stages of the product's lifecycle: by sharing data, giving dynamic feedback or potential impacts to the designers, *etc*.

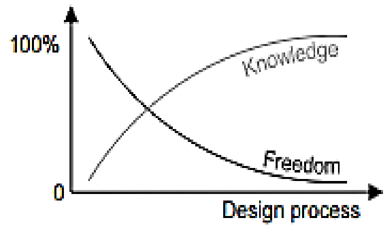

Figure 1 Freedom of changes in design versus knowledge about design's problem adapted from [3]).

Another way of viewing the integration and implementation of environmental aspects in the design process is to favouring a process that "pushes" the environmental information through the existing expert activities. The focus of this research is therefore driven by searching to characterise the information models that are able to support fluid environmental parameters considerations within existing expert tools and experts' activities. Perhaps information models supported by the information system of the company are facing issues that prevent the 'environmental parameters' to be transmitted within concerned activities. This generic situation would prevent environmental evaluation tools to be effectively used during design.

The main focus of this paper at this initial stage of this research is to provide fundamental and basic elements to answer to the following research question: *which information model characteristics are needed to support the 'yet unknown' environmental parameters to be transmitted during the design process and from the early design stages?*

The research hypothesis is to consider the availability of information model that would support the alteration of the traditional design process into an *easy going* DtE process. Examples of such information models would be taken from *Product lifecycle management systems*, *Product data management*, *Problem solving*, *Systems Engineering*, *Domain*

Specific Language, etc. To this purpose section 2 investigates the required information model characteristics defined from an operational level point of view (*i.e.* product designers' ones). And proposes links between such existing information models to envisage their integration together to support the variety of DtE aspects during design. Section 3 addresses suggestions for future work to furthermore investigate the research questions, and concludes the paper.

1. INFORMATION MODEL CHARACTERISTICS FOR DTE

Numerous information models have been developed and are already in use in industries to support the environmental design integration practices:

- Including product lifecycle considerations at different level of data management (*e.g. Product Lifecycle Data and Management (PDM/PLM), Systems Engineering (SE), Product based environmental management (PBEM), Ontologies);*
- More or less linked to specific environmental impact assessment considerations (*e.g. streamlined or full and standardised Life Cycle Assessment (LCA)).*

This section presents some of their characteristics to envisage DtE from an operational point of view of product designers.

1. Lifecycle Assessment (LCA) for DtE

From an environmental expertise point of view the environmental evaluation process during design seeks to evaluate the environmental impact of the product at each design iteration (baseline) by collecting the available lifecycle inventory-LCI. The final product would then generate a minimal of potential environmental impacts (impact indicators to be chosen) during its lifecycle, while delivering the required functions aligned with other product design expertise [4].

Lifecycle assessment is defined by the International Organisation of Standardisation (ISO14040-44 standards) as a method that allows direct environmental impact comparison between (products or its individual assemblies) that have the same functionality, in a way to evolve toward a more DtE and an enduring development of the product design [5].

Streamlined as well as potentially full LCA(s) have therefore their role to play in the DtE process. Capturing LCI data generated by product design expertise decisions, intervening in those decisions by an expert LCA result interpretation (*etc.*) are link to the design process management in each industries, as well as to the IT system managing data internally. Several illustrations of such combination of LCA and Product Based Environmental Management Systems (PBEMS) show their (partial) support to DtE practice (*e.g.* collecting the input-output data and assessing its potential environmental impacts [4]).

Yet, the evaluation of performance of the LCA in the ecodesign society and how it is supposed to support the DtE aspect is still under debate (not mature, not static), as it is investigated on many scales: industrial contexts and expertise involved (specific tools), results interpretation, dynamic linkage between cause and consequences, chosen parameters to evaluate environmental consequences, adequate decision moments during design to assess environmental performance, *etc.* A flexible to change PBEM Systems is necessary to make adjustments to immature DtE processes in industries. The next sections explore some of the characteristics required to support evolving DtE processes.

