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DESIGN FOR ENERGY EFFICIENCY: PROPOSITION OF A GUIDELINES-BASED TOOL

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1. Introduction

Since the beginning of the industrial era, the world energy supply has been steadily increasing, generating political and environmental concerns. Over the last thirty years, the world electricity production has been multiplied threefold [EIA 2006]. In the EU-27, this production is processed primarily by the combustion of fossil fuels, which have poor yields (averagely <50%) and generate nearly a third of the total EU CO_2 and PM10 emissions (respectively 31 and 27%) [Eurostat 2007]. Furthermore, energy dependencies between countries are increasing, creating competition for access to natural resources.

An important share of the consumption of this electricity is linked to the usage phase of electric and electronic equipments (EEE). In the US, according to the Energy Information Administration [EIA 2009] nearly the half of the electricity supplied to the households is consumed by EEE. According to several outlooks, this share is expected to continue expanding during the next two decades. In spite of all the improvements made to the energy efficiency of several appliances, the savings are largely counterbalanced by a higher consumption due to an increasing number of appliances [Tang 2008], in particular in the sector of information and communication technology (ICT).

There is therefore an interest on focusing on energy consumption of EEE products during design. This is what the European Union has done through its "Energy using products" (EuP) directive, which aims at defining eco-design requirements for a wide range of EEE, especially on the topic of energy use.

Although the directive was adopted in 2005, methods are still needed in order to implement it successfully in industry [Hansen 2005], and to help companies integrate the energy consumption alongside other design criteria. Unfortunately, in spite of the importance of the topic, there is still a knowledge deficit concerning energy efficient product design [Li 2008]. During our literature review, we have, however, found some tools (e.g. guidelines) and industrial examples of successful energy efficient products. Nevertheless, a comprehensive method is needed to integrate energy into the design process.

This paper presents an original contribution to the ecodesign discipline through the introduction of a new tool to support energy efficient product design. This tool is based on guidelines. Section 2 presents the industrial research project focusing on Design for Energy Efficiency while Section 3 presents a brief literature review on guidelines and design. Section 4 aims at presenting the guidelines-based tool and the way it was conceived and constructed. Finally, Section 5 discusses the current capacity of the tool and future research objectives.

2. Development of a comprehensive method for energy efficient design

2.1 The Synergico Project

Our research aims to develop a comprehensive method to integrate energy concerns in EEE product design. This research is part of a project funded by the French Environmental Protection Agency (ADEME) named Synergico (Synergy-Energy-Design), that brings together two research laboratories (G-SCOP [Grenoble - Sciences for Design, Optimization and Production] and G2ELab [Grenoble Electrical Engineering Laboratory]) and two EEE manufacturers (Neopost Technologies and Sagemcom).

Environmental impacts of products occur in each phase of their lifecycles: raw material extraction, manufacturing, transportation, use and end-of-life (Figure 1). However, in the case of EEE products, a significant share of the impacts is due to the use phase, and particularly to the energy consumption. So, the core of the Synergico project deals with energy in use, and this is what this paper is focused on.

However, as an ecodesign research project, Synergico adopts an holistic approach in which all environmental impacts are taken into account, considering that an improvement in the energy efficiency could lead to an increase in the overall environmental impact of the product if other lifecycle stages regress. These concerns have however been well established by scientific knowledge (through methods like e.g. Life Cycle Assessment [ISO 2006]) and are not presented in this paper.

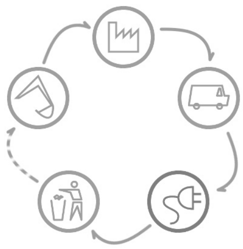

Figure1. The product lifecycle

This project also adopts an integrated design approach: design is a process where decisions are made regarding a large variety of criteria: cost, functional qualities, production time, security, technological risks, and so on. Dealing with trade-offs between these criteria is an integral part of the design process. Our project does not aim at the development of an optimization method, but rather a method to assess and bring relevant figures to decision makers in an integrated design context.

