THE MORPHOLOGICAL MATRIX: TOOL FOR THE DEVELOPMENT OF INNOVATIVE DESIGN SOLUTIONS

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ABSTRACT

In this paper, the use of a heuristic procedure aimed at improving the performances of the conceptual design stage of the design process is presented.
The approach proposed is based on the use of a modified Morphological Matrix, that allows designers an easier and at the same time a more effective generation and assessment of the design concepts.
This approach was developed throughout its application to an industrial case: the redesign of a rail boogie.

Keywords: Methodical Design, Morphological Matrix, Problem Solving, Conceptual Design.

1 INTRODUCTION

The development of modern industrial products has become a very difficult task for designers because of the great variety of parameters they have to take into account, starting from technical characteristics, company's bottom line, until the ever stricter regulations and laws mainly in the matter of safety and environment. In literature there exists a large number of tools and approaches developed both by companies' and academic researchers, aimed at support engineers in the development of industrial products. Nevertheless, it has to be underlined that most of such tools are focused on the improvement of already existing products, neglecting the possibility of rethink the product, providing innovative solutions.
On the other side, this aspect corresponds to the needs of most companies, particularly in the case of very complicated products and/or of small sized companies.
The research work carried out has investigated the different ways of supporting engineers during the early stages of the product development, the so called "conceptual design"[1], in order to develop and integrated design procedure able to help designers in the definition of:

- Different design solutions (i.e. concepts);
- Appropriate criteria on the basis of which to perform the selection among these alternatives in an objective and effective way.

More in detail, the research approach proposed is based on the development of a procedure aimed at improving the conceptual stage of the design process, modifying the use of the Morphological Matrix method with the aim of obtaining better performances in the concepts generation and assessment.
Moreover, in order to make the use of the Morphological Matrix more effective, the use of other tools such as heuristic and creative methods (e.g. TRIZ) was foreseen.
In order to verify the approach developed, such a procedure was applied to the redesign of the suspension system of a boogie.

2 BACKGROUND AND MOTIVATIONS

Development of industrial products with a high level of quality represents, nowadays, a path companies have to follow in order to both be in compliance with the numerous policies and regulations issued in recent years, and with the aim of satisfying the ever more detailed and varied requests of customers.
Such a trend significantly influences the company strategies for the whole product development process, beginning with the product planning and design to its production and distribution.
The necessity to put on the market competitive products reducing as much as possible the "time to market" has brought most of the companies to optimize activities for the development of new and innovative products, offering a diversified production able to satisfy different customer needs. In the field of product design and development significant examples of design tools can certainly be found: on the one hand, most of them are oriented at assessing performances of already existing products and improving their weak aspects, limiting the possibility for designers to "re-think" the product, proposing innovative solutions, or indeed innovative products. On the other hand, it has not to be neglected that such an approach usually corresponds to the real need of companies that in most cases have the necessity to upgrade their products and cannot risk investing time and resources in a completely new solution.

In fact, it has to be underlined that decision making in the earliest stages of the product development could be a very risky activity particularly for the small and medium enterprises, for which the failure of even one single product could cause serious financial consequences. Moreover, the increasing complexity of today’s modern products, ever more constituted by mechanical, electrical and electronic components, makes the task of designers very hard.
The study was focused on the integrated use of the design strategy supported by design methods and techniques (i.e. design tactics). As far as design strategy tools are concerned, in literature, several models of the design process have been proposed hitherto and, needless to say, all of them are characterized by a similar identification of the main design activities. In particular, the model used in this research work is divided in four main phases, in accordance with the most well known models proposed in literature, such as: clarifying the problem (task analysis); conceptual design (function analysis and organ structure definition); embodiment design (preliminary and dimensional layout definition, production characteristics’ analysis); test (constructive layout verification and validation [1, 2, 3, 4].
The research work focused on the analysis of the earliest design stages of the design process, and in particular on the so called “conceptual design” stage, with the goal of integrating the traditional approach based on the use of a systematic and methodical approach, together with effective design tools aimed at increasing the probability to find innovative solutions, such as TRIZ [5] and the TRIZ based methods, etc.
These stages, in fact, “allow extensive exploration of alternatives and principles” as well as “entail a choice of the most promising principles and embodiments, and optimization of the product” [6].
In such a context, a particular attention was paid to the use of the Morphological Matrix [4]: this traditional method, in fact, allows designer to select the best design concepts combining in a systematic way, the various function actuators that could satisfy each partial function.
On the one hand, such an approach is able to provide new solutions on the basis of an “objective” evaluation of the proposed alternatives. On the other hand, it has to be underlined that the use of the Morphological Matrix:

- gives a few indications concerning the feasibility of the solutions carried out,
- often leads designers to “over design” the system, decreasing the effectiveness of the problem solving activities;
- requires a team of experts in order to increase the possibility of obtaining innovative solutions.

