Strategic Design Research Journal, 6(2): 46-57 May-August 2013
 – doi: 10.4013/sdrj.2013.62.01

Method of decision making applied to the analysis of the environmental performance of a product: The case study of a Spirit fan

Método de tomada de decisão aplicado à análise de desempenho ambiental de um produto: estudo de caso do ventilador Spirit

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Abstract

This article proposes a case study to demonstrate the employment of a Multi-Criteria Decision Making Method based on studies developed by Simon (1972); Roy (1998); Masui, (2003) and others. It is applied on the evaluation of the design of existing products with regards to sustainability. Two ceiling fans available in the market are compared, based on several criteria related to best practices for reducing environmental impacts, also known as ecodesign. Results show that the method provides support for the establishment of performance indicators, which may favor the analysis of complex and important issues which are often subjective, allowing a better integration between disciplines and throughout the value chain of the project.

Keywords: matrix decision support, methodology, ecodesign, life cycle analysis.

Resumo

Este artigo propõe um estudo de caso para demonstrar o emprego de um Método de Multi-Critérios na Tomada de Decisão baseado em estudos desenvolvidos por Simon (1972); Roy (1998); Masui (2003) e outros. Ele é utilizado na avaliação de projeto de produtos existentes com relação à sustentabilidade. Dois ventiladores de teto disponíveis no mercado são comparados com base em diversos critérios relacionados às melhores práticas para redução dos impactos ambientais, também conhecidos como ecodesign. Os resultados demonstram que o método fornece suporte para o estabelecimento de indicadores de desempenho, o que pode favorecer a análise de questões complexas e importantes que são, muitas vezes, subjetivas, permitindo uma melhor integração entre as disciplinas e em toda a cadeia de valor do projeto.

Palavras-chave: matriz de apoio à decisão, metodologia, ecodesign, análise do ciclo de vida.

The need for an easier and more pedagogical method

In Brazil, concepts, strategies and tools related to ecodesign are gradually being built and implemented by industry and government programs while introduced in business by different professionals. Currently there are a lot of methods and tools for an ecodesign approach which, in a greater or lesser degree, allow to analyze or develop products with lower environmental impact throughout their life cycle. These methods also highlight potential impacts of products even during project development by means of recommendations or information about different strategies of environmental design (Manzini and Vezzoli, 2008; Vidal, 2002).

These procedures may involve distinct criteria that contribute to the development of more sustainable objects. In many cases, qualitative approaches are employed both in order to overcome the difficulty in obtaining quantitative data, and as an approach to analyze more subjective issues. Some strategies have the purpose of identifying opportunities for environmental improvement of a product at a certain phase or throughout its life cycle; they offer guidelines or suggest alternatives for the development of more sustainable projects; they compare different environmental criteria, or even quantify the improvement or impact of objects. Some types of software also assist in this process and can provide environmental information of great complexity on the products as they are produced, distributed, used and disposed, quantifying their environmental impacts (Byggeth and Hochschorner, 2006).

Authors such as Barbero and Cozzo (2009), Manzini and Vezzoli (2008), and Santos e Tanure (2005) propose guidelines or checklists that can guide a qualitative research for more sustainable products. These guidelines suggest possible strategies in the different phases of the product life cycle, but their se without the support of a systemic view may lead to wrong directions: certain strategies that reduce the environmental impact in a phase of the product life cycle can lead to an impact of greater magnitude in another step – it is the case, for example, of industries using recycled raw materials, that generate, on the other hand, a relative increase in pollutant emissions, causing a greater impact when the whole life cycle is accounted for.

In order to clarify and disseminate the application of ecodesign concepts within a systemic view, a database of examples – Eco-Cathedra – was developed at the Politecnico di Milano. The systemic view addresses the complexity of the existing relations between the environment and issues such as social, economic and cultural ones, taking the whole product life cycle into consideration: Eco-Cathedra presents a list of products with good environmental performance, highlighting the most important environmental aspects of each project within a context defined by the interaction of these multiple issues. The Portuguese version of this tool was developed by *Núcleo de Design e Sustentabilidade* at the Federal University of Paraná-UFPR (Universidade Federal do Paraná, 2012).

However, the most widely accepted methodology for conducting an assessment of environmental impacts of products or services is the Life Cycle Analysis (LCA) or Life-Cycle Assessment (Jeswiet and Hauschild, 2005). It is an environment management tool that allows a systematic and quantitative understanding and evaluation of the environmental impact of materials, processes and products, including phases ranging from the exploitation of raw materials to the final disposal of the product. With this information, organizations can generate environmentally friendly products; identify opportunities for environmental-related improvement in products and processes; assist in setting priorities at certain phases of the life cycle, or even formulate strategic marketing planning such as environmental labeling (Chehebe, 1997).

