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Eco-innovation and knowledge management: issues and organizational challenges to small and medium enterprises

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Abstract

The proposed methodology is based on a (global and multi-criteria) simplified environmental but thorough assessment. In this stage we do not directly give the solution to designers. It will therefore translate the results of evaluation design axes, but in general, the lines proposed are inconsistent or contradictory. Therefore, what we find is a compromise given to the solution. The challenge we are facing in an industrial reality is that one should not go for a compromise solution. TRIZ (Teorija Reshenija Izobretateliskih Zadatch) or the theory of solving inventive problems, in the field, will be reformulated and go through the contradiction matrix and then intervene with the principles of interpretation resolutions to give possible solutions. To assist small and medium enterprises (SMEs) in their product development, the objective of this paper is to propose a methodological approach named *Ecatriz*, that will allow us to achieve our eco-innovative goal. The applicability of this method is justified by the many contradictions in the choices in a study of the life cycle. As a starting point, a qualitative multi-criteria matrix will allow the prioritization of all impacts on the environment. A customized implementation of the inventive TRIZ (*Teorija Reshenija Izobretateliskih Zadatch*, Russian acronym for theory of solving inventive problems) principles will help us choose eco-innovative solutions. To that end, we have created a new approach named *Ecatriz* (ecological approach TRIZ), based on a new contradiction matrix. It was tested in various contexts, such as the "24 h of Innovation" competition and eco-innovative patents.

Introduction

Determining and taking into account the environmental impacts caused by small and medium enterprises (SMEs) is a major challenge. The traditional environmental assessment used when implementing an eco-innovation process is long and arduous, and furthermore, does not provide designers with direct solutions. In addition, SME employees responsible for innovation face a dearth of data, and even where data are available, it is most often hard to collect, and ultimately, the time needed to evaluate it is very long (Cherifi *et al.*, 2015).

Designers are also confronted with constraints such as the choice of eco-innovation tools to adapt to the context of the company, the interconnection of these tools with those usually used in the design process, and the acquisition of skills in order to be able to use the tool adapted at the right time (Tatiana, 2007).

For all these reasons, companies quickly become paralyzed when faced with the need to use eco-design tools (Rennings, 2000). With this reality in mind, we propose a methodological framework dedicated to designers with no eco-innovation tools expertise.

Starting from a methodological problem solving approach based on TRIZ (Teorija Reshenija Izobretateliskih Zadatch) (Altshuller, 1984), and associated with the use of knowledge already available within SMEs, we propose a framework that may enable these entities to develop eco-innovation practices. The *Ecatriz* (ecological approach TRIZ) tool proposed is user-friendly, and can be used by non-experts in eco-innovation.

In the first, we present the background and the need of eco-innovation in SMEs.

The need for eco-innovation in SMEs: challenges and problems

SMEs must consider innovation constraints both in their strategic and functional practices. These entities are characterized by specific aspects that make them vulnerable, due to their market, their context, their environment, their customers and their competitors. Most often, they follow intuitive strategies proposed by the founding manager. However ideally, climate and conditions conducive to successful innovation should be promoted. The key factors that generally determine the success of innovation projects include:

(a) the contractor's capabilities and their involvement;
(b) the presence of adequate human and financial resources;
(c) the control of tacit and explicit knowledge needed to create new knowledge that must materialize innovation

Eco-innovation allows environmental constraints (e.g., limiting the emission of CO_2 or other products, prioritizing the use of recycled materials, etc.) to be taken into account, which enables a connection with the objectives that promote sustainable development. The applied dimension of eco-innovation goes hand in hand with the product or service life cycle analysis model. Eco-innovation solutions must therefore integrate environmental compliance parameters, as stipulated by the ISO 14062 standard, based on the development and support optimization of the eco-efficiency ratio.

State of the art

Eco-innovation calls upon a set of strategy and perception approaches with prevention and thinking in terms of life cycle, as the focus of eco-innovation (Falk and Ryan, 2001).

It is therefore a response to the current practice of eco-design, which allows only one approach to reducing environmental impacts and optimizing current economic practices, whereas sustainable development requires more radical changes in products and services (Tyl, 2011). Eco-innovation therefore proposes a vision comprising a new environmental approach and business strategy.

Moreover, from an economic perspective, eco-innovation facilitates many opportunities, such as a new goal or benefit secured thanks to a new vision to open new markets for desirable goods (Baroulaki and Veshagh, 2007).

It is therefore important to have a twofold understanding of the term 'eco-innovation' (Tyl, 2011):

- The first one, through a horizontal reading, allows us to see the variety of definitions which have evolved in a recent past (Klemmer *et al.*, 1999).
- The second one, through a vertical reading, allows us to put eco-innovation in its appropriate context (Matthieu, 2008).