For these reasons, the development of a heuristic procedure aimed at improving the use of the Morphological Matrix was performed, augmenting the probability to achieve innovative solutions using the traditional design approach, whose use certainly reduce the occurrence of mistakes and neglecting significant aspects of the project.

3 METHODOLOGY

More in details, the approach proposed is based on the development of a heuristic procedure aimed at carrying out the Conceptual phase of the design process, performing the following steps:

a) *General Function*: the general function performed by the machine can be expressed as a transformation from an initial to a terminal state (as shown in Figure 1).

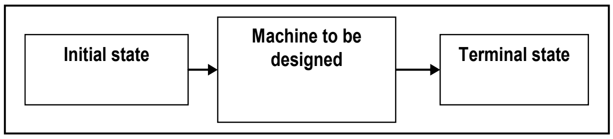


Figure 1 – Flow chart of the general function analysis.

b) *Physical Phenomenon*: the general function can be realized by the utilization of a general physical phenomenon. The search for such physical principle can regard the mechanical, or electric, or hydraulic field and so on. In such search can be utilized the “analogy principle” (Figure 2): the analogy can be defined as “a situation characterized by corresponding situations in different physical fields, represented by formally equal equations”. Very useful in the search of the physical phenomena can be the use of methods based on TRIZ, such as CREAX [5].

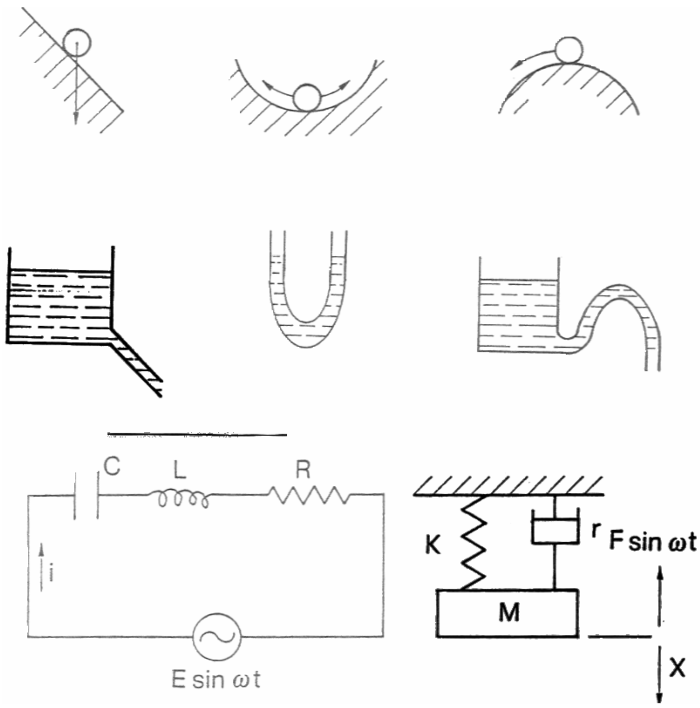


Figure 2 – Examples of the Analogy principles.

c) *Choice of the “Best” Phenomenon*: the output of the second step consists in a set of phenomena that can perform the given function; the optimal phenomenon can be chosen by means of the use of LCA or DfX criteria [7].

d) *Analysis of the General Function F*: Such a function, in general, can be analyzed dividing it in different "component functions"; for this purpose, the use of the Morphological Matrix results in being very useful, since it provides the possible way to define each partial function and/or sub-function of the system in accordance with the following formula:

$$F = F_1 + F_2 + \ldots + F_i + \ldots$$

where F represents the general function and F_i are the partial functions (sub-functions).

e) *Individuation of the principles for each component function P_i*: each component function F_i can be realized by using different physical (or, in general, natural) principles, called: P_{i1}, P_{i2}, ….P_{ij}…. The different principles can be distinguished respectively in:
- already known solutions, provided for instance analysing the historical heritage and/or the state of the art;
- novel solutions carried out applying heuristic methods or the TRIZ.

It has to be underlined that each principle can be realized by different constructive solutions:

$$S_{ij1}, S_{ij2}, \ldots S_{ijk} \ldots .$$

f) *Choice of the "best" principle for each component function*: the choice of the "best" principle, or in other words of the "best" constructive solution, can be made in relation to the behavior of the principle (constructive solution) itself in all phases of the system's life cycle, by using methods such as LCA and DfX. It is necessary to observe that the principle P_{ij} (related with the constructive solution S_{ijk}) performs not only the function F_i, but also function F'_i , which is not desiderated: it is important, then, to verify that F'_i has no negative influence.

g) *Synthesis of the selected principles (constructive solutions)*: repeating such an evaluation for each F_i, a congruent synthesis of the selected P_{ij} (S_{ijk}) can be performed: this output can be used as a source of new solutions.

