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# ON THE CO-EXISTANCE OF FBS AND TRIZ FOR SIMPLIFYING DESIGN PROCESS IN AN ITERATIVE WAY

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## ABSTRACT

Functional design model and in particular FBS model are, in recent years, most commonly accepted design theories to support design process. However, with regard to their use it remains widespread skepticism especially by industry engineers, more inclined to use problem solving methods. Reasons are varied and come from the way in which they approach design problem, often considered too abstract and far from everyday design reality.

This paper contains a number of measures to bridge this gap. In particular is proposed an integration between FBS and TRIZ to best rationalize designer efforts in a design process based on a large set of initial requirements. The considered method addresses the determination of the main function and its implementation on the device, and then it starts to iteratively overcome the other requirements (functions) by solving contradictions. In order to obtain more practically feedback, each phase is described with technical parameters. Furthermore the method allows a quickly and economic screening of the alternatives. A design process for a chips waste compactor is carried out by using that process.

*Keywords: design methods, design engineering, FBS, TRIZ contradiction*

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# 1 INTRODUCTION

Since the ‘70s, the product design has focus on the function of a device rather than its mere structure. An historical overview of the definition of function can easily be found in literature. According to Rodenacker (1971), function is an input-output transformation while Pahl and Beitz (1977) describe it as a verb that does not necessarily express a transformation but also as a conservation between input and output. These authors describe function as a black-box working in a specific way on a flow of information, energy or matter. In the same period, Miles (1972) considers economic aspects linked to functional design and Collins (1976) creates a first function database.

FBS researchers provide different definitions about function linking to behavior. According to Umeda et al. (1984), function is ‘a description of behavior recognized by a human through abstraction in order to utilize it’. Gero (1990) considers language use of the word “function”, differentiating the concepts of function and behavior: the first concept represents purposes of a device while the second one explains working conditions. Other authors (e.g. Vermaas and Dorst, 2007) or those already mentioned above (e.g. Umeda et al., 1995 or Gero, 2002) provide also other definitions.

They follow this approach agreeing on the definition of function as an heterogeneous set of requirements. Among them, there is the Useful Function (Altshuller, 1988) that represents the reason for which a device exists.

For industry, functional analysis and more generally the design science is not considered as one of the most popular methods (TQM, QFD, Taguchi, etc.) and it is considered a kind of engineering meta-science. (e.g. Eder, 1998, Sheldon, 1997). One of the reasons is that design theories work on a too high level of abstraction, without involving explicitly technical parameters by which engineer is more accustomed to work.

In this paper, our proposal is to facilitate acceptance and implementation of functional design as FBS by engineers, introducing the concept of contradiction of the TRIZ formulation bringing the design flow up to technical parameters level.

Section 2 introduces Gero’s FBS version (1990), which is taken as reference, and the concept of contradiction in OTSM version of Khomenko (Cavallucci and Khomenko, 2007), which is the most structured. Section 3 proposes a variation about the classic FBS model, introducing the concept of functional hierarchy and placing an orderly flow of work, trying to solve contradictions between functions at different levels with technical parameters. In Section 4 is showed a case study about a device for compacting a material. Finally, section 5 outlines the conclusions.

# 2 STATE OF ART

## 2.2 FBS - Design model

According to Coyne et al. (1990), design process of a new device progresses through five basic steps: identification of requirements of a device; production of project documentation; physical realization of the prototype; performance testing; comparison between experimental results and requirements. Many authors developed models based on this approach, considering only a few steps (e.g. Pahl and Beitz, 1977, Umeda, 1984) or all (e.g. Gero, 1990, Cao and Tan, 2007). SAPB and Function Behaviour State model lead from the first to the second step through different paths while Gero’s FBS model and FBES guide the designer through the entire creative process with a variable number of intermediate steps.

Other authors propose new schemes, based on Gero's FBS model of figure 1: Gero and Kannengiesser (2004) consider interaction with designer while Cao and Tan (2007) introduce physical effects and Cascini et al. (2010) analyze user’s role.

The comparison step in Coyne et al. (1990) is essential to check whether a device meets its requirements. About this step, Gero (1990) prescribes to compare expected behavior a device with its actual behavior. The first one is derived from the function via the process of abstraction while the second represents physical manifestation of a device.

