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ECO-DESIGN GUIDELINES AND ECO-KNOWLEDGE INTEGRATION IN PRODUCT DEVELOPMENT PROCESS

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ABSTRACT

The product eco-sustainability is recognized as a key factor for competitive products and recently lots of international directives (guidelines) have been issued. This paper aims to define a new methodology integrated in the product development process that, through the application of the most common eco-design guidelines and design past experiences, supports designers in the development of eco-sustainable products. Eco-design guidelines retrieved from the literature are subdivided according to a well-organized structure in “high level of abstraction” and “high level of detail” ones. In addition,
Eco-knowledge is defined as all the choices and their related environmental performances, designers made during the design process of a product.
The implementation of the proposed methodology in the product development process of an Italian cooker hood producer, allows to analyze the benefits achievable in terms of product eco-sustainability improvement. This analysis highlights that the proposed approach supports the implementation of eco-design principles, also in those companies without a specific background in eco-design.

Keywords: eco design, decision making, sustainability, eco-design guidelines, CBR

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1 INTRODUCTION

The concept of sustainability, defined for the first time twenty – five years ago (United Nations, 1987), has become important, due to the increasing environmental awareness in several sectors. The vertiginous growth of the world population and the increase in the amount of discarded goods are the main causes of the environmental problem. The only possible solution to promote the environmental consciousness with the aim to design and manufacture "green" sustainable products is the application of eco-design approaches. But usually, companies tend to follow the classical criteria of the design process, that are in accordance with requirements like costs, technical specifications, production time, thus neglecting the key concepts related to product environmental effects. In those companies considering the environmental issues, sometimes, the eco-design is recognized as an activity to carry out after the product design phase, so, it is not well integrated into the product design process.

Even if recently, International organizations have issued a high number of regulations, standards and technical reports regarding environmentally conscious design (International Organization for Standardization, 2002, 2011; European Parliament, 2009), their practice implementation is still not so much applied. All these documents only give to companies some general indications and guidelines about the aspects which are necessary to take into account, without providing a strategy to easily integrate an eco-design approach in the traditional product design and development process. The result is the unavoidable lack of application of the eco-design approaches in a great number of manufacturing companies.

The present paper aims to define a methodology to integrate the eco-design strategies in the product development process, in order to allow designers to consider and apply the indications given by the well-known eco-design guidelines in a rapid and efficient way. Even if these guidelines are commonly used by designers to implement an eco-design strategy, their effectiveness is quite low, especially for those designers without a specific eco-design background. The general indications provided by the guidelines do not represent a concrete support for the designers. In the proposed approach, the general eco-guidelines available in literature are combined with the design choices made by the designer after the implementation of a guideline (eco-design knowledge). Through the use of a Case Based Reasoning approach, the designers are guided in choosing the most proper solutions, considering the environmental aspects. All these eco-design indications are integrated in the several stages of the product development process, according to their typology and characteristic to permit their coherent and effective consultation from designers. In particular after a critic revision of the state of the art regarding the topic of eco-design and its strategies, the methodology is presented. Eco-design guidelines and eco-knowledge which constitutes the "Eco-design suggestions", guide and support designers in all the phases of the product development process. The most important benefits provided by the proposed method are demonstrated by a test case concerning the re-design process of a cooker hood. The implementation of such an approach in a software tool is a future work which will be presented in a further paper.

2 STATE OF THE ART

Literature analysis shows that indications provided by eco-design guidelines are related to different phases of product lifecycle and to different stages of the product development process (Bonvoisin et al., 2010). Since the general guidelines are valid for a wide number of products, they really do not provide tangible support for designers, who have to take decisions on specific and particular products. For this reason recent works have had the aim to contextualize the general eco-design guidelines to specific design phases, e.g. material choice phase (Pierini and Schiavone, 2006), or to specific products, such as rail vehicles (Lagerstedt and Luttropp, 2006), in order to facilitate their implementation during the product development process. The necessity to define specific guidelines and checklists for product typology is also highlighted in Vezzoli and Sciama (2006). Even if several researches has been done to contextualize the general guidelines, transforming them into more specific ones, the further challenge consists in their practical and effective implementation during the Product Development Process. The first field where this problem has been recognized (Wallace and Shorten, 2005) is the medicine. In this context, Spallek et al. (2010) highlight the most common barriers in the guideline implementation for the medical sector (i.e. changing current practice models, lack of trust in evidence or research).