2.2 Research methodology

We aim to be as close as possible to the reality of product design in industry. Our approach is thus inspired from the design research methodology (DRM) proposed by Blessing, which is based on four steps [Blessing 2002]:

1. Define an improvement criterion to measure the effectiveness of the research. The overall energy consumption during the usage phase of a product is the design criterion we want to improve, and which we can measure.
2. Lead a descriptive study to understand factors that influence the chosen criterion. We carried out a 6 months analysis of both the literature and the practices of our industrial partners. The latter was carried out via several semi-structured interviews with designers from both our industrial partners. This information has helped us to draw a precise picture of the existing situation and to understand the weaknesses in their current design methods regarding the chosen criterion. We found that both companies had very similar ways of considering energy in design. This was consistent with the few results that can be found in the literature. This study allowed us to define precise requirements for new tools and methods.

3. Lead a prescriptive study to modify the existing situation towards the desired one. We are working toward the creation of methods and tools that address the identified needs; the guideline based tool described in this article is one of them.
4. Lead a second descriptive study to measure the improvement. We are planning to test these tools on design projects of our industrial partners.

We are now at the third step of this methodology. We have designed an overall method to tackle energy efficiency in product design which answers the following questions (which are faced during design activities):

1. "What do I want to reduce?" Assuming that the environmental burden of energy using products is rather related to their energy consumption than to their power, use times must be considered. Thus, our method will be fed with usage patterns, and will help companies to define them.
2. "To what extent?" When defining an objective for energy consumption, several aspects have to be considered: regulations, labels, market, costs, and so on. Therefore, our method aims at helping project leaders to define relevant objectives according to their constraints.
3. "Am I far from it?" In order to reach an objective, design teams have to measure the gap between the current situation and the desired one. Thus, we are developing relevant indicators to help designers in measuring the energy performance of the product under development.
4. "What can I do to reach it?" Once the problem is defined, designers need to identify strategies and choose among them. To facilitate this, we propose a list of strategies embedded in a tool that helps designers select which strategies will help them to improve the energy efficiency of the product.

Synergico project plans to develop one tool for each question. This paper presents the tool that answers the last question.

3. Guidelines in (eco)design

3.1 Definitions of guidelines

Guidelines can be defined in general as "principles put forward to set standards or determine a course of action" [Collins English dictionary]. According to Bischoff, their use during design makes "the result of the activities of the designers more predictable and […] presumptively improve the results" [Bischof 2008]. Vezzoli combines these two concepts, defining guidelines as "procedures to orient a decision process towards given objectives" [Vezzoli 2006]. We adopt this last definition. Moreover, we note that what is called "guidelines" is usually a list of guidelines, which is a typical DfX tool [Bischoff 2008; Pahl 2007]. According to this definition, guidelines have two major functionalities:

- before any implementation choice: they give a wide list of promising strategies;
- after a choice: they allow the design to converge towards an objective.

Generic guidelines are relevant for a wide range of situations [Luttropp 2006], as they are transposable. They can also be useful in conceptual design phases, as they can be understood by multidisciplinary teams, without precise knowledge of technical details. However, although generic guidelines allow for a wide range of creative interpretations, it may be more efficient for day-to-day design work to use more specific ones: the more a guideline is specific, the more it can be handled efficiently by designers [Vezzoli 2006, Dahlström 1999]. Moreover, the relevance of guidelines may be dependent on the studied product [Vezzoli 2006]. Thus, it may be useful to obtain specific guidelines from generic ones through the:

- *selection* of the guidelines applicable to a specific industrial context;
- *reification* of abstract concepts into practical ones.

It can be concluded that generic and specific guidelines can be both useful and relevant in different situations.

