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DESIGN FOR ASSEMBLY AND DESIGN FOR DISASSEMBLY: TWO WAYS FOR THE DEVELOPMENT OF SUSTAINABLE PRODUCTS

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Abstract

Concerning the product life cycle as a closed loop, problems linked to Assembly and Disassembly of products are clearly interwoven and play a fundamental role in the attempt to improve the environmental compatibility of the products.

Keywords: Design for Assembly, Design for Disassembly and Recycling, Life Cycle Assessment, Sustainability, Methodical Design.

1. Introduction

In recent years, the desire for more and more green products has mainly come about because of the need to reduce the impact on the environment. Consequently the industrial world has adopted new specific standards and paid more attention to Sustainable Development; at times however the various paths followed have focused on the solution of single problems and have not always taken into account the varying aspects from a complete point of view.

In particular, concerning the product life cycle as a closed loop, problems linked to Assembly and Disassembly of products are clearly interwoven and play a fundamental role in the attempt to improve the environmental compatibility of the products.

The study carried out is set in this sphere: it is an attempt to find the right trend to follow to pursue improvements in design activity throughout Methodical Design, which take into account not only the direct environmental impact of products, but also make their development economically feasible, extending their life, optimizing components assembly and foreseeing their re-use, disassembly and recycling.

To verify the effectiveness of the study performed, the developed approach was implemented to a real case, and in particular to the re-design of a multifunctional vehicle to be used in an urban context, collaborating with the Agency for the Environment of the City of Rome, and in particular to the design of a multifunctional small sized vehicle suitable for high density traffic areas, which can be easily used for a variety of purposes.

2. Background

In such a context it is deemed that the “Design for Environment” is the most interesting and useful tool for Designers. It includes in design stages all aspects of a product’s life. Moreover it also includes the highest design level, concerning the passage from the product-object to the product-function, through which the generation of new ideas is achieved. The challenge of

“Design for Environment” is to modify the traditional design and production processes, in order to include environmental considerations in a systematic and effective manner.

Decisions that have to be taken, as shown by many Authors [Wimmer et al., 2002; Hesselbach, Hermann et al.,2002; Gruner , Birkhofer, 1999; Lagerstedt , Luttropp, 2001] in the field, mainly concern the following problems:

1. choices of materials and processes which allow a minimum environmental impact;
2. the extension of the product life span;
3. the easy disassembly;
4. the extension of material life (remanufacturing and recycling);
5. dematerialization.

In particular, the widespread development of new tools and methodologies of recent years is an index of the great attention given both to Design for Assembly (DfA) and Design for Disassembly (DfD), or to be more precise Design for Disassembly and Recycling (DfDR), since when we consider the disassembly of a product we always have to take into account its possibility of recycling [Billatos, Basalay , 1997; Myazaki, 2000; Hiroshige, Nishi et al. 1999].

In fact, such approaches not only exert an influence on energy and resources consumption during the phase of production and disposal (as may seem obvious) but can also influence in a significant way the use phase, which is universally recognised as being by far the phase of greatest consumption (Figure 1).

3. Methods

Many design tools have in recent years been put forward with the aim of facing, on the one hand the problems connected to Design for Assembly, and on the other hand those connected to Design for Disassembling and Recycling.