In this paper, it has been discussed how the Axiomatic Design can be integrated with the Failure Modes and Effects Analysis.

4 CASE STUDY

In order to verify the approach developed, such a procedure was applied to the redesign of the suspension system of a boogie: in particular, the function analysis and the use of the Morphological Matrix, carried out in the Conceptual stage of the design process are discussed.
The first step consisted in defining the structure of the function that the system has to perform.
In Figure 3 the "function tree" of the rail boogie, expressing the hierarchical relationships among the main function and the sub-functions of the system, is shown.

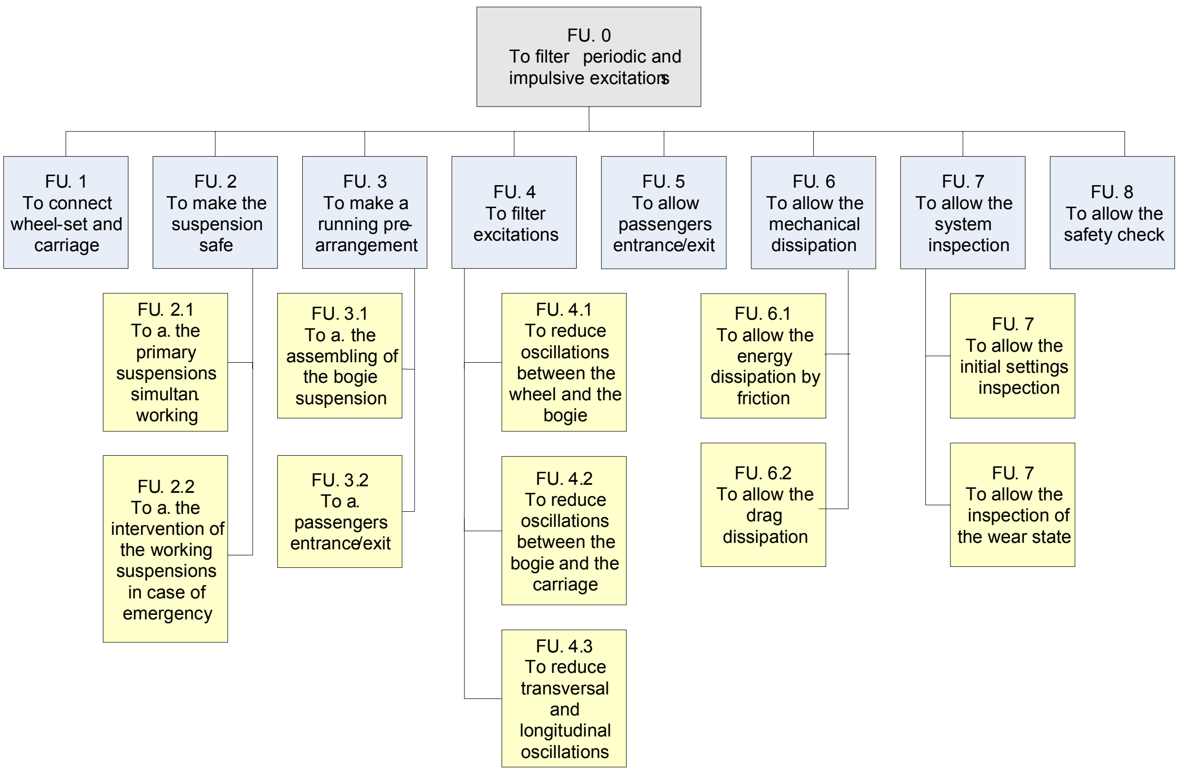


Figure 3 – Analysis of the system function using the Hierarchical Tree.

The following step consisted in the development of the Morphological Matrix. Such an activity was performed using an archive of existing solutions and carrying out also new solutions as their improvement [8, 9]. As a matter of fact, in this field the innovation is mainly represented by a new synthesis of known solutions, with upgraded behavior. The further step consisted in finding new solutions using the CREAX method [10].
Actually, the "function tree" resulted in being very useful in order to have a complete perspective of the system and implement in a more efficient way the Morphological Matrix. In particular, using the principles mentioned in the point b) of the previous section, a more immediate representations of the system sub-functions was performed (e.g. no scale, no technical details, etc).