3.2 An easy and flexible DfX tool, which has to be improved

According to Luttropp, guidelines "have been used in product design for a long time and for many purposes other than ecodesign" [Luttropp 2006]. The major advantage of guidelines is their simplicity

[Luttropp 2006; Vezzoli 2006]: they can be easily integrated in the design process by changing specific practices. They can also be easily handled by designers and engineers, without any training or technical operations, as they only offer directions to follow. As guidelines generally result from matured experience and knowledge [Vezzoli 2006], they are a useful means to introduce a new topic in design. Guidelines are also upgradable and adaptable tools. They can be easily updated for example by the addition of new guidelines, thanks to the experience gathered by people on projects [Vezzoli 2006]. Guidelines can also be reworded using company specific terminology.

However, having access to a wide list of guidelines may be insufficient as it does not answer the question: “Which of these strategies are the most relevant for my problem?” Indeed, in a given project or company, even if a guideline is generally recognized as an efficient one, it is not always relevant in the context. Guidelines thus need to be ‘attached’ [Dahlström 1999] to the company realities to be used in decision processes. Some guidelines can also be contradictory [Luttropp 2006]. Moreover, as argued by Henninger in the context of software design, the length of a list of guidelines may exceed the ability of the users to identify the more appropriate ones [Henninger 2000]. Thus, there is indeed a need for *selection* of guidelines. Selection should be supported by linking guidelines to the situations they are likely to be used in.

4. Proposition of a guidelines-based tool for energy efficient design

4.1 Structure of the tool

The core of our tool is a list of 56 guidelines gathered from the literature and classified into 8 criteria.

The tool is a spreadsheet (see Figure 2) where guidelines are in rows and criteria are in columns. Guidelines are kept as short and as simple as possible and usually contain one verb and one complement. However, for a better comprehension, hyperlinks pointing at more detailed descriptions allow the users to learn more about the guidelines. We will now explain the construction of both the list of guidelines and their classification.

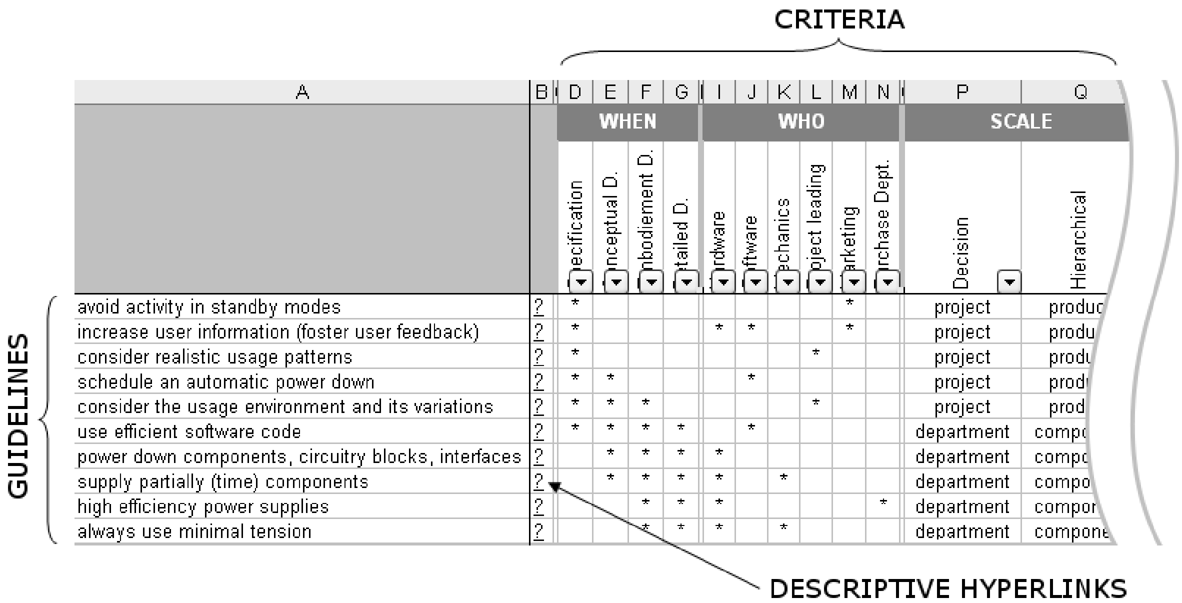

Figure 2. Screenshot of the tool

4.2 The guidelines list

We have collected and organized all of the guidelines within the available channels, including standards (e.g. Energy Star), regulation related publications (i.e. EuP European directive preparatory studies), conferences proceedings and journals. This has been done with an aim of completeness. We then added to this initial list a few guidelines based on our experience as eco-design researchers, helped by our industrial partners.