Currently, the software SimaPro 7.2, developed by the Dutch company Pre Consultants, allows the calculation of LCA with the help of Eco-indicator 95 and Eco-Indicator 99. The Eco-indicator methodology is an LCA weighing method developed specially for product design (the 95 version was amplified to include more aspects, resulting in the 99 version). However, it is only available in English and the information compiled in the database refers to a limited reality. In Brazil, the rules related to LCA are covered by a series of international standards on environment management compiled by ISO 14040, which defines general requirements for conducting LCA's, including ethical codes for the dissemination of its results.

There is a consensus that the application of LCA is complex, difficult and expensive, which restricts its application (Byggeth and Hochschorner, 2006; Chehebe, 1997; Luttropp and Lagerstedt, 2006; Manzini and Vezzoli, 2008; Masui *et al.,* 2003; Papanek, 2007; Vidal 2002). Some of the main difficulties in applying LCA to ecodesign are: the lack of available and reliable information on the environmental characteristics of products and services; the need for an extensive survey of technical data on materials and processes; the absence of inventories or database adapted to national realities; the high investment and time needed for compiling all the necessary information about the product; the need for technical expertise; among others (Carvalho, 1997; Vidal, 2002).

The software Eco-it, focused on designers, is less complicated than the software SimaPro. Based on European data (EcoIndicator 99), it calculates the environmental charge associated with each phase of the product life cycle allowing to identify possible environmental improvements. However, this tool also requires a lot of technical data on materials and manufacturing processes (Pre Consultants, 2012).

The purpose of the present research is to use the knowledge developed in the studies of decision-making to propose a method for qualitative assessment of a product with respect to the conditions and means in which decisions about its design can be based. A case study is used to show the possibilities of applying this simplified method of decision-making to evaluate a product available in the market in terms of sustainability. The method proposed is based on developing a decision matrix from the definition of ecodesign requirements and the characteristics necessary for complying with them. This matrix is defined to many alternatives, according to the need and to as many requirements as desired. Each alternative is classified with regards to each requirement that may be either qualitative or quantitative, based on related characteristics. In addition to evaluating existing products, the method also has the potential of being applied to design processes, because it has its origin in the knowledge developed to aid decision- making.

In design contexts in which the set of available actions is not clearly determined and not well defined, the method enables a better integration between disciplines throughout the value chain of the project, as it allows various actors to interact in order to make strategic decisions, each one of them bringing different perspectives, value systems and interpretation of events, which lead to differentiated goals, avoiding conflict.

According to Simon (1972, p. 172), the project presents an additional challenge in relation to other matters, since "the classical decision theory has been concerned with the choice between alternatives given" and "design is concerned with the discovery and development of alternatives". However, as in a chess game, if the players involved are able to lead a strategy to its end, they can build a plan step by step and study eventual adaptations throughout the process.

A decision-making support methodology applied to sustainable design

Some tools have already been used to incorporate the analysis of multiple criteria to environmentally conscious design. One of them is Quality Function Deployment (QFDE) for Environment, an adaptation of Quality Function Deployment (QFD). QFD is a systematic method used to transform user demands into design features, presented in 1966 by Akao (1990), a leading actor in the Total Quality movement in Japan. Originally implemented in the KOBE shipyards of Mitsubishi Heavy Industries in 1972 (Carvalho, 1997) the method can be applied to products, systems, subsystems, components, and ultimately to specific elements of the manufacturing process (Akao, 1990), revealing itself to be a very comprehensive tool that can be adapted for use in strategic planning, product development, to assess costs, for example.

QFDE, proposed by Masui *et al.* (2003), is therefore centered on the environmental demands of "customers" – including among these not only users, but also government officials and the environment itself. This perspective is in line with Roy's vision, which considers that the decision makers are not only the ones who make decisions, but also the ones on whose behalf decisions are made (the term "decision determiners" in this case would be more accurate).

QFDE initially consists in identifying the function units of the product, step after which the evaluation criteria of environmental requirements are chosen and given weights – values of market quality – according to consumer queries. The product and its components are then evaluated with respect to their compliance with the requirements that are related to its desired performance and the "scores" obtained are multiplied by the "weight" assigned by the consumer to each quality (Masui *et al.,* 2003; Puglieri, 2010). The data obtained is laid in a matrix since, according to Gomes and Mello (2000 *in* Picanço, 2007), it is the best organization to represent a relationship between criteria and alternatives.