The two studies conducted by Carrillo-Hermosilla et al. (2010) and Matthieu (2008) provide a comprehensive view of both these perspectives.

Dangelico and Pontrandolfo (2010) worked on eco-design tools that can help engineers in the ecological design of products. Other studies describe a new model to accelerate the preliminary design of an eco-innovative product incorporating the concepts of the TRIZ method (Cheng and Jahau, 2011). Several examples of eco-design are given to illustrate the capabilities of such process in the work of Jahau Lewis and Chih Chen (2001).

Russo *et al.* (2009) describe a way to use TRIZ concepts and tools to analyze, evaluate, and innovate a technical sustainability system that can be easily incorporated into design practice in daily life. Other studies compare the trends in the evolution of TRIZ with the eco-design strategies presented in the framework of the LiDS wheel (Lifecycle Design Strategies) to analyze its effects on environmental parameters (Chulvi and Vidal, 2009).

Some authors present a new forecasting model to acquire new ideas and to help design environmentally friendly products, while following new design assessments to see if it is more effective than those currently available (Houssin and Coulibaly, 2010).

Based on the Mal'IN (*Méthode d'aide à l'innovation*) and Eco-Mal'IN methods, a new eco-innovation tool based on the matrix invention was developed by Kallel (2010). Other authors have proposed the "Ecological Advanced Systematic Inventive Thinking" (Eco-Asit) tool for promoting the eco-ideation of sustainable systems (Tyl, 2011).

In spite of that Chechurin and Borgianni (2016) stated that actual scope of TRIZ goes well beyond technical problem solving, some other studies are already published applying TRIZ on ecologic problems. Since Russo *et al.* (2014) presented a method based on a set of eco-design guidelines specifically conceived to support designers in developing new greener products. They proposed TRIZ Eco-guidelines to support ECO-innovation in SMEs. Over 300 TRIZ based eco-design guidelines (Russo *et al.*, 2009) are selectively introduced to develop design variants with the aim of providing a lower global environmental impact (Russo *et al.*, 2015). Vidal *et al.* (2015) identified and prioritized TRIZ evolution trends that improve the environment.

The proposed innovative methodology helps designers to predict technological evolutions for more environmentally friendly products. TRIZ also used to improve the building environment (Wang *et al.*, 2015) where the enterprise environmental parameters are used to solve the management conflict matrix. Filippi and Barattin (2015) developed a new design method where systematic approach to innovation of TRIZ compensates for some lacks of the user centered interaction design process. Hede *et al.* (2015) proposed a conceptual multifaceted framework to address the issue of social sustainability in product development. They used evaluation technique is utilized for assigning numerical values to the pertinent sustainability related criteria of the multilayered decision model.

Diego *et al.* (2016) proposed an integrated model focused on the systematic generation of eco-innovations in Lean PSS environments. The proposed model enables an analysis of the existence of a waste or contradictions in the system, that is, the existence of a problem. They proposed TRIZ tools to analyze, to model, and to solve the eco-innovation problems.

Ben Moussa *et al.* (2017) showed how to evolve TRIZ to address green supply chain problems and the use of ARIZ to solve an operation management problem. Ben Moussa showed also the limits of using the classical TRIZ model for green supply chain problem solving. Also, Mansoor *et al.* (2017) used TRIZ for innovating problem solving for sustainable green roofs recognized as worthy strategy for making buildings more environmental friendly and sustainable. Therefore, we developed and tested *Ecatriz*, based on TRIZ, to find a solution avoiding compromise when integrating environment constraints in innovative product design. This approach allows us to move from a matrix of engineering parameters (EP) to a reduced matrix with eco-efficiency parameters.

It will be used for decision support in the case of contradictory ecodesign situations. The methodology is given in the following section.

From the TRIZ matrix of EP to eco-efficiency parameters for innovation

The environmental impact evaluation results of each assessment must therefore be translated into design axes, for practical purposes. However, the proposed axes are generally inconsistent or contradictory; hence, a compromise solution must be sought. However, a problem solved by compromise in the context of

