



Establishment of a methodology for eco-innovation based on inventive principle

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Abstract - Today, in the context of product innovation, the environmental dimension takes a new dimension and can not be separated from other product requirements which make it competitive. Tools are available but unfortunately proficiency levels required for their use are at the expert's level. In the present work we have adopted an approach using a qualitative evaluation matrix including parameters related to the ease of use of the product related to the organizational preparation for the appropriation of an eco-design approach, in addition to the standard factors of eco-efficiency. In order to help the designer to make a decision, an adapted TRIZ method is proposed (Téoria Rechénia Izobréatelskikh Zadatch or theory of inventive problem solving). The applicability of this method is justified by the many contradictions in the choices in a study of the life cycle and can help designers and companies to choose an approach to attain a satisfying level of eco-design for the resources invested in it. An application, based on inventive principles, will be adapted and completed. This matrix can help the designer to reduce the scope of his creative investigations. The results of our methodological approach have been tested on cases of creative projects and a certain number of recently patented projects.

Keywords- Eco-innovation, Eco-design, TRIZ; Indicators, Eco-efficiency

I. Introduction

Commonly called LCA (Life Cycle Assessment), this assessment tool takes into account the evolution of the product, from the raw materials that were used in its manufacture, its use and end of life characterized by an important step of destruction and recycling, as well as all the intermediate steps (transport, packaging, storage etc.), which all generate negative impacts on the environment [1].

Some studies on life cycle assessment simply focus on the stage having the most impact, while others accentuate the entire product life cycle characterized by an important step of destruction and recycling. It is now recognized that the latter is tedious, time-consuming, expensive and difficult to carry out on the following grounds [2]:

- Lack of firm-level experts to implement the tool.
- Most companies prefer, when they stick to the principle, to opt for more simplified tools.
- Lack of spatiotemporal data, or when such data exist, they are fluid and difficult to control, which can seriously affect the impact of the assessment results.

Studying a design process for an existing product in an attempt to improve or develop a new one requires that each step will be considered in order to integrate environmental parameters which will allow a focus on the most sensible approach to improve its environmental qualities.

While many methods and approaches exist for eco-design their analysis however reveals that they are not used nearly enough, for three main reasons [3]:

- Some of them are complicated methods that require a high level of environmental expertise.
- Mediocre quality of data for results given with a large margin of error.
- Some are expensive methods that require significant human and financial resources.

The proposed methodology in this study is based on a (global and multi-criteria) simplified environmental but thorough assessment. In this stage we do not directly give the solution to the 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 Izobretatelskikh 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. The applicability of this method is justified by the many contradictions in the choices in a study of the life cycle.

The TRIZ method which has been proven in other areas for finding a solution without compromise will be deployed to transform these eco-design contradictions which have not been discussed before now. For example, increasing the lifespan of a refrigerator has positive effect on the management end of life but also have negative effects due to energy consumption.

From the matrix of engineering parameters we will build a new matrix based on parameters or eco-efficiency indicators in relation to these parameters. We have developed a methodology for formulating and solving problems of eco-innovation based on an approach established on conflict. This framework can handle the multi-objective requirements and complex combinatorial nature of the research phase of solution concepts. There will be question of presenting the different stages of our methodological approach and justification of choice. This discussion will lead us to identify the main contributions of this research and the development of an eco-innovation tool focused on the phases of creativity as well as the development of an experimental protocol that will allow us to argue about the performance of this tool for eco-innovation.

Among the strategic tools based on creativity sessions, while taking into account the eco-design are included: the Eco-compass [4], the wheel of Brezet [5] or the BEC diagram Luttropp and Lagerstedt [6]. One may also mention some checklists such as the Ten Golden Rules [1]. Among the tools focused on structuring the results of the creative session, Jones [7] studied a tool combining the mind map with eco-design inputs. However, it is now necessary not to seek to use the innovative principles of the matrix, but rather to reinterpret them, or also to modify the technical parameters, and it is possible to work on systems other than products [8]. Dangelico and Pontrandolfo [9] worked on the eco-design tools that can assist engineers in the ecological conception of products. The work of Cheng [10] described a new model to accelerate the preliminary design of the eco-innovative product by incorporating the benefits based upon reasoning and the TRIZ method. Several examples of eco-design are given to illustrate the capabilities of such a method already starting with the work of Jahau Lewis Chen, Chih-Chen Liu[11]. Hsiang Tang Chang [12] proposed an eco-innovating method based on a design approach using TRIZ. David Russo [13] described a way to use concepts and tools of TRIZ to assess, evaluate and innovate a technical system in such a way that some practical activities to ensure sustainable results can be easily incorporated into the practices of design in everyday life. Vicenti Chulvi [14] compared the trends of evolution in TRIZ with eco-design strategies presented under the name of LiDS Wheel (Life Cycle Design Strategies) to analyze the effects on environmental parameters.