While following this procedure, design problem can be approached with different degrees of detail. Gero (1990) also introduces concepts of behavior variables and structure variables to guide designer towards a more quantitative level.

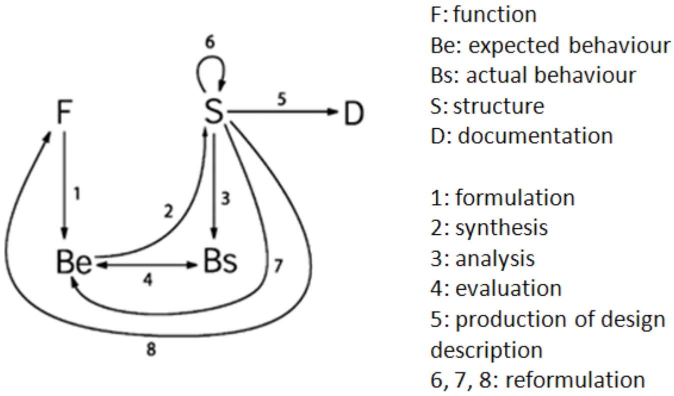


*Figure 1. Gero's FBS model (1990)*

## 2.3 TRIZ Contradiction

Contradiction is an instrument of the Theory of Inventive Problem Solving (TRIZ) (Altshuller, 1988). The starting point for its application is typically a technical problem. For instance, a device that for some reason does not work the way we want or do not realise all its requirements. There are several ways to solve this problem: avoiding it, treating it with a compromise, etc. TRIZ offers a no compromise solution. According to Khomenko's OTSM contradiction model (OTSM-TRIZ, 2013) if a device must satisfy two requirements respectively called Evaluation Parameter 1 (EP1) and Evaluation Parameter 2 (EP2), the overcoming of the contradiction leads to this goal (see figure 2). For this reason, TRIZ suggests to act on a Control Parameter (CP) belonging to the device and which can be modified. The theory also provides several tools and tips in order to help designer in this task.

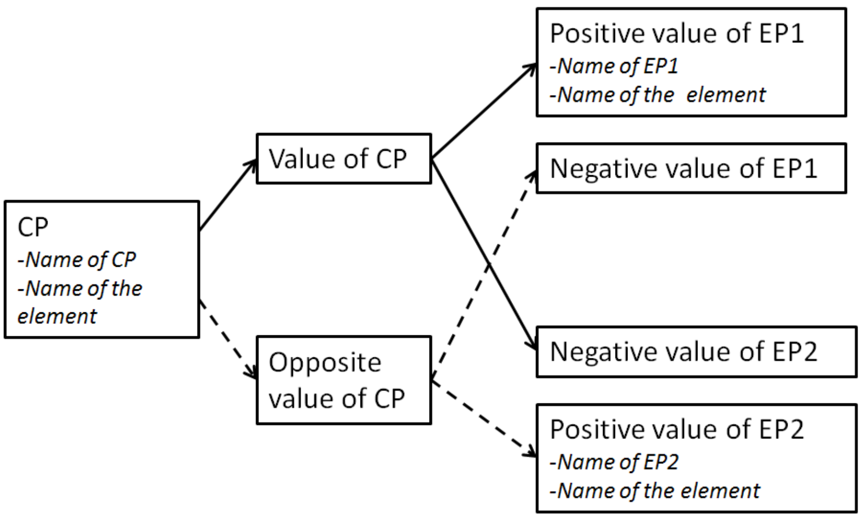


*Figure 2. OTSM scheme of contradiction*

# 3 METHODOLOGICAL PROPOSAL

Ascertained utility of a step-divided design methodology, all theories start with the identification of a function and describe it as a set of requirements. Subsequent steps guide designer from the function to the physical configuration of a device, considering simultaneously all the requirements. Our proposal is to identify the main function and the secondary functions in the set of requirements, where the first one represents the essence of a device. For example, the main function of a car is to carry the passengers while the secondary functions are comfort, safety, fuel consumption, aesthetics, etc. The main function can also be identified as the Useful Function of TRIZ. With our method designer considers firstly only the main function, basting a test structure working for this purpose. Until this structure does not realise its main function, the designer cannot consider the secondary functions. Of course the goal of this approach is the realization of the final structure but the followed path streamlines the efforts ensuring the desired results. Last but not least, this approach aims to reduce attempts than a trial and error method.

