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VERS DES PROCESSUS D'ECO-CONCEPTION PROACTIF VIA LA MODELISATION DES CONNAISSANCES D'INTERFACE ENTRE LES ACTEURS DE LA CONCEPTION

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Résumé:

Cet article part du postulat qu'un processus de conception agissant comme un système proactif est la clef qui permettra aux produits éco-efficaces d'émerger.

Ce système proactif se définit par l'ensemble "concepteurs et analyste du cycle de vie" interagissant d'une manière dynamique. L'interaction proactive est obtenue par le développement de plusieurs interfaces de transformation de connaissances, entre les modèles de connaissances relatifs aux activités multi-métiers rencontrées tout au long du processus de conception. Concepteurs et analystes du cycle de vie peuvent ainsi échanger d'une manière bilatérale des données et de la connaissance relatives à leur expertise.

Le but de cet article est triple: présenter et argumenter les propriétés des mécanismes d'interfaces permettant l'amélioration de la collaboration entre les métiers de la conception et l'expertise environnementale, proposer une méthode pour construire ces interfaces et tester ces mécanismes à travers un cas d'étude industriel.

Les résultats de cette expérimentation se mesurent essentiellement au travers des paramètres "temps" et "bénéfices pour l'environnement."

Mots clés: *éco-conception, proactivité, processus de conception, interopérabilité, ingénierie dirigée par les modèles de processus, outils de collaboration, connaissance.*

1. Introduction

Environmental legislations oblige companies to integrate environmental concerns when designing products (for instance: Authorisation and Restriction of Chemical substances (REACH), Waste Electrical and Electronic Equipment (WEEE) [1]. To reduce the total environmental impacts of a product in its life cycle perspective, the environmental aspects have to be integrated in the development of the product [2, 3]. Therefore numerous and diverse ecodesign methods and tools have been developed (see example of state of the art: [4]). Beyond legislative obligations and potential profits, convincing managers and designers is an important issue to consider [5]. This paper assumes that helping designers and Life Cycle analyst to collaborate (by improving the use of the methods and tools they judge appropriate for their tasks) increases their motivation to adopt ecodesign practices. The ecodesign tools are then complementary and must be considered in the systemic context of sustainability [6]. Lofthouse [7] showed the importance of keeping the *culture* of industrial designer, and reinforce "their way of working better, communicates in a language that they understand" and use an appropriate set of ecodesign tools.

For those reasons the article focuses on the interaction and communication between the available ecodesign tools and the other design tools, by defining rules of knowledge transformation based on models related to each tool. This paper proposes a method to technically build those dynamic knowledge transformations. This research is part of the field of design research that aims at "mak[ing] design more effective and efficient, in order to enable design practice to develop more successful products" [8].

In this paper, section 2 introduces the complexity of engineering processes, where collaboration is an important issue to conduct ecodesign in a proactive manner. Section 3 describes a method to support collaboration by building dynamic knowledge interfacing that satisfies specific properties. Those interfaces are technical supports that integrate the environmental parameters among designer's parameters. The core of the proposal is based on knowledge transformation models, identified and

presented in section 4. The last section concludes on the reliability of interfacing when improving collaboration and proposes possibilities for further work.

2. Research context: key issues

2.1. Multi-domain collaboration and multi-stages complexities of the design process

Blessing and Chakrabarti [8] define Design as “a complex, multi-faceted phenomenon, involving: people, a developing product, a process involving a multitude of activities and procedures; a wide variety of knowledge, tools and methods; an organization; as well as a micro-economic and macro-economic context”. As seen in literature the numerous constraints of design, such as cost, quality, environment, force this multi-domain design process to be collaborative. Collaboration is thus “a sine-qua-non” to create value in organizations [9]. This is especially the case in a Design To Environment approach, where the complexity of the process is increased by the necessity to explore unusual domains such as biology or climatology to validate the environmental impacts of a product ([10,11]). And Karlsson and Luttrupp to add that “EcoDesign can be interpreted as Design with more intelligent interrelationship to Nature” [12], which considerably increase the complexity of it.

