AN ECO-KNOWLEDGE TOOL TO SUPPORT ECO-DESIGN IMPLEMENTATION INSIDE DESIGN DEPARTMENTS

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ABSTRACT

In last years, an increasing attention on environmental matters is registered. Companies face environmental matters to increase the environmental performances of their products, forced by numerous legislations, normative and protocols and induced to the growing attention of consumers toward environmentally friendly products. However, observing the industrial context, it emerges there are several barriers for implementation of eco-design strategies inside design departments. The paper presents a tool which aims at both providing a basic guide on environmental sustainability issues and favouring the knowledge sharing among the different actors of the product design process. The core of the tool is a repository in which company materials, organized and collected in different forms, are collected. The repository contains several parts: training, guidelines, knowledge and milestone, accordingly to the type, structure and form of materials stored. The eco-design tool functions, structure, and workflow are presented and then preliminary test cases are described.

Keywords: Ecodesign, Sustainability, Design engineering

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1 INTRODUCTION

In last years, an increasing attention on environmental matters is emerged. Public legislators directly set regulations and rules, and indirectly stimulated a growing consumers' awareness of sustainability and resource efficiency. In this context, in fact several EU legislations have been issued with different objectives: *(i)* the mitigation of energy consumption, *(ii)* the adoption of recyclable materials and, *(iii)* the reduction of critical materials. The household appliance sector is particularly affected by these requirements (EU, 2009b; EU, 2010), and companies that are playing in this field are forced to implement improving eco-design initiatives.
Two drivers represent the main inputs behind this research work: (i) eco-design legislation and related directives emanated by the European Union (EU), and (ii) several surveys realized on European industrial companies. From the surveys analysis, it emerged that environmental sustainability is recognized as an opportunity for company business even if several barriers for its implementation have been identified. Additionally, technical design departments highlighted some criticalities, such as "limited collaboration", "poor/difficult communication" and "inefficient organization and data sharing". In particular, designers, without the appropriate knowledge on eco-design themes, recognized the need of eco-design supporting tools, which can guide them towards more environmentally design choices in the development of products. At the same time, designers identified the need to support eco-knowledge sharing inside companies. Starting from these issues, the present paper proposes a methodology and a tool aiming to increase company's competences on environmental sustainability and to support the development of environmental sustainability products. After the analysis of the context and the literature investigation (Chapter 2), the authors define the research objectives (Chapter 3). The methodology and the tool implementation aims at both: (i) providing a basic guide on environmental sustainability issues, and (ii) favouring the knowledge sharing among the different actors of the product design process (Chapter 4). Finally, conclusions and future work investigate the benefits related with the introduction of the proposed approach in company's design departments (Chapter 5).

2 CONTEXT AND LITERATURE INVESTIGATION

2.1 Environmental sustainability and implementation in companies

Nowadays, an increasing number of European companies face environmental matters to increase the environmental performances of their products. A reason behind this aspect is the growing consumers' awareness about environmental-friendly products (Gadenne *et al*., 2011). In addition, legislations, and normative developed by European Union (EU) are pushing consumer choice towards more sustainable products. Within EU 20-20-20 framework, the Energy and Climate Package (EU, 2009a), the eco-design directive (EU, 2009b) and the energy labelling directive (EU, 2010) have been issued. These actions allowed to formalize eco-design strategies, such as the minimization of energy performance, and forced companies on this aim. However, a lack of a real and effective implementation of eco-design principles and strategies within technical departments of manufacturing companies emerged from the literature analysis (Pigosso *et al*., 2016). With the aim to understand the "real" situation in manufacturing industries, several surveys realized on the European context have been performed. Among them, Favi *et al*. (2017), Dekoninck *et al*., (2016), Pigosso *et al*., (2014), Bey *et al*., (2013), Santolaria *et al*., (2011) examined product manufacturers that operate in different contexts, investigating the concrete knowledge and awareness about eco-design. Several conclusions emerged as results of these surveys: *(i)* environmental sustainability is considered as an opportunity, since enables companies to innovate products and services satisfying the current market needs; *(ii)* environmental sustainability is still not the main driver to consider during the daily design activities; *(iii)* a lack of tools and methods for eco-design is observed; *(iv)* the need to share eco-knowledge and to favour collaboration on eco-design topic through the implementation of internal management strategies.
Starting from the mentioned outcomes, the literature was analysed in terms of interaction between eco-design and knowledge sharing tools and methods.