According to Gero (1990), F usually coincides with a set of requirements:

$$F = (f_1, f_2, \ldots, f_n) \tag{1}$$

while Be, S and Bs are designed to fulfill all the requirements of F. In addition to these elements, the paper also suggests several variables completing Gero's FBS. Then we can define all functions and variables using technical parameters in order to get a clear reference point on the objectives.

However we do not work at this stage on the scheme but first we determine the main and the secondary functions. To achieve them, it is necessary to classify requirements according to the degree of importance. In this task, we can use a variety of tools (e.g. a new hierarchy ranking derived from axiomatic design, Multi criteria analysis, etc.) that are not detailed in this paper. Only the first of these requirements is the main function, the other ones are called secondary. Our approach does not consider the whole set F from the beginning but it invites designer to an iterative work process that is described in the following paragraphs.

***Iteration 1***

At the first iteration, the set of functions contains only the main function:

$$F^1 = (f_1) \tag{2}$$

In this way, as shown in the figure 3, $Be^1$, $S^1$ and $Bs^1$, obtained from Gero's FBS model, realise only the main function and they may be different than Be, S and Bs, which are designed to satisfy all requirements.

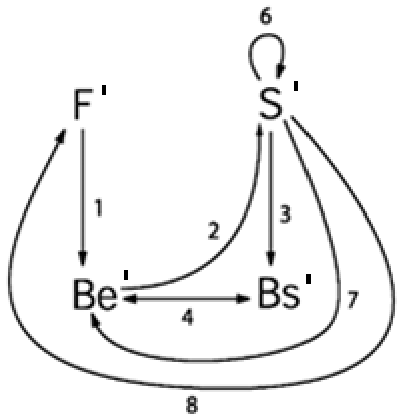


*Figure 3. Gero's FBS model  for the first iteration*

$S^1$ is considered valid if it satisfies $f_1$.

If so you can move on to the second iteration, otherwise it is necessary to modify $S^1$ until it makes its job.

***Iteration 2***

In the second iteration, as well as $f_1$, $f_2$ is taken into account. Consequently, the set of functions is enlarged:

$$F^2 = (f_1, f_2) \tag{2}$$

The objective of this second iteration is the determination of a structure $S^2$, which realizes both requirements $f_1$ and $f_2$. The first iteration gave us structure $S^1$ that realizes $f_1$. The structure $S^2$ arises as a modification of $S^1$ to also achieve $f_2$. In order to get this result we use TRIZ instrument of contradictions, which allows us to obtain the structure $S^2$ we want.

So, we think a temporary structure $S^{2}*$ that only realises $f_2$. $S^{2}*$ can be a different structure from $S^1$ or the same working in a different configuration. To support this stage, it is possible to use Gero's FBS model on fig.3.

At this point we formulate and solve contradiction to get the final structure $S^2$. Acting in a suitable manner on a CP belonging to $S^1$, the contradiction aims to simultaneously realise EP1 and EP2 that respectively coincide with $f_1$ and $f_2$.
Technical parameters can also be used to solve contradiction quantifying the functions. Then we evaluate f1 and f2 respectively with technical Parameters PT(f1) and PT(f2). In this case the EPs coincide with PTs (see figure 4).

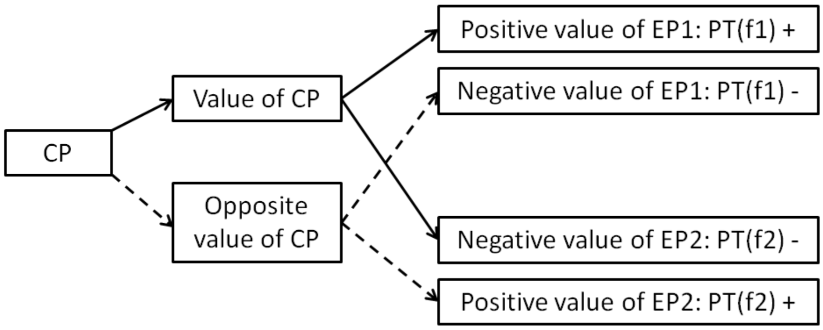


*Figure 4. Contradiction in second iteration*

Thus, given $S^1$ that realises $f_1$ and $S^{2*}$ that satisfies $f_2$, solution of contradiction gives us $S^2$ that realises both $f_1$ and $f_2$.
At this point we can go to the next iteration and so on until the last.