In the industrial sector, instead, literature proposes different methods to foster the guideline implementation. Regazzoni et al. (2009) present a structured set of eco-guidelines based on TRIZ theory, with the aim to support designers in improving a product, a process or a service, according to eco-parameters. Each eco-TRIZ guideline has been structured as a set of questions followed by a set of operative rules. Even if this method is a step beyond the traditional methods for the eco-design guideline implementation, it does not consider the knowledge the designer acquires during the development of new products. The past experience is useful for designers to estimate how product eco-sustainability changes after the implementation of the suggestions proposed by the guidelines. In Yang and Chen (2004) the CBR (Case-Based Reasoning) and TRIZ methods have been linked defining a new model to acquire innovative ideas more easily to design eco products. A CBR system connects the innovative idea to the cases located in a database to accelerate the product innovation process. Even though the proposed method provides tangible benefits for the development of innovative products, it does not provide strong support for the eco-design guidelines. CBR is historically a very useful method for knowledge management. Its application ranges among different fields, such as the workflow exception management (Weber et al., 2004; Mengoni et al., 2010) and manufacturing cost estimation (Duverlie and Castelain, 1999).

In the field of knowledge management, the knowledge elicitation and modeling phases are crucial during the definition of a method or a tool. Houe and Grabot (2007) propose a tool to verify the compliance of a product with a set of norms and standards. They also present how the knowledge contained in standards and norms in textual forms can be translated into constraints which can then be propagated through the product structure to identify the inconsistencies between the present design solution and a given norm.

According to the proposed literature review, there is a lack of methods and tools to manage and apply eco-design guidelines (the envisaged guidelines are a collection of those ones available in literature) and knowledge to support the product design/re-design process. In particular, it is necessary to underline that the possibility for designers to consult indications, coming from guidelines and knowledge, during the design process allows them to apply general suggestions, taking into account the specific characteristics of the product under analysis; the connection between eco-design guidelines and information related to past choices supports therefore the correct application of eco-design principles and the consequent product improvement in terms of sustainability. The present paper aims to develop a methodology based on this integration approach, in which designers are guided in the development of eco-friendly products.

3 METHODOLOGY

The methodology proposed in this paper consists in the collection and organization of a set of existing Eco-design guidelines and company eco-knowledge that converge in a list of "Eco-design suggestions". These suggestions are organized in a structure that results the most suitable for designers, by their classification in different categories. Their consultation during all the phases of the design process permits to designers to improve the environmental behaviour of the product under analysis.

3.1 Eco-design guidelines

The analysis of literature related to eco-design guidelines shows that a high number of eco-design guidelines exist and that they often provide only general indications to designers. This generality makes, from one side, eco-design guidelines referable to a lot of different design process stages, but on the other, it does not guarantee their efficacious consultation by designers, and above their effective translation into design choices. (Bonvoisin, F. et al., 2010).

For these reasons, in order to facilitate the guidelines consultation, to make them useful for designers, eco-design guidelines retrieved from the literature (ECODESIGN PILOT, 2013; Georgia Institute of Technology, 2013) are subdivided in two main categories according to their level of abstraction: "*high level of abstraction*" and "*high level of detail*" guidelines. In order to guarantee the generality of eco-design guidelines and their application to different products of the same family, *standard components* have been defined. They are all the components that can be considered as representative for a specific product family, as they can be found in different modules of the same product family; an illustrative example is the cover of a cooker hood: every cooker hood has this component, and therefore it can be defined as *standard*, but each hood model has a different typology of cover (with or without visible welding, with or without aesthetic glass, with or without touch control, etc…).

Table 1. Examples of "high level of abstraction" guidelines related to product families

Product family	Examples of high level guidelines
Household appliances	Reduce the environmental impact of the use phase, which is the most important in terms of environmental impact
Household appliances	Consider the complexity of disassembly strategies and its influence on the environmental impact of the End of Life stage
Electronic devices	Consider the presence of WEEE in the EoL phase
Electronic devices	Value the presence of precious materials

Table 2. Examples of "high level of abstraction" guidelines related to product components

Component	Examples of high level guidelines
All component	Material selection influence significantly the separation time
Plastic components	Consider the material compatibility and its influence on the "path" toward recycling
Iron or steel components	Avoid the contamination with copper, tin, zinc, lead or aluminum because reduces the recyclability
Iron or steel components	Production processes for these materials have more environmental impact than those for plastic materials