2.2 Eco-design and eco-knowledge

Design activities are strongly depending on knowledge, which can be defined as the sum of individual designers' education and company experience. The knowledge is recognized as a crucial element for

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the growing of industrial organizations (Bonjour *et al*., 2014, Asrar-ul-Haq and Anwar, 2016) and its sharing among employees is a critical aspect for the success of these organizations (Witherspoon *et al*., 2013; Mcharek *et al*., 2018). The reuse of company knowledge is particularly useful for companies that are operating in mature domains (Zhang and Li, 2016). Observing engineering practices in daily activities, designers spent approximately 24% of their time in identifying, acquiring and providing information (Marsh, 1997). Companies develop knowledge related to their products and usually, there is no mechanism for selecting, storing, and reusing it. (Esmi and Ennals, 2009). Furthermore, the heterogeneity of design data and of the documents where these data are stored affects the knowledge reuse negatively (Zhang and Li, 2016; Mcharek *et al*., 2018). This issue becomes particularly critical if the knowledge creation and sharing concepts are associated to eco-design. Despite the eco-design literature has registered in the last years an important growth providing numerous tools and methodologies (Baumann *et al*., 2002; Bovea and Perez-Belis, 2012), these systems are not really internalized in industrial contexts (Pigosso *et al*., 2016). Consequently, most of the companies do not have eco-knowledge to share, because they have only few experiences on the matter of environmental sustainability (Pigosso *et al*., 2013; Bonou *et al*., 2016; Dekoninck *et al*., 2016; Ilgin and Gupta, 2010). Only few companies have developed competencies on eco-design subject, but remains a knowledge-action gap that limits the implementation of eco-design strategies in design and technical departments (Martens and Carvalho, 2016). The possibility to acquire, create, share and use eco-knowledge plays a key role and it represents a great advantage for manufacturing industries (Baoucha *et al*., 2004; Domingo *et al*., 2015). The developed methods and tools aiming at the collection of general eco-knowledge providing it in the form of guidelines, procedures, etc. (Bonvoisin *et al*., 2010). Among them, some examples are represented by the works of Vezzoli and Sciama (2006), Bischof and Blessing (2008), Koh *et al*. (2007a), Rose *et al*. (1999), including the well-known ten golden rules proposed by Luttropp and Lagerstedt (2006) or the Ecodesign Pilot project (Ecodesign Pilot, 2015). Usually, eco-design guidelines provide only general indications and the translation into effective design choices is difficult (Vezzoli and Sciama, 2006; Koh *et al*., 2007b). Most of the mentioned eco-design solutions have a given knowledge, and a customization is not allowed. More complex is the case of integration between eco-design guidelines and other strategies or tools. This is the case proposed by Russo *et al*. (2011), which provided an approach to integrate Life Cycle Assessment (LCA) and TRIZ eco-guidelines, with the aim of supporting the implementation of the eco-design approach in small and medium European enterprises (SMEs). On this aim, Garcia-Diéguez *et al*. (2016) developed a complex framework to integrate the criteria provided by quantitative environmental indicators on the basis of Fuzzy Preference Programming method features and fuzzy logic reasoning. However, both studies are prototype versions, which present several complexities in understanding and using their functionalities.

3 OBJECTIVES AND FUNCTION DEFINITION

Taking into account the results of the state of the art analysis and observing the recent grow of sustainability role in the development of products, the following needs and related requirements (Figure 1) have been defined:

- Increase the knowledge of designers and managers on the environmental sustainability issue (Hallstedt *et al*., 2013; Bonjour *et al*., 2014, Asrar-ul-Haq and Anwar, 2016);
- Increase and support designers and managers in knowledge creation and sharing, stimulating their collaboration (Lindahl, 2005; Le Pochat *et al*., 2007; Schulte and Hallstedt, 2017);
- Support the customization of the eco-knowledge and stimulate its sharing (Zhang and Li, 2016; Baxter *et al*., 2008; Mcharek *et al*., 2018).