***Iteration n***

With the iteration n, $S^n$ must implement all the functions:

$$F^n = (f_1, f_2, \ldots, f_n) \tag{3}$$

The iteration n-1 has provided us with $S^{n-1}$ that realises the functions from $f_1$ to $f_{n-1}$. In order to obtain $S^n$, we search $S^{n*}$ such that it achieves $f_n$ and we solve the contradiction as in the previous steps. If $S^n$ is considered valid, it is possible to produce design documentation D.
We can summarize the first three step of our method with the following scheme of figure 5, where $S^i(f_{1, \ldots,} f_i)$ means 'Structure $S^1$ that performs functions: $f_1$, ..., $f_i$'.

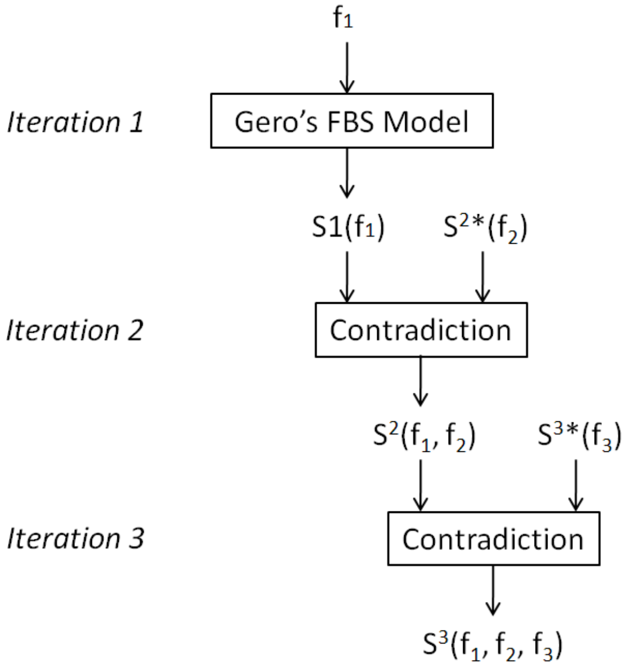


*Figure 5. Iterative process for the new product design*

With this approach, the most expensive part of design work is the first iteration, during which we outline the test structure $S^1$. After that, we need to substantially change the structure $S^1$ to go along

with the new requirement of each iteration, without losing those already satisfied. The expected and actual behaviors, and with them the physics of the problem, do not significantly change during various iterations. Therefore determination of expected behavior is a crucial point in design process of a device. A suitable choice of the expected behavior is the basis of a winning design. In order to raise the quality, a good idea to go through an evaluation can be to consider a wide spectrum of possible alternatives (e.g. Russo and Montecchi, 2011, Russo and Montecchi, 2011b, Russo et al, 2011, and Montecchi, 2012). However the following experimental activity can be very expensive and difficult to carry out. In this sense, our approach can solve this problem: if we work directly on the final structure testing a number n of behaviors, we must build and test the same number of complete structure. With the considered method we develop and experience only test structures instead. In relation to this aspect, Reich (2010) tells us that valuation yardstick of a method generally depends on the parameters of cost and effectiveness, which they are influenced by operative context. Thus, if product is simple and inexpensive, all FBS based models and ours are competing, otherwise our method is instead winning least about costs.
Usually, the design of the entire structure means trying to achieve a compromise between the main function and one at a time all the secondary functions, in order to implement all. In our case we seek primarily to accommodate the main function without compromises. So compromises can exist only on the secondary requirements.
However, in most cases (such as electronics and the domains where standardization is very high) the optimization approach is sufficient to fulfill a new secondary requirement without formulating a new contradiction.

