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AN EXPLORATORY STUDY TO INTEGRATE FEASIBILITY INTO THE ECO-DESIGN PROCESS: AN APPROACH TO LINK DESIGN AND ENVIRONMENTAL PARAMETERS

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Abstract

To support environmental practices in industrial design, many software tools have been developed. These tools aim to provide environmental information in a decision context for designers and environmental experts. Although Life-Cycle Analysis tools can provide relevant and precise information, the question of feasibility remains crucial in proposing realistic solutions. In our study, we built a database linking design and environmental parameters in order to facilitate the consideration of technical, organizational and economic constrains in eco-design. We used knowledge engineering techniques, applied to a collection of documents from a young company, to identify the relevant design parameters to implement.

Keywords: Ecodesign, Decision making, Design methodology

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1 INTRODUCTION

The integration of eco-design in industries is becoming more and more considered as a necessary condition of Sustainable development. Eco-design must be deployed at each step of product design. It allows at reducing the impact of production on environment while favouring the implication of the actors of design and of the whole value chain. It should be noted that the consideration of environmental issues in design can modify the objectives, outputs, resources, processes and performance indicators of a company. Technical and economic modalities leading to the development of products can play a major role in reducing the environmental impacts while stimulating innovation (Dewulf, 2003; Pimenta et al., 2012). Eco-design goals (using of renewable materials, recycling, reducing energy, etc.) coupled with economic and social objectives (implication of stakeholders, sharing knowledge, considering culture aspect, etc.) are more or less considered in proactive or prescriptive way. These approaches lead to develop innovative solutions (circular economy, hybrid energy production, etc.). We can note that eco-design joins the environmental innovation logic (Depret and Hamdouch, 2009) allowing to reduce material and energy impact.

Nowadays, several tools are developed to help designers to consider environmental parameters in their activities. Nevertheless, without linking these parameters to design indicators, the study of feasibility of innovative solutions is still compromised. In this article we propose an exploratory study to link design criteria to environmental parameters. We use knowledge engineering techniques (Studer et al, 1998) in order to define design indicators from documents.

2 ENVIRONMENTAL PARAMETERS IN THE DESIGN PROCESS

The integration of environmental issues in design was clearly identified by Victor Papanek in his book 'Design for the Real World: Human Ecology and Social Change' (1971). The 70's is a period characterized by a growing interest in environmental studies to support innovative design: Coca-Cola was the first company to realize a multi-criteria study to assess the environmental impacts related to the production and the end-of-life of their product (Harry and Teastley, 1969). The methodology was formalized twenty years later as "Life-Cycle Assessment".
The Life-Cycle Assessment (LCA) allows designers to access environmental information about their products. The method is based on the whole life-cycle of the product: from the raw materials extraction to the end-of-life treatment of the product, considering as well the steps of supplying, production, distribution, use and maintenance. The LCA methodology is now part of the ISO14000 environmental management standard since 2006.

Based on a functional unit, LCA can provide an overview of potential environmental impacts of a product. With a bill of materials and data about the whole life-cycle (production processes, transports, treatments, energy, etc.) connected to an impact database, we are able to generate a Life-Cycle Inventory (LCI) listing all the inputs and outputs flows related to a product. These inputs and outputs quantify many substances and elements, depending on the used database. Each substance or element, extracted or emitted, has a potential impact on environment: several characterization methods can translate the LCI into an overview of the product impacts. The choice of the characterization method depends on the selected impact categories (problem oriented or damage oriented), its international acceptance and its geographical representativeness (European Commission - Joint Research Centre, 2010). By this way, a material or a process can be attached to an "impacts picture", composed of several indicators. These environmental indicators are separated in two impact categories: the mid-point impacts and the end-points impacts. Mid-point impacts are commonly representative of environmental problems: it quantifies an effect but not a consequence. A carbon dioxide emission is an environmental problem and represents a well-known mid-point impact: the global warming. The end-point impacts are representativeness of an environmental damage, a final consequence: it could be a loss of biodiversity or the climate change (which is a consequence of the global warming).
In our study, we used the FD E01-008 booklet (2014) to get environmental data about materials and processes of mechanical engineering. This allowed us to access six indicators:

- Primary energy (MJ).