As with QFDE, the proposal here presented is based on a desire to have more environment-friendly products but it makes an attempt to simplify QFDE methodology: although it also uses the fundamental instrument to support decisions – the decision matrix – it suppresses the two final steps of QFDE, which evaluate the effect of changes in the products that were suggested by the first steps; it also eliminates the attribution of weights to the criteria adopted, a step that involves more subjectivity and that is treated through different approaches in different decision making methodologies, showing the existing controversy on the matter. It also differs from QFDE because it restricts itself to an approach from an environmental standpoint and excludes the other market priorities that would be included by a focus on the consumers' point of view. The focus here is on the part played by decision makers as a whole in the search for sustainability. The matrix has therefore a qualitative character and the analysis proposed is subjective, although sometimes based on quantitative data, and it searches for possible environmental improvement, without actually evaluating environmental impacts. It allows placing the emphasis on a more pedagogical discussion, provoking a debate about the choice of requirements for each product, and the criteria to be used to evaluate each of them according to different perspectives.

The proposal is therefore based on the methodologies of multicriteria decision support, a set of techniques that are designed to investigate a number of alternatives, considering multiple criteria and conflicting objectives (Gomes, 1999 *in* Picanço, 2007). The proposed methodology will be named "MADA" – Matriz de Auxílio à Decisão Ambiental (Environmental Decision Aid Matrix). According to this methodology, decisions are to be made by an expert or group of experts. There are no rules as to the number of people to be involved in this process but the more interdisciplinary the group is, the less biased the decisions made tend to be. A systemic view of the problem and the direction to be given to it are provided as a result of discussions integrating producers, designers, users, environmental experts and others. The first step for its elaboration consists in the choice of products to be used as a reference for the product to be designed or analyzed. For a better evaluation of the product in focus, it will be compared to other products with the same functions and similar characteristics; by doing so, it is possible to confront them and identify possible advantages or disadvantages of ecological products. The second step is the determination of the environment requirements for each phase of the product life cycle.

After defining the requirements or attributes that are relevant for each phase for that kind of product, sometimes qualitative ones, certain characteristics of the product (indicators) are selected in order to express the extent in which the product is effective in fulfilling that requirement: the use of a smaller amount of material in production, for example, is a requirement for attaining sustainability at this stage – it will be affected by characteristics or indicators such as the weight of the product; the number of parts and components, or the number of types of different materials used to manufacture it– which are all quantifiable characteristics. They are called "Engineering Metrics" by Masui *et al.* (2003), and will be called "function units" here. These function units can vary from product to product according to their technical structure and characteristics. They may include, as seen, the weight of the product; its volume; the number of parts it is composed of; the number of types of materials that are used to manufacture it; or yet, the likelihood it has to get dirty; its hardness; its physical lifetime; the amount of energy it consumes when in use; the rate of recycled materials that is used to produce it; the noise, vibration or electromagnetic wave it produces; the mass of air pollutant, water pollutant or soil pollutant it produces; its biodegradability; toxicity and so on.

In order to relate the requirements considered relevant to each phase of the product life cycles to characteristics that reflect them, a matrix is generated: environmental requirements are listed in the lines and function units of the products (characteristics) in the columns. Scores are given to each function unit with respect to each environmental requirement – depending on the extent the design of the analyzed product presents features that comply with the requirements established. Assigned scores correspond to the performance, values or levels of acceptability of each function unit under each requirement, i.e., how much the decision makers consider that alternative viable regarding the performance of the product with respect to that requirement. They express a "Relational Strength" between requirements and function units and are marked at the crossing points between these two factors, indicating the magnitude of the relation between them. "9" shows the relation is strong, "3" shows it is moderate and "1" shows it is weak. No score is assigned when there is no correlation (Table 1).

Finally, the value obtained by adding the columns will identify a higher or lower compliance of each product to environmental requirements.

A case study: the environmental decision aid matrix applied to a fan

In order to demonstrate the application of the Environmental Decision aid Matrix, a case study was conducted with a product which received several design awards and gained recognition and prominence in national and international market for its eco-efficient solutions: the SPIRIT fan, developed by Indio da Costa Design office in 2001.