Murillo-Luna et al. [13] showed that one of the five major internal barriers to a environmentally proactive strategy of a company is “the lack of technological information [given to ecodesigners] and communication” during the design process. Designing to reduce environmental impact of a product therefore make designers and ecodesign experts collaborate to exchange *crucial* information about the product. Especially because ecodesign is characterized by the *life-cycle-thinking*, which relies on a transversal integration of the environmental concern in each stage of the development of the product (at different scales [14]): from cradle to grave (or cradle to cradle [15]). The collateral impacts, resulting from the multi-domain choices taken separately by different experts (local choice), have hence to be managed at a global and transversal level (as argued in previous research [16]). Some expert tools are thus specific to assess the life cycle of the product, which can be qualitative or quantitative (such as the: Life Cycle Assessment (LCA), 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]). For the author’s paper, this ubiquity between local and global activities explains the diversity of ecodesign settings [18] (expert vs. non expert tools), and the type of collaboration needed, in companies.

2.2. Three settings for collaboration between environmental experts and designers (in environmental impact analysis perspective)

Observations made of industries shows that ecodesign expertise (at an operational level: to perform environmental impact analysis) can be (1) externalized (consulting agency), (2) treated as a distinct department in the company (3) integrated in expert activities, such as mechanical engineers activities (eg. ISO standard [19]). Those situations are characterized in table 1.

Ecodesign situations	Drawbacks	Benefits
(1) Externalized (eg. Consulting agency)	- unilateral data exchanges; - most of the time only LCA are performed;	- reliability of the results; - scientific results;
(2) In a distinct department in the company	- reactivity; - difficulty of (eco)design knowledge sharing;	- possible communication and data sharing between departments;
(3) Integrated among designers	- Not adapted to the transversal vision required to avoid impact transfer;	- minimum of knowledge sharing; - capacity to learn and to anticipate; - Design To X and Design For X approaches.

Table 1: Characterization of the integration of ecodesign in industrial design processes

2.3. Proactivity as a key factor of ecodesign integration in the industrial design processes

Comparing ecodesign to engineering design, Karlson and Luttrupp [12] argued that “the synthesizing ability in design and product development processes is dependent on dialogue and cooperation that combine visionary, creative and analytic and experience based capabilities. EcoDesign should support and promote proactive development of such synthesizing abilities”. In contrast to reactivity, proactivity anticipates and is dynamic. The capacity for designers and environmental experts to be proactive from the beginning until the end of the design process is fundamental, especially because “in the early phases of the design of a new product, the knowledge of the product is small, but the designers freedom is large since nothing is settled yet” [20]. A proactive (eco)design process would thus allow environmental decisions to be taken in the early stage of the product development process, which considerably increases the chance to tackle ecoeffective design [15]. Regarding table 1 the environmental parameters will be considered as early as possible if they are integrated among designers and if the environmental expertise is synchronized to their activities (allows anticipation). The aim of this research is consequently to reach this last proactive system (table 2). **And this can be achieved by using knowledge interfaces based on transformation models, in the domain of Model Driven Engineering (MDE).**

Ecodesign Setting	Proposal
Environmental expertise is in a distinct department (int. or ext.) + Environmental parameters are integrated among designers	- <i>Bilateral data exchanges</i> : linking design parameters to environmental consequences; - <i>Minimum of knowledge sharing</i> in multi-domain collaboration; - Complementary <i>DTX and DFX approaches</i> performed and capacity to choose the environmental assessment method needed for <i>each context</i> (not only LCA).