Nevertheless, such a graphic representation allowed us to obtain a complete and operative scheme very useful in order to take into account all functional problems related with the system.
In order to better clarify our approach, in Figure 4 a comparison between the traditional Morphological Matrix and the one obtained using the analogy principles is shown.
More in detail, in Figure 4a an excerpt of the traditional Morphological Matrix is represented: for each component function, a set of known constructive solutions is proposed is represented; the figure 4b, instead, represents the same part but in a schematic version, more useful and faster to be understood than the previous one.

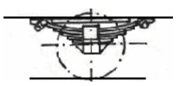
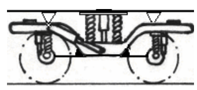
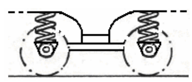
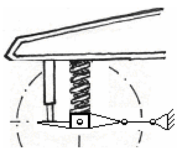
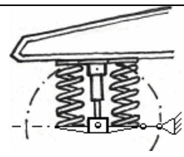
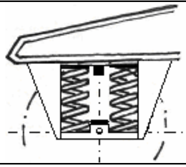
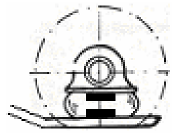
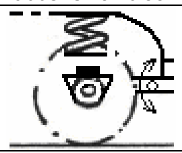
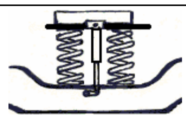
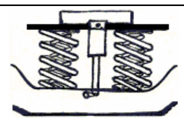
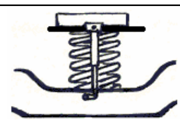
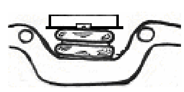
N°	FUNCTION	ACTUATORS			
1	To connect the wheel-set and the carriage	A Carriage spring	B Bogie	C Bogie with single-stage suspension	
					
2.1	To allow the primary suspensions simultaneously working)	A Coaxial helical springs + shock absorber	B Helical springs working in parallel + shock absorber	C Helica springs working in parallel + shock absorber	D Pressure spring + rubber small block
					
		E Torsion bar +helical spring + rubber small block	F Absent	G Absent	
			Single-stage suspension with bogie	Bogie is absent	
4.2	To reduce oscillations between the bogie and the carriage frame (secondary)	A Helical springs working in parallel + shock absorber	B Coaxial groups of helical springs working in parallel + shock absorber	C Coaxial helical springs + shock absorber	D Pressure springs (torpress)
					
		F Absent	G Absent		
		Single-stage suspension with bogie	Bogie is absent		

Figure 4a – Analysis of the system function using the Hierarchical Tree.

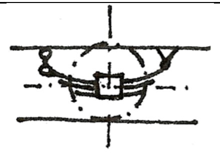
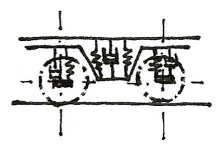
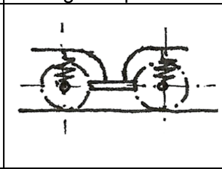
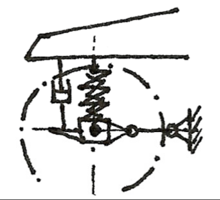
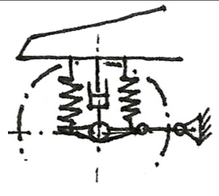
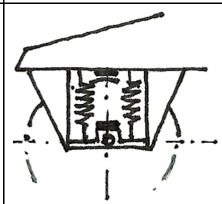
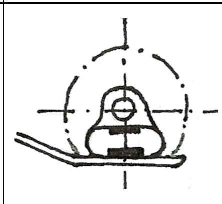
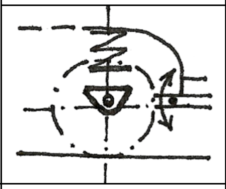
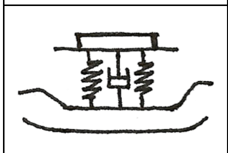
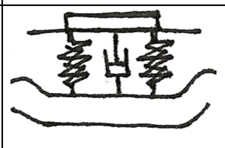
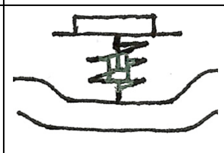
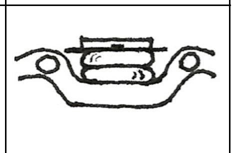
N°	FUNCTION	ACTUATORS			
1	To connect the wheel-set and the carriage	A Carriage spring	B Bogie	C Bogie with single-stage suspension	
					
2.1	To allow the primary suspensions simultaneously work	A Coaxial helical springs + shock absorber	B Helical springs working in parallel + shock absorber	C Helical springs working in parallel + shock absorber	D Pressure spring + rubber small block
					
		E Torsion bar +helical spring + rubber small block	F Absent	G Absent	
			Single-stage suspension with bogie	Bogie is absent	
4.2	To reduce oscillations between the bogie and the carriage frame (secondary)	A Helical springs working in parallel + shock absorber	B Coaxial groups of helical springs working in parallel + shock absorber	C Coaxial helical springs + shock absorber	D Pressure springs (torpress)
					
		F Absent	G Absent		
		Single-stage suspension with bogie	Bogie is absent		

Figure 4b – Analysis of the system function using the Hierarchical Tree.