At the base of the Mal'in and Eco-Mal'in methods, Kallel [15] developed a new eco-innovation tool based on the invention matrix. Benjamin Tyl [16] proposed the Eco-asit tool to promote eco-ideation of sustainable systems.

Strasser and Wimmer worked [17] worked on the combination of ecodesign and inventive principles TRIZ tool. Meant for design engineers providing a clear procedure for innovative ideas when developing environmentally conscious products.

Jones and Harrison [18] have shown that it is possible to extract the "principles" to resolve the contradictions encountered in strategic environmental management product.

These authors are based on practical cases of eco-innovation: the development of energy-efficient lighting fixtures. By analyzing in detail the evolution of these devices through patents, the authors showed that these innovations are the result of the use of TRIZ in solving several contradictions in relation to the objectives of ecoefficiency parameters previously set.

These last two methodological approaches in the context of research ecoinnovative solution is based on a similarity sought between engineering parameters and parameters of selected eco-efficiency. Exploitation of the contradiction matrix with organizational steps will guide the designer to one or more ecoinnovante solutions.

We considered two new parameters not least for ecoinnovative Design: User settings and ownership of ecodesign by stakeholders, which no proposed approach will be validated in our view.

In addition, we propose a rather simplified upstream prioritization of impacts and downstream phase of ideation for choosing the right solution ecoinnovative.

II. Research basis

The contribution of all this research through the models developed seems to us lacking support tools that are easily accessible to the uninitiated where applications can be accessible to scantily trained participants and the degree of ownership of the

designer of the company or service provider ecodesign. This, on the one hand; on the other, these days eco-innovation must support two very important dimensions to say the least: the parameters of use of the product as well as the readiness of companies and designers to eco-design. These two parameters are introduced for the first time in our methodological approach and are considered as factors of eco-efficiency to support any project of eco-innovating design [19].

The importance of introducing the use parameters that need to take care of, in addition to environmental factors, social needs of the user in the context of a 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 engineering parameters and adapt it to ecoinnovation chosen parameters, it was necessary to combine engineering parameters by category ecoinnovation parameters considered.

III. The Methodology

The methodology has been developed through the following characteristics (Fig. 1):

- Simple qualitative, comprehensive and multi-criteria evaluation, followed by a prioritization of impacts;
- TRIZ method for resolution of uncompromising problems;
- Choice of eco-efficiency factors related to engineering parameters;
- Establishment of an eco-innovative matrix;
- Justification of design parameters.

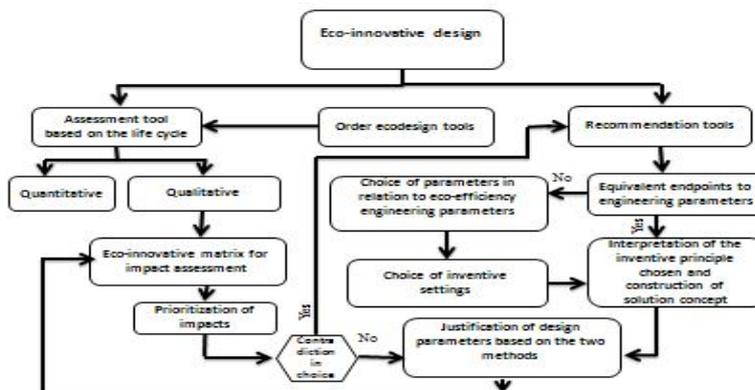


Fig. 1 Initiative of the eco-innovating process

A. Choice of the eco-design tool

The first phase of our approach is a review of most of the tools developed in eco-design. We felt it was necessary to separate them following two criteria: one of evaluation and the other one being one of prescription or interpretation of the results for the reduction of impacts.

Among the assessment tools we chose to work with are a qualitative matrix with a comprehensive and multi-criteria analysis. This is justified by the ease of ownership since the user does not require data based on a simple-to-use matrix, difficult acquisition and whose quality is often a source of uncertainty about the final outcome when it comes to using a quantitative tool, including no less important parameters related to factors of ease of product and of organizational preparation for the appropriation of the eco-design approach, in addition to the usual eco-efficiency factors. Finally, this tool allows to prioritize impacts. To help the designer to decide the method of solving inventive principles was proposed. This manner of procedure can help the designer to choose an approach and achieve a level of eco-design in proportion to the resources available to him and guide him, in the ideation phase, towards an eco-innovative solution.