Table 2: Proposal of this research regarding environmental experts and designers collaboration

3. Research proposal: knowledge interfaces based on transformation models to integrate environmental concerns proactively in the design process

3.1. Context of the proposal: Virtual Product Development is a set of models usually shared and exchanged by data exchange systems and PLM systems approaches

Design activities “generate and develop a product from a need, product idea or technology to the full documentation needed to realise the product and to fulfil the perceived needs of the user and other stakeholders”[8]. The activity of a designer thus consists of using his expertise to find a solution for the final product to verify a (given) function. During the design process the future product is progressively defined by the sum of Bill Of Material (BOM) (eg.: as-specified F-BOM, as-designed Product-BOM) emerges from the multiple activity and support involved along the design process. This digital information constitutes the digital mock-up of the product. Improving collaboration among designers is therefore also about improving the data exchanged through the digital mock-up, especially when 1/5 of time spent by designers is about gathering information needed as input to perform a design activity [21]. So far specific collaboration has been improved by **data exchange approaches (for instance, the STandard for the Exchange of Product model data (STEP) [22])** or **shared collaboration spaces as implemented in PLM (Product Life-Cycle Management) systems**. However, the **lack of dynamic and integration of the later systems is a common criticism** given by many users and recognized by the authors. PLM and PDM (Product Data Management) systems indeed mainly rely on a central database (gathering the various files from the different experts’ supports) associate to a management workflow (repositories, versions, access permissions, etc.) [23].

3.2. Aim of the proposal: modelling the design process and developing dynamic frameworks between activities (using the activity knowledge)

Since the introduction of **concurrent engineering** (simultaneous data exchanges between the stages of the design process [24]) numerous models describing the design process have been proposed. In previous research, the authors have worked on how to *model the knowledge of the multi-domain*

stakeholders in a collaborative process [25,26]. Taking the example of the IPPOP software demonstrator, three fundamental aspects to improve collaboration can be retained from this example: (a) the dynamic framework based on the exchange and (b) the integration of (c) the focus on crucial information (eg. Knowledge) [27,28]. By considering the difficulty of collaboration when dealing with the **new constraint of environmental impacts of the product during its life cycle**, the authors propose to build **dynamic interfaces** (refers to (a)) **between ecodesign experts and designers tools** (sharing crucial information (c)), as an **alternative to standard approaches and PLM systems**. The core of the proposal is the **integration** of environmental parameters within designers activities (refers to (b)) **driven by models (MDE)**, which are defined along the design process.

3.3. Integration of environmental parameters using Model Driven Engineering environment

Model Driven Engineering (MDE) relies on multiple levels of abstract representation of models. This is a unifying software concept, which is *not new* for developers but **its application on ecodesign in this research fundamentally differs from common applications in industry**. The authors believe that this environment is appropriate to connect two models, one from the activity of the designers and the other from the environmental analysis activity [29,16]. The IEEE standard defines Interoperability as “the ability of two systems to exchange information and use the information that has been exchanged”. **Each model evolves separately but interoperability makes synchronization possible between the models**. This is especially **suitable in a complex ecodesign process**, where the environmental impacts of the future product can only be calculated from **the compilation of heterogeneous choices taken separately by asynchronous design activities**. Interoperability can be afforded by three approaches: integration, unification and federation [30]. Iraqi et al. [31] argue about federation, that “this distributed approach seems to be the more flexible one since only local changes have to be treated when adding new concepts”. This research hence relies on the **federation approach**. **The knowledge transformation models are in fact used to federate the tools**.

3.4. Properties of the proposal: knowledge transformation models

The definition of *knowledge interface modelling* given by the authors is therefore based on a federative approach of MDE. The *interface* is a set of knowledge transformation models, which federate the design and environmental analysis. This *interface* (proposal) confers the following properties:

- **(H1.1) Be adaptable to different contexts;**
- **(H1.2) Use of any crucial available data;**
- **(H1.3) Involve a minimum of specific knowledge when sharing information between designers (by the least commitment approach);**

The information exchanged through the interfacing is **calibrated** according to the contextual needs **(H1.1)**. The core of the interface is therefore a **set of transformation models**, which are based on multi-domain engineering design knowledge and ecodesign knowledge. The models can be upgraded according to the **evolution** of the knowledge of the activities involved.