In figures 5a and 5b there are two examples of new concepts (design of bogie) derived from an evaluation of the constructive solutions row by row and by congruent synthesis of a chosen construct solution for each function. They are the inputs of a new analysis that will provide, as output, the optimal solution.

5 RESULTS AND CONCLUSIONS

The procedure proposed in the paper allowed us to achieve good result concerning the development of the conceptual design phase of the design process.
Such an approach brought to light the importance of the use of the "Morphological Matrix" for the concept generation and assessment: in fact, such a tool has to be considered not only as an example of archives, with the existing constructive solutions for each component function: but also as a "heuristic method", useful to reach innovative solutions, helping designers in taking into account all the available solutions, as well as in developing innovative ones.
A further research work is foreseen in order to implement the proposed procedure with informatic archives, and to test its effectiveness throughout the application to different case studies.

6 ACKNOLEDGEMENTS

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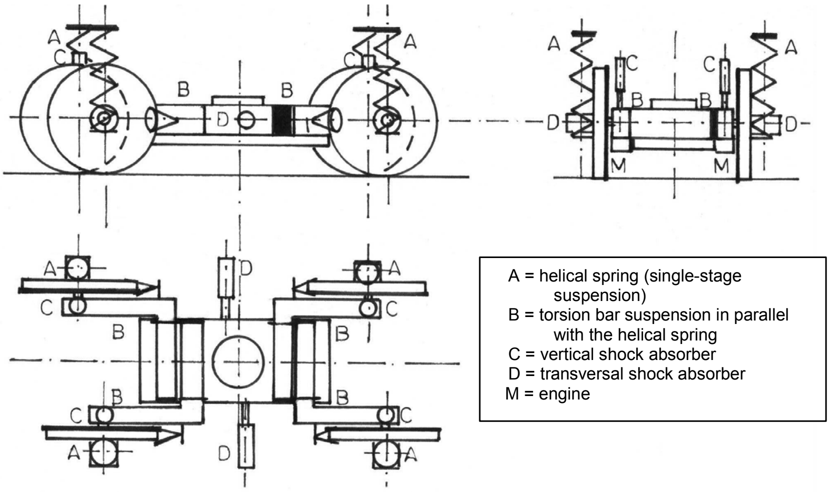

Figure 5a – Analysis of the system function using the Hierarchical Tree.

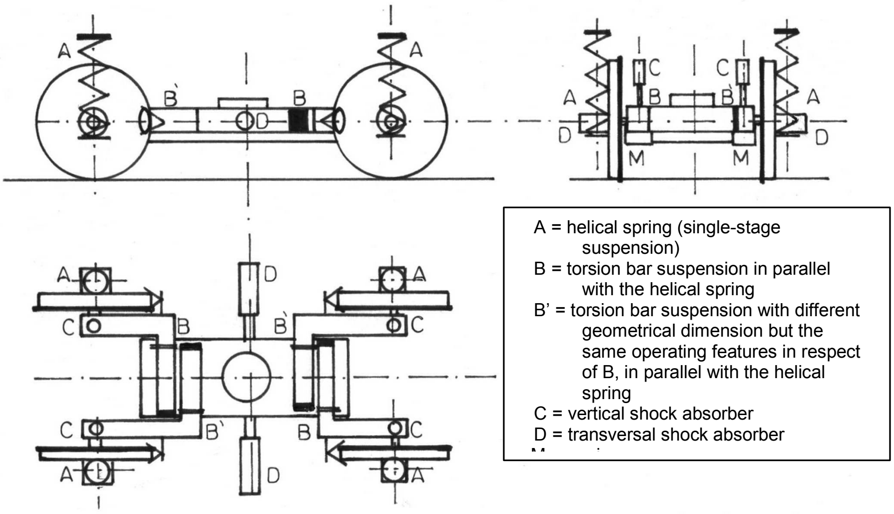

Figure 5b – Analysis of the system function using the Hierarchical Tree.

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