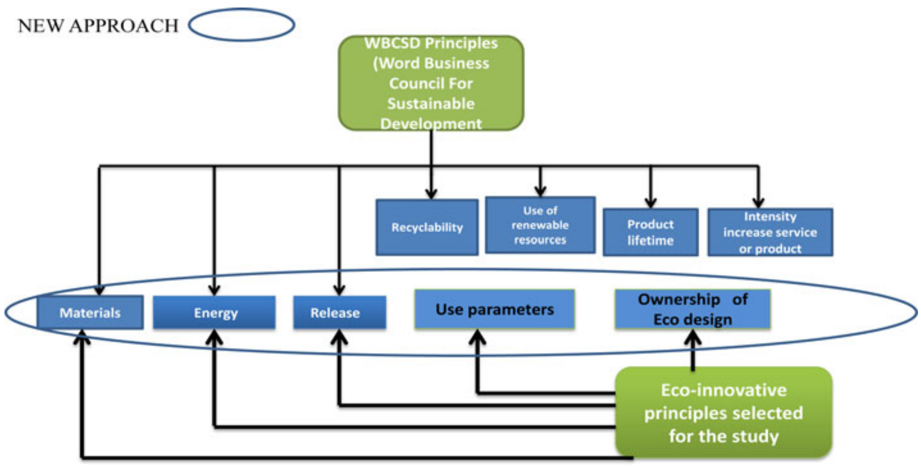
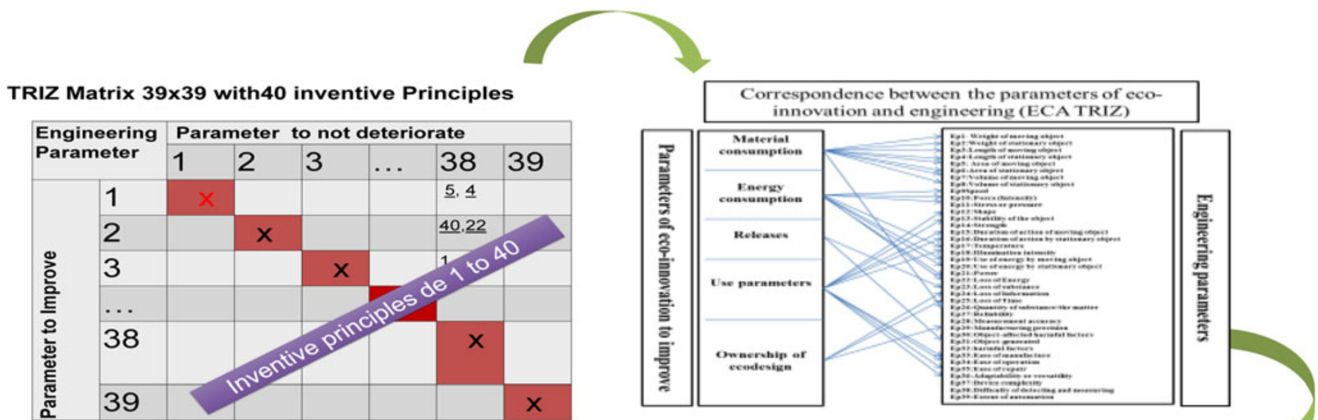


Fig. 1. Choice of ecoefficiency parameters.



Ecoefficiency parameters	Materials	Energy	Releases	Utilisation parameters	Ownership of ecodesign
Materials	x	5,4,40,22,	35,3,5,22	2,35,1,25	1,32,10,35
Energy	19,18,6,3	x	35,2,27,18	19,2,35,1	10,19,35,18
Releases	35,6,22,3	35,2,27,18	x	2,35,39,40	10,35,15,4
Utilisation parameters	3,35,27,25	1,13,15,2	2,35,40,28	x	10,4,32,1
Ownership of ecodesign	10,35,28,32	32,10,19,2	35,10,18,22	10,32,35,1	x

Eca TRIZ Matrix 5X5

Fig. 2. The approach to obtaining the *Ecatriz* matrix.

the industrial reality often results in an insufficient long-term solution.

Initially, we built a matrix to determine the general environmental profile of the potential product from a series of questions related to its life cycle. The impact assessment is done at each stage of the product's life cycle.

The advantages of such a matrix are:

- Ease of use and ownership.
- Consideration of all environmental concerns (multi-criteria) throughout the (global) product life cycle.
- Does not require data figures since the assessment is qualitative.
- Introduction of new eco-efficiency factors, including consideration of the product from the user's point of view and the level of ownership of eco-design at the company level.

TRIZ is based on the similarity that may exist between an inventive problem and a solved similar problem in another context or field. The TRIZ matrix is a solution principles database that can overcome some contradictions.

To apply TRIZ in the field of eco-innovation, we built a simpler eco-innovative matrix from 39 EP. These EP are classified and grouped under five types of eco-efficiency parameters selected from the World Business Council for Sustainable Development, considering materials, energy, and waste (liquid, gaseous, and solid).

We introduced two other new settings, which was the first time this had ever been done: parameters used by the designer or user of the final product in general (shape, stability, strength, etc.) and the degree of ownership of ecodesign (culture, the degree of involvement in eco-design within SMEs, etc.).