Only the available data considered as *crucial* by the owner of the knowledge involved in the given activity is transferred to the activity which needs it **(H1.2)**. The transformation models **detect any of the crucial data** from a model A, **transform and transfer** the transformed data into model B. Only the data needed for the transformation involved is taken from model A. And consequently model B do not have to be fully completed to feed activity B. In the models *crucial data* can be added or released depending of the specificity of the process (context (1)). That is why such interface is a relevant support for driving engineering by process models.

The **(H1.3)** property refers to the knowledge included in each design activity. The interface mechanism is indeed deals with multi-domain interactions. One of the difficulties is thus to **overcome the lack of understanding between the design parameter of the activity X and its environmental consequence**. Therefore the transformation model is used to transform information *understood* by knowledge A to the same information understood by knowledge B. Knowledge A is related to the

knowledge of the designer A of the activity A, idem for B; one of this two is the environmental expert. Then, the transmitted knowledge in activity B can be *represented by a plugin* to help the designer B interpret the information (when this is appropriate: giving geometrical view, graphs, etc.) and help him reiterate his choice. In addition to the model transformations, *links to complementary supports* can be added: to a library, a guide, previous projects reports, websites, etc.

The proposed system composed of interoperable software **is supporting human being collaboration**. Such a system *facilitates the interaction and the communication* between activities and does **not suppress human action**. Each activity is indeed performed by an expert (*global environmental analysis activity included*).

4. Three step method for modelling knowledge transformation and application to a case study

4.1. Modelling the design process

The **first step** of the method to build the knowledge transformation models along the design process, consists of **studying** the design process and the activities involved (tasks, expertise required, support used) and modelling the whole process (process diagrams) (fig.1). Figure 1 is a graphical representation of a design process involving several design activities (Computer Aided Design, logistic, design, etc.) with their relative support. In this method, the *Global Environmental Activity (GEA)* performed transversally along the design process, such as LCA or any other environmental analysis method or tool, is represented in the upper part of the figure, whereas the *local activities* are represented in the lower part of the figure.