B. Selection of eco-efficiency parameters

The concept of eco-efficiency is popularized by the World Business Council for Sustainable Development [20]. Eco-efficiency is usually described as a reverse ratio between two elements: environmental impact, to be reduced, and value of production, to be increased. That is to say, a larger eco-efficiency means more value created with less impact induced [21].

The basic expression proposed by WBCSD is adopted, which is written as: $\text{eco-efficiency} = \text{product or service value} / \text{environmental influence}$ [22]. The work of Chen and al [23] focused on the contradiction matrix of TRIZ. The authors sought, at first, to establish a correlation table between the 7 principles of eco-efficiency by WBCSD described below and the parameters of the TRIZ matrix.

- A/ Reduced demand for the materials for products and services;
- B/ Reduction of the energy intensity of goods and services;
- C/ Reduction of the dispersion of toxic substances;
- D/ Improvement of the recyclability of materials;
- E/ Optimization of the sustainable use of renewable resources;
- F/ The extension of the durability of products;
- G/ The increase of the operating intensity of goods and services.

In the present work we have grouped some factors given by the WBCSD considered materials, energy, waste (liquid, gaseous and solid). Two other new ones that we have to introduce for the first time are the use of parameters (form, strength, stability, durability and facility of use) and the degree of ownership of the eco-design by the designer.

Presentation of a matrix (with 25 cells) which consists in answering a series of questions related to the situations, and then noting the environmental impact (from 0 to 5, with 5 representing minimal impact) of five phases of the life cycle (prefabrication, manufacture, transport and packaging, use, end of life) for five environmental components (materials, use of resources, rejections of matter, user parameters, eco-design capacity). The total score varies between 0 and 125 (125 being the maximum of points to be collected for an eco-designed product). A_{ij} : Score obtained at the end of the evaluation following the answers to questions (grid 0-5, where 0 is the worst case). The results of this matrix will help the designer to focus his vision on one or more stages of the life cycle related to environmental (eco-efficiency factors) to be considered.

C. Selection of the TRIZ method

. TRIZ is a multitude of tools allowing to help solving creative problems. The simplest of tools and the best known of them is the resolution of technical contradictions matrix. It concerns a statistical summary of 400,000 patents of which were extracted the 40 000 most inventive ones.

The remaining patents have been analyzed in more detail in the following areas:
- The relationship between the problem before the patent has an opposition between 2 technical parameters which can be reduced by 39 generic parameters (Table 1);

- Methods having allowed to obtain the solutions in each patent are grouped into 40 families of Inventive Principles (Table 2). The resolution matrix is based upon thousands of resolved and past situations because these cases are similar in view of the engineering parameters in opposition, and could lead to resolutions through inventive principles most frequently used.

D. TRIZ in our methodological approach

For designers the problems arising from two or more conflicting parameters are often complex. These contradictions are often encountered when we are challenged by environmental assessments, particularly when it comes to dealing with situations of transfer of pollution. Different models of problem solving by TRIZ are used. We chose to apply the contradiction matrix. This matrix consists of 39 engineering parameters (Table 1) disposed on the abscissa axis and ordinate (Table 2).

Since the principle itself of the resolution without compromise is perfectly suited to the challenge of eco-innovation we adapted the method of Inventive Problem Solving using TRIZ

Table 1 The 39 engineering parameters [24] .

Num	Characteristic	Num	Characteristic
Ep1	Weight of moving object	Ep21	Power
Ep2	Weight of stationary object	Ep22	Loss of energy
Ep3	Length of moving object	Ep23	Loss of substance
Ep4	Length of stationary object	Ep24	Loss of information
Ep5	Area of moving object	Ep25	Loss of time
Ep6	Area of stationary object	Ep26	Quantity of substance/matter
Ep7	Volume of moving object	Ep27	Reliability
Ep8	Volume of stationary object	Ep28	Measurement accuracy
Ep9	Speed	Ep29	Manufacturing precision
Ep10	Force (intensity)	Ep30	Object-affected harmful factors
Ep11	Stress or pressure	Ep31	Object-generated
Ep12	Shape	Ep32	Harmful factors
Ep13	Stability of the object	Ep33	Ease of manufacture
Ep14	Strength	Ep34	Ease of operation
Ep15	Duration of action of moving object	Ep35	Ease of repair
Ep16	Duration of action by stationary object	Ep36	Adaptability or versatility
Ep17	Temperature	Ep37	Device complexity
Ep18	Illumination intensity	Ep38	Difficulty of detecting and measuring
Ep19	Use of energy by moving object	Ep39	Extent of automation
Ep20	Use of energy by stationary object		