2. Product Lifecycle Management (PLM) for DtE

Product lifecycle management (PLM) is an effective approach to organise systematically the product data throughout the product's lifecycle. Its main objective is to deliver a plethora of IT solutions for sharing and managing data, numerical information and knowledge amongst all the internal and external driving forces in the company including (product designers, experts, stakeholders, suppliers *etc.*) [6]. PLM encompasses under its category PDM, product data management, which in its turn assists PLM processing more efficiently through a variety of customised functions (*e.g.* document management, Product structure management, Classification, *etc.*) [7].

For example, a study carried by Trotta [8], has explained how PLM through a *workbench structure* approach that uses numerous information and assessment tools, is capable of supporting environmental integration: by comparing, evaluating, optimising and linking production information together.

The workbench structure comprises five elements [8]:

1. Impact Assessment System (IAS), derived from the analysis of the lifecycle by using Eco indicator 95;
2. Structure Assessment Method (SAM), which collects information about the product including (Material, disassembly time, durability, functionality, *etc.*);
3. The advisor agent, a tool that delivers a computed information about the materials (high/low impact), which in turn can be linked to the IAS;
4. Knowledge agent, a tool to hunt and explore potential material with specific characteristics;
5. The Report Generator gives the possibility to compare with the product's initial condition.

This *workbench* supports DtE through the structure and tools proposed, linking product designers and environmental expertise together. However the complexity of the IT system behind addresses specific issues when *comparing, evaluating, optimising and linking production information together*: regarding

(1&2)–IAS & SAM: issues of data format(s) (*e.g.* standard) and syntax(es) (*e.g.* ontology(/ies)), of queries, (*e.g. unique* customised PLM) to collect information about the product under development involving different expert information models, with potential conflicting information behind tacit/explicit information. Addressing those issues to product designers [10] proposed to illustrate this topic a 5 steps method to improve information transfer between available sources on usage from various expert outputs to lifecycle inventories, to support the emergence of explicit environmental impact knowledge from LCA results adapted into feedbacks to design experts. (3)–About the advisor agent: issues of computing information about a design choice (*e.g.* material) and providing feedback to the expertise(s) concerned with the specific characteristics related to this design choice (*e.g.* material expertise, ergonomic, industrial designers, mechanical engineering) [10]. Address the interoperability issues of product designers and environmental impacts assessment tools together through integration, unification, and tool federation possibilities. (5)–The report generator addresses the issue of comparing different versions of the same product during design iterations: frequencies alignment with data exchanges between design expertises. (1-5)–An example would be required to measure the effectiveness of the expertise interaction and synchronisation for pushing a design process that deeply integrates the environmental parameter considerations.

3. *System Engineering (SE) for DtE*

System engineering (SE) is defined by INCOSE (The International Council on System Engineering) as an interdisciplinary problem solving approach. It stresses on outlining the ideal necessary criterions and required processes in the early stages of the development cycle, recording requirements and management needs, and then it proceeds with optimising the design and validating the system [10].

The SE is therefore meant to be a collaborative process integrating required expertise methods to create a tailored development method that advances from concept to production to operation within the entire system lifecycle. In a DtE approach the SE would equally be taking into consideration the ISO standards 14001-14040-44 stakeholders/business constraints and the technical activities of the process with a focus on delivering a value package that meets with the designers planning [10].

The 2015 technical report of the IT system developer group *Dassault Systems©* [11] proposes a methodology or strategic protocol to support the environmental integration through SE, comprising some of the followings objectives:

- Prioritise environmental indicators (Primary and Secondary);
- Consolidate the existing methodology for collecting environmental information (*e.g.* using sustainability leaders and combined with *Dassault Systems© Real Estate and General Resources Management based on the environmental reporting protocol*);
- Define scope for gathering environmental data which comprises *Primary indicators*: energy consumption; total greenhouse gas emission; water consumption & general waste treatment; paper and packaging [11].

Finding supports in the use of SE for environmental integration seems relevant to overcome technical IT issues related to the complexity of expertise and processes supported by a *plethora* of specific software. Nevertheless some environmental expertise issues (*e.g.* prioritising the environmental indicators as primary and secondary; excluding some environmental considerations (materials and process selection, logistic, industrial design tools and transversal global environmental tools, *etc*., in primary indicators) should perhaps be taken in a dialogue with IT developers to permit a rapid evolution if expertise change advice. Some explicit explanation could be brought to challenge issues in managing the collected data; and explain how the integration of this developed method using SE enhance and ease the information exchanges between the product designers and environmental expertise.