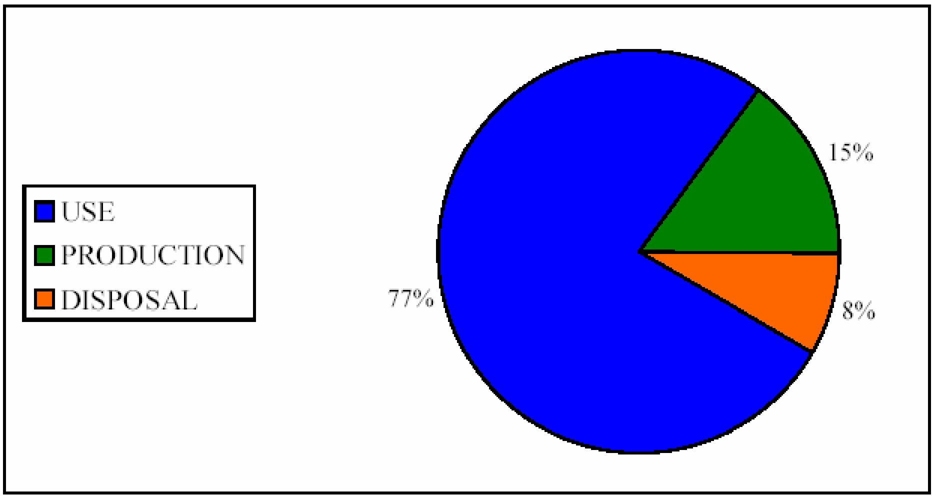

Figure 1. Percentages of total energy consumption of the life cycle of a vehicle.

All of them differ in use, complexity, effectiveness and efficiency; but they are disconnected from each other, or focused only on solving particular problems. Nevertheless, the evolution of market requirements in the last years has deeply transformed the designer way of thinking and operating, obliging designers to consider a great number of parameters and constraints.

On the scientific basis of Methodical Design, the research performed has led to an Integrated Design Procedure aimed at the development of more eco-efficient products, which takes into account tools both oriented to solve Design for Assembly, and Design for Disassembly and Recycling problems.

The first step in this direction was a detailed study on such products properties in order to define all aspects regarding them: all available methods and techniques which can improve each one of the above mentioned aspects were singled out, obtaining, in this way, a set of "Design Tools" at the designer's disposal. Particularly, Design Methods and Techniques focusing on the following aspects were taken into account:

1. Choice of optimal design solutions
    1.1. Design Environmental Review (DER)
    1.2. Quality Function Deployment for Environment (QFDE)
    1.3. Value Analysis (VA)
2. Design for Assembly Methods
    2.1. Boothroyd Dewhurst Method
    2.2. Assemblability Evaluation Method (AEM)
    2.3. Extended Assemblability Evaluation Method (EAEM)
    2.4. Lucas-Hull Method
    2.5. DFA 2
3. Design for Disassembly Methods
    3.1. Disassembly Evaluation Chart (DEC)
    3.2. End-of-Life Strategy Environmental Impact Model (ELSEIM)
4. Choice of production processes
    4.1. Design for Upgrading (DfU)
    4.2. Design For Modularity (DfM)
5. Design for Recycling
    5.1. Material Recovery Opportunity (MRO)
    5.2. Material Input Per Service (MIPS)
    5.3. Recyclability Evaluation Method (REM)
6. Reliability improvement
    6.1. Fault Tree Analysis (FTA)
    6.2. Fish Bone Diagram (FBD)
    6.3. Failure Mode and Effect Analysis (FMEA)
7. Techniques for rapid evaluations and results representation
    7.1. Environmental Product Life Cycle Matrix (EPM)

7.2. Ecodesign Strategy Wheel (ESW)

7.3. Triangle Tool (TT)

7.4. Ecodesign PILOT

4. Results

All such Design Tools were implemented in the Design Strategy: for each of these were defined the proper moment of use and the proper sequence in order to reach results with the maximum effectiveness during each phase of the Design Process. Such integration between Design Strategy and Tactics leads to a very effective Design Procedure, which can be used by any designer without great difficulties when it is required by the specific conditions. In the practice the use of the methods is not separate, but extremely connected to each other, through the development of “design modules”, which can be used for the solution of partial design problems.

So, in order to not belittle the generality and flexibility of the Procedure which, it should be underlined, may be implemented on any Mechanical System’s design, design tools are not explicitly integrated. A similar consideration should be made referring to methods and techniques not considered in the procedure: in fact we have only considered the “Design Tools” that more directly should affect a Mechanical System’s Assemblability and Disassemblability, but any other Design Tool may be used considering the specific problem that should be solved.

It’s clear that standards (both law regulations and ISO standards) also were considered within the Design Procedure; Figure 2 shows a possible example of the application of the Procedure.