Table 2 Part of the contradiction matrix table [24]

Engineering parameters

Parameter do not degrade		Ep1	Ep2	Ep3	Ep4	Ep39
Parameter to improve		Weight of moving object	Weight of stationary object	Length of moving object	Length of stationary object	Productivity
Ep1	Weight of moving object	-		15,8 29,34			35,3 24,37
Ep2	Weight of stationary object		-				
Ep3	Length of moving object	8,15 29,34		-			
Ep4	Length of stationary object		35,28 40,29		-		30,14 7,26
.....						
Ep39	Productivity					30,7 14,26	

inventive principles used most

The improvement of a parameter selected on the y-axis (vertical column) can degrade another one placed on the abscissa (horizontal line): the solution is to have generic principles that allow to eliminate the conflict rather than to be a compromise. Once the conflicting parameters (to be improved and deteriorating) have been chosen, the designer will be placed in the contradiction matrix (Table-2). The inventive parameters from 1 to 40 (Table-3) which can be a solution to the contradiction at the root of the problem are given by the matrix (Table-2) at the intersection of the conflicting parameters.

For some inventive principles that appear most often in the 39x39 matrix engineering, it is clear that their consideration leads to a high success rate for solving innovative design.

To apply TRIZ in our field of eco-innovation, we have built a new matrix by combining engineering parameters in relation to eco-efficiency corresponding parameters (Fig.2). The distribution of engineering parameters in the eco-efficiency settings is often done by associating parameters of assessment or evaluation in relation to the situation to be resolved with one or more engineering or generic parameters [25]. In this situation several cases can arise

Table 3 The 40 inventive principles [24]

Num	Principle	Num	Principle
1	Segmentation	21	Rushing through
2	Extraction	22	Convert harm into benefit
3	Local quality	23	Feedback
4	Asymmetry	24	Mediator
5	Combining (Integrating)	25	Self-service
6	Universality	26	Copying
7	Nesting	27	Disposable objective
8	Counterweight	28	Replacement of a mechanical system
9	Prior counteraction	29	Pneumatic or hydraulic construction
10	Prior action	30	Flexible film or thin membranes
11	Cushion in advance	31	Porous material
12	Equipotentiality	32	Changing the color
13	Inversion	33	Homogeneity
14	Spheroidality	34	Rejecting and regenerating parts
15	Dynamicity	35	Transformation of the physical/chemical states
16	Partial or excessive action	36	Phase transition
17	Moving to a new dimension	37	Thermal expansion
18	Mechanical vibration	38	Use strong oxidizers
19	Periodic action	39	Inert environment
20	Continuity of useful action	40	Composite materials

1 - The assessment parameter(s) are equivalent to one or several engineering parameters: this situation is the easiest since the inventive parameters to consider are those that can be read at the intersection of the engineering parameters and which are considered inconsistent.

2 - The parameter(s) of assessment are synonymous with an engineering parameter in the matrix: in this case, this or these parameter(s) can also be used to resolve the contradiction.

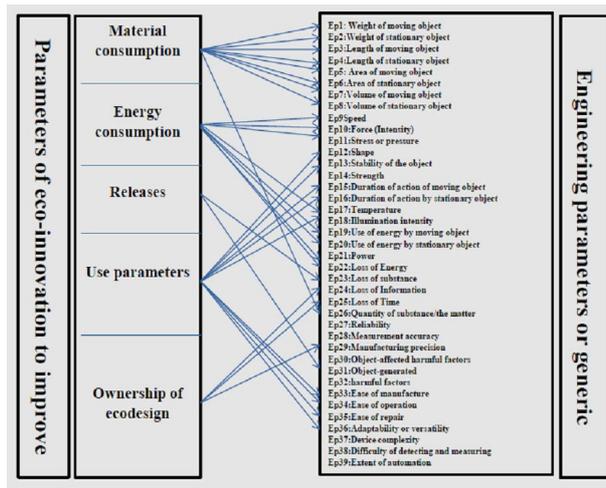


Fig.2 Correspondence between the parameters of eco-innovation and engineering

3 – The assessment parameter has no equivalent or synonym among the 39 parameters: in this case, we propose to associate each group of parameters selected in affinity with each environmental topic considered. The goal is to find creative parameters that can remove the contradiction and that lead towards the solution, especially when there is no action where engineering parameters are not present or have no equivalent or synonymous among the 39 parameters

