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Design to Environment: Information Model Characteristics

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Abstract

Design to Environmental (DtE) proposes an environmental parameter optimisation among the other design parameters to support the emergence of ecodesigned products that bring environmental value to the society. Numerous information systems have been developed to support the integration of domain-specific parameters. However, it is still unclear how well they perform together in supporting the emergence of ecodesigned products. This research focusses on identifying the information model characteristics needed to change a conventional design process into a DtE process. A framework for industry to find out the proper information models that will support their DtE practice is proposed through a model-view-controller structure, accessed from an operational level. Supporting frequent environmental information sharing, encouraging environmental and product designers operational initiatives, as well as measuring the environmental performance of the DtE process through local operational indicators are fondamental characteristics required for supporting product designers and environmental expertise successful collaboration in DtE. The novelty of this research is to provide a clear method to industries to find out in their information system a environmental optimisation support.

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Keywords: Product design, Design to Environment (DtE), Design models, Ecodesign, Process modeling, Environmental indicators

1. Introduction

1.1. Introduction to Design To Environment

Design is an interactive and evolving process, complex by the requirements and constraints coming from several contextual aspects (*e.g.* society, legislation, industrial sectors), as well as materials, technologies and organisations. Among those, the environmental aspect related to all the lifecycle stages of the product/system under development requires a specific environmental expertise to be integrated. *Design[ing] to Environment* (DtE) supports an environmental parameter optimisation among the other design parameters through a systemic approach. In addition DtE envisages value creations as an opportunity to make DfX (X standing for environment [1], remanufacturing, upgrading, etc. [2]) focus(es) converge along the design process to improve the global product and service lifecycle environmental value. In this view this research considers the environmental parameter integration in the company across its strategic-tactic-operational layers [3]. This ensures a DtE coherency through performance indicators' alignment between: the medium to long term environmental strategy; the project managers medium term tactics; and the operational and short term design activities of product designers [4].

1.2. Paper's objective

Information models define in this paper any information system that would bring support to DtE practices (product lifecycle management and data models, ontologies, *etc.*). Envisaging this practice in the company's system this research focuses on finding the characteristics of the information models adapted to support the DtE operational practices, *i.e* involving product designers from various expertises including the environmental one (Section 2). Considering how numerous and diverse such models are a framework is proposed to structure such DtE supports across current information systems used in industry (Section 3). Based on the possibilities offered by existing information models Section 4 presents further work that will be conducted through a case study to illustrate DtE combining PLM and SE as an attempt to clarify the concepts and terms used in computer engineering semantics for product designers and the environmental expertise.

2. Research issue: which information models to support Design To Environment practices?

2.1. Design Process models structuring multidisciplinary collaboration

Several design process models have been proposed by the *engineering design* community, including mechanical design engineering and product designers, since the seventies of the

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last century. Generic design process models given by Pahl and Beitz (1984), Hubka and Eder (1984) provide a framework to integrate the multiplicity of expertises required to design a complex product lifecycle. In a DtE process the environmental considerations starts from the need specification in the earliest stage, followed by the definition of the required task and the related experts to be included (embodiment and detailed design stages from [5], *cf.* [6,7] detailing the DtE task integration in the process stages). Since then the emergence of a new process models have brought complementary focuses adapted for DtE which practice encourages business innovation [8]: from the first design stage Wilson (1980) considers societal needs integration, Urban and Hauser (1980) the identification of opportunities, Cooper (1986) the "ideation", Andreasen and Hein (1987) the need recognition, the problem recognition (Ray, 1985), the idea, the need, the proposal and the brief definition all together for Hales (1993), the market considerations are added with Pugh (1991), and Baxer (1995) introduces the innovation opportunity assessment [9].

Many other process models are indeed developed in other disciplines than mechanical engineering: PPS, Service engineering, building design, industrial design, system engineering, software design etc. They confer various characteristics that may be necessary to combine when supporting DtE practices. However considering this plethora of process models [14] shows that supporting interdisciplinary design (including DtE practice) cannot be eased through a consensus model of the existing discipline-specific models. Otherwise the very high degree of abstraction required will make those model loose their substance.