At this point, data collected concerning the fan SPIRIT Wind 200 will be described and analyzed, and also compared to the data related to a traditional product – fan "A" (Figure 2). The comparisons on the various characteristics displayed by the two fans seek to identify which of them has a better ecological performance.

The methodology described refers both to products yet to be developed and to products already developed and manufactured: as the present case refers to an existing product, instead of having a group of experts define requirements, interviews were conducted with the original decision makers, in order to learn about the requirements that defined their decisions, the reason they were chosen, their suitability and convenience. A questionnaire was also submitted to the designers of the product analyzed. This investigation sought information concerning the process of design and production. Questionnaires containing open and closed questions aimed at clarifying issues especially regarding design solutions and production-related life cycle phases and also distribution, use and disposal ones. The theoretical research, on the other hand, allowed setting the parameters for which the characteristics related to each requirement would result in a good performance. Subsequently, the data concerning the fo-

Table 1. MADA –Environmental Decision Aid Matrix applied to a product in production stage.

Correlation between environmental requirements and product characteristics: 9. strong correlation 3. moderate correlation 1. weak correlation		**Function units of the product**													
		Researched product							Similar product						
Environmental Requirements		Weight of the product (kg)	Numbers of parts and components	Numbers of types of materials	Amount of energy consumption	Optimization of the structure (use of ribs)	Number of assembly elements	Percentage of recyclable materials	Weight of the product (kg)	Numbers of parts and components	Numbers of types of materials	Amount of energy consumption	Optimization of the structure (use of ribs)	Number of assembly elements	Percentage of recyclable materials
Production (phase)	Use of a smaller amount of material	9	9	9		9	9	9	3	1	3		1	1	3
	Ease of assembly		9				9			1				1	
	Reduction of energy consumption		9		9		9	3		1		3		1	
Environmental attributes of the product		9	27	9	9	9	27	12	3	3	3	3	1	3	3
Environmental attributes (average)		14,5							2,7						

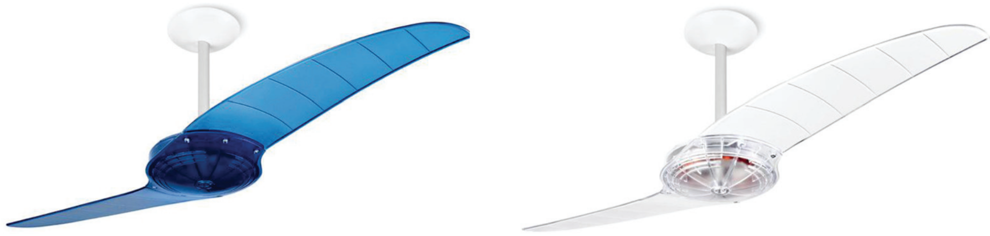

Figure 1. SPIRIT Wind 200 fan without lamp.
Source: SPIRIT.

Figure 2. Ceiling fan "A" with three blades, produced in Brazil in 2001.
Source: Tron.

cus product and the reference product were compiled and interpreted by means of the matrix proposed for the life cycle phases: production, distribution, use and disposal.

Identification and analysis of function units and environmental requirements related to the production phase

Despite being rather different when considering its morphology and the materials it is made of, fan "A" was selected for comparison due to the fact that it was available in the market at the time SPIRIT was launched in 2001. It can be considered representative of the existing types of product in this period in which ceiling fans with three or four blades prevailed, employing materials such as steel or MDF. Table 2 compares the key function units of the two products, showing the differences found.

The first significant dissimilarity between the products is the employment of materials. Thermoplastic material – polycarbonate – PC – is employed to make Spirit's casing. According to Lima (2006), the main characteristics of this material include good impact resistance, good thermal and dimensional stability, excellent electrical insulation, flame resistance and recyclability.

Table 2. Technical specifications of ceiling fans SPIRIT 200 and fan A.

Technical Specifications	 **SPIRIT fan**	 **fan A**
Model	wind 200 Without lamp	without lamp
Design	Indio da Costa	-
Material	policarbonate	steel
Function	ventilation and oscillation	ventilation and oscillation
Speed	03 (low, medium and high)	01 (high)
Number of propellers	02	03
Turn on	wall control	wall control
Voltage	127 Volts	127 Volts
Energy efficiency	A	A
Power	120 Watts	130 Watts
Air flow	2,62 m^3/s	2,24 m^3/s
Aprox. weight	3,15 kg	4,2 kg
Weight w/ package	3,77 kg	-
Dimensions	1,14 m diameter	1,10 m diameter
Dimensions w/ package	24x 17,5x 55cm	19,5 x 16,0 x 47,1

Compared to carbon steel, used in the production of fan A, polycarbonate has lower density (1.20 g/m^3 opposed to 7.8 g/m^3 of carbon steel), which directly reflects into a reduction of nearly 35% in weight. In addition to using light material, SPIRIT's designers created transversal ribs along the fan blades to stiffen the structure, requiring an even smaller amount of material (verbal information)[1] which is exactly, according Manzini and Vezzoli (2008), one of the solutions to reduce material intensity.