The "high level of abstraction" guidelines are characterized by a significant degree of abstraction and are referred to a large number of product families; they contain sort of alarms useful to underline general criticalities associable to products in terms of environmental sustainability. These guidelines can be further subdivided in two subsections, depending if they are referred to a defined product family or to components. Illustrative examples are shown in Table 1 and Table 2.
The "high level of detail" eco-design guideline typology is subdivided in:

- Product-oriented general eco-design guidelines: they are all those indications which can be associated to different product families, and that provide general recommendations valid for different products;
- Component-oriented general eco-design guidelines: they are all those indications referable to almost all components of different product families and provide suggestions about specific components (e.g. cover, support, motor, damper, etc…) of a particular product family (e.g. cooker hoods, washing machines, refrigerators, etc…). Designers can use these advices to understand how to improve components in terms of environmental sustainability. They are related to standard components and referred to different life cycle phases of the product, from material selection to End of Life (EoL) phase;
- Component-oriented specific eco-design guidelines: they mainly derive from EuP directives (European Commission 2009, 2010a, 2010b) and they are associated to the standard components (e.g. electric motor, water pump, motor impeller, lamp, etc…) of the specific product family under analysis (e.g. cooker hoods, washing machines, refrigerators, etc…). These specific guidelines refer principally to the use phase and aim to minimize the energy consumption of the energy using components and as a consequence of the whole product.

All these eco-design guidelines are related to several attributes, e.g. life cycle phase to which they are associated, objective they allow to reach and standard components to which they concern. This classification allows to link guidelines to company eco-knowledge, as showed in the successive sections.

3.2 Eco-knowledge

The eco-knowledge is represented by all the choices made by the designers during the design process of a product. These choices are related to the product/process data, such as material, dimensions, chemical and physical properties, manufacturing processes, transportations, end of life strategies, etc., and can be referred to a specific product/standard component. By the use of LCA software tool, designers evaluate the environmental impact of the product they are designing and as a consequence the environmental performances of specific design choices. This information can be stored in the knowledge database and retrieved by designers during future design activities.

In order to facilitate designers in the consultation of the product knowledge and past experiences, also in this case, it is necessary that choices are stored and ordered according to specific attributes, e.g. *life cycle phase*, *objective* and *component* which are referred to; in this way they can consult only necessary and appropriate information. Data that represent the eco-knowledge for a specific component/product are for instance the material used in a specific component, the production processes, component dimensions, weight and geometry; the environmental data are represented by the environmental impacts. In the case of a cooker hood cover design, some related choices can be "stainless steel" for the material, "laser cutting", "bending" and "resistance welding" for the production processes, and "carbon footprint" value for the environmental impact.

If designers have the possibility to know the correlation between design choices and their environmental impact, they can rapidly understand the consequences of specific choices on sustainability and how to modify a component or a product to reach clear objectives. In order to guarantee uniformity with the guidelines classification, also the knowledge is connected to product structure through standard components; all the past choices are in fact made on specific components that it is possible to link to standard ones. One of the most appropriate approaches to retrieve and re-use eco-knowledge information is based on CBR, which allows to rapidly and efficiently retrieve past information. Designers, during the design or redesign process, define first of all a specific environmental objective they want to reach, they retrieve information (past design choices with the related environmental impacts) analyzing the data stored into a knowledge database, they choose the solution which best satisfies the objective, and finally, they verify the effectiveness of the implemented choice. These four steps, which represent the classical structure of the CBR methodology, permit to apply solutions that in the past and in similar context, have been implemented by someone inside the company, and as consequences allow solving in a rapid and efficient way, design issues, knowing in advance the related environmental consequences.

3.3 Eco-design guideline and eco-knowledge connection

The proposed methodology has the aim to provide a valid support for the design of products with high level of environmental sustainability. This objective is reached if the suggestions contained within the eco-design guidelines and the eco-knowledge are connected each other and the designer is guided in their application. The CBR approach is therefore used both in the consultation of eco-design guidelines and knowledge; these suggestions are linked together thanks to their correlation to the same specific attributes: standard components, objectives and product life cycle phases. By the identification of a specific objective, life cycle phase or standard component, a set of recommendations (guidelines and past experiences) linked to them, are presented to the designers. These recommendations contain suggestions related to possible solutions to improve the analyzed product, through general indications coming from the eco-design guidelines and specific ones coming from the eco-knowledge. Figure 1 explains this connection.

