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AN INTEGRATED PROCEDURE FOR THE DESIGN OF SUSTAINABLE PRODUCTS

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1. Introduction

At present, the environmental problems have risen to an importance and clarity which cannot be neither disregarded nor undervalued. In the past century the mankind, owing to his way of life and to his industries, in a very short time influenced the environmental conditions in such a way that a great danger for the man survival was produced.
It follows that it is really necessary to realise as soon as possible a drastic change in the human life, but this trend does not appear easy to be accomplished. In fact the studies concerning this problem lead to the following considerations:

- The causes, which induce environmental problems, are numerous, grave and differentiated.
- The human intervention, performed in order to eliminate or reduce such causes, requires always an high financial engagement.
- The technical choices, taken in order to reduce the importance of the environmental impacts, if possible, also involve sociological and political problems.

For the solution of the over mentioned problems the designers seem the more suitable persons, whether for their basic knowledge or for their ability to perform usually activity of “problem solving” (Schott, Gruner, Birkhofer).
Nevertheless it is clear that, in order to solve the environmental problems it is necessary the convergence of many experts. In fact together with designers it is always necessary the presence of other experts such as: physicists, chemists, physicians, psychologists, sociologists and statesmen.

2. Background

Up to now the researchers have already singled out many environmental problems, which have been included in different categories. In this way the different sites, in which the interactions between Man and Environment can arise, are pointed out (for instance: cities, industrial zones, forests, sees, etc.).
It is also very important to set a valuation of the spatial and temporal range of the environmental problems. In fact they can concern the whole planet, a region or a limited zone (city or country) and moreover such problems can be, in the different cases, steady or transitory.
A deep study of the eco-problems allowed to understand that the sustainability can be achieved only step by step. Five phases were detected through which a complete evolution can be realised, beginning from the condition when the environmental problems are unknown till the state in which the complete Sustainability is achieved.
Even if the eco-problems look very differentiated, general strategies have been proposed in order to solve them.

Up to day it is completely clear that it is necessary the valuation of the whole Life Cycle of the product, as each phase can exert a more or less important influence on the environment (Life Cycle Design, Hundal). In product design a very important principle is that of "De-Materialisation", through which the designer tries to reduce the use of material to a minimum, in order to spare also the consumption of energy. Moreover there are other strategic decisions concerning the following problems:

- the choices of materials and processes, which allow a low environmental impact;
- the optimisation of the duration of the product life;
- the easy disassembling;
- the extension of material life (remanufacturing, recycling).

3. Methodologies and Design Tools

At present, owing to several studies on the problem, many design tools have been developed and proposed. The number of different offers is high and it is not easy to carry out a general valuation in order to state the best choices, especially taking into account the development in the next future. Some examples of them are collected in Table 1.

Table 1. Methodologies and tools up to now developed

	NAME	Subject	Source
1	EMAS	Eco-management and audit scheme	EC
2	ECOLABEL	CEE 880/1992	EC
3	LCA	Life Cycle Assessment	SETAC,1991 - ISO 14040:1997
4	ALCA	Abridged Life Cycle Assessment	ISO
5	RLCA	Reverse Life Cycle Assessment	ISO
6	ECODESIGN	Design Methodologies	TU Wien – TU Delft
7	ECOINDICATOR 95	Eco Analysis and valuation	PRè-Consultant, NL-1997
8	EPS	Environmental Priority System	Environmental Swedish Institute (IVL), Volvo Car-1992
9	MET	Material Energy Toxic Emissions	"Promise Manual"
10	ISO 14001	Standard for Eco Certification	ISO
11	IPPC	Integrated Pollution and Prevention Control	61/1996 EC (1999)
12	IE	Industrial Ecology	Gertler, 1995
13	QEFD	Quality and Environmental Function Deployment	Birkhofer, 1999

Among the whole it is deemed that the Eco-Design Methodology is the more interesting and useful tool for Designers (Brezet, Jacobsen, Wimmer) It includes all aspects of a "Design for Environment", starting from the choice of materials, through the product manufacture, utilisation, distribution and end of life. Moreover it includes also the highest design level, concerning the passage from the product-object to the product-function, through which the generation of new ideas are performed, e.g.: dematerialisation, goods-sharing, function optimisation.
For this aim the use of the tool RCLA (Reverse Life Cycle Assessment) becomes very important. In fact starting from the function (human need), the tool helps in finding the product which obtains that function with the minimum eco-impact.