Another factor that differentiates SPIRIT from the other fans is that it was produced with only two blades instead of the usual three or four, further reducing its material load. Another aspect related to the production phase is also essential for environmental analysis: it concerns the number of components, parts and assemblies used in the products. According to ecodesign strategies proposed by Manzini and Vezzoli (2008), the reduction of the number of parts can optimize manufacturing processes and assembly. It can also mean lower energy consumption and reduced use of material resources.

Table 3 provides a more accurate comparison of the number of components that are used in each fan. SPIRIT presents a reduced number of components compared to the traditional fan. The most outstanding aspect of this difference is the use of fewer fasteners (screws, nuts, washers) required for the complete fan assembly.

As it can be seen, the design of the SPIRIT fan proposes a significant reduction in the number of parts and components. This reduction also leads to a significant reduction in energy consumption during production. The fact that SPIRIT has fewer parts and fasteners also implies easy assembly and disassembly, repair and replacement of parts. Besides, it allows an increased production capacity, a reduced energy consumption, facilitating thus the recycling process at the end of its useful life.

The Environmental Decision Aid Matrix (MADA) (Table 4) provides a qualitative comparison between the SPIRIT fan and a traditional one based on some key environmental requirements and function units. Although parameters are based on quantifiable characteristics and correlation factors (grades) are expressed by numbers, they represent a level of quality and not an exact quantity – of items, parts nor types of material, for example. Correlation factors definition is also dependent on a certain degree of subjectivity, since the choice between a weak, moderate or strong correlation varies according to different parameters for each characteristic and the decision on the boundaries to be established for each grade is to be made.

Identification and analysis of function units and environmental requirements related to the delivery phase

According to ecodesign strategies, the reduction in the volume of the package can bring significant environmental gains. During product transportation, there is an increase in the storage capacity and a reduction in the number of trips per truck. Therefore, strategies used in order to design detachable, foldable or stackable products are essential to reduce the volume of packaging.

Table 3. Comparing the amount of components used to produce SPIRIT and the traditional model produced in 2001.

components description	 **amount of components SPIRIT fan**	 **amount of components fan A**
Ceiling support	01	01
Superior scutum	01	-
Locking pins	03	02
Rod	01	01
Canopy	01	02
Blades or propellers	02	03
Motor housing	01	01
Screws	08	16
Bushing	02	02
Lower bushing or bushing support	01	01
Nuts or washers	04	27
Cotter pin	-	02
Claw to secure blades	-	03
Total number of components	**25**	**61**

Source: Fan installation manuals.

[1] Information obtained from Luis Augusto Indio da Costa (design diretor of Indio da Costa A.U.D.T.) Interview in Rio de Janeiro, August 8th, 2011.

Table 4. *Matriz de Auxílio à Decisão Ambiental* (MADA) comparing environmental requirements of the SPIRIT fan and a traditional fan - production phase.

Correlation between environmental requirements and products characteristics: 9. strong correlation; 3. moderate correlation; 1. weak correlation; (-) insufficient data		Product function units											
		 SPIRIT Fan						 Traditional fan					
Environmental Requirements		Number of parts and components	Number of types of materials	Optimization of the structure (use of ribs)	Efficiency of the productive	Number of assembly elements	Percentage of recyclable materials	Number of parts and components	Number of types of materials	Optimization of the structure (use of ribs)	Efficiency of the productive process	Number of assembly elements	Percentage of recyclable materials
PRODUCTION	Use of a smaller amount of material	9	9	9		9	-	3	9	3		1	-
	Ease of assembly	9				9		3				1	
	Reduction of energy consumption	3			-	3		1			-	1	
Environmental attributes of the product		21	9	9		21		7	9	3		3	
Environmental attributes (average)		**60**						**22**					

Table 5. Technical specifications of the SPIRIT fan and a traditional fan (A).