IV. Results

According to the steps described in Table- 1 the designer will make the choice of the most relevant eco-efficiency parameters, consistent with the frequency of occurrence of each parameter. The choice of the corresponding inventive principles will be made from the engineering parameters. To apply TRIZ in the field of eco-innovation, we have constructed a new matrix consisting of the engineering parameters, as indicated in Table- 4 in relation with eco-efficiency related parameters.

To account for strategies to be implemented for the operating parameters, we give in Table5 5, a detail parameters to improve. In each scenario, the inventive solutions are shown at the intersection of the parameters that can be inconsistent (for example, if we want to improve the strength of a product without material consumption, the inventive principles that can be a solution to the problem are in order of importance or of frequency of occurrence 40,1,29,27). In the example mentioned, principle 40, the use of composite materials, seems to be a solution to this problem, without excluding the other principles which can also be solutions. The goal is to find creative parameters that can remove the contradiction and direct towards the solution. In each case, the selected inventive parameters are those that appear frequently.

Table 4 New Ecoefficiency matrix of inventive parameters

Parameters do not degrade Parameters to improve	Material consumption	Energy consumption	Releases	Use of parameters	Ownership of eco-design
Material consumption	-	18,19,6,3	35,3,5,22	2,35,1,25	10,35,28,24
Energy consumption	19,18,6,3	-	35,2,27,18	19,2,35,1	10,35,18,19
Releases	35,6,22,3	35,2,27,18	-	2,35,39,40	10,35,15,4
Use of parameters	3,35,27,25	1,13,15,22	2,35,40,28	-	10,4,32,1
Ownership of eco-design	10,35,28,32	32,10,19,2	35,10,18,22	1,32,10,35	-

We wanted to highlight the usage parameters in relation to eco-efficiency parameters. This reflection has become possible because the original matrix contains settings for using the designer may operate individually to solve issues related to the situation considered. The search of the inventive parameter, in this case, will be thinner.

Table 5 New user parameters matrix of inventive numbers

Parameters do not degrade Parameters to improve	Material consumption	Energy consumption	Releases	Ownership of eco-design
Shape	10,36,8,15	14,2,6,40	35,14,1,29	32,14,10,30
Stability	35,15,21,26	27,14,13,4	35,2,40,14	35,27,18
Strength	40,1,29,27	10,35,19,17	35,15,18,22	3,29,27,28
Durability	19,35,5,3	18,35,6,28	21,28,39,27	10,3,20,27
Brilliance	10,36,8,15	14,2,6,34	35,29,8,1	32,14,10,30
Ease of use	13,25,12,6	13,2,1,19	28,32,2,24	10,4,1,32
Reparability	2,35,25,28	15,1,32,28	35,2,27,34	10,25,32,1
Adaptability	15,19,1,3	35,18,19,15	15,10,2,13	35,28

In Table 4, the notion of general use parameters so that the inventive parameters obtained differ from those obtained in Table 6. However, we can find in Table 5 and column the same inventive principles as corresponding to the same position in Table 4.

Table 5 presents the new resulting matrix obtained from the matrix of contradictions and covered widely in the literature. The new inventive principles were obtained based on their repetition frequency relative to the new matrix configuration starting from the original matrix. From the preliminary remarks, we find for the eco-design box, the inventive principle 10, notably that the “prior action” is found in all cases. This is in accordance with the principles of eco-design for early action in terms of environmental protection. The parameters used were divided into several properties. As a simple example of consistent results obtained from the inventive principles when we want to improve the strength of a product without consuming materials, principle 40, i.e. the use of composite materials is a perfect example to test our approach, which is consistent with the practices used before.

A. Application: case study

In order to validate our methodological approach and verify its application with other examples we have applied this approach to different projects and challenges that require eco-innovating solutions. The proposed matrix has been used by work groups during ideation sessions and the results have been compiled in Table 6.

