INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19 - 22, 2008.

DESIGN 2008

FROM FUNCTION TO SOLUTION: A SYSTEMATIC APPROACH

F. Panetta and R. Viganò

Keywords: design methods, methodical design, systematic design.

1. Introduction

Studies in design methodologies provide various procedural approaches to the design process. These design methods are devoted to create a process able to aid the designer for finding suitable solutions of an engineering problem. These approaches aim to define a sequential procedure to reduce the complexity of the product design stage. Many authors base their methods on the decomposition of the product functionality, from the primary function, or functions, to the last elementary sub-function (Hubka, Suh, Andreasen, Eder, Pighini, Biggioggero and Rovida). In this way, the designer can be able to define the general solution for the product through the union of the single solutions identified for a particular sub-function required. One issue with design methodologies is often that such approaches prescribe what a designer should do but not how. In fact, the hazy aspects of these methodologies are especially how complete the route from the function to the solution and how the systematic methodologies cannot stifle the designer's creativity. There is the need of design process models that facilitate the designer' work and aid him/her to identify a way able to find quickly the product solutions.

This work is devoted to explore a systematic methodology and its use in an application case. So, a methodology able to conduct a designer from the identification of a function to the definition of a set of possible solutions able to satisfy it will be presented. Moreover, an example in the home automation, also called domotics, field will be presented in order to better explain the application of the methodology proposed and to demonstrate how the steps and their sequential nature aid the designer to deal a problem and to find a solution able to supply the product requirements.

2. The methodology

The proposed methodology has been derived especially from the functional theories (Hubka, Koller, Pahl and Beitz) already presented in the classical literature of design. As the other approaches, our methodology proceeds from the identification of the primary functions that has to be satisfied by the product till it takes the designer to a suitable solution of the problem. The identification of the functions required can be carried out in different ways: customer's requirements, standards and all other source of information that says and explains what the product has to do and what requirements it must to do. It is important highlight that a good designer should find information not only from a source, but he must to take up all possible information by all possible sources. In fact, the main functions of a product are usually specified by the customers, but a few numbers of specifications, technical characteristics, construction constraints and other kinds of information about the product are not made explicit by the customer and the designer should obtain them in other way.

The diagram of the approach is shown in Figure 1 and it is composed by two main phases called, respectively, technical process and technical system. During the technical process step the designer is called to find solutions for each function. During the second step, which is the technical system, the solutions found for each function are composed with each others in order to define the final solution. In this way, at the end of the design process, will be obtained few solutions that will be evaluated in order to be sure that the final solution will be the most suitable in compliance with some final assessment parameters. The evaluating techniques able to be applied to this purpose are a lot, for example derived from the application of the typical morphological matrix approach (Zwicky).

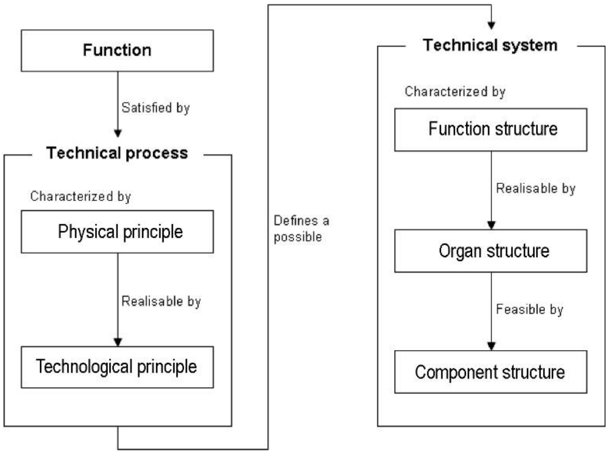

Figure 1. Diagram of the steps followed in the presented approach

The presented methodology has been used during the solution of problems in different field: home furniture, washing machine, electrical connector and others. In the case of home forniture, an enterprise operating in the kitchen field asked for the study about the possible solutions of automatic kitchen door locks. This lock had to be inserted in pieces of furniture, as cabinets, characterised by a single door. This system had to be invisible too, that is to say hidden in the side of the piece of furniture characterised by a small available space.