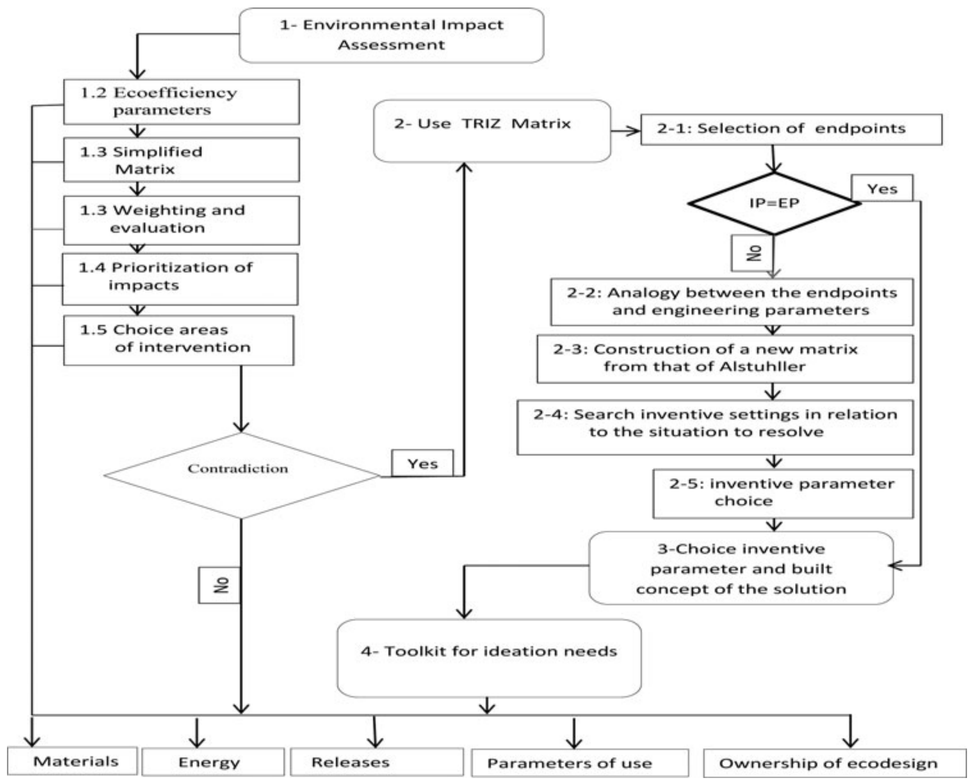


Fig. 3. Eco-innovating *Ecatriz* process.

The importance of introducing the use parameters that needs to take care of, in addition to environmental factors, social needs of the user in the context of an eco-innovative approach.

The second criterion introduced for the first time, which is a priority in our opinion, is the degree of ownership of the designer of the company or service provider ecodesign.

In order to exploit the matrix of EP and adapt it to eco-innovation chosen parameters, it was necessary to combine EP by category eco-innovation parameters considered.

We considered the introduction of these two parameters important in the case of innovative design, for the first case, and for the appropriation of eco-design by the company's designer in the second case.

The eco-efficiency factors retained for this study are presented in Figure 1 (Cherifi *et al.*, 2017). These choices are justified by the fact that recyclability, renewable resource use, product lifetime, as increased product or service intensity can be incorporated into materials or discharges. Inventive principles were selected and grouped from the initial matrix according to their frequency of occurrence.

To maximize the probability of occurrence of each parameter in the eco-efficiency parameter, we established a maximum number of settings. We obtained a new matrix, 5×5, composed of eco-efficiency parameters, and an x- and a y-axis, with new inventive numbers. Figure 2 presents the TRIZ matrix to the new matrix called *Ecatriz* (ecological TRIZ). The overall methodological approach is given in Figure 3. A set of rules to improve a particular aspect in the life cycle must be given. This constitutes the core of a state-of-the-art exploration approach used to achieve eco-design products. In this approach, we could use technical troubleshooting tools that have proven themselves in other areas, such as the generation of new concepts that may be tested in eco-innovation.

The matrix is composed of the same EP (horizontal to be improved and vertical not to deteriorate). Each situation of pairs of contradictory parameters chosen will correspond to numbers of inventive principles (cross in the matrix) that may be possible solutions to the problem.

Thirteen principles motivated by the frequency of occurrence of these tracks of solution in the new matrix called levers for eco-innovation (segmentation, extraction, inversion, sphericity, periodic action, prior action, mobility, color change, vibratory action, composite material, and cheaper object) are chosen.

The designer will choose the best-suited of these selected inventive principles to solve the problem in accordance with the given situation (Fig. 4).

The levers or actions developed in Figure 4 allow the *Ecatriz* matrix to be more user-friendly for designers, who find the principles to solve it need in the rectangle. The matrix aims to improve the product development process or establish environmentally friendly procedures in an innovative approach and uncompromised solution. It can be applied to the launching of a new product or used to improve an existing one.