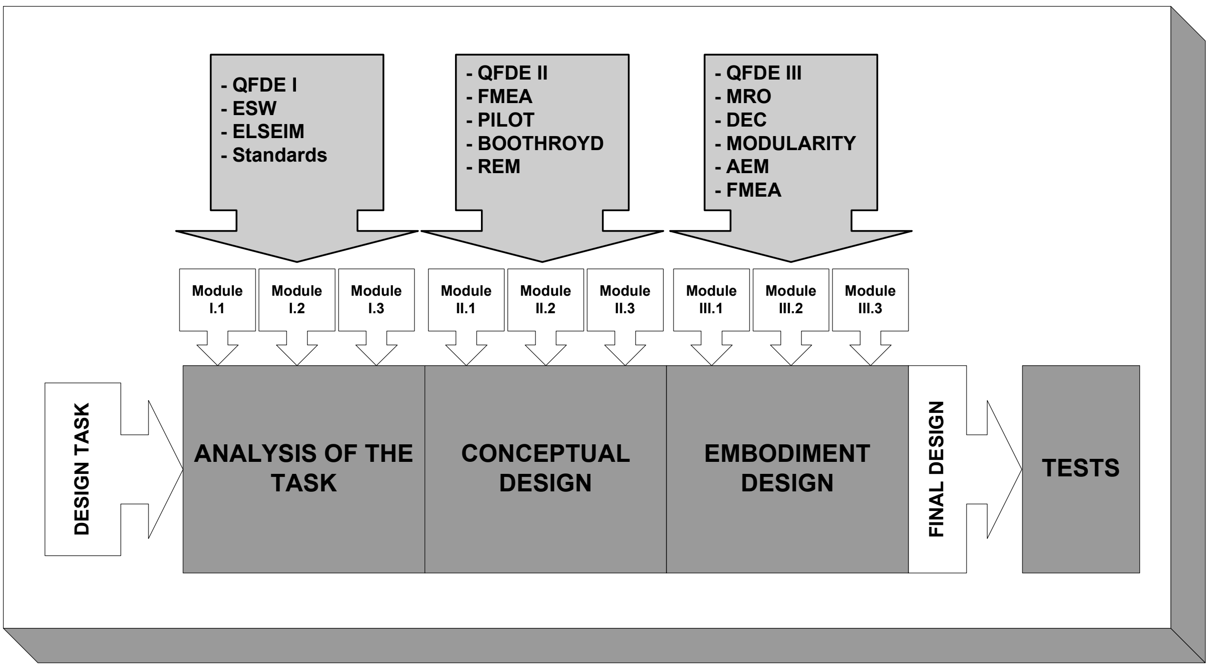

Figure 2. Scheme of the implementation of DFA and DFRR tools within the Design Process (example).

5. Case Study

As mentioned above, to verify the effectiveness of the study performed, the developed Procedure was implemented to a real case, in cooperation with the Agency for the Environment of the City of Rome: the aim of this research was to verify the possibility to conceive a Mechanical System which makes it possible to combine in the same vehicle different needs of mobility both in terms of the transport of goods and people, and in terms of different travelling distances (short – medium routes), obtaining at the same time a reduction of pollution both during production phase, and during the use and disposal phases of the vehicle itself.

Defining the exact meaning of "green car" is surely a difficult task: in fact, traditional design concepts have to be balanced (performances, price, safety) and simultaneously adapted to the producers bottom line. The main characteristics of the vehicle to be redesigned are the following:

- dimensions and performances suitable for an urban vehicle
- high level of reliability, in order to lengthen its use phase, reducing in this way the amount of material used
- easy use and maintenance
- suitable for intensive and multi functional use (both for private and public sector use).

5.1 Analysis of the task

In accordance with the above mentioned Procedure, in order to clarify the design task (first phase of the Design Process), all necessary data to understand and explain the problem were collected; in particular we considered customer requirements, standards, characteristics and typologies of main existing similar vehicles. In order to establish a preliminary selection among all possible structural shapes on the basis of the information collected, we applied the Ecodesign Strategy Wheel method (ESW): the best choice resulted in the hybrid system in which the fuel engine has to be used only in order to support the electric motor, as shown in Figure 3.