4. *Product Based Environmental Management System (PBEMS) for DtE*

A case study conducted by LUCENT© presented a PBEMS integrating the ISO standard 14001 [5] allowing the:

- Identification of product-based environmental aspects (*e.g.* LCA, concept development, *Eco-Environmental* Requirements, such as recycling rates, *etc.*);
- Applicable legal and other requirements introduced through the *roadmapping* method in product realisation phase;
- Incorporation of numerous significant segments into the design and development process by using ecodesign tools that acts as an input for these processes: creation of the *ecodesign* program at different moment of the design process to implement the PBEMS policy (*e.g.* an *Eco-roadmap* during benchmark, integrating *country and customer eco-environmental* requirements to other design requirements, deploying design for environment methods to establish design specification, LCA, *etc.)*[4].

PBEMS comprises approaches that allow an effective communication keys amongst all the driving forces throughout the lifecycle. It consists of (1) documenting manually, (2) processing document patterns and (3) recording them, creating by this a documents management tool. For instance, this management tool can be accessed promptly on-line and it acts as a unified information storage, where it is constantly possible to stock, organise, manage and share electronic documents, as well as, it comprises the possibility of keeping track, archiving and auditing these electronic materials [4].

This PBEMS bring support to DtE practices. A deeper investigation of its technical characteristics is necessary to investigate the following issues:

- How *ecodesing* tools of the PBMES are *plugged* to usual tools along the design process;
- How streamlined LCA provide enough choices or options for designers to alter and adjust their product design decisions;
- Which techniques are used to allow a flexible and dynamic information exchanging among the product designer and the environmental expertise [12];
- Which level of environmental expertise is required for using the chosen *ecodesign* tools: expert tools for environmental practitioners, streamlined tool for mechanical engineering designers and other data management tools, *etc.*

5. *Ontologies and domain models for DtE*

The rapid growth of Knowledge-Based Systems (KBS) in the mid ’80 was the direct cause of development of the ontologies in computer science and artificial intelligence (AI) [13]. This has been defined by Gruber (1993) as an accurate specification of conceptualisation [14].

Ontologies provide a summarised, systematic and an analytical approach for semantic information. They are defined as the resources used to formally design the model of a system by using the most pertinent entities and data based integration methods. When using domain models, ontologies give more accessibility to the information by matching and merging the work of diverse types of specific ontologies from various domains [15]. Moreover, ontologies can serve DfE (*e.g.* in evolving sustainable product development) when they are combined with SE, PLM and Engineering tools (assessment, design, *etc.*).

The ontology based system proposed by Giovannini et al [14] for instance, presents some relevant characteristics to supports DtE practices by “defining the product view and the conceptual models about equipment, materials, and resources including the sustainable effects of a function achievement”. This system includes the following steps:

- Based on well-defined principles, the product parameter values are compared with the function effects values (*e.g.* material property, its value and unit of measure);
- The implications on other product modules, processes and resources are assessed (comparison of the input and output function’s effects);

- Relations are defined between the instance of the product, resources, processes and functions, and hence alternatives are use in case they satisfy the same functions;
- Assessment tools are then used to evaluate the advantages of the alternative used.

A study conducted by Fotineau (2013) [13-16] based on existing ontologies has identified 5 roots concept that will help developers sharing a mutual core product modelling for the whole lifecycle and that could be used as a central meta-model in PLM systems. The core model of this approach is grounded on the concepts of products, process, resource, rule and business. As PLM, SE and Ontologies work together in a multi-constrained environment which comprises various fields of expertise, they can be all a part of an environmental information systems that support DtE throughout the product lifecycle [16]. The question that remains to ask is how to structure, formalise and validate all these information systems in an organised means to be able to support the DtE [17].