- Resource depletion (Sb eq.).
- Climate change (CO_2 eq.).
- Acidification (SO_2 eq.).
- Eutrophication (PO_4^{3-} eq.).
- Photochemical ozone creation (C_2H_4 eq.).

The booklet provides characterization factors based on a reference unit of materials (kg) or processes (kg, hours, meters, etc.). For example, depending on its type and on its quantity, the use of a material can lead to several of these potential impacts (Figure 1).

Example of the comparison of a stainless-steel spoon (120g) and a wooden spoon (120g):

	Primary energy	Resource depletion	Climate change	Acidification	Eutrophication	Photochemical ozone creation
	5,06E+00 MJ	2,23E-03 Sb eq.	2,51E-01 CO2 eq.	1,24E-03 SO2 eq.	1,28E-04 PO4 eq.	1,33E-04 C2H4 eq.

	Primary energy	Resource depletion	Climate change	Acidification	Eutrophication	Photochemical ozone creation
	2,98E+00 MJ	1,80E-04 Sb eq.	2,54E-02 CO2 eq.	1,55E-01 SO2 eq.	2,88E-05 PO4 eq.	1,20E-05 C2H4 eq.

Figure 1. Comparison of stainless-steel spoon and wooden spoon

The red bars represent 100% of the maximum impact for one indicator: for example, with the primary energy, the stainless-steel spoon has the maximum impact (5.06 MJ) and the wooden spoon reaches 59% of this maximum (2.98 MJ). In this simple case, without considering the production processes and the whole life-cycle of the spoons, the obtained results could lead to prefer the use of wood to design the spoon (depending on the goals of the environmental improvements).

Although that kind of indicators allows the designer to integrate environmental aspects in his decision process, the question of the feasibility remains fundamental on several aspects: technical, economical, organisational.

3 DESIGN-TOOLS VERSUS ECO-TOOLS

3.1 The importance of linking design and environmental goals

The issue of linking design practices and environmental changes has become major in industry. Since the emergence of eco-design, multiple tools and methods has been developed and are still evolving with experts and industries (Rio and al., 2013). These tools are enlisted by two different types of users: on one hand, the environmental experts, who are usually not aware of technical and organisational issues of design, and on the other hand, the designers, who have no environmental knowledge at their disposal. That leads to difficulties to apply a practical and efficient use of these tools (Rossi and al., 2006). For example, the use of Life-Cycle Assessment requires a lot of time from the designer and a lot of environmental knowledge and data (Michelin and al., 2014). Finally, separating the environmental parameters obtained with LCA tools from the design process does not allow the designers to support their decision-making process.

3.2 Eco-design approach of designers

Aware of the issue of linking environmental and design parameters, some developers tried to implement environmental data into designer's software, such as Dassault Systèmes or Granta Design.

Dassault Systèmes (France) is a software company specialized in 3D design, 3D mock-up and product Life-Cycle Management (PLM). They developed an add-on for on their product: SOLIDWORKS, called SOLIDWORKS Sustainability. This tool enables the designer to get environmental information at the CAD stage (Computer-Aided Design) on a 3D modelling. It provides a picture of the potential impacts of the future product, using environmental indicators from a LCA database.

Granta Design (United Kingdom) is a spin-out from the University of Cambridge specialized in material engineering. To support designers in their decisions about re-design, they developed a software allowing to select and compare several materials, cross-referencing the technical material properties (density, elasticity, conductivity, etc.), called CES Selector. Granta Design provides a way to get environmental information from their software: the Granta's Eco Audit tool. Based on the selected materials, the software is able to calculate an estimation of the potential environmental impacts with two indicators: the CO2 emissions and the energy consumption.