The information collected, especially that related to customer requests, laid the basis to identify the first Design Specifications through the application of the first matrix of the QFED method, taking into account the needs of both private users and company workers (Figure 4). The output of these analyses was used to work out the "List of Requirements", which is the final step of this phase.

Moreover, we used the End-of-Life Strategy Environmental Impact Model (ELSEIM) in order to determine which characteristics mostly influence Disassembly aspects.

5.2 Conceptual design

During the second phase of the design Process, the mechanical system starts to take on a more concrete shape and now it is possible to apply various methods both for Reliability evaluation and for Environmental impacts assessment:

- the Ecodesign Checklist Method has been helpful to determine what the characteristics that most influence environmental impact are;

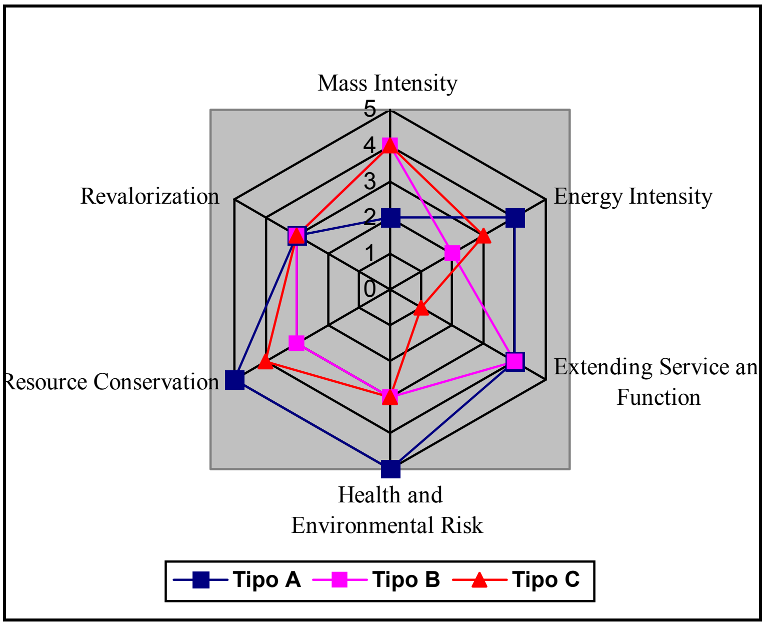

Figure 3. Preliminary environmental evaluation of the possible structures.

- the FMEA analysis has been applied in order to assess the reliability level of the vehicle, also in order to point out which components have to be modified in order to extend the life span.

			Property of mechanical system														
			General				Function							Utility			
		Importance	Disposition	Price	Dimensions	Weight	Hybrid system	Traction	Work speed	Max speed	Autonomy	Work autonomy	City autonomy	Ordinary maintenanc	Managment	Spare parts	
Customer requirements	Versatility	3					7		3	5	7		7		5	5	
	Cost	10		1	3	3	1		3	3	3		1	5	3	5	
	Consumptions	7			1	1	5		1	1		1					
	Autonomy	7				1	5				7		7				
	Facility to use	7	5			1	3	5	5	5		3			5		
	Safety	7	5			5			7	1		1		7	5	7	
	Robustness	5				7				1					3		
	Habitableness	2	3		1			1					1				
	Reparability	2							3					7	1	7	
Environmental requirements	Assembly	6	7		7	5								7			
	Materials	5		1	1	3				1				1		1	
	Manufacture	5		1						3							
	Distribution	3		3	1	1			5	3							
	Use	10			1	1	5		1	1							
	Inspectability	3	3		3		3							7	3		
	Reliability	6							5		7		7	7	3	5	
	Disassembly	6	7		7	5								7			
	Recycle	7		3													
	Cost	5		1	1	1	1		1	3		3	1	5	1	5	
	Raw score		169	55	155	474	185	37	196	1331	142	50	129	290	164	188	3566
	Relative weight		0,047	0,015	0,043	0,133	0,052	0,01	0,055	0,373	0,04	0,014	0,036	0,081	0,046	0,053	Total
			anterior	<13000€	traverse	600-700kg	mixed	anterior	20 km/h	80 km/h	100 km	8 hours	40km	minimum	mechanical	available	

Figure 4. Use of the QFDE matrix in the first phase of the Design Process.