Numerous compatible models with product designers practices in industry have been developed to find a pathway toward interdisciplinary design (here ecodesign in particular). A set of 52 integrated models developed between 1994 and 2013 has been analyzed by [10]. An operational lecture of this analysis describes the currently used models in industry integrated:

- at a meso level dealing with the formal incorporation of environmental requirements in the product development process and portfolio management;
- at a micro level dealing with the implementation of customized ecodesign tools and integration of environmental aspects into project management: for *e.g.* in 2012 concerning problem solving [11], and choosing the environmental evaluation and integration tools within other design requirements [12], including the integration of 61 maturity assessment indicators in product development process practices, with a focus on operational practices [13].

This paper hypothesis is therefore that the characteristics found in ecodesign models required to perform DtE could be expressed by various information models from different disciplines, such as system engineering or software design. A clarification of categories of information models existing in industry supporting multidiscipline collaboration is welcome to propose in a second stage the suitable supports for DtE in a given context.

The envisaged method to that purpose would support product designers in combining the required characteristics of information models within existing ones in a given company to enable them practicing DtE.

2.2. PLM, PDM, SE, MBSE, ontologies, LCA, etc. for DtE?

To find out which information models characteristics are required it is first necessary to explore the most common ones used in companies.

Product Lifecycle Management. The PLM is an integrated approach supporting the collaborative management of the product's numerical lifecycle database on Information Technologies (IT). From an operational point of view the adoption of a PLM system by a company implies a multiplicity of IT solutions and tools to enable product designers from different expertise to share their distributed competencies along the design process. PLM are supported by Product lifecycle Data Management tools (PDM): to edit data (authoring), and to automate treatments or processes using workflows, *etc.*

System Engineering. The SE aims at providing a cooperative and interdisciplinary process of problem solving seeking to bring solutions to an operational need identified by measurable efficiency criterion. Solutions are meant to satisfy stakeholders' constraints, while optimising the environmental and economical cost within the whole system lifecycle. For instance if the company uses *Model Based Systems Engineering* (MBSE) [15] a complex system will be discretised into sub-components easier to interact with. Systems architects will therefore enable a certain type of collaboration between product designers by considering their different point of views related to subcomponents.

Ontologies. Ontologies have multiple purposes. They can be developed to generate a product model along its lifecycle: in specific lifecycle stages (*e.g.* oriented toward manufacturing [16]), with the focus to integrate several expertises together using knowledge based integration (*e.g.* product design and manufacturing interface [17]). Ontologies can be also combined with engineering tools to support DtE (*e.g.* sustainable product development [18]).

DtE and Life Cycle Assessment (LCA). The product functionality is central for product designers when specifying the product lifecycle requirements. The environmental impact indicators footprint (*e.g.* carbone dioxyde equivalent emission during lifecycle stages, the recyclability rate, *etc.*) are meaningful product performances if they are compared to a product reference (*e.g.* same product versions) delivering the same function. The International Organisation for Standardisation defining Life Cycle Assessment (LCA) method (ISO 14040-44 [19]) specifies the Functional Unit (FU) as a metric to compare product versions of equal functionality. The question of standardising functional units for product design is still under debate in the community of ecodesign experts [20]. For industries designing products concerned by the Environmental Product Declaration(ISO 14025 standard compliance) some *product category rules* are defined to practice DtE, in which the function delivered is central because a quantified input resource, and energy demand for its delivery can be assessed. The integration of such standardisations and its effect on DtE practices deserve to be deeply studied in ontology-based models for product configuration and product family developed at the moment in the community of SE (*e.g.* [21,22]).

Ontologies for DtE. A first attempt to find existing and compatible ontologies to DtE practices could seek for the following concepts: the product, the processes and the resources, aligned to the product's functional view, so as to generate values for environmental impacts calculation. Then the way a given ontology manages the different data sources from the different point of views (*ie.* expressed into different semantics) involved in the design process to satisfy product's functions for a minimum of environmental cost should be questioned.

Giovannini et al. (2012) [24] proposes an ontology able to align the product, process and resources informations on common semantics and to associate these with the fonctions related concepts. A deeper understanding of the concepts involved are proposed in this paragraph to illustrate how this ontology could support DtE practices.