The other requirement was that the lock observed the reference standard. So, the first step of the design study was devoted to subdivide the requirements and the constraints of the design problem ruled by the BSI (British Standards Institution) and DIN (Deutsches Institut für Normung) standards. This step is the base of this approach because it allows obtain the principal and secondary functions required to the product. The product functionality was subdivided into principal sub-functions. Now each sub-function was analysed by mean of the presented methodology.

Finally, the needed system can be described as a system able to lock a door; this system must be activated or deactivated by a command and when the lock is closed, the system mustn't be forced: there must be a security sub-system. Moreover, according with the BSI 12209 and DIN 68852, the system must be guaranteed in case somebody tries open the door with a force of 500 N: the system is not an anti-burglary, but it is only a deterrent system.

The conclusion of this analysis is the base of the proposed methodology and it allows the designer to find the needed functions able to guarantee the product functionality. In our practical example the main functions that characterised the lock system and that have to be supply are:

- "locking" that is translated as "block degrees of freedom"
- "removable" that is translated as "create motion" and "transfer motion"
- "security system" that is translated as "block degrees of freedom"

Now, the designer is in position to dissociate the problem of the lock system design in three secondary problems that are simpler than the main problem. The identification of the functions which characterise the product allows the designer to face up to the main problem in different sub-problems in order to:

- Solve simple problems instead of solving a complex problem

- Avoid searching possible solutions in function directly of the studied product.
- Avoid missing possible solutions that could be competitive.

2.1 The technical process

After the definition of the functions which characterise the product, the following step of the design process is devoted to the definition and the choice of the technical process which is able to supply in principle the required function under study: each function required has to be analysed independently in order to semplify the investigation.
The term technical process means and identifies the theoretical principles able to supply each function studied. In order to define a possible technical process which characterises a solution, there are two considerations to be done:

- What possible physical principle can be on the base of the solution functionality in order to supply the function required?
- What the technological principle can applies the chosen physical principle in order to realise the required function?

So the technical process is composed by two phases which are respectively called physical principle and technological principle.

2.1.1 The physical principle

The choice of the physical principle is the first step of the technical process. During this step the designer should identify the kind of physical field could supply the function required. So he can define the nature of the system which will characterise the searched solutions of the problem. In this manner the designer can choose the physical law which will be on the base of the system. The typical physical principles can be mechanic, magnetic, electric, hydraulic, pneumatics, etc, and their combination. In our idea the physical principles are the base elements used to supply the function required, which can be subsequently carry out by means of several technological principles.
To analyse this step applied to our case of the looking system, in this paper only one function will be treated, for example the first main function listed in the previous paragraph that is the "locking" function, but the same considerations could be done about the other functions required by the system.
The choice of the physical principle is conducted in accordance with the standards BSI and DIN because they impose some constraints about what the physical principle was admitted to supply the function in the specific field under study. So, the three types of physical principles are chosen:

- Mechanic
- Magnetic
- Electromagnetic

2.1.2 The technological principle

The second step of the technical process is characterised by the choice of the technological principle which is based on the physical principle in exam. In fact, during the previous step, the designer defines a few physical principles and each physical principle has to be analysed separately.
The technological principle characterises the solution by mean of its typology of working: it describes how the solution works. The technological principle defines through what kind of application, tied to the area specified by the physical principle, the solution can supply the required function under study.
So, the aim is define for each physical principle a collection of technological principles able to realise physically a system that can supply the required function using the physical principle in exam. The search of the different solutions can be executed in different way and with the aid of different tools. The first support is an archive of different solutions catalogued (Viganò et al.) in accordance with the described principles (physical and technological) and elementary functions. When a valid solution is not found through the use of this archive, the principles can be used for a search of patents when the searched claims are just the defined principles. In this way it is possible find solutions usually used in different field, but able to be applied in the specific problem. In any case the search of patents is a good habit because it allows finding solutions which, otherwise, it's difficult to find. Finally there is

the design creativity which is always admitted. These two alternative ways for the solutions finding allows to complete the archive which is always able to be refresh.
Through the application of this methodology to the locking system problem, in the case of a physical principle of mechanical type, the main technological principles found and chosen for the solution searching are:

- Ratchet
- Wedge
- Friction
- …

After the definition of both physical and technological principles, the solution related to each function is practically obtained. There could be some variations about how the solution can be applied, but it is fundamentally defined. The variation could be due to the manner of application of the same principles. In conclusion for each possible combination of physical and technological principles some possible solutions can be obtained and these solutions are certainly able to supply the required function.
The list of the found solutions which supply the "locking" function in the case of the study of the locking system is showed in Figure 2. The locking fuction, that could be represented, with reference to the figure sketches, by a horizontal force able to fix the door to the cabinet structure, is obtained by means of rackets, wedges and frictions solutions shown to the left, the center and the right positions of the figure.