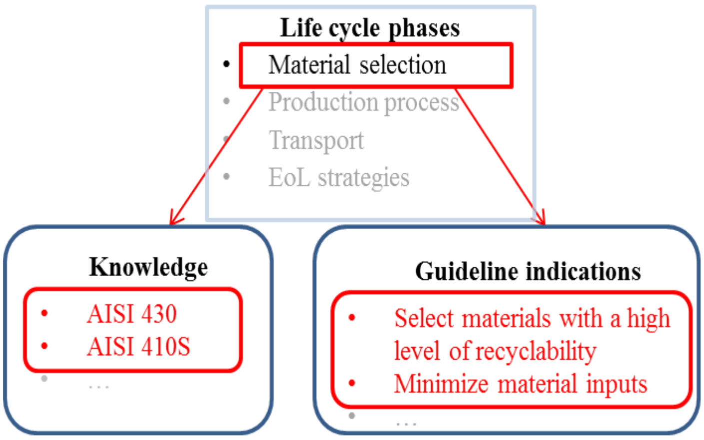

Figure 1. Eco-design guidelines and knowledge connection

4 METHODOLOGY CONTEXTUALIZATION TO PRODUCT DEVELOPMENT PROCESS

The methodology proposed in this paper aims at showing the benefits that it is possible to achieve by the integration of the eco-design suggestions in all the phases of the product development process. In this innovative design approach, in fact, traditional and eco-design strategies are integrated to satisfy the fixed requirements and to reduce environmental impact of the product.

The benefits can be summarized in the correct and effective application of eco-design principles that allow designing eco-sustainable products. The lack of eco-design principles application during product design process it is well known and it is also recognized that if eco-design methods are applied, this happens in the embodiment design phase, when a high number of variables are no more modifiable. In this case therefore, not significant product modifications are possible and as a consequence not substantial improvements in terms of sustainability can be obtained for the product under analysis.

In the following sub-paragraphs, after a brief description of the activities related to each phase of the traditional product development process, the integration of the proposed methodology in these different stages and the relative achievable benefits, are shown.

4.1 Traditional product development process

According to Pahl et al. (2007), planning and design process can be subdivided into the following main phases:

Planning and task clarification. In this phase the collection of information about requirements that have to be fulfilled by the product is realized; also product constraints and their importance are defined.

Conceptual design. After the definition of product tasks, this design phase determines the principle solution by abstracting the essential problems, establishing function structures, searching for suitable working principles and then combining those principles into a working structure.

Embodiment design. In this phase, from a concept (working structure, principle solution), the construction structure of a technical system is determined. The derived solution meets the technical and economic product requirements, defined in the previous phases.

Detail design. This is the design process phase in which the arrangement, forms, dimensions and surface properties of each product component are defined, the materials specified, production possibilities assessed, costs estimated, and all the drawings and other production documents produced.

This schematic structure is followed whenever it is necessary to design a new product or to re-design a particular one with the aim to improve some specific characteristics. All these phases have a precise meaning and a specific role in the success of the process.

4.2 Eco-product development process

In order to obtain an efficient application of the eco-design practices it is necessary that methods and tools based on the proposed methodology are correctly integrated in the traditional steps of the design process. In particular it is possible to underline how this integration can occur in the different phases and what consequent benefits can derive.

4.2.1 Phase 1: Planning and task clarification

In the first step of product development process, planning and task clarification, the requirements list is obtained by considering specific needs for the product under analysis (performance and environmental considerations have to be considered). The result of these first activities is the composition of a list in which all product characteristics are contained. In this first phase, the consultation of "Eco-design suggestions" became an important additional element; in fact the consideration of specific constraints related to environmental performances of the new or redesigned product offers to designers the possibility to reflect on specific product environmental characteristics, related to specific life cycle phases. The environmental requirements together with traditional ones are in this way considered yet in this first design process stage, thus permitting to examine them in deep in the following ones. In particular, according to the guidelines classification explicated in the section 3.1, the design team in this stage can consult the "high level of abstraction" guidelines. They are useful to define possible solution strategies for the criticalities associated to the analyzed product. The definition of the product environmental requirements yet during the product preliminary analysis, it will allow the designers to consider the environmental aspects that could become more critical and more difficult to solve in the advanced phases of the product development processes. Also the most critical product hotspots in terms of environmental impact could be identified and as a consequence taken into account by designer. All these general suggestions coming both from mandatory regulations, legislations and standards, and supplementary recommendations, contained in the "high level of abstraction" guidelines, associated to the specific product analyzed. Designers can in this way, hypothesize product environmental performances, more advanced than the obligatory ones.