Table 6 Comparison to other research results

Practical cases inventive	Reference	Improved parameter	Not adversely affected parameter	Inventive principles from the authors' results	Inventive principles from our matrix (table 4)
Human powered lifesaving radio : very convenient product for use in case of emergency	(Chih-Chen, L., Jahau Lewis, C, 2001)	Energy consumption	Parameters use	35, 19, 2, 10	35, 2, 19, 1
				Inventive principle 19 selected « periodic action ». It can listen to the radio for one hour, give the alarm signal for twelve minutes, or provide five minutes of light.	
Ultrasonic washing machine: Innovative ideas for developing ultrasonic washing machines	(Chih-Chen, L., Jahau Lewis, C, 2001)	All situations: - materials - energy - releases	Consumption of : - materials - energy - releases	35, 2, 18, 10	35, 18, 27, 2
				Inventive principle 35 (transform the physical/chemical state to washing machines design problem is to change the physical state of water. Therefore, the washing machines may fill with micro air bubbles during clothes washing processes) and 18 (“mechanical vibration” can be interpreted as to utilize the method of ultrasonic vibration to clean clothes)	

In our case, the results of our contradiction matrix obtained by our approach shows several cases of inventive numbers that can be the no-compromise solution to the problem. It is obvious that not all principles are applicable. It is at this stage that the designer or group of ideation will intervene to choose from the inventive principles selected and build a solution concept based on the situation.

B. Example of applications to publication patents

As another application, we considered interesting to apply the results of our methodological approach by focusing on some cases of published patents for products designed ecoinnovants. We have audited the methodology compared to other cases, including published patents. The results are given in Table 7.

Table 7 The methodological tool applied to examples of published patents

Name of concept or product	Presentation	Choice of inventive parameter consistent with our approach
Shoe sole [26] Publication number EP1928277A	Choosing a shape and sole with improved strength, with minimizing energy consumption and recyclable. Concept: antibacterial composite yarn, three-dimensional textile structure and multilayer	To improve Ep12: Shape Ep13: Stability Ep14: Strength Without damaging: Energy, materials and releases (Table- 5) Inventive principles selected 40: Composite materials 17: Multidimensional structure, multilayer assembly
Ceramic based on clinker garbage [27]	The present invention relates to a crystalline based material of clinker. It finds particular	To improve - Energy consumption



<p>Publication number EP 1215182 B1</p>	<p>use in the field of the crystalline ceramic-like materials. Objective: Save energy by lowering the temperature while maintaining the mechanical properties.</p>	<p>Without damaging shape, strength and stability Inventive principles: 19,2,35,1 (Table. 4) Inventive principles selected: 35 parameters change</p>
<p>cross railroad [28] Publication number EP2539508A1</p>	<p>Composite rail sleepers essentially polyurethane material typically, with excellent mechanical properties.</p>	<p>To improve - use parameters (Ep14: Strength, Ep12: shape, Ep13: stability) Without damaging - Releases (Table 6) Inventive Principles: 2,35,40,28 35,2,40,14 - Material consumption Inventive Principles: 40,1,29,27 - Energy consumption Inventive Principles:14,2,6,40 Inventive principle selected: 40 (Composite materials)</p>

V. Conclusion

The methodological approach implemented has given quite interesting results which can be a direct and easy application for any user. The developed tool has helped to build an inventive matrix that will guide the designer towards eco-innovative solutions, particularly in situations of contradiction in the choice of eco-design solutions. The basis of our initiative is the idea of using a simplified matrix taking into account the life cycle of the product or of the process with a multi-criteria approach and a resolution of contradictions by using a suitable TRIZ. Potential inventive principles for possible solutions are obtained. Some of these principles may not apply to cases of design. However, the matrix can help the designer to reduce the scope of his creative investigations.

The results obtained were tested on recognized case studies and published patents and related to situations of resolution of environmental issues.

We note for the eco-design case, the inventive principle 10, namely that the “prior action” is found in all cases. This is in accordance with the principles of eco-design for early action in terms of environmental protection.

Among the inventive principles obtained, when we want to improve the strength of a product without consuming materials, principle 40, i.e. the use of composite materials, is a perfect example to test our approach, which is consistent with the practices used before.

The results of our methodological approach applied to the different situations considered show perfect consistency in the choice of the strategies used for solving problems occurring. This method can be applied to any resolution of conflicting issues, in particular in a situation of ideation. It can also serve as a referential kit for businesses’ objectives for improvement and innovation of their products or processes with support for environmental concerns without transfer of pollution. Moreover, it is worth noting that this tool, which was developed to be a solution approach, cannot explain some design problems which are only determined by a thorough and detailed analysis.

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