# 4 CASE STUDY

So far, we have told the theory of our approach, this section describes instead a real design case. Considering the design of a device for compacting some waste material chips with a specific final configuration. The device has to fulfill many requirements:

- $f_1$: compactness of the sample;
- $f_2$: weight of the device;
- $f_3$: energy consumption;
- others (aesthetic, maintenance, cost, easy of manufacturing, ease of use).

First, if we want to approach to the problem with our method, we have to work on requirements, determining the main and the secondary functions. In our case, the main function is the realisation of a compact sample, which represents the essence of the device, i.e. the reason why it is designed. At the first iteration we determine a test structure that realises the main function; for this reason, we use Gero's FBS model, considering only $f_1$. According to this logic, we hypothesize an expected behavior $Be^1$ that allows realisation of $f_1$. So we thought to an axial compression of a cylindrical sample of the material (see figure 6).
Then we can design, implement and experience the test structure based on $Be^1$ in order to validate the latter. Thus, we consider a hydraulic press to perform this task. The comparison phase is parametric: technical parameter of $Be^1$ is the required value of density $\rho^*$ after compaction of the sample. By experimenting with this structure, we find the actual value technical parameter $\rho_1$. The parametric comparison clarifies the test structure and validity of the expected behavior.

*Table 1. Technical parameters for density of a chips material sample.*

| **Technical parameter (density)** | **Value** g/mm$^3$ |
|---|---|
| $\rho^*$ minimum admissible value | $7 \cdot 10^{-3}$ |
| $\rho_1$ tested by axial compression test (a) | $8 \cdot 10^{-3}$ |

However, the first step cannot stop at this point. It is a good idea to experiment alternative behaviors in order to identify the best result. So we consider operating with a cylindrical sample, by testing two other behaviors:

- $Be^{radial}$: radial compression and axial rotation of the sample;

- $Be^{necking}$: necking side of the sample.

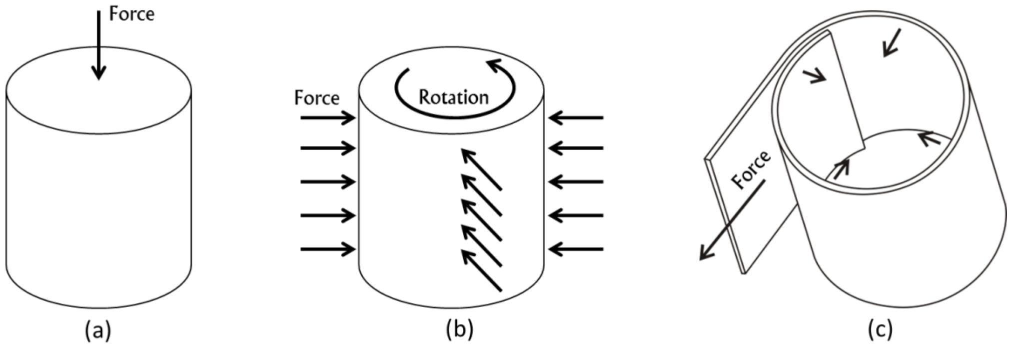


*Figure 6. Alternative behaviours for compacting waste material chips: axial(a), radial and rotational (b), and stricking (c) configurations*

To characterize the new behaviors, two other test structures are designed and experimented:
- $S^{1B}$: roller compactor;
- $S^{1C}$: belt compactor.

Both roller and belt compactor are considered valid because they produce compact samples with a greater density than ρ* (see Table 2): at this point we have three valid test structures. In order to choose the best one, we consider another technical parameter: energy consumption En. In this case, reference value derived from $f_2$ is:

$$En^{*}=30\ J \tag{4}$$

Now we choose a good test structure between our alternatives $S^{1(a)}$, $S^{1(b)}$ and $S^{1(c)}$. Of course it must satisfy of $\rho_i > \rho^*$ and not necessarily $En_i < En^*$: for the moment the technical parameter of energy is used as a selection criterion and not as a binding value. For this reason, even if $S^{1(b)}$ does not realise En*, we can consider it, because it has the lowest consumption of energy. (En* is considered as a constraint at its iteration).