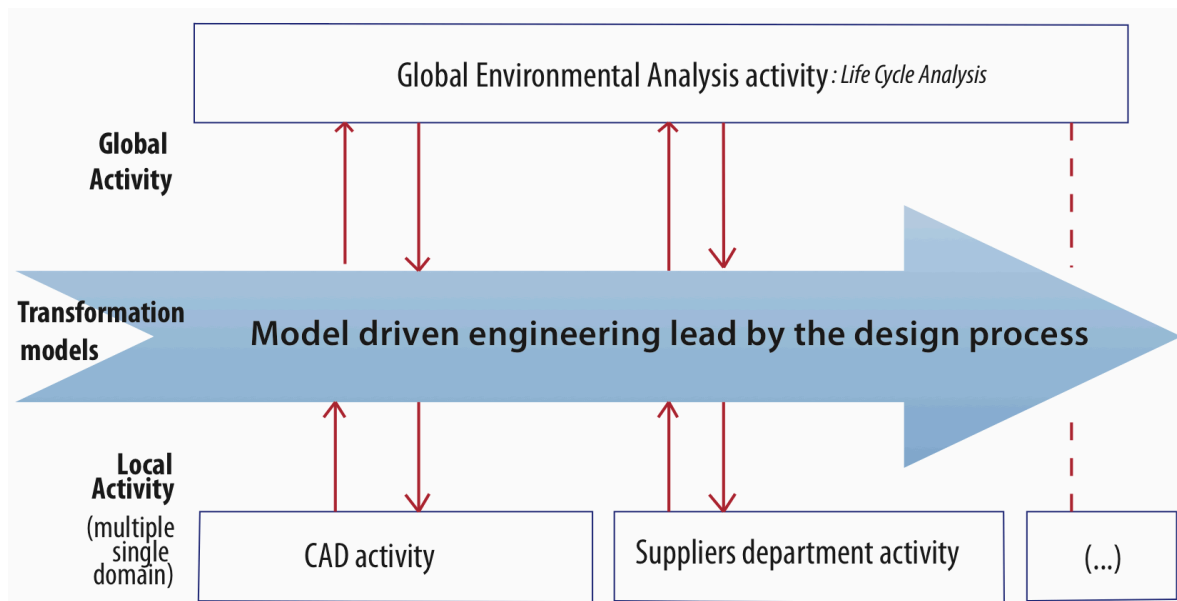


Figure 1: Representation of the first step of the method: modelling the design process

This first step is supported by the meta-model language UML (Unified Modelling Language), using process diagrams. Figure 2 is an illustration of a part of the design process of a mechatronic product of the industrial partner of this research. The whole process is not presented in this figure 2, only the activity of *Global Environmental Analysis* is modelled. The round-corner squares are describing activities (such as “Search for GEA inputs”) and the squares are describing data (such as “GEA Inputs”). In this case, the GEA activity is iterative, as the environmental expert will search for the more appropriate environmental analysis, regarding the types of Inputs he has at his disposal. Then, he edits the recommendations for each design expert: by extracting and translating the detailed results from the environmental analysis to the given expert. The Outputs of this GEA activity are then distributed to the various designers activities. Those data are Inputs for their related activities. They will thus be able to take into account the environmental parameters in their activity, and generate new Inputs for the GEA activity.

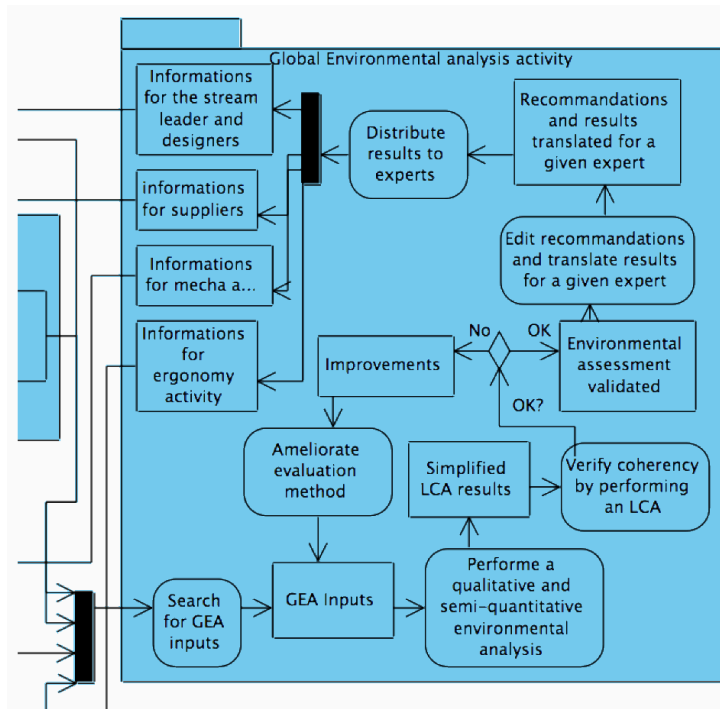


Figure 2: Part of the model of the design process of an industrial case study of a mechatronic product (including multi-domain activities involved) using Unified Modeling Language (UML)

4.2. Modelling the activity

The **second step** of the method consists of **highlighting and modelling** the crucial data Input and Output (I/O) *required* to perform the activities linked to environmental analysis, using class diagrams in UML (cf. fig.3 for an illustration of Inputs needed to conduct an LCA).