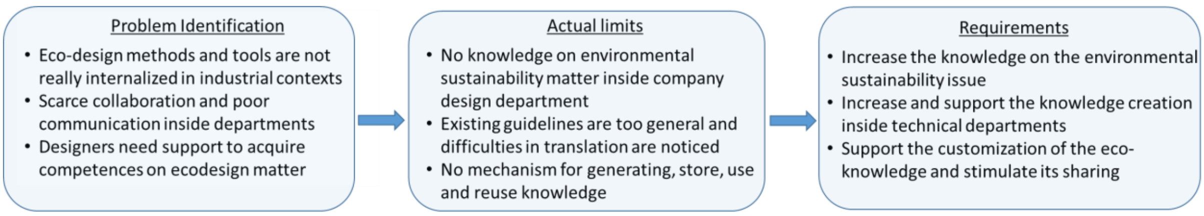

Figure 1. State of the art overview, limits and requirements

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Considering these aspects, the authors supposed that the creation of a structured database (DB) easily to be accessed, consulted and upgradable by users could represent a suitable solution to face the identified needs. In particular, the developed database should contain material related to product environmental sustainability and carry out the following functions (F):

- To provide a tangible support for designers aiming at the growth of their knowledge about environmental sustainability, eco-design issues and strategies to effectively implement them in the development of new products (F1). This function shall be supported by using training material, and universal eco-design guidelines, which are organized in a clear and structured form. Training section is organized with the objective to easily increase designers and managers' competences by short lessons in the form of videos, presentations, documents and links to relevant materials. The user can further examine the subject following a systematic approach organized in flexible levels.
- To provide a tangible support early in the design process for the implementation of eco-design actions in the phase where the degrees of freedom are higher (F2). This function shall guarantee an effective assistance in the design/redesign process thanks to the consultation of guidelines and company's best-practices. Guidelines and past best practises are derived and adapted from several sources of literature (Luttropp and Lagerstedt, 2006; Wever *et al*., 2008; Telenko *et al*., 2008) and from company's experience. The knowledge is characterized by the use of attributes (Table 1) and stored in a hierarchical organization.

Table 1. Guideline attributes

Guideline attributes	**Attribute explanation**	**Example**
Product type	Specify if the guideline affect several products or only a specific one	Dishwasher
Product module	Specify if the guidelines is related to the entire "product", or a specific "module" of the product	Light module
Interested design phase	Specify in which stage of the product development process the guideline is involved based on the Pahl and Beitz classification (Pahl and Beitz, 1996)	Conceptual design
User	Specify the technical figure which has to be involved in the guideline implementation	Mechanical engineering,
Source	Specify the source reference of the guideline (e.g. internal knowledge with reference documentation or other references)	Internal (doc #4556)
Category	Specify where the sustainability issues is relevant (e.g. design, material, energy consumption, EoL, etc.)	EoL (recyclability)

- To stimulate the customization of the stored eco-knowledge and the creation of new knowledge related to eco-design (F3). This function is supported by the definition of: (i) an *eco-design score* able to establish guideline priorities, and (ii) an *applicability index* level able to evaluate guidelines accordingly to company's specificity. In this way, designers and mangers can evaluate in which measure guidelines could be implemented in the particular context of the company (e.g., structural design, electronic design, marketing), and how these guidelines can be stored into the repository (e.g., studies, analysis, experimentations) by following a systematic procedure. The user is guided in the definition of a guideline that summarizes the content of the knowledge he/she wants to store, in the specification of guideline attributes and in the optional uploading of additional material. The system allows to update/modify/eliminate knowledge previously uploaded in order to trace all the improvements that the company records on eco-design activities.
- To support the knowledge sharing among the actors involved in the product design thanks to the thematic organization of material and supporting the definition of milestones and their verification (F4). This function foresees the possibility to consult materials clustered according to thematic organization (e.g. typology of problem, key work, and product type), to analyse projects under different perspectives, and to take into account past experiences and knowledge accumulated during different activities on specific issues. In addition, this function supports the definition of project milestones and the verification of their achievement both supporting project activities and stimulating the reuse of experiences.