Looking more for creative ideas with Ecatriz

The inventive principles obtained, which are potential levers which assist the designer in the ideation phase, are divided into two categories, as shown in Figure 5. At this stage, we can choose strategies (deconstruction of the problem) that have been adapted to eco-innovation.

The idea generation phase consists in building stimulating sentences from four product phases (words of the problem):

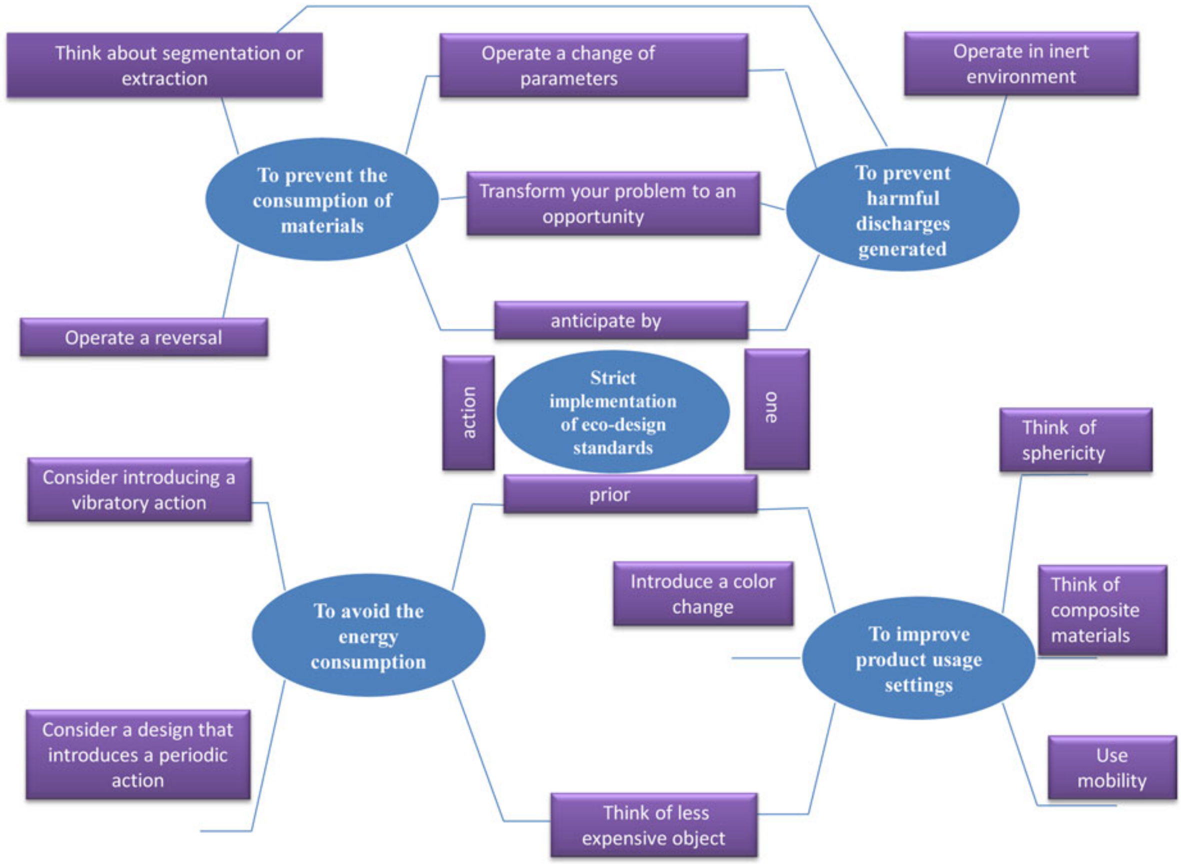


Fig. 4. Summary of the main possible actions for eco-design innovation based on the *Ecatriz method*.