Technical Specifications	 **SPIRIT fan**	 **fan A**
Model	wind 200 without lamp	without lamp
Aprox. weight	3,15 kg	4,2 kg
Weight package	3,77 kg	-
Dimensions	1,14 m diameter	1,10 m diameter
Dimensions package (box)	24x 17,5x 55cm	19,5 x 16,0 x 47,1

Both products analyzed have removable parts, resulting in compact packages. However, SPIRIT has a significantly bigger box when compared to fan A's, which implies losses of maximizing the capacity of transport and storage (see Table 5).

On the other hand, SPIRIT is lighter, which leads to a lower fuel consumption and reduced emissions during transportation and in the possibility of stacking a greater amount of boxes on top of each other.

The matrix shown on Table 6 compares some of the major technical and environmental requirements evidenced by subjective analysis of SPIRIT compared to the traditional fan during the distribution phase.

Unfortunately, more accurate information regarding logistics was not obtained and although it generates a significant impact, it could not be analyzed. This impact depends on the kind of vehicle and fuel type usedand on the distances covered.

Identification and analysis of function units and environmental requirements related to the usage phase

Each product type has a lifespan determined by different characteristics that may depend on its function, durability, serviceability and even on its aesthetic, functional or technological obsolescence. Products that consume energy during their use often have their greatest impact during this phase of the life cycle (Manzini and Vezzoli, 2008; ABNT, 2004). In this sense, the production of more

Table 6. *Matriz de Auxílio à Decisão Ambiental* (MADA) comparing environmental requirements of the SPIRIT fan and a traditional fan - distribution phase.

Correlation between environmental requirements and products characteristics: 9. strong correlation 3. moderate correlation 1. weak correlation (-) insufficient data		Product function units									
		 SPIRIT fan					 Traditional fan				
Environmental Requirements		Weight	Volume of package	Fuel consumption	CO^2 emissions	Distance	Weight	Volume of package	Fuel consumption	CO^2 emissions	Distance
 DISTRIBUTION	Use of a smaller amount of material	9					3				
	Ease of dismantling		9					9			
	Maximizing transport capacity and storage	9	3				3	9			
Environmental attributes of the product		18	12				6	18			
Environmental attributes (average)		**30**					**24**				

Table 7. Comparison of energy efficiency and air flow between the ceiling SPIRIT fan and the traditional model A.

Brand	Model	Average air flow de ar (m^3/s)	Efficiency [(m^3/s)/w]	Classification	Energy consumption (kwh/momonth)*	"Procel" Lable Class
		Speed	Speed		Speed	
		HIGH	HIGH	HIGH	HIGH	
 SPIRIT	Wind 200	2,62	0,024	A	3,32	Yes
 Fan. A	x	2,24	0,020	A	3,42	Yes

Note: (*) Energy consumption through the use of equipment for 1 hour per day per month.
Source: Adapted from efficiency table from INMETRO (2011).

efficient objects from the energy consumption point of view is extremely important to reduce negative impact. Moreover, designing a suitable life span for each type of function is also important to minimize the environmental burden caused by the disposal of the object.

With respect to fans, it is essential to analyze their efficiency regarding energy consumption as well as their efficiency of ventilation during operation. According to INMETRO's references (2011), when placed under the same conditions of use as fan A (high speed), SPIRIT presents higher energy efficiency, with an approximately 17% smaller monthly consumption.

This reduction in energy consumption may seem not very relevant, but throughout the fan's life it represents significant savings. It is due to SPIRIT's aerodynamic shape which increases its technical efficiency with an important improvement in air flow (- 2.62 m^3 /s against 2.24 m^3 /s).

Another important factor to be considered at this stage of analysis is the influence of certain aspects concerning the product's durabilitity, which include its aesthetic characteristics, its conditions of use, as well as its maintainability and resilience. With regards to the aesthetic characteristics, SPIRIT presents a minimalist design and aerodynamic shapes, also offering different color possibilities, which allows it to adjust to different needs and to be used for a long period of time. Fan A has a more traditional design and offers no diversity of colors.

When in normal use, SPIRIT also presents some advantages over fan A due to the fact that it is produced in thermoplastic material, which has higher strength, facilitates cleaning, resists to the weather wear and has insulating properties. The traditional fan may be affected by corrosion due to the use of steel and may offer some risk to the user during maintenance and cleaning due to the fact that it is manufactured with electric conductive material.

With regards to the possibility of repair, which extends to the time of use, both fan A and SPIRIT can be disassembled and admit replacement of parts and repair in case of dammage.

All these environmental characteristics and techniques related to the products have been compiled and evaluated in the matrix presented in Table 8.