Guidelines found in literature are scattered amongst several documents. Once gathered in a unique list (step 1 in Figure 3), they were obviously heterogeneous as they were originally written for different purposes. We have processed the guidelines (step 2 in Figure 3) with respect to the following principles:

- *non-redundancy*: some ideas were covered by several sources; in order to keep the number of guidelines as small as possible, guidelines with similar content were grouped into a unique one.
- *concept non-overlaps*: some guidelines combined several different concepts, like "user-adjustable automatic switch to energy save modes" which mixed the ideas that a product shall have "energy save modes", which can be "automatically switched", with a "user-adjustable" time frame. For readability concerns, we decided to formulate one idea per guideline.
- *general applicability*: some guidelines were too specific to be applicable at the EEE sector level. Therefore, we generalized guidelines when necessary. As an example, "set the standby power to 1W" became "set minimal performance consumption for standby (to be expressed in [W])". However, we didn't go as far as Luttropp, and did not generalize in order to get only a few abstract concepts (10 in his case). Thus, whereas our guidelines can all be named "generic", they still have different levels of abstraction.

For traceability purposes, we also documented our modifications to allow users to refer to the original sources of guidelines.

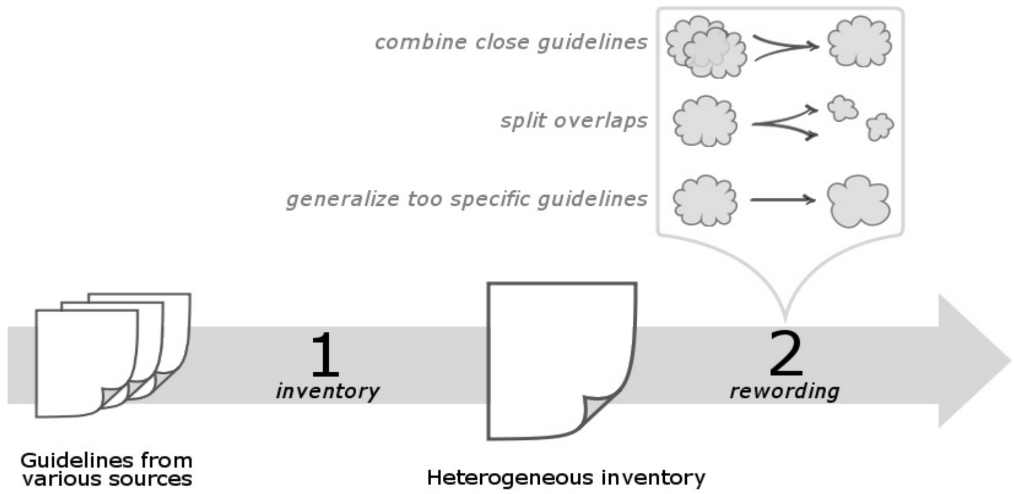

Figure 3. Steps in the guideline list generation

4.3 Criteria used to classify the guidelines

As we stated in section 3, a simple list of guidelines (more than 50 in our case) does not seem structured enough to allow for an efficient choice. Therefore, we decided to structure our list with classification criteria in order to allow users to filter the most relevant guidelines according to the design context. We have selected eight criteria and have defined their levels. These criteria are divided into three categories:

- *design related criteria*, that are related to organizational concerns, and help users to select the guidelines that are more likely to be used in the current design situation;
- *guideline related criteria*, that give information about the type of the guideline;
- *power management related criteria*, that are specifically related to energy and emphasize on important concepts related to energy management.