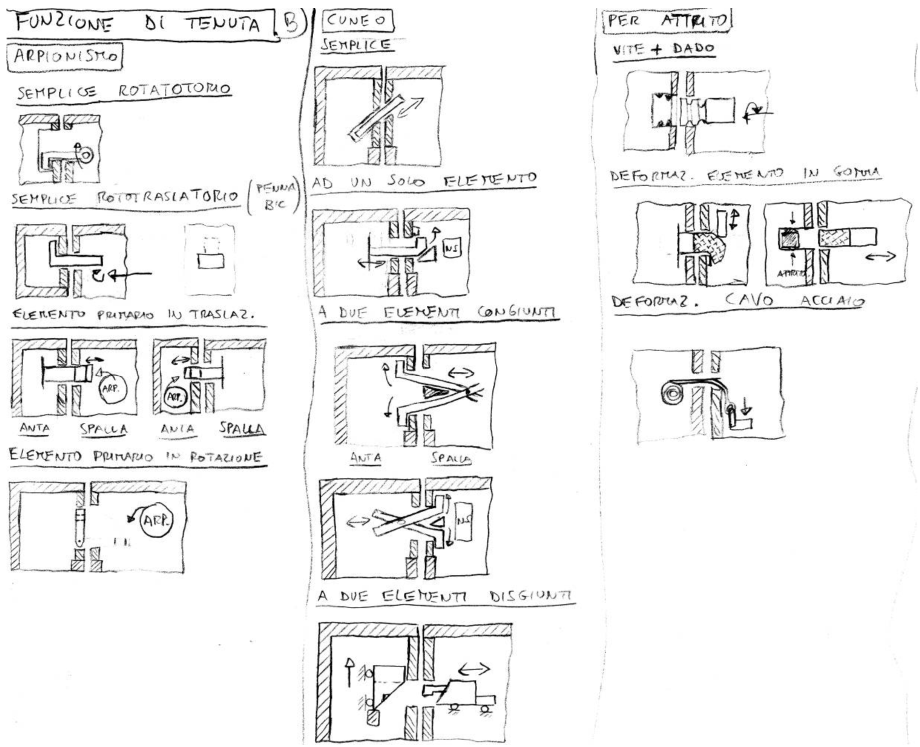

Figure 2. Summary of the found solutions for the locking function

This part of the presented methodology must be repeated for each analysed functions that describe the studied problem. At the end of this step a list of solutions able to satisfy separately each function can be obtained. This kind of approach allows the designers to find a huge number of solutions for a particular function. So, the found solutions will not be the hole of the possible solutions, but the number of missed solution will be appreciably decreased: the quantity of the missed solution will be inevitably functioning of the designer's ability and knowledge. Moreover, during this step the designer is not able to do any considerations about the found solutions: an a priori negative judgment on a solution could be the cause of the loss of possible final solutions. Anybody can evaluate if these lost solutions are good or not.

2.2 The technical system

The first part of this methodology allows the definition of a set of solutions able to supply some functions. These functions derive from the decomposition of the studied problem. So, the methodology begins with the study of each sub-problem separately. In the technical system all these functions and their solutions converge in order to define the final solution. This solution will obviously guarantee all functions needed to the product.
In order to realise the fusion of the functions and their solutions the technical system is structured in three steps. During these steps the designer defines the function structure, the organ and, finally, the component structure.