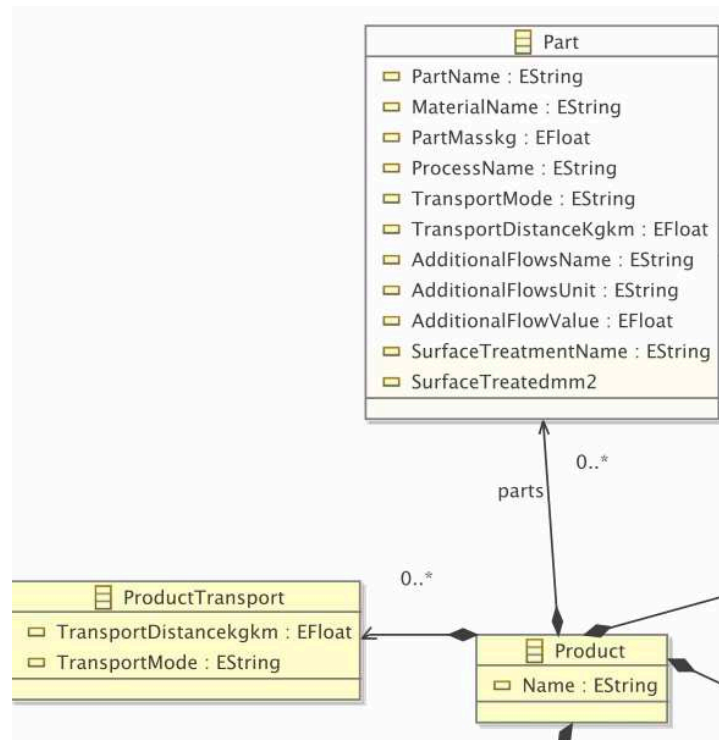


Figure 3: Detail of a part of the LCA inputs expressed in UML (class diagram), using EMF

From each activity knowledge, the data needed to perform this activity, as well as the data created by the activity are defined in class (relations between elements: heritage, association, etc.) with attributes (format, type of data, name, etc.). From fig. 2 each I/O (small square) are described by a class diagram expressed in the meta-language UML. Each class has several attributes (type defined) and is related with other classes (association, heritage, etc., “0..*” signifies that the class can be instantiate “n” times). The Fig. 3 shows the class diagram of a product, composed of *n* parts, each part has attributes (a name, a material name, a masse, a manufacturing process, etc.). Each stage of the life cycle of this product is specified in the class diagram: extraction of raw material, design and part assembly, transport, use, end-of-life (only transport and raw material and design are showed in fig. 3).

The previous step (process diagram) and this step (class diagram) give an *object oriented representation* of the process and the data, from which the links needed to connect the data from local to global (and reversely) activities can be identified and modelled (step 3), to *drive* the whole process.

4.3. Modelling the knowledge transformation models

The **third step** of the method is about **defining** and **modelling the transformations** needed to **link two models** from the GEA and local activity. The knowledge transformation models are the core of the interface modelling (computer code). Those transformations are modelled by The ATLAS Transformation Language using Eclips Modelling Framework (EMF). The authors have chosen EMF because this framework presents the asset to be a software groundwork based on ISO standard, Open Source. The UML class diagrams are modelled and instantiated in EMF (Ecore metamodels) and the ATL transformation is directly created from the metamodels. ATL is a *generative approach* of the model transformations (unidirectional): generate a *target model* from a *source model* (source = read-only, target = write-only). ATL is based on the principle of pattern-matching and rules: at each element from the metamodel source is associated a transformation rule (toward target elements) and several auxiliary constructions. Fig. 4 is an example of the transformation between two models.