In both cases, the targeted user is the designer (not an environmental expert) who follows the same process through four steps (Figure 2):

- 1: A technical definition of the framework: the designer should provide a bill of materials that are linked to simplified data about the product life-cycle; and potentially some information about geometry and product shape. The global output of this step is a "technical inventory".
- 2: An impact calculation: the chosen tool, connected to an environmental database and calculation methods, calculates the potential environmental impact of the product, based on the technical inventory.
- 3: An optimization of the product composition: based on the results, the designer is in a position to make some technical parameters vary in order to reduce the potential environmental impacts.
- 4: An impact comparison: the designer can check the potential environmental improvement of his optimized technical framework.

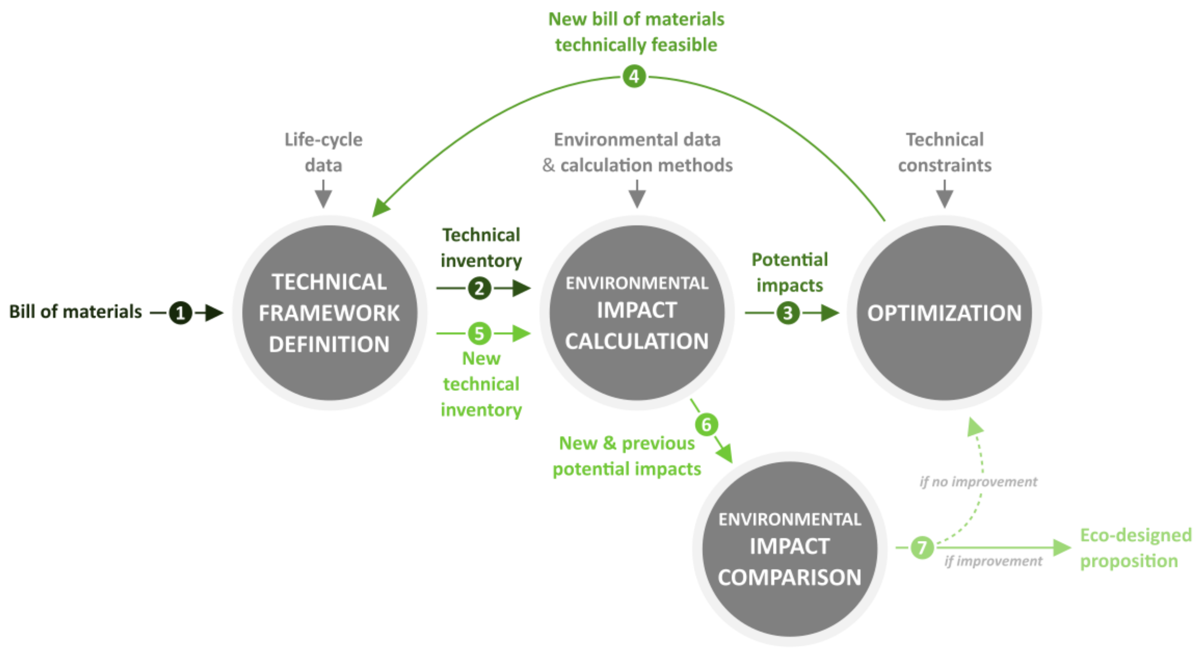

Figure 2. Eco-design process for a designer

This kind of approach compels the designer to keep and modify the product concept from the first technical framework he defined previously. He is not able to propose other concepts, because he is not expert in environmental issues: through this eco-design process, the designer tries to reach environmental goals depending on technical constraints in order to make sure of the technical feasibility of the proposition.

3.3 Eco-design approach of environmental experts

If an eco-designed proposition is feasible on technical aspects but also on economic aspects (costs, benefits, etc) and organisational aspects (availability of technologies, integration in the company, etc), it would be considered as valid from the company point of view (Knight and Jenkins, 2009). However, the classic designer and expert tools do not allow to integrate all these elements of feasibility.
Although environmental experts are usually not able to access the necessary knowledge to model feasible proposition on a technical point of view, they use Life-Cycle Analysis tools in order to propose "eco-improved" concepts directly. Among the main LCA software tools used in that re-design process, we can name SimaPro, GaBi, Umberto and openLCA. All these tools are connected to environmental databases and calculation methods, as the designer tools, to evaluate the potential impacts of the product. However, contrary to the designer tools we presented previously, LCA tools usually include many environmental indicators and allow to connect several databases and calculation methods: that leads to more precise results and an ability to make environmental parameters vary (instead of varying some technical parameters).
The process can be separated in four steps (Figure 3), as follows:

- 1: A technical framework definition: the environmental expert should provide a bill of materials and life-cycle data (transports, use, end-of-life, etc.). This step gives a technical inventory of the product life.
- 2: An impact calculation: this step gives the potential impacts of the product.
- 3: A concept generation: based on the results, the environmental expert is able to propose alternative concepts of the products, varying environmental parameters. At this stage, he is sure to generate "eco-improved" solutions but cannot guarantee its technical feasibility.
- 4: A feasibility study: this last step is decisive to deliver a real eco-designed solution.

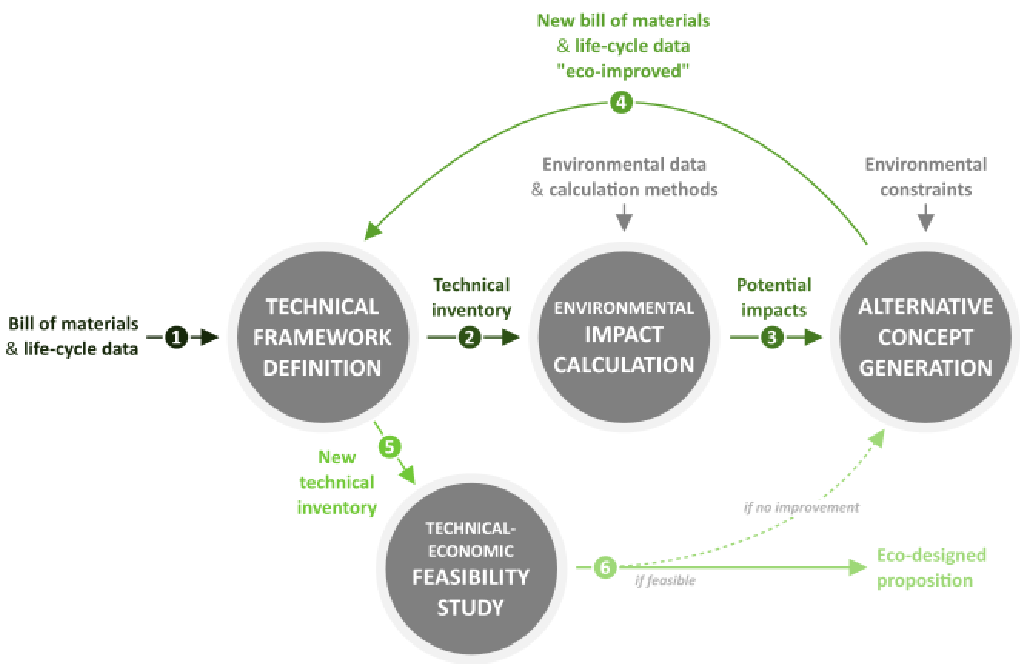

Figure 3. Eco-design process for an environmental expert

The fourth and last step of this process is particular: contrary to the re-design process described in Section 3.2, there is actually no tool integrating all these steps. The technical-economic feasibility study is made with the designer. Indeed, the environmental expert always integrates the designer knowledge to make sure of the feasibility of his solutions (Kozemjakin da Silva, 2015).

In the first approach, the technical constrains guide the possible changes on the product. However, these constrains differ depending on the targeted designer who could be the software user. According to his position in the company (and on the size of the company), his skills can be more appropriated to logistic, industrial systems, ergonomics or other. For this reason, the environmental expert seems to be the most appropriate person in the company to imagine eco-improved solutions. Nevertheless, all the technical skills we described before have to be integrated in a feasibility study phase: that involves to collect this knowledge and to access the data for the environmental expert.

4 LINKING DESIGN TO ENVIRONMENTAL PARAMETERS

As first steps of this study, design indicators can be identified from analysing experience feedback. Therefore, expertise documents gathered in a young company, containing design data about materials and processes, are analysed. We show in this section how the features defining these materials and processes have been identified.