2.2.1 The function structure

All functions studied separately during the technical process, converge in this step of the procedure with the aim to study the function structure of the product. The function structure highlights how the different functions analysed during previous step interact with each others. With the use of the function structure, it is possible define the interactions between the different functions and, consequently, between the different technological solutions founded.
So, the goal is researching combinations of the required functions. By the analysis of the different configurations of the interactions between the functions, some different possible solutions can be found.
The importance of the study of the function structure of the product is based on the systematic research of all possible configurations. This approach guarantees the discovery of functional structures of the product that may be differently not detectable and, otherwise, they could be missed.
In the studied case the problem is composed by a little number of functions and, in consequence, the number of the possible function structures is not a lot. In the Figure 3 are highlighted the different functional structures that could supply the product requirements and guarantee its functionality. The difference between the functional structures are characterised on how the function marked "Security system" interacts with the other functions of the structure.

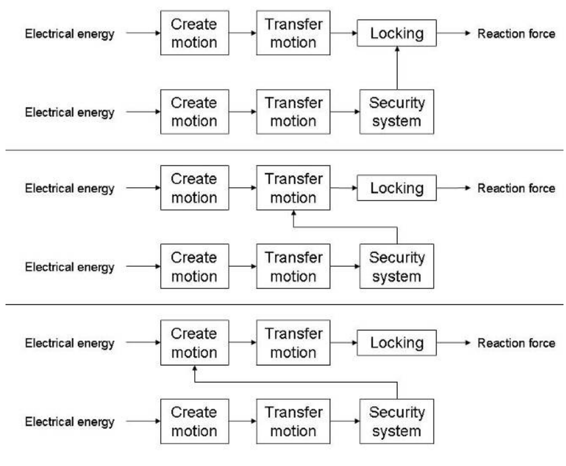

Figure 3. Examples of possible function structures for the locking system

The wording “Security system” and “Locking” are not exact and both the real names of these functions, able to search the function in a functional dictionary in order to find the possible solution, should be “Block degree of freedom”; on the other hand these names allow a better interpretation of the structures schemes.
This example is easy and trivial, but it highlights how the number of the possible function structures can increase in accordance with the number of the required functions.

2.2.2 The organ structure

At this point the procedure involves that the designer analyse, for each function structure, the possible combinations of the solutions found for the functions and study how each solution interact with the other: he should define an organ structure which can be just an outline of the solution.
During this phase the aim is study the compatibility between the found solutions according to the function structure in exam. In fact, the procedure plans that the designer chooses a function structure and, after that, he must verify if the different solutions found for each function are able to be interfaced. For example, if the “Locking” function is supplied by a hook with a simple rotational movement, this solution is not compatible with an articulated quadrilateral for the “transfer motion” function and so on. Obviously, these incompatible solutions of the organ structure step will be not considered.
At the end of this step the design obtains the sketches of all possible solutions. These solutions supply all functions needed and so they guarantee all the products requirements. Moreover, the designer is sure about the organ feasibility of the found solutions.
The application of this step of the procedure to the case of the locking system allows obtaining a lot of organ structure of possible solutions as shown in Figure 4.