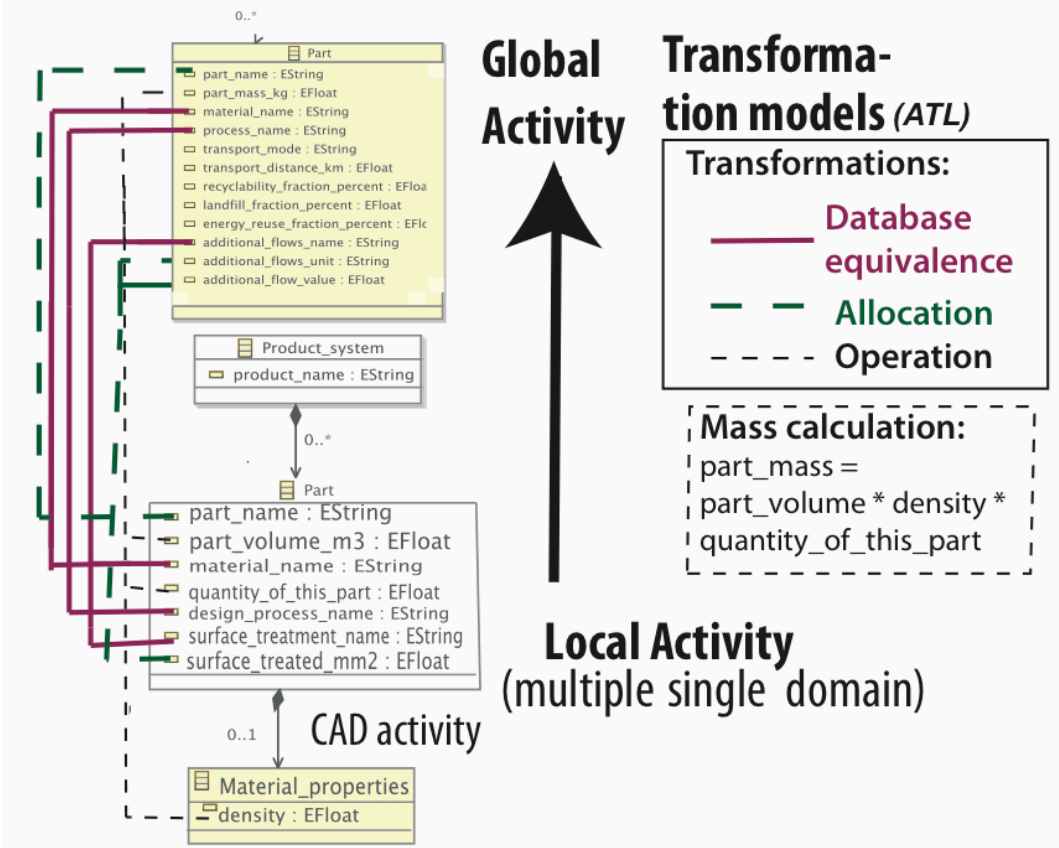


Figure 4: Illustration of the third step of the method: modelling the knowledge transformation models between structural designer class diagram outputs and global environmental analysis inputs

4.3.1. Categorization of knowledge transformation models

The observation of existing situations (involving data exchange between multi-domain designers and the ecodesign activity) leads to the consideration of several types of data exchanges such as automatic allocation, database equivalence or operation (table 3).

Automatic allocation: transfer the value (type: float, string, etc.) of one data model attribute to the same attribute from another model.

Database equivalence: correspondence between denomination of values from several database. The Ecoinvent databases for instance are used in the SimaPro LCA software (PreConsultant), whereas CES (material selection software developed by Granta Design) is based on the Ashby databases on materials and processes. The denomination of a given material is therefore related to a set of primary energy and material flows in Ecoinvent, whereas the same material is related to a set of properties (density, Young modulus, etc.) and flows in CES. To make a material choice from output activity A (eg.: material choice supported by CES) correspond to Inputs of the activity B (eg.: LCA), a rule of *database equivalence* can be used.

Operation between data of one (or more) initial models, to calculate the value needed as inputs in another data model. Operations can be based on operators, such as multiplications, functions (internal method related to an object type), or more complex functions (using one or more source models and one or more target models, *cf.* equation of the case study for an example), which are obviously in accordance with the Object Oriented Programming (OOP) paradigm.