4. Design Procedure DFSP

The designer can face the eco-problems, using three classes of Design Tools, as follows:

Class no.1. In this class it is set the Eco-Design Methodology, which concerns generally all problems related with Environmental Impact from the choice of materials till liquidation (Wimmer).

Class no.2. To this class belong some DFX Techniques, which are oriented to solving specific ECO-problems, e.g.: Design for Packaging, Design for Disassembling, Design for Recycling, etc. (Hundal, Johnson, Meerkamm, VDI).

Class no.3. Various Design Methods for Creativity are considered in this class, e.g. TRIZ, Synectics, Brainstorming, etc.

The whole of the different tools is shown in Figure 1. In it the relations among these tools are pointed out in order to make clearer the use of the procedure, which can be further explained through the following notes:

- The designer follows as usual the design steps, shown in the flow diagram of the Design Process. In order to solve the different problems, "ad hoc" methods and design rules, pointed out by the Techniques DFX, are used.
- During the Design Process, Eco-Design Methodology is widely utilised by means of special checklists, which allow to solve the different Eco-problems.
- Together with the over mentioned Methodology, the designer can use the techniques DFX more suited for solution of Eco-problems.
- Problems, which involve Creativity, can be solved by the use of the special over mentioned methods.

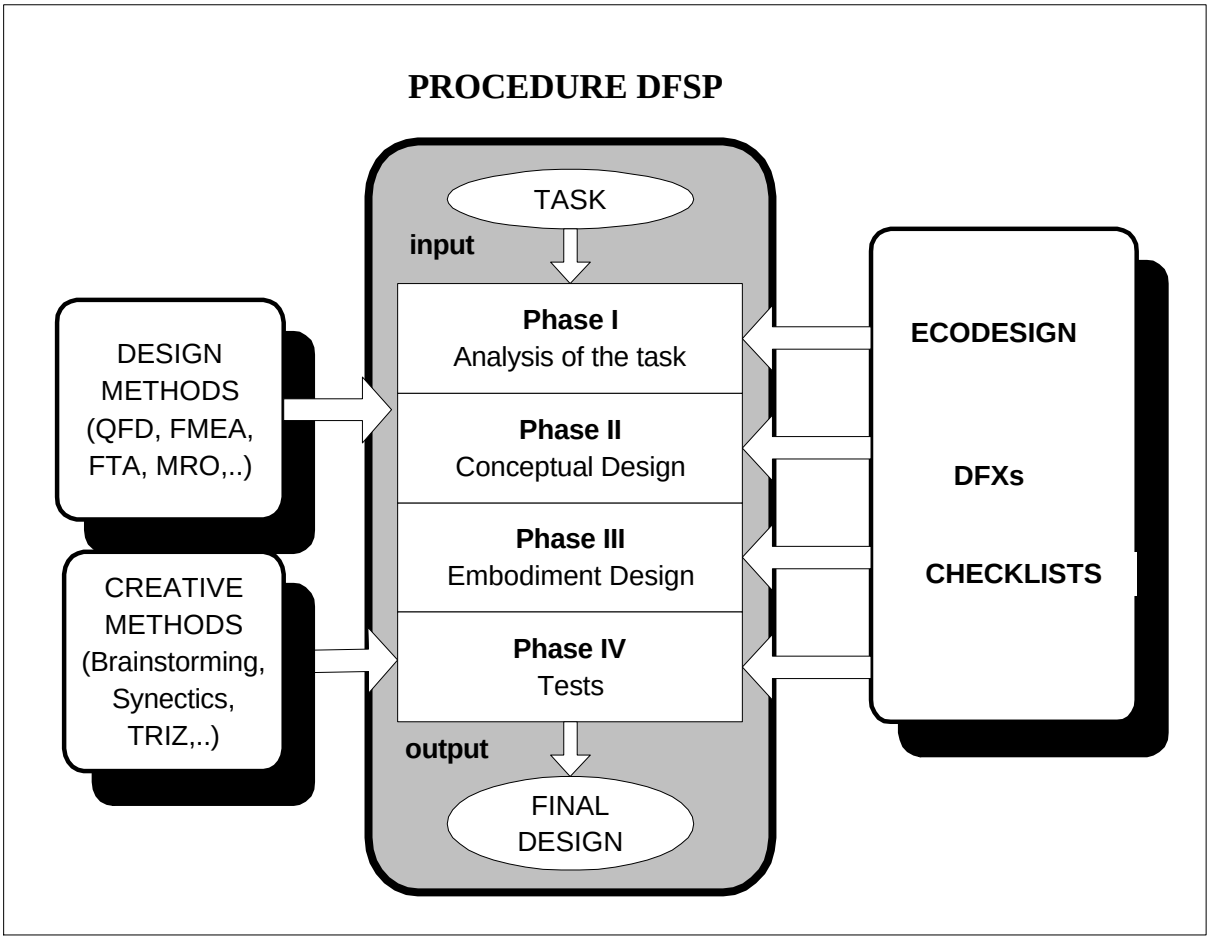

Figure 1. Design for Sustainable Products (DFSP), Concept of Procedure

The formal complication of the explained procedure can be overcome through a deep knowledge of the methodical Flow Diagram of Design and of the various Tools (Methods and Techniques) already at disposal of Designers. The development and the subsequent use of special software can help very much the design work.

5. Case Study

5.1 General Data

In order to test the Eco-Procedure DFSP, it was carried out the design of a small vehicle. The features of this vehicle, collected in Table 2, can be considered like the Design Specifications of the System.

Table 2. General characteristics of the Eco-vehicle

Characteristics		
1.	Mechanical System	Multipurpose Eco-vehicle
2.	Dimensions:	
	- length	3100 mm ÷ 3500 mm
	- breadth	1250 mm
	- height	1650 mm
3.	Propulsion	Zero or Low Emission Motors