4.2.2 Phase 2: Conceptual design

In the second phase, designers study the general and essential solutions to reach the tasks defined in the previous phase, by examining original and more suitable strategies and ignoring particular or secondary requirements. The objective of this phase is to focus the attention on the *crux of the task* (Pahl et al., 2007). It is possible to underline that if the main objective of the design/re-design process is to realize a product with a lower environmental impact, designers necessarily are forced to consider eco-design strategies. But because often, design or re-design drivers are different (e.g. improve technical functions, reduce weight, reduce cost, etc.) the "Eco-design suggestions" consultation become useful for the implementation of environmental strategies, that otherwise could be neglected. As it is possible to correlate "high level of detail" eco-design guidelines to specific objectives to reach, designers can obtain the fixed target, not only by the implementation of traditional strategies, but also by the application of recommendations coming from the "Eco-design suggestions". In this way, even if the improvement of product environmental performances is not one of the explicit goals, it will be considered in the design process. An example of "high level of detail" guidelines related to specific objectives that designers have to consider in this phase is shown in Table 3.

Table 3. Examples of "high level of detail" related to a specific objective

Objective	Examples of low level guidelines	Environmental improvements
To minimize weight or space	Prefer high quality materials	Reduction of material phase impact
To significantly shorten delivery times	Prefer standardization of material and dimension	Improvement of benefits retrieved form the EoL phase
Improve the technical functions	Increase product lifetime	Reduction of use phase impact

4.2.3 Phase 3: Embodiment design

The embodiment design phase is characterized by the definition of the overall layout design, the identification of the form design and the choose of production processes, by considering all the technological and economic requirements. In this case, several steps are performed, also in an iterative process to find the solution that fulfills technical, economic and safety requirements. All the choices made in this phase, will determine a significant effects on the global environmental impact of the future product, and therefore the integration in this phase of the proposed eco-design methodology become essential. The "Eco-design suggestions" support designers by providing them suggestions retrieved from past choices and from guidelines. In particular company past choices related to similar products, and retrieved according to the CBR methodology, allow designers to understand what a particular decision can produce on the product environmental behavior and how it is possible to improve its environmental performances by analyzing different alternatives. Also "high level of detail" eco-design guidelines can represent a support for the individuation of the best design for a particular product, by providing eco-friendly recommendations. In this step, the indications provided to designers are more specific than in the previous one, since the development of the product under analysis requires a higher level of concreteness. Component-oriented eco-design guidelines and specific indications coming from past choices, offer accurate recommendations useful for the definition of the best product configuration. By the knowledge of solutions that in the past have been made, and by the consultation of specific guidelines, designers are guided in the implementation of eco-design principles. In this way, the product will respect not only the technical and economical requirements, but also the environmental ones. In this phase, a simplified LCA (S-LCA) analysis of the product should be carried out in order to understand the environmental consequences of specific choices and quantify the possibility to further improve product environmental performances. The integration of "Eco-design suggestions" and the use of Life cycle assessment tools, according to the characteristics of this phase, have an iterative path which aims to improve, through successive steps, the product environmental performances. Figure 2 explains the concepts expressed above.

4.2.4 Phase 4: Detail design

The definition of the final product/component layout, supported by all the definitive elaboration of production documents, including detailed component drawings, is the main activities of the detail design phase. Also in this product development stage, "Eco-design suggestions" can be used by designers to optimize the product/component and to implement the final improvements. In particular the guidance coming from the eco-knowledge, related to specific products and components, will result useful to optimize the product functionalities, in environmental, economic and functional terms, to obtain the best product behavior and its total correspondence to the fixed requirements. Given that in this phase all the product characteristics, from materials to production processes are well defined and fixed, the use of S-LCA methods would be advantageous. This kind of analysis permits to value if the realized choices have successfully influenced the environmental behavior of the product analyzed and to exactly quantify the benefits achieved. Moreover the product/component environmental impact will constitute an additional element of company knowledge to use in next design processes. Figure 2 shows the integration of "Eco-design suggestions" in the Detail design phase.