This ontology is based on an extended version of *product-driven ontology for product data management interoperability within manufacturing process environment (ONTO-PDM)* [25]. This domain ontology is based on two standards (STEP-PDM and ISO/IEC 62264, 2002), used and extended in [24] to define the product view and the conceptual models about equipment, material, resources and processes, including the *sustainable effect* of a function achievement. Resources, related properties, product parts, processes and related parameters are instantiated via mappings between the ontology and the required informations once provided. Based on specific rules defined, the product parameters values are firstly compared with the functions effects values. An input can be for *e.g.* a material property, its value and unit of measure. Secondly, the inference on other product components, processes and resources are evaluated (comparaison of function effects - outputs with input values). Thirdly, some relations are defined between the instance of product, resources, processes and functions deduced from the previous steps (instance per functions and inference on other per functions). Alternatives inference can be composed: inference of relations between functions rules inputs and satisfied functions inputs are permitted. For instance an alternative of material choice on a given product part involving specific resources to be manufactured would be proposed only if the same function is satisfied. The authors specify that "the fulfillment of a sustainable constraints is added on conditions required for function effects. That is to say, a sustainable alternative needs to satisfy also functional requirements (expressed by function effects)" [24]. So fourthly proper queries are used to calculate the effect of the alternative taken satisfying the same function.

In regard to the focus of this paper seeking supports for DtE practices this example of ontology based system:

- is only focused on manufacturing choices (which restraints the complexity of the related mapping, rules and queries required);
- seems to be able to quantify environmental impact values for a given function fulfilled related to the product under development. Some practical applications would be required to verify its compatibility with ecodesign methods (*e.g.* LCA) : how the scope considered by the environmental assessment is defined, as well as the level of discretisation chosen (*e.g.* product scale: sub-components)–to start with goal and scope stage I of LCA basic principles [19];
- targets "sustainable" choices. However, there is no clear definition of what sustainability stands for: is it targeting triple-bottom-line compliance (social, environmental and cost effective) regarding a provided metric or standard (which reference value would be used? Any comparaison made out of the product scope?). Quantifying social aspects remains a difficult task;
- In this approach sustainable alternatives can be associated to a certain type of evaluation. However, no evaluation method for sustainability can be proposed. The way to add evaluation criteria (based on resources, manufacturing processes, calculated impact of a given function, *etc.*) would be by formalising "manufacturing sustainability" using constraints to achieve sustainable functional effects. This suppose that effects are known.

Fortineau (2013) [23] reviewed existing ontologies and defined five roots concept for developers to share a common core of product modeling for the whole lifecycle that could be used a as a *common* and *pivotal* meta-model in PLM systems. This *core model approach* is based on the concepts of product, process, resource, rule and business, which adequacy to DtE process model could be furthermore investigated.

This succinct review of information system in industry shows that PLM systems, engineering systems, ontologies, *etc.* are all part of the environment of information models to support DtE. Because they participate to improving collaboration in multi-constrained context involving multiple domain expertises. The question is therefore how to analyse such information models in a structured manner.

A suitable framework to identify supports of DtE is necessary in particular for non IT developer experts.

3. Proposition: an existing framework adapted to structure supports for DtE

3.1. A model-view-controller framework accessed from an operational point of view of DtE practice

The complexity of DtE is due to the complex nature of the design activity, where multi-domain collaborations are essential to address and properly integrate the environmental dimension into the product design process. As seen in the previous section PLM, SE, Models, ontologies, *etc.* have in common to support this collaboration. A table to organise those collaborative supports can be taken from [28] offering a lecture through: a model-view-controller horizontal scale, and a strategic-tactic-operational vertical scale.

The horizontal scale is based on an usual IT system pattern of *Model-View-Controller (MVC)* declined in a multidisciplinary design context. *Model* refers to the non-visual object containing the data and the behavior to be represented to the user. The *view* stands for the user interface that controls, write and manipulate information. The *controller* changes the model and the view by accepting input and converting it to specific commands.

The vertical scale focuses on the operational level of the company, including product designers and environmental expertise collaboration entertaining dynamic links to the tactic of the company [4].

This model-view-controler organisation of supports accessed through the operational window presented by [28] of-

fers a perfect matching lecture of existing product designers and environnmental expertise collaboration supports for DtE practices. Examples of DtE usage of such supports are taken in the following paragraph for each categories: the operation model, the operational view, and the operational controllers.

3.2. Illustration of the structuring framework for DtE

Operational model. Models supporting collaboration at an operational level animate complementarily bottom-up and top-down exchanges.