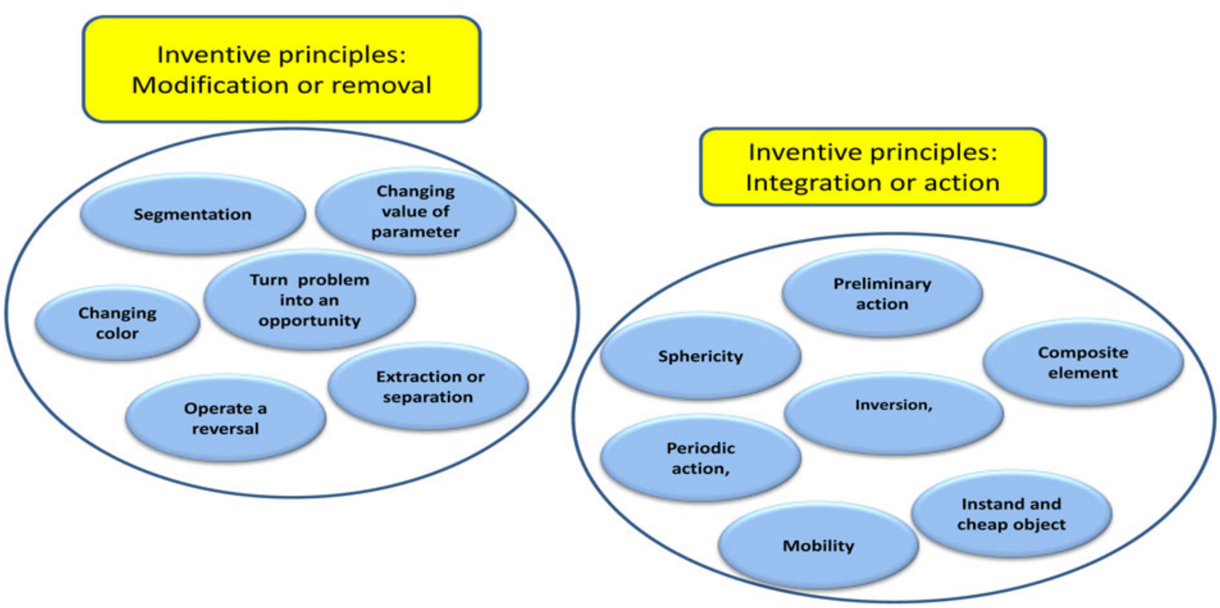


Fig. 5. Categorization of the inventive principles obtained.

1. raw materials
2. product phase
3. use phase
4. end of life phase

and two actions promoting life cycle thinking:

1. modification or removal (six inventive principles)
2. integration or action (seven inventive principles).

A summary of 52 sentence possibilities ($6 \times 4 + 7 \times 4$) is given in Figure 6. To generate creative ideas, the *Ecatriz* eco-innovation

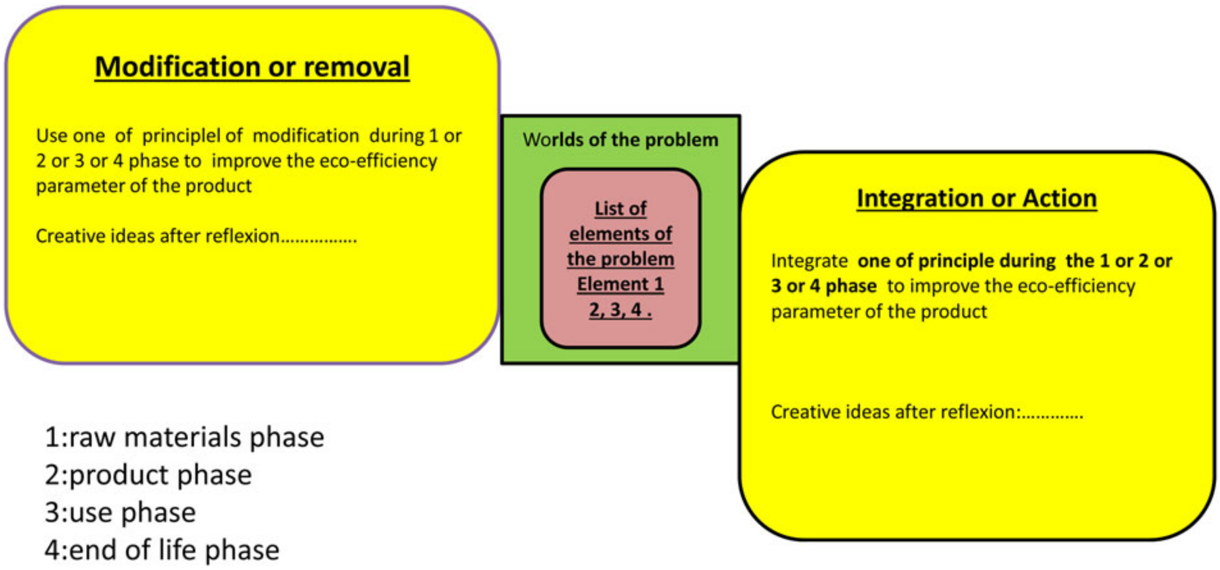


Fig. 6. Stimulating sentences from words of life cycle and tools composed by inventive principles.

Table 1. Matrix of Nonaka and Takeuchi

	Tacit knowledge	Explicit knowledge
Tacit knowledge	Socialization	Outsourcing
Explicit knowledge	Internalization	Combination

approach can be made operational and enriched by knowledge management elements developed in the following section.