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4 DESIGN AND DEVELOPMENT

4.1 Methodology definition

Starting from the defined functions and objectives, the following five-step methodology is defined:

- Step 1: Define the objective, the problem or the issue to face for the project. In this step, designers and/or managers define the reasons driving their work (e.g. increase the recyclability of a product).
- Step 2: Asses the level of knowledge. In this step, designers and/or managers reflect on the competences, knowledge and company experiences (both present and past) on the project matter.
- Step 3: Acquire knowledge. This can obtained by the consultation of training materials or company's past experiences and best practices;
- Step 4. Define strategies to face the problem and to answer to the identified objective, including the way to verify their effectiveness.
- Step 5. Capitalization of knowledge, i.e. derive material for knowledge generation. Company in this way stores the useful material related to the project, which will be useful in future projects. In case no successful results have been reached, company will register the reason related to the failing or possible alternatives.

4.2 Eco-design score and applicability index

The guidelines collected in the proposed DB are stored in a hierarchical organization and ranked by *eco-design score* and *applicability index*. The aim of the hierarchical organisation allows the users to efficiently filter and select the most suitable guidelines according to the design context and objective.
Each guideline is presented in the form of a short sentence, which proposes to the user actions, strategies and advices for the reduction of environmental impacts. The user has the possibility to go deeper in the subject, by accessing accessory relevant materials related to each guideline (e.g. graphs, formulas, sources, related reports, documentations, etc.). The *eco-design score* and the *applicability index* are aggregated scores (ranked from 0 to 10), based on the concept proposed by Hallstedt *et al.* (2017) and adapted for the purpose of this method. Guidelines are firstly sorted according to their *applicability index* and then according to the *eco-design score*. The *eco-design score* is defined to establish priority among guidelines based on their potential environmental benefits. *Eco-design score* is following three criteria:

- *Sustainability*, it evaluates if the guideline faces all the three pillars of sustainability (ecological, social, economic) and how much the suggestion proposed can affect their values;
- *Life cycle phase*, it evaluates which phase the guideline affects (among material, production, use, transport, end of life);
- *Process design phase* it evaluates which phase of the design process the guideline affects (among conceptual, embodiment, detailed).

The three criteria, which represent an evaluation of a previous guidelines classification (Rossi *et al.*, 2013), encourage users to think about environmental aspects in a global perspective and considering the three pillars of sustainability (Robert *et al*., 2013). The second score related to each guideline is the *applicability index*, which is defined to have information on the applicability of guidelines in the specific context of the company. This index is quantified by designers/managers during the knowledge customization.

4.3 Tool structure and workflow

In this section, the tool structure and its workflow are presented (Figure 2). The core of the tool is a repository in which materials, organized and classified in different forms, are collected. The repository contains several parts: training, guidelines, knowledge and milestone, accordingly to the type, structure and form of materials stored. The repository is connected with several modules which can read, write or elaborate the materials. In addition, materials can be stored in specific sections of the repository properly defined, including the access to each section and who has the right to access. The *Training module*, through its interface, queries the repository and provides as outputs lessons and material useful to "educate" designers and engineers on eco-design and environmental sustainability matters. The script option is also available, allowing to upload new and additional training materials.