*Table 2. Technical parameters of density and energy consumption*

| Structure | Technical parameter ρ | Technical parameter En |
|---|---|---|
| $S^{1(a)}$ | $\rho_1 = 8 \cdot 10^{-3}$ g/mm$^3$ | $En_1 = 200$ J |
| $S^{1(b)}$ | $\rho_2 = 8{,}1 \cdot 10^{-3}$ g/mm$^3$ | $En_2 = 60$ J |
| $S^{1(c)}$ | $\rho_3 = 7{,}5 \cdot 10^{-3}$ g/mm$^3$ | $En_3 = 80$ J |

The roller compactor $S^{1(b)}$ contains four rotating rollers that compact the cylindrical sample along its lateral surface. Since the rollers are contained in a special cam they rotate and approach the center of the device making the sample itself rotate.

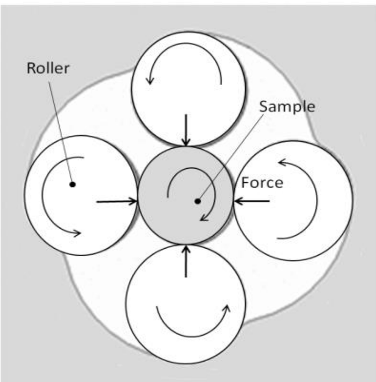


*Figure 9. $S^{1B}$(Section)*

At the second iteration we need to realize the requirement $f_2$ that explains the mass of the device by the technical parameter m*. In order to formulate the contradiction we compare the present structure with steel rollers with the structure $S^2$* made with plastic rollers. The first solution manages to compact the material with the desired density but has a mass too high, the second one vice versa. Consequently we define EP1 and EP2 as the technical parameters ρ* and m*; while CP represents the material of the rollers.

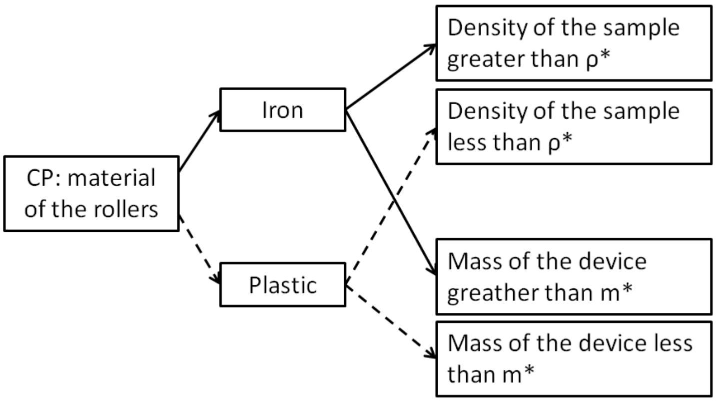


*Figure 10. Formulation of the contradiction*

To solve the contradiction we use the principle of 'Separation of conflicting properties in space' on the control parameter. According to it we realise plastic rollers with an external ring-shaped metal making the mass of the structure lighter, while ensuring the compactness of the material. This iteration satisfies three requirements: the compactness of the powder, low weight of the device and the energy consumption. With the following iterations, we fulfilled also remaining requirements as aesthetic, maintenance, easy of manufacturing and ease of use. The final structure resulting from all iterations is still similar to the device in fig.9.

## 5 CONCLUSION

Methodological proposal presented in this article has the objective to reduce the gap between design theories and design demand from industry. This method is merged from an experimental activity based on design theories.

First step we propose to put order in the heterogeneous set of requirements by underlining the main and the secondary functions of a device. Design process proceeds via realisation of main function by applying FBS model in a parametrical way. Afterwards the secondary functions are addressed iteratively by using TRIZ contradictions with technical parameters.

The considered method is useful to concentrate the attention on the essence of the design problem. It allows a screening of design alternatives in a quantitative way bringing the theories of design to industrial practice meanwhile saving times and costs. The method is particularly efficient where the problem is described with many requirements, because it aims at limiting just the prototyping phase.

A case study, conducted by an European company, leader in household appliance production and dealing with a device for compacting chips waste material has been presented in order to show the proposed method.

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