4.1 Expertise documents

Altermaker is a young start-up specialized in software development to support design for sustainability. The company led analysis on industrial materials and processes used in mechanical engineering with its partners. The results are stocked as MsPowerpoint documents in which several elements are defined for each material or process: advantages, disadvantages, short description and specific comparisons. This database contains hundreds of slides on which it is impossible to automate queries. In total, 80 families of materials and 157 types of processes used for mechanical engineering are detailed. In these documents (Figure 4), several features are interesting to consider and other ones need more analysis. Our study aims at analysing these documents in order to define the concepts that show the main features of given materials and processes.

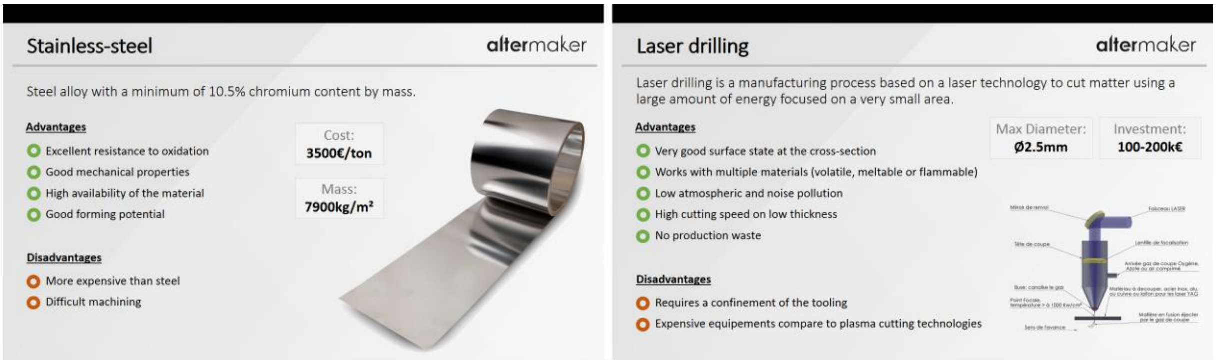

Figure 4. Example of Altermaker documents (material card and process card)

It is important to highlight that these documents were completed by several experts. This approach inevitably created some “knowledges holes” in the documents. For example, depending on who created the slide, the conductivity characteristic might appear or not if the experts judged it was important or not to provide that information to the designer. Based on this observation, we also need to identify these “holes” in the study in order to ensure an acceptable completeness rate to the user.

4.2 Analysing approach

Knowledge engineering techniques (Studer and al, 1998) are used to analyse Altermaker documents. In this type of approach, expertise documents can be analysed in order to identify the role that elements can play in problem solving related to a specific domain, what is called concepts. Several techniques

can be used in documents analysis, we note especially TextMining (Feldman and al, 2007) that is based on repetition of words and on relations between words. In this study, each slide presents a specific material or process. Therefore, using automatic TextMining tools cannot be the easiest way in our case because we cannot automate it: documents should be analysed manually.
Two months were needed to analyse the entire MsPowerpoint database and exhaustively identify all the reported characteristics. That led us to identify 20 to 130 characteristics per family of material or type of process. At this stage, we do not know yet which characteristics are relevant in terms of feasibility study.