	Power	6 kW ÷ 30 kW
4.	Max. Speed	45 km/h
5.	Minimum Operating Range	60 km
6.	Utilisation	Persons and goods transportation
7.	Places	Limited zones (in road or off road)

In designing this vehicle many choices, suited for reducing the environmental impact, were carried out. Some of them are collected in Table 3.

Table 3. Preliminary choices for reducing Environmental Impact

Strategies		**Choices**
1.	Structure	• Space Frame • Modular Structure
2.	Low eco-impact materials	• Aluminium Alloys • Low Weight Materials
3.	Low Eco-impact during the use	• Electric Motor • Low Impact Batteries
4.	Long economical use	• Easy Maintenance • Easy Technical Up-grading
5.	Optimisation of liquidation properties	• Easy Disassembling • Easy Recycling

In our opinion, the development of this vehicle represents an attempt directed to the solutions of environmental problems, like the control of noise and pollution.
The vehicle will be specially suited for zones where these features are especially required, like historic centres, hospitals, camping, tourist villages, campus. The modular structure allows easy modifications, which enable many uses, like microbus, lorry or mixed.

5.2 Application of the DFSP procedure

Following the methodical Design Process, during the analysis of the task, it was collected a wide information, which allowed to confirm clearly the real importance of this choice.
In this phase the method QEFD was initially used in order to detect whether the characteristics which are to be considered, or their relative importance. In the 2nd Phase of the Process, through the study of the main function and of the function structure, it was possible to develop the morphological matrix, achieving two different concepts of the Eco-vehicle.

In this phase some creative methods and the Ecodesign Pilot were successfully used in order to check the different choices and to detect the most interesting solutions. In the development of the mechanical system it was given great importance to the use of modular structures, in order to have the possibility to obtain many types of Eco-vehicles by means of simple modifications.
For instance: the mechanical system can be used for 2 or 4 persons, only increasing the length of the lower frame and adding a new module in the upper part, Figure 2. In this case the wheel base was increased from 1.800 mm. to 2.150 mm.