Furthermore, before concluding the second phase of the design process, a further study was carried out using Boothroyd Dewhurst Method in order to evaluate different solutions (concepts) also from the point of view of Assembly problems. Particular attention has been paid to the possibility of charging batteries: in fact, because of the vehicle has to be suitable for a multifunctional use, a battery detachment system has been foreseen (Figure 5).

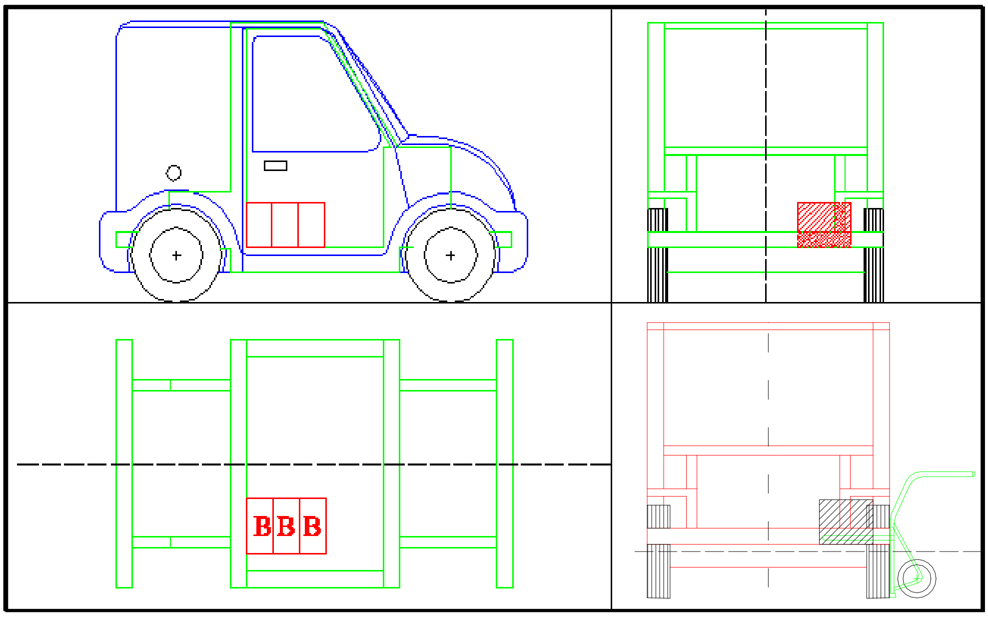

Figure 5. General layout of the battery detachment system.

5.3 Embodiment design

During the third phase some general characteristics such as materials and dimensions were defined in order to attain a further detailed design.

In particular, for the chassis the Aluminium alloy 6061 T6 has been selected, which guarantees at the same time excellent mechanical properties as well as a remarkable reduction in weight. For the other elements, the Aluminium alloy 6063 has been chosen, which is less resistant and less expensive compared to that used for the chassis, but compatible with it as far as recycling is concerned.

In this way, using the alloy 6063, the weight of the whole batteries support system is approximately 27 kg. For the other parts of the system, which have not to bear high pressures, the plastics material PA66 has been chosen.

Optimal results were achieved using the methods QFDE, MRO and DEC. Once this task was done it was possible to carry out a further analysis aimed at the improvement of the system. In particular, we have thought of developing the design of the battery detachment system because its realisation is much simpler on an already existing machine, as in our case (Figure 5 and 6).