Identification and analysis of function units and environmental requirements related to the discard phase

According to Manzini and Vezzoli (2008), there are a number of options for a product's final destination when it comes to disposal, amongst which, reusing and recycling are important ones. Regarding the possibilities of reusing a product or its parts, well-preserved objects – clean and well-maintained ones – are known to be more likely reused. Also, the fact that some objects are easily dismounted facilitates the reuse of their parts. Therefore, SPIRIT has higher chances to be in good conditions to be reused at the end of its life since polycarbonate is easily cleaned and has little risk of being damaged due to the action of the weather. SPIRIT's parts are also easily disassembled, facilitating the reuse of its parts.

Moreover, according to ecodesign strategies, reduction in the number of components can significantly enhance the disassembly process, since it reduces the time spent in this process and makes it easier to separate parts that are incompatible for recycling (Manzini and Vezzoli, 2008; Papanek, 2007). SPIRIT presents, thus, advantages from this point of view when compared to similar products, because it has significantly fewer parts and gussets, as shown in the production phase. SPIRIT's parts are also 100% recyclable due to the characteristics of polycarbonate which can be turned into raw material for other different products.

Products employing fewer different types of material or fewer incompatible types of materials also favor the separation and recycling process, as each type of material used needs to go through different recycling processes. Concerning this issue, the two products use an equivalent quantity of types of different material, so this aspect will not be detailed here.

Having different types of material identified according to standardized encodings is also an important factor to be considered when it comes to recycling processes (Manzini and Vezzoli, 2008; ABNT, 2004). Materials used in the production of SPIRIT's components are partially identified, while no coding was found in fan "A".

As to the use of toxic substances in the composition of the material used, it was not possible to evaluate this aspect due to lack of reliable information about both products.

The matrix in Table 9 compiles some of the data discussed above in relation to the disposal phase.

Final remarks: MADA as an user- friendly tool to support sustainable product development

Figure 3 shows a compilation of the results obtained from the analysis of the phases of the life cycle of SPIRIT and fan "A", comparing the environmental performance of both products according to the requirements used in the

Table 8. *Matriz de Auxílio à Decisão Ambiental* (MADA) comparing the environmental requirements of the SPIRIT fan and a traditional fan (A) - phase of use.

Correlation between environmental requirements and products characteristics: 9. strong correlation; 3. moderate correlation; 1. weak correlation; (-) insufficient data		Product function units: SPIRIT fan							Traditional fan						
Environmental Requirements		Aesthetic obsolescence	Resistance of product parts	Materials employed	Life span	Energy consumption	Air flow	Ease of disassembly	Aesthetic obsolescence	Resistance of product parts	Materials employed	Life span	Energy consumption	Air flow	Ease of disassembly
USE	Durability	9	9	9	-				3	3	3	-			
	Ease of maintainability			9	9			9			3	3			9
	Energy consumption reduction					9							3		
	Ventilation effiency						9							3	
Environmental attributes of the product		9	9	18	9	9	9	9	3	3	6	3	3	3	9
Environmental attributes (average)		**72**							**30**						

Table 9. *Matriz de Auxílio à Decisão Ambiental* (MADA) comparing the environmental requirements between SPIRIT Fan and a traditional fan (A) – disposal phase.

Correlation between environmental requirements and products characteristics: 9. strong correlation; 3. moderate correlation; 1. weak correlation; (-) insufficient data		Product function units											
		SPIRIT fan						Traditional fan					
Environmental Requirements		Materials employed	Variety of materials	Number of parts and components	Number of assembly elements	Materials identification	Toxicity of materials	Materials employed	Variety of materials	Number of parts and components	Number of assembly elements	Materials identification	Toxicity of materials
DISPOSAL	Ease of reusing the products or its parts	3						3					
	Ease of disassembly			9	9		1			3	1		1
	Ease of separating different materials		9	9	9	3			9	3	1	1	
	Ease of cleaning and maintenance	9						3					
	Safe for incineration, without the release of toxic emissions						-						-
Environmental attributes of the product		12	9	18	18	3	1	6	9	6	2	1	1
Environmental attributes (average)		**61**						**25**					