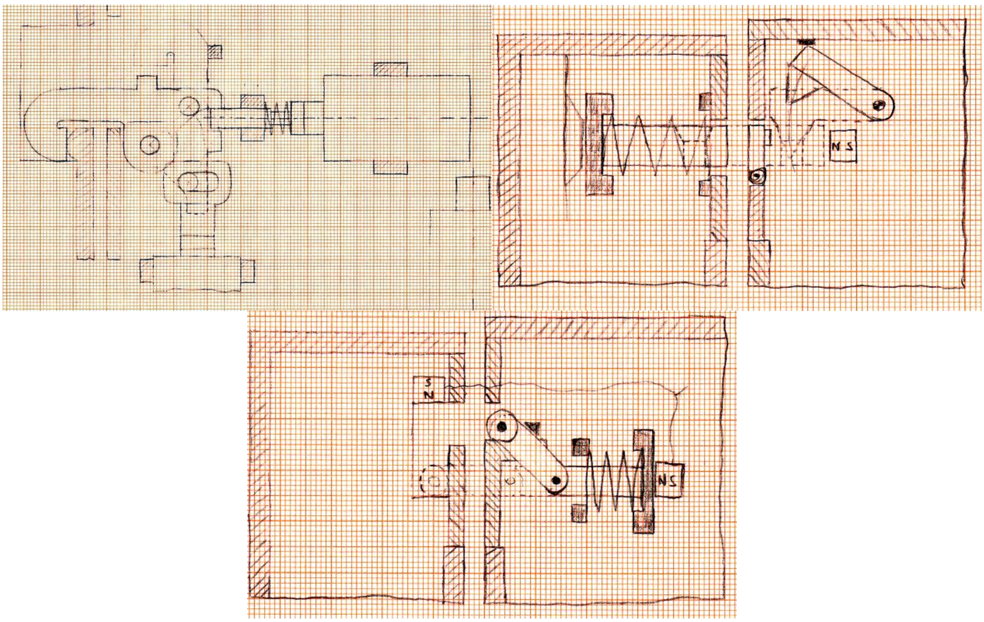

Figure 4. Examples of possible organ structures

2.2.3 The component structure

Finally the found organ structures must be transferred to concrete solutions; the component structure is able to be defined and represents the real design of the product.

So, the last step of the procedure is characterised by the dimensioning of all solutions which have passed all the previous steps of the procedure. At the end the designer obtains the design of few solutions as represented in Figure 5. All these solutions are suitable to be used for the realisation of the searched product.
Finally, all the solutions have to be evaluated. The technique used is characterised by the use of the morphological matrix. This methodology allows evaluating the efficiency of the solution in function of some chosen topics.
In this way, the product which will be elected as final and definitive solution, not only it supplies the required functions, but also it will prove to be the best solution in function of the assessment parameters.

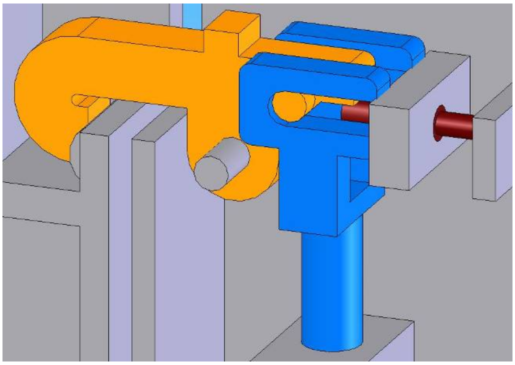

Figure 5. Example of 3D model of a solution

3. Conclusions

In this paper, a methodical approach to the design process has been presented. This approach is characterised by a sequential route composed by simple activities. Starting from the identification of the functions that a product must supply, these activities let obtain a solution that guarantees both the functions needed and its efficiency related to some particular topics: these topics could be costs, easy assembly, etc.
The methodology has been validated by means of the resolution of some problems characterised of different levels of complexity and different fields: home automation systems, washing machines, electrical connectors and others. Just the study of locking system in the home automation field has been reported to validate the proposed approach. In fact, the found solutions have been presented to the enterprise which has required the study; at the moment, the final solution is going to be evaluate and if the judgement will be positive, its production will begin.

References

Biggioggero, G.F., Rovida, E., "Design for quality". In Huang, G.Q., "Design for X – Concurrent engineering imperatives", chapter 16. Chapman & Hall, London, 1996.

Hubka, V., "Principles of Engineering Design",London: Butterworths, 1982.

Hubka, V., Andreasen, M., Eder, W. & Hills, P. (advisory editor), "Practical Studies in Systematic Design", London: Butterworths, 1988.

Koller, R., "Konstruktionslehre für den Maschinenbau" (2 ed.), Berlin/Heidelberg: Springer-Verlag, 1985.

Pahl, G., Beitz, W., "Engineering Design: A Systematic Approach", London: Design Council, 1984.

Suh, N.P., "The Principles of Design", Oxford University Press, Inc., 1990.

Viganò, R., Rovida, E., De Crescenzo, A., Raco, D., "Preliminary studies for the creation of a functional archive", proceeding of Wonderground, Lisbon, 2006.

Zwicky, F., "The Morphological Method of Analysis and Construction", Courant Anniversary Volume, New York Wiley-Interscience, 1948.

Fabio Panetta
PhD Student
Politecnico di Milano, Mechanical Department
Via LaMasa 34, 20156 Milan, Italy
Tel.: +39 02 2399 8297
Fax.: +39 02 2399 8202
Email: fabio.panetta@polimi.it