Knowledge management elements to complete Ecatriz

Given the situation of SMEs (scarcity of resources, limited staff, etc.), designers can rely on the tacit and explicit knowledge the company possesses. This knowledge will help find new solutions to improve the analysis of the life cycle as well as the eco-efficiency ratio (Nagano *et al*., 2017). Eco-innovation initiatives should ideally be structured according to the knowledge creation model of Nonaka and Takeuchi (1995), see Table 1.

An example is given in Table 2 in the case of the consumption of materials. Through socialization characterized by situations of direct contact or observation, everyone can give an account of the tacit knowledge they possess (Dalmanco *et al*. 2017). Similarly, outsourcing activities, based on explicit knowledge, allow encoding the eco-innovation solutions already used in other contexts of the project (Albers and Brewers, 2003); thus, inducting concrete solutions to reduce the consumption of resources and energy. Finally, internalization, characterized by the appropriation of explicit knowledge that is held individually contributes to the management of existing knowledge and to the production of new knowledge, which increasingly affects the eco-efficiency ratio.

Nonaka's and Takeuchi's production-of-knowledge model (generic framework already associated in the methodological guide) – in operational terms – is necessary to integrate the functional rosette of communities of practice (Nonaka and Takeuchi, 1995). It characterizes all the knowledge management activities that contribute to the creation, sharing and dissemination, and valorization of knowledge needed to rationalize and optimize the eco-innovation process (Albers and Brewers, 2003; Nagano *et al*., 2017). Figure 7 shows how the community of practice proposed by the Prax (2003) model may be a useful aid in the proposed *Ecatriz* approach, especially in terms of solutions to be found regarding the specification of the problem to be solved, the choice of adequate materials, the identification of suitable energy solutions, etc.

The combination above illustrates the application of basic knowledge to the eco-efficiency factor improvement process. It is very obvious that the knowledge base serves as much for the consumption of materials as for energy choice, or for the product settings as well, with all these elements being dimensions that are included in the eco-innovation model. These factors are well fed by an internal as well as external knowledge base (Albers and Brewers, 2003; Nagano *et al*., 2017). This combination therefore offers a more robust eco-innovation model because it is practical and based on knowledge available to and easily appropriated by non-experts.

Application of the *Ecatriz* method

Challenges of 24 h of innovation competition

We applied the *Ecatriz* method to assess the solutions proposed by the student teams to meet the challenges of the "24 h of innovation" competition. As part of the 24 h of innovation, a marathon during which students must answer problems created businesses, we established a simplified evaluation grid which helps participants conduct an ecological evaluation of a suggested design. The idea here is to take into account the environmental aspects of the product, employing a simple, easy-to-use tool, which can be applied rapidly, and does not rely on a database, thus making the application quantitative.

The other advantage that this tool presents is that it allows a multi-criterion analysis throughout the life cycle of the product.

This simple and rigorous application can be used by the designer.

Table 2. Example of an application of the knowledge base

Eco-efficiency factor	Principles	Actions (new knowledge)	Bases to generate the new knowledge	Activities for generating new knowledge
Material consumption	• Segmentation • Extraction • Converse action • Transform the problem into an opportunity • Change settings • Prior action	• Split an object into independent parts • Make the object removable • Increase the degree of segmentation. • Separate parts of the object • Inverse action, • returning • Use adverse factors, eliminate the detrimental effect, amplify the damaging effect until it disappears	Tacit knowledge Explicit knowledge Benchmarking External databases Internal database Experience from previous projects	Socialization Outsourcing Combination Internalization

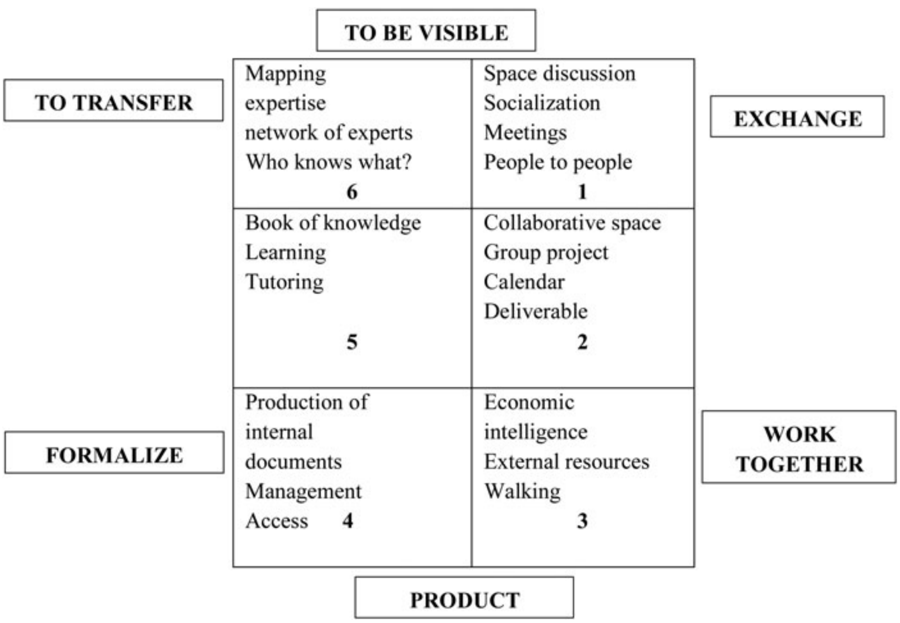
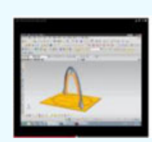
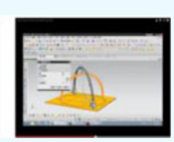
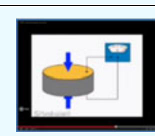
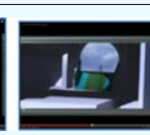