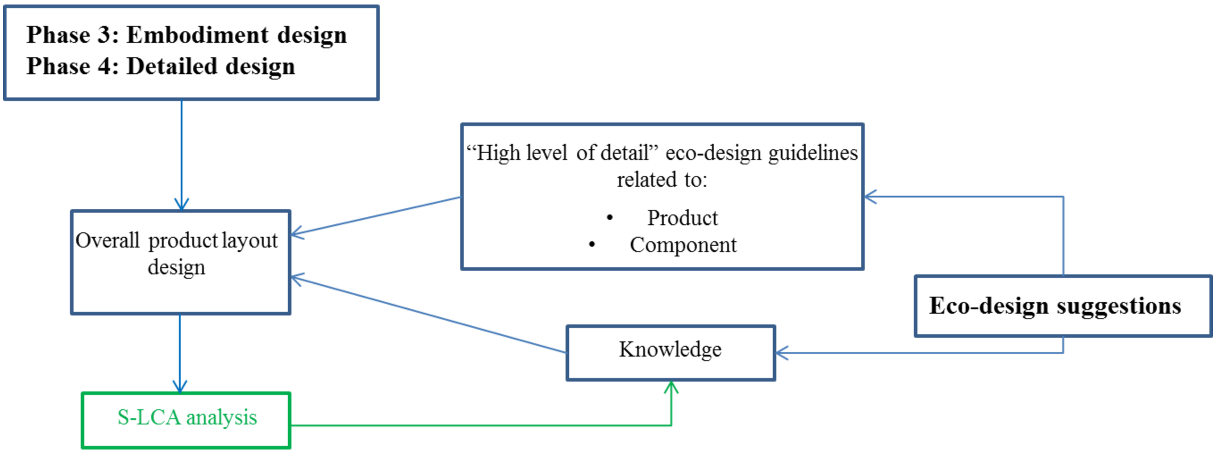

Figure 2. Integration of Eco-design suggestions in the Embodiment and Detail design phases

It is possible to underline that passing from the first to the final phase of the product development process, there is a growing relevance assumed by suggestions coming from the knowledge. As the process become more concrete, the indications that designers need, have to be more specific and directly associable to a specific product, component or to a precise objective.

4.3 Methodology implementation: test case example

In order to clarify the usefulness of the knowledge indications, the method has been used during the re-design process of a cooker hood, required to improve its environmental sustainability. The analysed cooker hood is a basic model product, made by an Italian company, with these principal characteristics: Maximum air flow: 660 m^3/h, Maximum power consumption: 230W, Lighting devices: 2 x 20 W halogen lamps. The S-LCA Analysis results have been useful to understand where the major environmental impacts are located and as a consequence the environmental criticalities for the analysed cooker hood. In this case, the results allow individuating the lifecycle phases and components where it is necessary to focus the attention:

<u>Use Phase</u>: Electric motor (Single-phase AC asynchronous motor) and halogen lamps. These are the energy using components, responsible of energy consumptions in the hood;

<u>Material Phase</u>: Chimney, cover, aesthetic panel, which are the components representing the heaviest components of the product.

The company knowledge suggests that the use of brushless motor and led lamps typology, that company installs on higher class model of hoods, determines a smaller environmental impact if compared with the impact of Single-phase AC asynchronous motor and halogen lamps. Concerning components with a high environmental impact on the material phase, looking at the company knowledge on past design choices for chimney, cover, and aesthetic panel, is possible to select different materials with similar properties such as Wrought Annealed AISI 410S which reduce the environmental impact of these components. The consultation of the company knowledge and the reapplication of past design choices to the new product allow to improve the environmental performances, satisfying the objective of the Eco-design guidelines, such as “minimize the energy consumption of the product” for the use phase and “prefer high quality materials” for the material selection phase.

5 CONCLUSION

This paper aims to propose a new methodology for the implementation of an eco-design strategy during the design process; the integration of the most common eco-design guidelines and design past experiences in the product development process has been identified as a well-organized strategy to develop sustainable products. In particular, the main focus of this work consists in presenting how to concretely integrate an eco-design approach in all the four steps of the traditional design process, from the planning and task clarification phase till to the detail design phase. The proposed method is based on the CBR approach, which can guarantee a valid support for the knowledge management process. Following the proposed methodology a company is supported in the overcoming of the typical difficulties in the practical application of the eco-design guidelines. As a consequence, companies can easily improve the sustainability of their products, keeping the quality and the competitiveness on the market unchanged.

Future works will consist in the validation and optimization of this methodology. In particular, though the development of a software tool supporting the proposed methodology, it will be possible to really validate the methodology, thanks to the designer’s feedbacks. Furthermore, with the development of a tool, the visualization of eco-knowledge and eco-design guidelines will be automatic, and as a consequence rapid and easily to retrieve, allowing designers to overcome the difficulties in the application of eco-design principles during the design process.

The use of the tool in different case studies will permit to measure the benefits obtainable by the implementation of the “Eco-design suggestions” in the product development process and to consequently quantify the product improvements in terms of environmental impact.

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