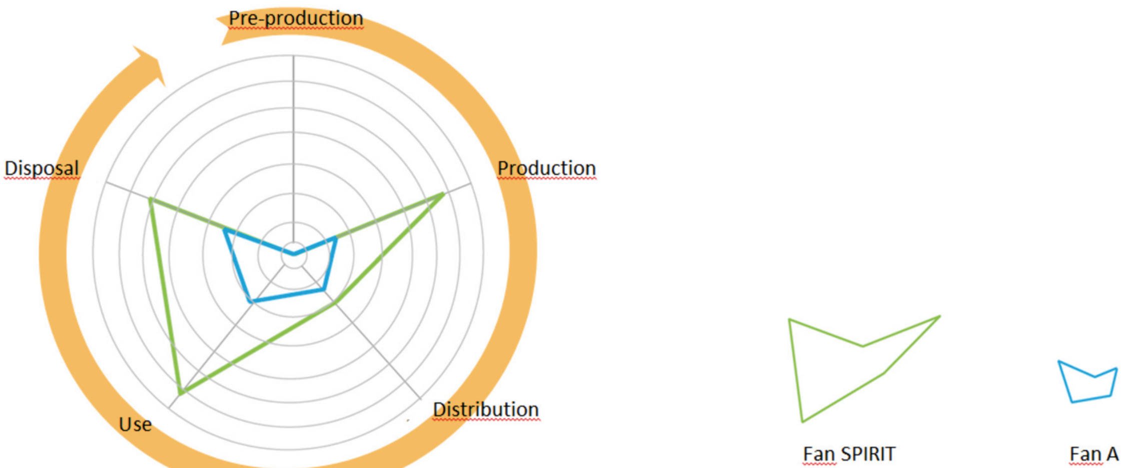

Figure 3. Environmental performance of products throughout the phases of production, distribution, use and disposal.

qualitative assessment performed by MADA matrix during the phases of production, distribution, use and disposal.

According to the analysis, SPIRIT presented a better performance in virtually all phases of the life cycle investigated, as well as a significantly greater percentage of desirable technical and environmental attributes concerning sustainability when compared to fan "A".

Moreover, through all phases of the life cycle analysis, but especially in the phases of production, use and disposal, SPIRIT presented significantly better environmental attributes compared to the similar product.

MADA proposed methodology does not evaluate the final environmental impact or environmental performance of products, nor does it measure how environmentally efficient a product is, but it shows which of a series of produts has a better environemental performance. It may be used to compare an existing or projected product against one or mulitple reference products. It may also be used to indicate the best suited project among a number of possible candidates. Despite its limitations, it provides subjective data on environmental attributes presented by products and thus constitutes an important tool to aid decision, which can be used to support projects related to sustainable products development or even encourage environmental improvements to existing products.

Therefore, the use of the matrix along with ecodesign strategies may contribute to a qualitative evaluation involving the life cycle of products and may also be easily incorporated into the daily routine of designers as a decision and evaluation tool due to its simplicity in construction and comprehension.

However, this research encountered some difficulties that may have directed its course of research and influenced its results: the fact that the information related to the product life cycles was restricted reinforces the theory of various authors such as Byggeth Hochschorner (2006); Chehebe (1997); Luttropp and Lagerstedt (2006); Masui *et al.* (2003), Papanek (2007), Vidal (2002), about the problems of getting all the data involving the entire life cycle of products, due to its high complexity. Despite these difficulties, case studies can bring contributions to increase knowledge of sustainable production practices in Brazil, aggregating important information that may guide different ecodesign strategies.

The example presented privileged requirements concerning mostly functional traits of the products. But sustainability is also linked to more subjective issues such as those related to the attractiveness of the product or to the affective component it carries, which were briefly brought up. The methodology addresses, therefore, all kinds of requirements – the choice amongst a large number of possible requirements is one of the most important steps of the process. According to Roy (1998), the world is made of limited "processors" of information. They deal with it in a serial form within an environment of infinite complexity when compared to their ability to capture and process data. If it is impossible to cover all the complexity, it is, however, necessary to determine which processes may be more representative of the problem and put them as the focus of attention.

The amount in which the use of the matrix and of ecodesign strategies could eventually be misleading was not the focus of this research – but rather they seem to bring information to light and contribute for conscious decisions. As Roy (1998) states, the aim of the decision support process is mainly the development of knowledge about the conditions and means in which decisions can be based, in light of what is believed to be appropriate.

Design is known to be a highly interdisciplinary subject, and the complexity linked to the LCA of products and the investigations of environmental issues also reinforce the importance of a systemic approach. A new environmental, social, productive and economic rationality depends on integrating the different disciplines involved in product development.

Acknowledgements

We acknowledge the support provided by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

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Submitted on March 05, 2013
Accepted on July 05, 2013