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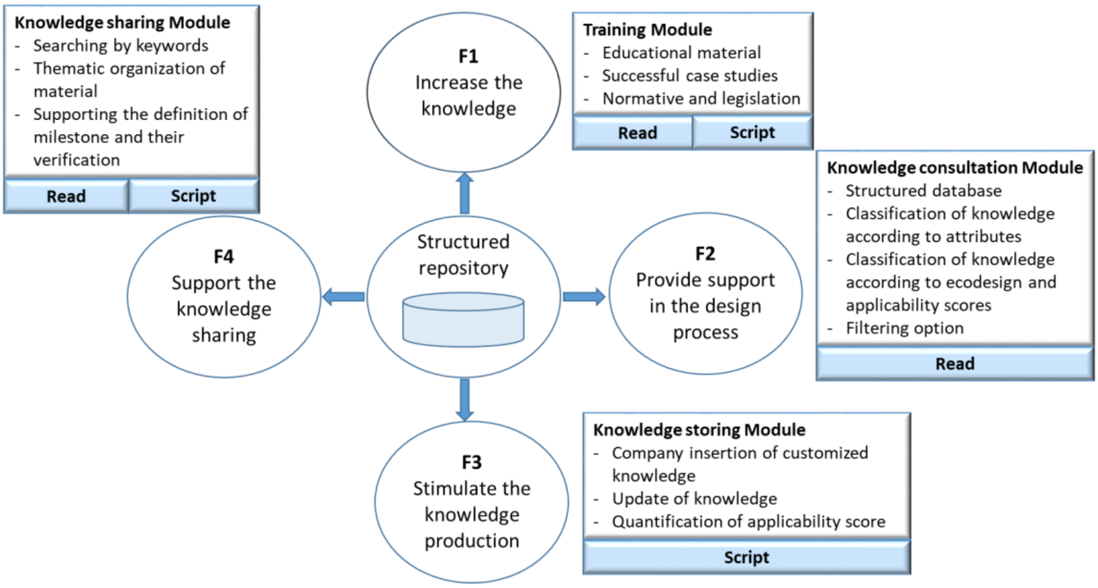

Figure 2. Tool functions and related modules

The *Knowledge storing module* allows, through dedicated interfaces, the customization of existing knowledge by the quantification of the *applicability index*, the updating of existing knowledge and the uploading of new knowledge. The *Knowledge sharing module* can read the data inside the repository and provides, as output, the material organized according to specific users' queries. The script option is available for this section through a dedicated interface, which allows the user to define project milestones and strategies to monitor and verify their achievement. It is worth noting how the tool repository contains, at first, material in the training and guidelines part, while it is empty in the knowledge and milestone ones. Designers and company managers can be considered the main users of the repository. The use of the tool has two different objectives: *(i)* the repository customization and, *(ii)* the repository consultation. The first objective allows customizing the tool by the definition of company's best practices and the evaluation of the *applicability index* for those guidelines, which comply with the company projects. The second objective allows acquiring or increasing skills on environmental issues, to support the implementation of eco-design strategies during the design phase and to share the company knowledge. The first objective should be repeated regularly in order to have an updated version of the repository. The necessary steps for the repository customization are:

- To access the tool and open the Knowledge storing module;
- To select the user attributes for making the first guidelines filter;
- To select other attributes for a deeper filtering;
- To retrieve the selected guidelines and select the *applicability index* quantification function;
- To quantify the *applicability index* according to the scale shown in the user interface;
- To save the result and repeat this operation for all the retrieved guidelines.

The necessary steps for the repository consultation are:

- To access to the tool and open the Knowledge consultation module;
- To select the user attributes for making the first guidelines filter;
- To select other attributes for a deeper filtering according to the objective of the project (e.g., product typology interested, life cycle phase affected);
- To analyse the retrieved guidelines on the basis of their *applicability index* and *eco-design score*;
- To evaluate the related additional material to deep the subject;
- To eventually update the guidelines or the related additional materials if relevant conclusions (positive or negative) have been derived from their application;
- To save the result if modifications have been made on the repository content.

4.4 First implementation and evaluation

In order to have preliminary outcomes of the effectiveness of the proposed methodology and tool, the system has been implemented in two companies. The two companies are involved in the field of household appliances. In particular, the first one dealing with the design and manufacture of

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cooktops/ovens and the second one with cooker hoods. A one-day training has been performed before to start the eco-design initiative and the initial phase (e.g., knowledge classification, applicability evaluation) has been done together with the authors of the paper.