Table 1. Example of identified characteristics for Tube assembling

Caractéristiques	Slides concernées	Occurrences	Pourcentage
Absence de pli	309	1	1%
Adapté à la réalisation des empreintes des moules par injection plastique	239	1	1%
Adapté au prototypage fonctionnel	278	1	1%
Adapté aux matériaux réfléchissants	229	1	1%
Ajustage et serrage au plus près des pièces assemblées	260	1	1%
Amélioration résistance	!68, 269, 270, 294, 301	8	10%
Applications	!65, 271, 272, 295, 296	6	8%
Approvisionnement matière première	276, 310	2	3%
Après polymérisation, opération nécessaire	282	1	1%
Aucun usinage de la matrice ; Aucun stock des outillages (matrice)	250	1	1%
Aucune rétrécissement ou déformation	240	1	1%
Automatisable	!52, 253, 261, 295, 299	5	6%
Bi composant	283	1	1%
Caractéristiques mécaniques du résultat du procédé (en sortie)	!95, 299, 306, 308, 309	23	29%
Collerette réalisée avec la rouleuse	309	1	1%
Compacité des matériaux (en sortie)	248, 285	2	3%
Contenance	301	1	1%
Déformation après usinage	231, 232	2	3%
Déformation/Affection thermique	229, 230	2	3%
Dégraissage du tube	305	1	1%
Densité du produit fini	!67, 270, 274, 275, 277	6	8%
Dépendance au refroidissement et au fluide lubrifiant	308, 309	2	3%
Dimension des pièces (en entrée/sortie)	!84, 287, 297, 300, 308	18	23%
Economie d'usinage	245	1	1%
Economies / Pertes matières	!44, 245, 257, 258, 310	11	14%
Encombrement	310	1	1%

In total, the 80 slides were analysed for materials and the 157 for processes. Processes documents are already classified on manufacturing, assembling and cutting. But there is no classification of materials slides. Analysing steps, the procedure can be summarised as:

1. Characteristics are identified from description, advantages and disadvantages (Table 1).
2. The number of occurrences of characteristics are counted.
3. Results are then presented to two mechanical eco-design experts of Altermaker in order to eliminate noise, conflicts and to validate the relevance of each characteristic.
4. Characteristic categories are detailed and split in sub-groups.
5. Groups are then validated by the eco-design experts.
6. Finally, analysing of omissions in order to possibly complete classifications (Table 2).

Table 2. Results of process documents analysing

Process Types	Nb slides	Nb characteristics					
		Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
		Ident. characs	**statisitics**	**Validation 1**	**Splitting**	**Validation 2**	**Missing**
Manufacturing	68	113	113	28	33	32	25
Assembling Tubes	6	45	45	20	23	21	20
Assembling Tubes	47	115	115	52	55	51	39
Heatting	7	23	23	19	20	19	17
Micro-drilling	5	22	22	15	15	15	14
Micro-manufacturing	6	20	20	15	16	14	14
drilling	12	26	26	17	19	19	16
Contacted joins	6	22	22	18	18	18	17
	157						

4.3 Characteristics classifications and database structuring

Repetition of characteristics is then used in order to classify them. On one hand, our classification aims at emphasizing the impact of process and materials on the environment and, on another hand, at helping designers to deal with process and materials in eco-design. For instance, the main process characteristics are identified as: cost, consummation, pollution, technicity, etc. (Figure 5). Depending on its type, 14 to 39 characteristics per process were retained, because of their high repetition rate.

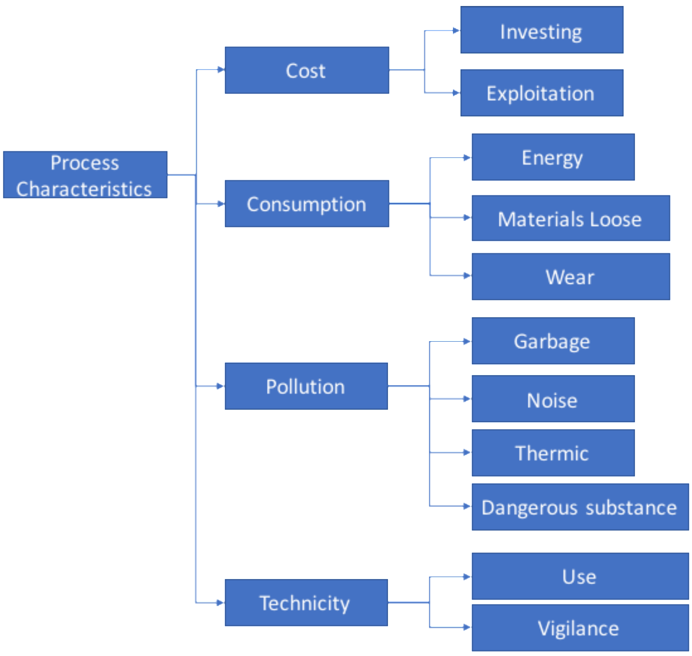

Figure 5. Extract of process characteristics

For materials, 24 characteristics per family were retained. For example: resistance, compacity, disassembling, modification, etc. (Figure 6).