- The integration of editing tools based on standards (*e.g.* model integration, unification and federation) supports bottom-up collaboration. FESTivE for Federate EcodE-Sign Tools mEthod [26,27] develops UML class diagrams and transformation models between them to support product designers and environmental expert tools interoperability. Transformations are defined "locally" between targeted and source models, made specific to the semantic context of the related input and output information.
  Unified approach tempt to use a common or "pivot" model, according the semantics associated to the targeted and source models information contained inside. Whereas integration considers a meta-meta-model that defines a unique standard for all the models involved in the heterogeneous environmental of product designers. Semantical losses associated to the data expressed locally in the expert tool (involving local syntax and format) are resulting from such integrative approach. Model federation is the only approach that has the capacity to avoid such losses, however transformations are much more difficult to establish as expertises are required to elaborate them. Unification proposes a trade-off between federation and integration by referring to a standard. The issue face by environmental consideration today is that models supporting environmental tools are not mature enough to propose such standards without losing the reality of the information exchanged and its dynamic supposed to translate the "physical" collaborations of designers above. LCA standards could be used for defining unified or "pivot" models [29], but this would only cover bottom-up collaboration: from product designers to the environmental expert tools (*i.e.* only LCA in this case). For instance a lifecycle inventory of resources, material and energy flows is partially compiled by automatic data transfert from bottom tools to upward LCA tool (*e.g.* [30], European GENESI project on ecodesign software platform development [31]).
  Top-down approaches are therefore complementary to ensure an adapted collaboration from environmental expertise to product designers.
- Core Product Model (CPM) and Product Process, Organisation (PPO) models rather provide a top-down collaboration support. Such models are aligned with the original Function Behavior Structure (FBS) of product models used in mechanical engineering. The CPM propose a generic support (simple and extensible) to model the information linked to the product lifecycle independently from the local expertise software that use those information. The CPM product model is continuously enriched by specific extensions, such as the Reverse Engineering (RE) [33], or the *Core Product Model extension for environmental evaluation* developed to capture and reuse ecodesign information [32], supporting DtE practices.
  PPO models add a link between the product data model to the organizational and decisional dimension of product design [34]. An example of UML class diagram of the PPO model developed by [35] shows that the decision center of a given project defines a design framework and a decision framework entertaining some constraints and relations together.

Operational view. Collaborative engineering supporting environments for synchrone and distant works are another key aspect to support DtE approach. A majority of company do not yet have an environmental expertise internally. Consultant are frequently involved in the design process of products from early to detailed design stages. However if collaboration supports are lacking their exchanges with product designers can be reduced to delivering a report at the end of the product development process for environmental legislation compliance (*e.g.* for a EPD). The environmental impacts assessment results are indeed difficult to analyse for non-expert (multi-impacts indicators used for multi-stages and items considered). The environmental community keeps questioning how to represent, or illustrate such results. One aspect of collaborative supports therefore deals with visio-conferencing, or sharing screen and sound with adapted facilities. Another aspect deals with ensuring a coherency between the design experts asynchrone work (*e.g.* versioning conflicts, information coherency along the process development). This second aspect involves approaches driven by models and processes as presented in the previous paragraph.

Operational controller. Process models present several interesting contributions to the controller approach mainly linking the tactic to the operational level (top-down approach), through workflows and program management modules. Section 2.1 presented the evolution of process model accros disciplines rather on a tactical level. Their declination at the operational scale considers the time spent to achieve a local objective [36], as well as the way to manage a local activity by the local expert. A sufficient precision of processes and activities description is necessary to support DtE. While some flexibility should be kept to ensure the processes and activities contextual interpretation, regarding the project, the human resources and company specificities, *etc.* Workflows and program management module can be customised in PDM to be adapted locally:

- *workflows* used in PDM provide mechanisms to model and manage some processes automatically. An environmental information can be routed automatically: the related data is transferred to the nominated local expert tool. The PDM system provides support to record and manage model versioning. The environmental expert has access to the change history of all information recorded along the design process stages.
- *program management modules* are defined tactically (*e.g.* the Work Breakdown Structure of the project (WBS)) and used at an operational level by multi-expertise product designers intervening during the design process. Resources dedicated to environmental assessment are defined there. Such supports are adapted to support DtE management

method *cf.* [37,38].