These criteria are detailed in the following sections. Examples of guidelines are also used to illustrate them.

4.3.1 Design related criteria category

These criteria help the designers to select the guidelines they are likely to use depending on the context. We suggest that the usability of a guideline is conditioned by three factors:

- *Stage in design process*: the usage of guidelines is linked to the stage in the design process [Luttropp 2006]. We therefore included in the tool a criterion called "when". This criterion indicates the stage where the decision to implement a guideline can be made. We based our choice list on the standard Pahl & Beitz [Pahl 2007] design process ("planning and task clarification", "conceptual design", "embodiment design", "detail design"), as the design processes of our industrial partners are quite similar to this model.
    - Examples:
        - "*Avoid activity in standby modes*": this guideline may have a significant impact on the product, its structure, its functionalities, and the way it is used. It should thus be decided to implement it in the earliest design stage, i.e. at the first stage of the design process ("planning and task clarification"), in order to be able to implement it throughout the design process.
        - "*Use high efficiency power supplies*": choosing a power supply is one of the later design steps, so it can be implemented in "detail design".
- *Department targeted by the guideline*: each guideline does not concern every department in the company. Some guidelines may propose specific technical changes that cannot be tackled by everyone in the company. Thus, we added a criterion called "who" that indicates the particular department(s) that has(have) to be involved in the implementation of a guideline. We based our choice list on the typical distribution of department we have found within our industrial partners' organizations (selecting those which have an influence on energy efficiency performance), namely "mechanics", "electronics", "software", "marketing", "purchase", and "management".
    - Examples:
        - "*Use efficient software code*" refers to software designers only.
        - "*Power down components, circuitry blocks, and interfaces*" should be tackled by both software and hardware designers. Hardware must offer the possibility to shut off components. Software must organize the turning off and on, and must continue to operate with the few components still on.
- *Decision scale*: some guidelines can generate major changes in the overall design; meanwhile others ones have fewer "side effects". Thus, some guidelines can be tackled by individuals through their own initiative; some others need a consensus in the team. To consider this, we added a criterion "decision level" that refers to the hierarchic level where the "go or no go" decision is taken. We have identified three different scales: "department", "project", and "company".
    - Examples:
        - "*Always use minimal voltage possible*" concerns electronics design, and has no effect on others department. The decision for its implementation can therefore be done at the electronics "department" level.
        - "*Increase user information and foster user feedback*" can be done by putting displays on the product. This may involve mechanics (e.g. shape of the product), electronics or/and software (e.g. for displays). Thus, the decision must be handled at "project" level.

4.3.2 Guideline related criteria category

Further classification can be made depending on the user needs:

- *Hierarchical scale*: guidelines may affect different physical scales on the product. Some may involve the modification of a "component", the entire "product", or the overall "system".
    - Examples:

        - "*Consider the usage environment and its variations*" encourages designers to think about the relationships between the product and its environment (the user, the place, the air, the light, etc.). Thus, the guideline does not only consider the product but the overall "system".
        - "*Use high efficiency power supplies*" only refers to the choice of a single "component" (here, power supplies).
- *Type*: some guidelines deal with modifications of product/component functions within the system while others deal with changes in the technologies used:
    - Examples:
        - "*Increase user information and foster user feedback*" focuses on the man-machine interaction functionalities, but doesn't specify what technique to use.
        - "*Schedule an automatic power down*" is one technical solution to influence users to switch off the device.
- *Application*: some guidelines may concern the product being designed, others may concern the design process itself. The first ones offer merely "solutions" to implement on the product, while others give advice about the organization (i.e. a "method"), and focus on the creation of a favorable environment for designers to find new solutions.
    - Examples:
        - "*Schedule an automatic power down*" is a "solution".
        - "*Consider realistic usage patterns*" is part of a "method".