	Type	General purpose	Source model	Target Model
A	Simple allocation	Injection attribute value of an initial model into a target model	Value	Same value
B	Database equivalence	Transform source attribute denomination into target model denomination (via intermediary models)	Database model	Equivalent denomination in target database model
C	Operation	- Extract several data from one or more source models; - perform operation; - inject operation result into target models.	Data from several models	Result of the operation
D	Mix of A, B, C			

Table 3: Categorization of knowledge transformation models

4.4. Added value of the research on knowledge transformation models

Based on the OOP paradigm this three steps method allows the modeller to provide interoperable expert supports. In terms of organization, experts have the capacity to focus on their related domain and collaborate with each other via the *rules of knowledge transformation models*. This *federative* approach of models organizes the *knowledge* where it is *needed*. **The knowledge transformations are defined as the process evolves and they have the capacity to evolve if the internal knowledge evolves.** This ability to evolve (dynamic, flexibility) is what distinguishes the proposal from the approaches based on *integration*. Therefore, this research is based on model driven engineering *by process*. The knowledge transformations are thus specific to the company context, but taken separately they can be used in distinct companies and exchanged between them. **Little by little the knowledge that companies have of their process is improved.**

A case study have been used to apply the method on a real project in an international company, and the transformation models have been successfully modelled by ATL. A first survey has been performed in this company to model the activities and the design process of a project that involved environmental analysis. A proposal has been then proposed to federate CAD tools and Suppliers tools

with LCA (fig. 4). To measure the effective gains of the author proposal two main studies are now conducted:

- Time gained: by measuring the time spent in an iteration of the design process before and after the implementation of operability proposals.
- Environmental improvements: by comparing the environmental impacts of a product design in a classical process to the same product design in process, which involve interoperable models (knowledge transformation models).

Environmental performance can lead to remarkable improvements in terms of eco-innovation. In addition to environmental impact improvements, other assets are measured by the second survey. And the improvement of ecodesigners frustration regarding the capacity to interact with designers during the design process is an efficient indicator to measure the proactivity between multi-domain designers.

The authors are currently working on indicators and methodologies to measure the intangible and financial gains for widened companies (innovation, improved human satisfaction; capitalization of know-how in the company, long term sustainable strategy). This is the object of a research project named Convergence conducted in France with four research centers, an institute and an international company.

5. Conclusion and discussion

In this work it was found that the complexity of the multi-domain design process is such that the collaboration between the activities (ecodesign included) appears essential to succeed in designing ecoeffective products. This collaboration would be implemented through the capacity of multi-domain tools to exchange information dynamically (bilateral data exchanges). Especially because an environmental analysis has to deal with the collateral impacts generated by the different choices taken separately in the *local* activities (other expert domains involved in the design process).

Therefore the authors have proposed a methodology to allow any future and actual environmental analysis tool to interoperate with any tool involved during the design process. This federation of tools help multi-domain designers (ecodesign included) to work proactively. The proposal refers to the domain of Model Driven Engineering, using Unified Modeling Language (UML) to model the design process and the activities involved (integrated in this case to Eclipse Modelling Framework (EMF)). This three steps method (modelling process and activities, and defining rules of knowledge transformation between models) is based on the knowledge of each activity (the input and output and the support used) and aims to determine the transformation rules needed to connect the *crucial* data from one activity to another. The authors have proposed several rules of transformation, which can be used in various industrial contexts and products. The transformations are modelled by the appropriate ATL (modelling language) integrated to EMF. A case study has been conducted to test the method (not presented here). The direct gains measured were about reducing time consumption and designers frustration for the same project (for the same environmental performance). The long terms benefits of the proposal need further research to be measured, notably on the company scale: financial gains and intangible gains (such as eco-effectiveness, knowledge capitalization).

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