Currently, the main effort for the implementation phase of the eco-design initiative inside the two companies is related to the fulfilment of the system repository with in-house company knowledge (internal eco-knowledge), while the use of the tool for the development of new products is an on-going activity. The eco-knowledge classification and the repository data filling is a core activity to start the eco-design initiatives inside the technical departments of the mentioned companies. The development of the repository allows company personnel to get access to the four system modules: (i) Training module, (ii) Knowledge consultation module, (iii) Knowledge storing module and (iv) Knowledge sharing module. As an example, here below are reported few instances about the guidelines definition for both case studies (Table 2).

Table 2. Examples of eco-knowledge classification for system repository data filling

#	Guideline	Prod. type	Prod. module	Design phase	User	Source	Category
1	Choose local suppliers where possible and select those that allow to minimize the distance from the production site	All products	All modules	Detail design	Procurement dpt.	Azevedo *et al.*, 2012	Design and transportation
2	Use a glass ceramic with low heat conduction coefficient to increase efficiency of product	Glass-ceramic cooktop	Cover module	Embodiment design	Engineering dpt. (Electronic)	Internal (doc #180224	Material and Energy consumption
3	Maximize useful life of the product	All products	All modules	Conceptual design and Embodiment design	Engineering dpt.	EC eco-design directive; Luttropp *et al.*, 2006	EoL
4	Reduce surface coating (e.g. paints) and bonding agents (e.g. glues) to avoid contamination of recyclable materials	Cooker hood	Aesthetic module	Detail design	Engineering dpt.	Ardente *et al.*, 2011	EoL

Eco-design guidelines are defined with attributes and collected with hierarchical organization. The goal of the tool is to derive a manageable and applicable list of design guidelines which are kept as short/simple as possible. The aim of the hierarchical organisation is to structure the guidelines in order to allow the user their efficient filtering and choosing, according to the design context. The guidelines

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are organised in the form of table and classified on the base of following attributes: (i) *Product Type*, (ii) *Product Module*, (iii) *Interested design phase*, (iv) *User*, (v) *Source* and (vi) *Category*.
As preliminary feedbacks from the end-users, the system appears as a useful support for the training on eco-design subject, in particular for the new employees, which are involved in design and engineering activities. Firstly, the development of the proposed method, together with a structured partnership with environmental experts from university brought the two companies to share important tips related to environmental sustainability, creating a desired level of specific eco-knowledge about their products. This aspect is demonstrated by the fact that the involved personnel reached a good level of knowledge about eco-design practice after a brief period of use, as showed by an assessment test performed after a couple of months from the introduction of the eco-design system. Secondly, related to the tool reactivity in supporting eco-design training initiatives, the proposed approach provides a ready-to-use system, which works as a framework to "educate" new generation of employees in the environmental subject. The repository with its defined structure allows practitioners to get the required level of knowledge and to be supported by specific guidelines at the time that they need.
On the other hand, the tool has not been tested yet for the development of new products and additional time is necessary to retrieve useful results about the implementation of this system inside technical departments. During this second part of the test, the usefulness of the tool during the design activities and the evaluation of its integration with traditional tools used will be realized and quantified by the definition of proper key performance indicators (KPIs).

5 CONCLUSION AND FUTURE WORK

The paper describes the development of a tool that supports companies in the implementation of eco-design strategies through a structured repository of guidelines, best practices and training material on eco-design matters. The tool functionalities have been defined starting from the analysis of the state of the art and accordingly to indications coming from direct surveys realized on industrial contexts. Barriers that actually limit the implementation of eco-design strategies have been faced and a structured repository with multiple objectives have been proposed. It allows users to increase their competences on environmental sustainability through training materials, to be guided in the identification of possible solution strategies through the consultation of guidelines, while favouring the company knowledge storing and sharing by a guided procedure to catalogue best practices and company's analysis. The first version of the tool has been preliminary tested and customized in two manufacturing companies, which will then use the tool during daily design activities to evaluate its validity, effectiveness and integration level. Moreover, authors are working on the updating of guidelines, with the objective to include also other aspect of sustainability, such as social aspects.

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