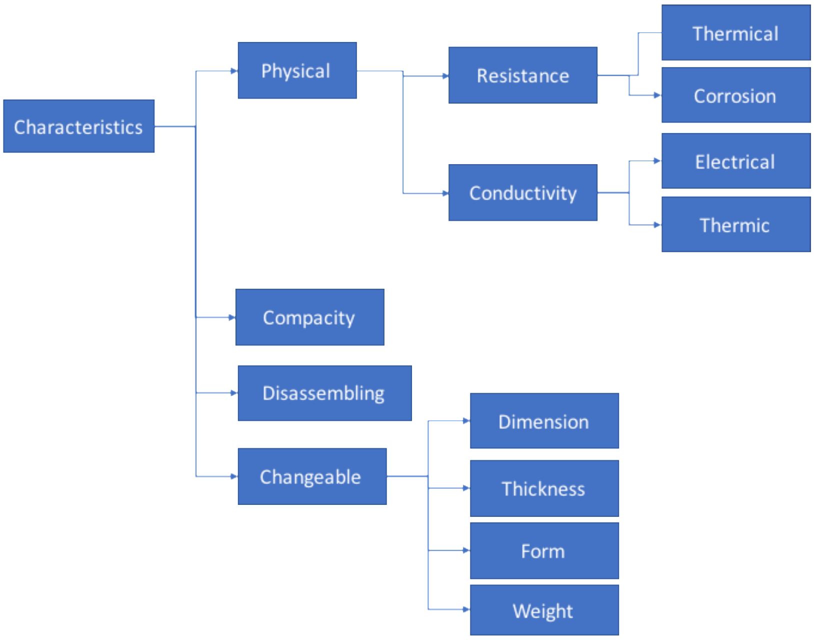

Figure 6. Extract of material characteristics

These identified characteristics and classifications allowed us to build a database of processes and materials with technical, organisational and economic data.
The environmental data from the FD E01-008 booklet was parsed and integrated in a unique database with the information from the collection of documents belonging to Altermaker. Environmental and design parameters are now linked and ready to be implemented in a software to support decision making of environmental experts.