4.3.3 Power management related criteria category

We added two criteria to our list to emphasize on strategies that seems of major importance for EEE design:

- *Power management scale*: power management is generally considered at product level. However, we found several guidelines that go beyond that level and attempt to manage energy more subtly at the component scale. As this issue has not yet been well explored by electronic manufacturers but seems to have potential in energy efficiency improvements, we decided to put an emphasis on this criterion. It has three levels: "classic", "advanced" or "NR" (non relevant).
    - Examples:
        - "*Schedule an automatic power down*" is a "classic" power management feature, already implemented in several products and required by some labels and regulations.
        - "*Supply partially components*" is found at the component level. It can be for example the use of afterimage effect to supply an LED for a few milliseconds within a duty cycle. This feature would be "advanced" as it tries to reach lean consumption.
- *Mode*: definition of modes is a central issue in EEE energy efficiency improvement and has so far been limited to the distinction between operational and non operational ones. In order to highlight the potential of "mode" oriented design, we decide to introduce it as a criterion. It has four levels : "mono" (meaning that the guideline applies to a single mode), "multi" (meaning that the guideline deals with more than one mode), "trans" (meaning that the guideline deals with transitions between modes), and "NR" (non relevant):
    - Examples:
        - "*Avoid activity in standby modes*" is classified as "mono", as it only considers the standby mode.
        - "*Consider realistic usage patterns*" aims at encouraging designers to consider the time repartition of modes. It is classified as "multi".

4.4 An adaptable tool

We have aimed to design a tool that is usable within different companies from the EEE sector. Our guidelines can therefore be considered as EEE generic. They are not all relevant for all companies and products and they may need to be translated into a more technical language or reified into technical solutions.
However, we designed the tool in order to allow companies to reach a desired level of specificity and linkage with the company constraints. This can be done by updating either the criteria or the guidelines list (see Figure 4):

- *Criteria update*: companies can link the guidelines to their contexts by adding criteria columns. These criteria could concern for example the energy gains that can be attained thanks to each guideline, or impacts on cost of the product induced by the guidelines.
- *Guidelines update*: companies can derive practical solutions adapted to their products from generic guidelines by rewording or adding lines in the list. As our list might not be sufficient for the individual needs of each company, the tool can by adapted by the addition of new generic or specific guidelines. Lastly, companies can generate guidelines by analyzing what has been done to improve energy efficiency within their previous product development projects.