Fig. 7. All knowledge-management activities.

Table 3. Summary of the main applications

Title challenge	Problem	Solution provided by the method	Solution given	Illustration
Reduction of the size of the tent poles in a circus	Impact on the visibility of some seats behind the mats. Increase their values in the sale of tickets in circus.	• Sphericity • Composite materials	• Structure in bow • Light alloy	 
Re-inventing stairs	Find new ways to increase the use of stairs	• Prior action • Change color	• Piezo-electric recovery • Effect color for better visibility	 
Road sharing	How to promote safe road sharing	• Sphericity • Mobility and prior action	• Linear curve forms • Generation of electricity	 

Source: http://24hinnovation.agorize.com/.

Table 4. The methodological tool applied to examples of published patent

Name of concept or product	Presentation	Choice of inventive parameter consistent with our approach
Shoe sole (Olivier and Brunot, 2007) Publication number EP1928277A	Choosing a shape and sole with improved strength, that minimize energy consumption and are recyclable. Concept: Antibacterial composite yarn, three-dimensional textile structure and multilayer.	*To improve* EP 12: Shape EP 13: Stability EP14: Strength Without damaging: Energy, materials and releases *Inventive principles selected from the method* 40: Composite materials
Ceramic based on clinker garbage (Vincent, 2007) Publication number EP1215182B1	The present invention relates to a crystalline-based material of clinker. It finds particular use in the field of crystalline ceramic-like materials. Objective: Save energy by lowering the temperature while maintaining the mechanical properties.	*To improve* • Energy consumption *Without damaging* shape, strength and stability Inventive principles: 19, 2, 35, 1 *Inventive principles selected from the method*: 35 (parameters change)
Cross railroad (Eric and René, 2013) Publication number EP2539508A1	Composite rail sleepers essentially polyurethane material typically, with excellent mechanical properties.	*To improve* • Use parameters (EP 14: Strength, EP12: shape, EP 13: stability) *Without damaging* • Releases *Inventive Principles:* 2,35,40,28,35,2,4014 • Material consumption *Inventive Principles*: 40,1,2927 • Energy consumption. Inventive Principles: 14,2,6,40 *Inventive principle selected*: 40 (Composite)

The best concept of solutions provided by participants generally agreed with all the *Ecatriz* principles. Table 3 provides an overview of the best eco-innovative solutions proposed to cope with some of the challenges.

Patents published in the area of eco-innovation

Another interesting application we considered was the use of *Ecatriz* to assess the published patents for products designed with the eco-innovative method (Table 4).

Conclusion

The idea of replacing the EP for the parameters of eco-efficiency is an approach justified by the existing of many contradictions of environmental factors and to adapt our approach to the situation.

Our main contribution is the creation of a simplified matrix which takes into account the life cycle of the product with a multi-criteria approach and the resolution of eco-contradictions using a suitable TRIZ principles selection. This leads us to obtain potential inventive principles (some of these principles may not be applied to all design configurations). However, the matrix may help the designer focus on helpful creative innovations.

The results obtained with the *Ecatriz* method were compared with the solutions given by students during the "24 h of innovation" competition as well as with the published patents relating to resolutions of environmental issues. This comparison showed that our methodological approach can be applied to different situations, with a high level of consistency regarding the proposed principles. *Ecatriz* could also be used as a referential kit to obtain environmental objectives without transfer of pollution. To sum up, the results obtained by the *Ecatriz* method will guide designers along potential eco-innovative tracks.

Acknowledgments. We presented some of this work at the ICED conference held in August 2017 in Vancouver. Results from a PhD thesis completed in 2015 enriched this article. The participation of all co-authors is noteworthy, I thank them for their valuable contribution.

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