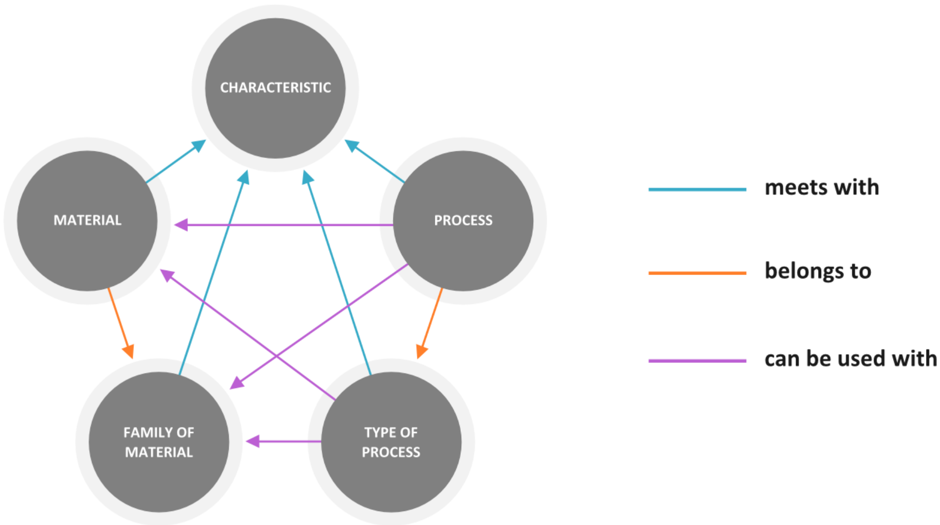

Figure 7. Relational data model resulting from the analysis

This final database, built with the ArangoDB technology, is constituted of five classes: the materials, the families of materials, the processes, the types of processes and the characteristics including environmental data and feasibility criteria. A query on this model can return design solutions that respects some feasibility constraints and that are conform to environmental objectives.
For example, in a re-design context, if the company wants to improve its environmental performance in terms of acidification, climate change and eutrophication, it is possible to send a multiple query to this database, integrating certain feasibility constraints such as a maximum investment cost and a product watertightness criterion. Some materials may match the query and help the designer in the re-design

process, but it can also return other wider solutions through the model's relational approach: a waterproofing process may belong to the type of process of "surface treatments" which can itself be used by a certain family of cardboard and thus constitutes an eco-enhanced feasible re-design solution.

5 CONCLUSION

Considering environmental parameters becomes a necessity in design. Industries use more and more eco-design system to answer this need. These environments can be classified in two categories: 1-for environmental experts and 2- for designers. Parameters are used in these two types of tools which help to identify the impact of a design on the environment and the feasibility of this design. In this work, we aim at characterising the link between these two aspects in order to help environmental experts to improve the feasibility of their eco-designed solutions. So, processes and materials characteristics are identified using knowledge engineering techniques, from a collection of documents built by a company specialized in eco-design software. In this paper, we show different steps to analyse this type of documents. The identified characteristics have been integrated into a relational database that allows to automate re-design choices based on environmental performance criteria coupled with feasibility constraints. This database will be then integrated in an eco-design tool (developed by Altermaker) in order to test their use by environmental experts and to enhance the whole cycle of eco-design: from study of the environment impact to feasibility improvement of a solution. This tool can be used by eco-design students in our university in order to obtain beta test of our proposition. Other documents will be studied in order to obtain complete representation of characteristics and tend for ontology of eco-design characteristics considering as well as environment and design parameters.

REFERENCES

Depret, M. H., Hamdouch, A. (2009), Quelles politiques de l'innovation et de l'environnement pour quelle dynamique d'innovation environnementale?. *Innovations*, (1), 127-147.

Dewulf, W. (2003), Design for sustainability-anticipating the challenge. In *DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm*.

FD E01-008 (2014), Mechanical products – Environmental data.

Feldman, R., Sanger, J. (2007), The text mining handbook: advanced approaches in analyzing unstructured data. Cambridge University Press.

ISO, I. (2006), 14040: Environmental management–life cycle assessment–principles and framework. *London: British Standards Institution*.

Knight, P., Jenkins, J. O. (2009), Adopting and applying eco-design techniques: a practitioners perspective. Journal of cleaner production, 17(5), 549-558.

Kozemjakin da Silva M., Remy S., Reyes T. (2015), On providing design process information to the environmental expert. Research in Engineering Design 26:327–336.

Michelin, F., Vallet, F., Reyes, T., Eynard, B., Duong, V. L. (2014), Integration of environmental criteria in the co-design process: case study of the client/supplier relationship in the French mechanical industry. In *Proceedings of the DESIGN 2014 13th international design conference. Dubrovnik* (pp. 1591-1600).

Papanek, V. (1971), Design for the real world: Human ecology and social change.

Pimenta, H. D., Gouvinhas, R. P., Evans, S. (2012), Eco-efficiency within extended supply chain as product life cycle management. In *Sustainable manufacturing* (pp. 255-262). Springer Berlin Heidelberg.

Rio, M., Reyes, T., Roucoules, L. (2013), Toward proactive (eco) design process: modeling information transformations among designers activities. Journal of Cleaner Production, 39, 105-116.

Rossi, M., Charon, S., Wing, G., Ewell, J. (2006), Design for the next generation: incorporating cradle-to-cradle design into Herman Miller products. *Journal of Industrial Ecology*, *10*(4), 193-210.

Studer, R., Benjamins, V. R., Fensel, D. (1998), Knowledge engineering: principles and methods. Data & knowledge engineering, 25(1), 161-197.