6. Synthesis of model characteristics to explore for DtE

This sub-section is an attempt in considering together the previously presented systems, easing collaborations between different information technologies driven approaches, to support DtE practices. Previous sub-sections have presented the opportunity offered by a numerical platform based on PBEMS and PLM systems for product development, industries with such systems have the capacity to launch a secure computing environment, whereby all factors involved in the workflow would assist in the process and product innovation.

The PBEM Systems by [4] proposed during a first design iteration to identify the general elements, requirements, characteristics and specifications (*e.g.* technological options, financial, operational requirements, customers, competitors *etc.*) of the product including the environmental aspects. An *Eco-roadmap* would explicitly states the relevant environmental drivers identified in this context by the environmental expertise; such as legislations and product requirements. Furthermore, these drivers would be ranked according to their importance for the environment based on an internal rating, this would allow to compare the current status of the product to the future desired one. This process is a way to systematically outline and highlight the most relevant and required driving factors (including the environmental one) at the very early stage of the product lifecycle. Then, when investigating thoroughly the product's essential requirements, PBEM outlines updated environmental and other requirements related to the product and could further transfers these to the PLM system where all the product and lifecycle related information items are stored, nominated and categorised under different classes, groups and ranking, *etc*. [4]. These information and numerical data can be diffused into the PLM through an appropriate interface (*e.g*. web-browser customised for each expertise). Additional PLM systems are developed to compare, evaluate and optimise (*e.g.* using IAS and the advisor agent) product requirements. Also PLM helps to link production information (specifications, existing models, performance figures, and reviews) to the design [14]. In this idealistic view of applying the ISO 14001 standard, numerous issues have been previously mentioned.

More technically PLM and Systems Engineering (SE) do not consider a system as a monolithic object, but rather as a set of interfacing and interacting components. However and apart from this similarity, these two approaches are quite different and they serve in different domains. In fact, PLM aims at contributing to processes throughout the entire lifecycle, while SE focuses mainly on the development phase of the product [18]. Hence, it can be assumed that if the SE standards are high and principally work within the required expertise (such as avoid data and information losses, *etc.*) [19].

An additional question to mention here is for the PLM to operate efficiently: the need for a centralised interface approach enabling the management of a complex databases and structure information in order to keep consistency between model in a (Bottom-up) model approach; which in turn allows individuals (designers and environmental experts) to access the content data and to connect them straightforwardly to other associated systems through the mediation of central flow management [14].

The fundamental principle of SE includes MBSE [18]. This makes it possible to decompose the system into sub-systems that interact between each other to meet with the desired requirements through a (top-down) model approach. Hence, the whole system is decomposed into narrowed smaller units until reaching the simplest model. This refinement of the system is supplemented by creating a number of representations and resolutions that reflect the behavior of the system [19]. Similarly to PLM, these different models are structured and ranked under different groups, in order to make it possible to create a link between them. Thus, this collaboration could correspond to the consideration of the product designers from different fields of expertise by system architects [18].

The SE aims to provide a collaborative and incorporative process of problem solving. This can be enhanced by using PLM (and PDM), combining these two approaches (PLM-SE) and putting their qualities in synergy. A better integration of SE into PLM would enable the SE to have a direct impact on the development cycle as well as on the product designers' decisions [18].

Essential characteristics of the SE-PLM to reduce the distances between the various stakeholders and disciplines involved in the product lifecycle by minimising time and relevant information losses should be specified in detail. Enhancing decision making and making it part of the design process through more frequent and more regular feedback of accurate operational information models are fundamental aspect but to general out of a given industrial context. The information models therein could be directly related to on-going tasks, requirements or problems encountered by the related design teams.

IV. CONCLUSION AND FURTHER WORK

This paper investigates possible information model characteristics that could be adapted and integrated in the design process in order to support DtE practices. An existing proposition made by [18] illustrates how a tailored combination of some current information models characteristics may contribute to increasing the environmental performance of the process.

A rational design model as the one proposed in [18] could aim at combining PLM and SE in the purpose of supporting a better DtE practice. This combination is envisaged in on-going research experiment with industries to elucidate the concepts and terms of computer engineering fundamentals and measure the effect of such proposition.

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