Bottom-up controller approach that have been particularly studied by [28] concern the agile methods (*cf.* the Agile Manifesto 12 principles) that plays an important role in:

- improving collaboration by ensuring frequent and regular design information sharing between product designers and the environmental expertise; as well as providing them the capacity to take some initiatives (operational initiative, from product designers to the environmental expertise rather situated on a tactical level conferring a global environmental view on the product);
- this latter aspect is also facilitating decision making. Product designers as expert in their own domain are the only one to know how to deal with their constraints. However as they have to take into account the collateral impact of their design choice on the environmental performance (*via* adapted operational environmental indicators), their need a frequent and updated global view on the environmental performance of the product. From this cause to effect understanding of their own choices the agile methods would support their local and (made transparent) choices.
- Agile methods also play an important role in ensuring a decision and data traceability by supporting local operational indicators. In DtE local indicators are crucial to align the local expertise parameters to the environmental parameters without semantical loss associated to the data used in each expertise. DtE practices suffer from unadapted local operational indicators that are supposed to guide product designers to make "environmentally friendly" choices. In fact operational indicators to support environmental integration are well established by the local expertise him/herself (*e.g.* for a mechanical design choice: mechanical and material variable or properties: Young modulus, corrosion *etc.* for optimal lifespan, density for masses, recyclable fraction contained in the material for end of life treatment, *etc.* The Ashby material databases *Granta Design* software propose relevant local indicators as well as a method to align local to global parameters. The representation of material families by the properties function targeted is an operational viewer for DtE practices supporting material selection [39].

This review of existing information models in industry, structured through a *Model-View-Controller* framework [28] demonstrates by the diversity of supports available that a company has the capacity to adopt DtE information models by: (1) questioning the key characteristics required for bringing its own DtE context to maturity (through a model-view-controller framework fulfillment for instance), and (2) identifying the lacks in its information models to perform accordingly, taking into account the agile method requirements.

3.3. Synthesis of information model characteristics observed

The basic characteristic of an information system supporting DtE is to allow multi-domain collaboration with the environmental expertise, on the operational level and during the design process, finding supports through the existing and adapted models, views and controllers of the company, *cf.* Fig. 1. Then to ensure an agile DtE approach: (A) the environmental information need to be shared frequently within other design information, (B) initiatives should be given to local operational experts (at least the product designers and the environmental expert), and (C) local operational environmental indicators to mesure the environmental performance are required.

Information System/DtE	Model	Controller	View
Strategic			
Tactical			
Operational	Bottom-up and top-down exchanges *eg. FESTivE [26,27,30, 31], CPM and PPO [32-35]*	Top-down workflows and program management modules to achieve environmental local objective. e.g. *customised PDM* and *project Work Breakdown Structure including DtE management* methods [37,38] Bottom-up Agile principles for DtE [28]	Collaborative engineering for synchrone, distant and asynchrone works. *e.g. versioning conflicts and experts' view sharing*

Which **operational product designers and environmental expertise collaboration supports** for DtE practices?

Which **local operational environmental indicators** to measure the **environmental performance** of DtE practice?

Fig. 1. Proposition of the model-view-controller framework accessed from an operational point of view of DtE practice, adapted from [28]

4. Further work and conclusion

A practical illustration of DtE combining PLM and SE is being conducted as an attempt to clarify the concepts and terms used in computer engineering semantics for product designers and environmental expertise. The proposition of [28] is chosen for this case study, which considers the imbrication of three concepts: a Collaborative Actions Framework, Workspaces, and a Branch and Merge support.

Those three concepts will be populated by referring to the systemic literature review of existing ecodesign models presented in [10], that connects: (a) a strategic, tactic and operational level of integration (defined as macro, meso and micro level, *cf.* Appendix 1a,b and c, for a summary content of the publications and models identified from 1993 to 2013, as well as the stages of the Product Development Process to integrate them); with (b) top-down and bottom-up flows that promote vertical integration; and with (3) a transversal integration axis dealing with change and people management within a perspective of the organisation's culture.

This case study will then measure the effect targeted by this integration of SE into PLM observing: (1) if this integrations of SE into PLM is appropriate to support ecodesign model integrations, for instance through specific patterns directly integrated in PDMs; (2) if the integration of all product lifecycle stages when developing the consolidated model elaborated by system engineers is more systematic; and (3) if system engineering verification methods are adopted more systematically during the product design integration of the environmental expertise in the PLM.

The effects of such *information model* implementation have a chance to contribute to DtE, by supporting a frequently upgraded environmental global view to identify the collateral im-

pacts of the different design choices made by experts on the environmental aspects. This would ease environmental decision making (typically for project managers); this also may be improved by dynamic information exchanges from local expertises to global ones and reversely. Finally the traçability of the data system definition designed, and decision made during the product design process would help new "environmentally conscious" decisions to be taken.

To conclude, this paper proposed a framework to structure companies' product designers and environmental experts investigating the information models supporting a Design to Environment process. Some elementary information models characteristics have been provided to them.

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