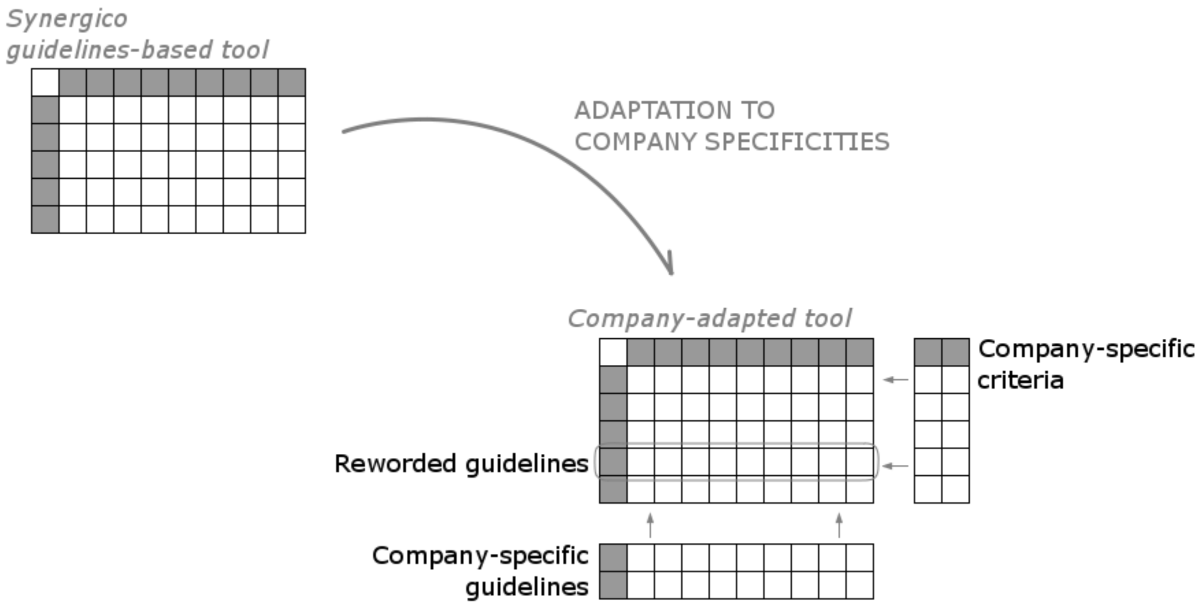

Figure 4. Adaptation of the tool by a specific company

5. Discussion

5.1 Compliance with the objectives identified in literature

The list of 56 guidelines and their classification have been constructed in collaboration with ecodesign leaders from our two industrial partners. It has been reviewed and validated by design experts and department leaders from both companies as well. We have received our first positive feedback on the tool from designers, saying that our guidelines formalize implicit rules they have been applying in the design of energy efficient products.
In our analysis of the guidelines-related literature, we have identified two main issues:

- both generic and specific guidelines are relevant in design but for different purposes;
- choice among guidelines must be supported.

From our perspective, the presented tool gives an appropriate answer to these two issues:

- Designers can create specific guidelines. By using either original or adapted guidelines, designers have access to both specific and generic guidelines, depending on the objectives they want to reach.
- Criteria are provided to help designers filter the guidelines and focus on a shortened, relevant list. Moreover, through the addition of company-specific criteria, designers can link guidelines to their realities. Thus, they can choose the most relevant guidelines within a multi-criteria decision process.

5.2 Limits

We have gathered guidelines with the aim of completeness, and reworded them in order to express *one* idea per guideline, and to have *one* guideline per idea. However, there are still unavoidable redundancies and gaps in the information. Indeed, our guidelines have different levels of abstraction and some of the more abstract guidelines still overlap with some of the more practical ones. Avoiding the overlaps would result in a more concise list but would also generate information losses.
This could certainly be avoided by using a tree instead of a list, or at least a hierarchic representation. In all the studies found, guidelines are structured by themes, but there is no explanation about the way the guidelines have been aggregated. From our point of view, further research should be carried out to identify a method of constructing a list free of gaps and redundancies from a heterogeneous list. However, considering that perfect completeness does not exist, we plan to design an extension of the tool that will aim at inspiring designers in order to fill the blanks.
Finally, whereas guidelines seem to be recognized as a useful design tool, no studies directed towards characterizing their usefulness in real design teams were found in the literature. It could, however, be interesting to know why and how guidelines are useful. This could allow guidelines designers to improve guidelines efficiency in design.

5.3 Further research

We would like to be able to measure the improvement that guidelines can make. According to the DRM methodology, the next steps would be directed at developing a method for determining if it is effective in industry design processes. We are now planning a second descriptive study based on two parallel strategies with our industrial partners:

- leading a retrospective analysis on product designs and showing how the guidelines-based tool could have been useful at the time of the design;
- analyzing and contributing to the design of a new product and testing the ability of the tool to contribute to energy efficiency improvements.

However, the tool cannot be fully validated until a test of the overall Synergico method, which combines all the tools developed within the project. The final validation will be conducted with a product development project of our industrial partners.

6. Conclusion

In this paper we have presented a tool for energy efficient product design based on a structured list of guidelines. We first identified from a literature review requirements for efficient design guidelines. We then explained how the tool we have developed within the Synergico project was designed to comply with them. The tool was initially based on guidelines gathered from the literature, which we processed in order to form a homogeneous list of 56 ideas. Guidelines were classified according to 8 criteria, which are detailed in the paper. Finally, in order to design a tool that applies to the whole EEE sector as well as for individual companies, we explained how the tool could be adapted to each company's individual context. A first series of validations have been carried out. They will have to be completed by a large scale test of the overall Synergico tools on the design of new products.

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