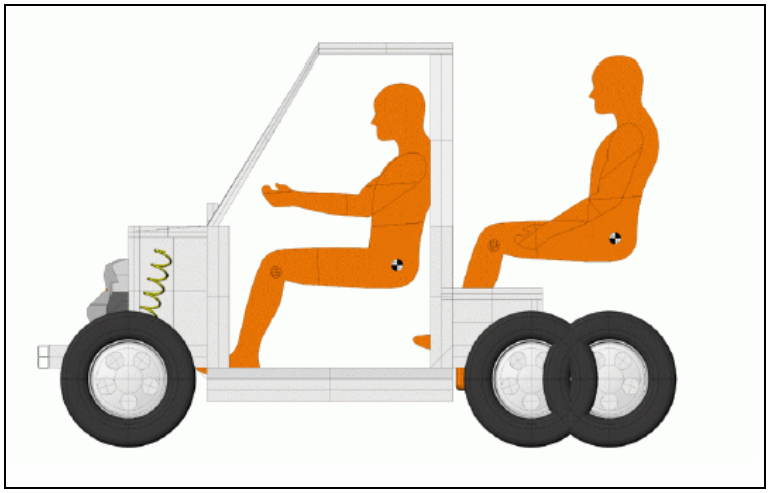

Figure 2. Scheme of the modular structure

The most important problem, which was faced during this preliminary design, concerns the development of the space frame of the vehicle.
Many solutions were attempted before singling out the best one, which is shown in Figure 3.
This solution was reached through accurate calculations with solid modeling and Finite Element Analysis. Through the calculation it was possible to study the frame from every points of view: static resistance, fatigue resistance, crash resistance, vibrations and deformations. The materials, used for the structure, were the following ones:

- 6061 - Alloy for the basic structure
- 6063 A - Alloy for the lower stressed elements
- 6015 - Alloy for the parts in stamped plates.

The design of this vehicle was performed considering many design properties like Aesthetics, Safety, Reliability, Ergonomics, Standards agreement, Performances, Maintainability, Cost. The specific choices, made in this case in order to reduce the environmental impact, concerned the following problems:

- **Vehicle structure:** space frame with possibility of easy modular changes.
- **Structure simplicity:** ease of manufacture, assembling and disassembling.
- **Materials:** high recycle ability (Aluminium Alloys,...).
- **Motor:** zero or low emissions system (e.g.: electric motor, hydrogen motor, air compressed motor, hybrid motor).

For this study proper techniques DFX were used just in time, when the related problems occurred. Moreover, also LCA was used during the first stages of the 3rd Phase of the Design Process.

6. Conclusions

The development of the Eco-vehicle has shown the validity of the proposed procedure DFSP.
In Author's opinion it can be used successfully on the basis of the methodical Design Process and of the different design tools (Methods and Techniques), which are at present at disposal of all designers.
The implementation of this procedure in a special software is in execution. When the program is ready, it will be extremely useful for cutting design times and costs.

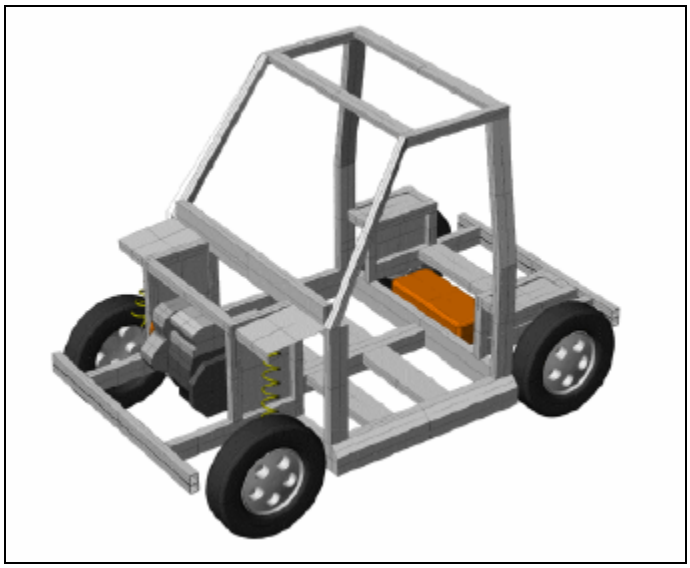

Figure 3. Optimal solution of the space-frame

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