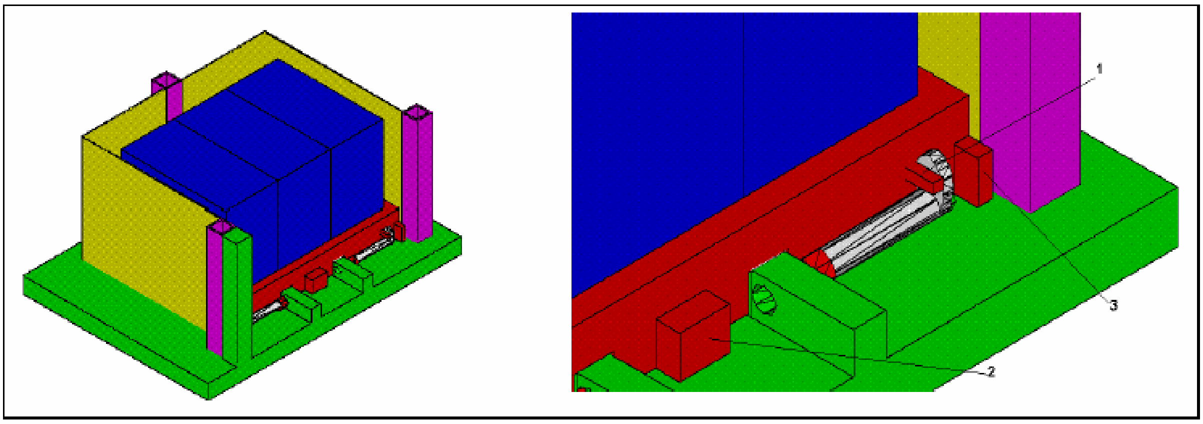

Figure 5. General layout of the battery detachment system and in particular the blocking system, consisting in a stop pin which can be easily operated by any user.

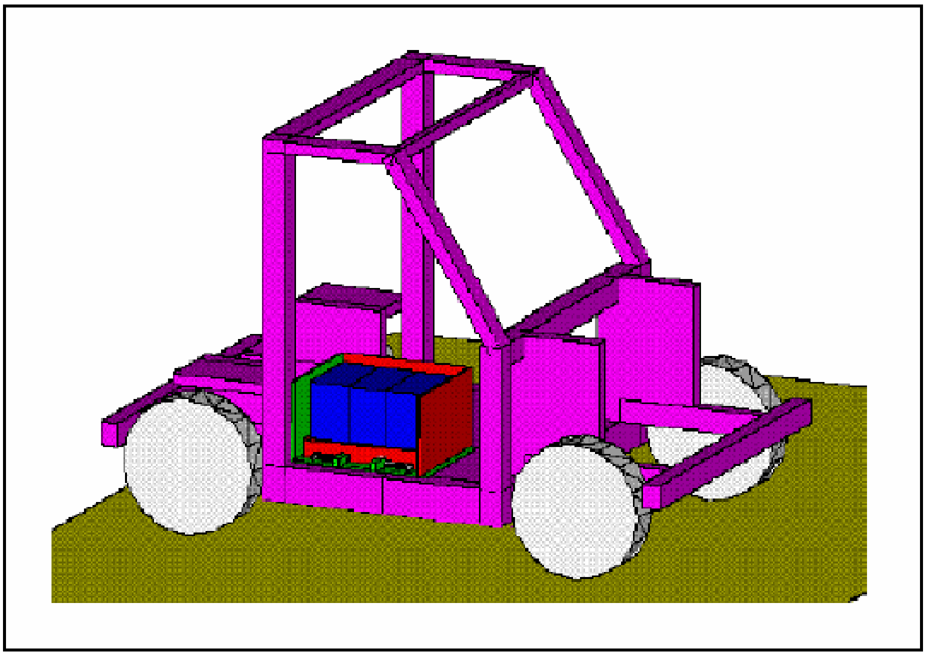

Figure 6. General layout of the battery detachment system.

6. Conclusions

Results can be considered very positive: problems related to both the assembly and disassembly of the mechanical system have been improved, not only at product level, but also at components level; in particular:

- the redesign of the chassis has allowed us to obtain a modular structure not only easy to produce and assemble, but also able to ensure an effective versatility of the vehicle;
- thanks to the battery detachment system, the redesigned vehicle can ensure a greater autonomy in the urban context, also able to be used as a working vehicle;
- the replacement of the batteries can easily be carried out by any user.

Moreover, the Design Procedure developed can certainly be applied to any type of product. In fact, it allows a systematic development of Design, that makes the occurrence of mistakes or the pursuance of wrong solutions difficult.

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