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# REFLECTIONS ON THE FBS MODEL: PROPOSAL FOR AN EXTENSION TO NEEDS AND REQUIREMENTS MODELING

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## 1. Introduction

Several papers have been written about Gero's Function-Behaviour-Structure (FBS) framework since its first formulation in 1990; Gero himself has further developed and integrated his model as in [Gero and Kannengiesser 2004], which is here assumed as the reference starting point. The scientific debate about the FBS framework has revealed some ambiguities (e.g. the absence of a stable definition of function [Vermaas and Dorst 2006]) and limitations (e.g. in the representation of human-machine interactions [Wang et al. 2002]). Nevertheless, still it remains a reference model to describe design processes and tasks.

Among the aspects which are just marginally considered in the literature about the FBS model and its limits of validity, a relevant issue is related to the representation of needs and requirements in the design process and their relationships with the Function, the Behaviour and the Structure of an artefact. Indeed, the formalization of Needs and Requirements into a design framework is extremely important in order to represent the customer perspective and user's expectations. Nevertheless, as clearly discussed in [Ericson et al. 2009], these terms are not straightforwardly defined in literature and a relevant direction for research is answering to questions like: "How do needs and requirements affect the early phases of product development? Do needs and requirements correlate, and if so, how?".

The goal of this paper is to provide a contribution in this area of study, by extending the FBS framework to the representation of Needs and Requirements, which can be modelled as further types of variables to complement Function, Behaviour and Structure. Moreover, the integration of these variables allows to describe with the same formal approach the transformation processes which occur in the earlier stages of design, when the requirements still need to be specified. It is interesting to notice that Gero's classification in terms of External world, Interpreted world and Expected world still remains useful also to "situate" Needs and Requirements.

The authors believe that a proper identification of user needs and consequently a suitable formulation of design requirements is a crucial step for product development, both for processes driven by the Voice of the Customer and also for design activities inspired by codified laws of evolution of technical systems as suggested in [Cavallucci 2001]. In facts, the identification of the "right" customer needs is essential to achieve customer satisfaction and represents a key step in product development. Besides, widespread customer satisfaction is not normally attained largely due to problems of inadequate requirements definition. This lack of understanding is an undesired consequence of the semantic gap existing between customers and system developers, while exploring requirements.

The product development process, and consequently the included design processes, can be defined as processes including many ''generic decision'' points, likewise ''decision perspective'' as in [Krishnan and Ulrich 2001]. Some contributions concerning decision process, e.g. [Urban and Hauser 1993] and the definition of the critical decisional points in the design and development processes, e.g. [Büyüközkan and Feyzioğlu 2004] exist in literature. For this reason, it sounds promising to apply a decisional perspective on the FBS framework in order to better analyze and carefully comprehend it. In particular, some reflections and observations can be made by reviewing the FBS model in comparison with the Simon's model proposed in 1960.

The paper starts with a critical analysis of the FBS model according to the scopes of the present work. Then, in section 3, the reviewed model is described with details about the integrated representation framework and its transformation processes. The following paragraph clarifies the proposed model by means of a simple, but comprehensive example related to the design of a kettle. Eventually, the conclusions which can be drawn by the results achieved so far are presented.

## 2. Observations on the FBS model

The FBS model analyzes the design process as consisting of elementary steps, which are defined in terms of the key concepts of function, behaviour and structure. In particular, it distinguishes eight elementary steps in designing. Five of them convert the posited functions sequentially into design descriptions. The first is called the *formulation* step and transforms functions F into a description of behaviour Be of an artefact that is expected to perform the previous functions. Then, the expected behaviour is transformed by a *synthesis* step into a structure S of the artefact by which it may show its behaviour Be. Subsequently, in a third step, called *analysis*, the actual behaviour Bs of the artefact with this structure S is derived. Fourthly, this actual behaviour is evaluated by comparing it with the expected behaviour. If this *evaluation* is satisfactory, a design description D is *documented* for manufacturing the artefact with the structure S. If the evaluation is not satisfactory, the design process returns to previous steps, defining three elementary loop-back stages and defining the design process as an iterative procedure. The model is shown in figure 1.

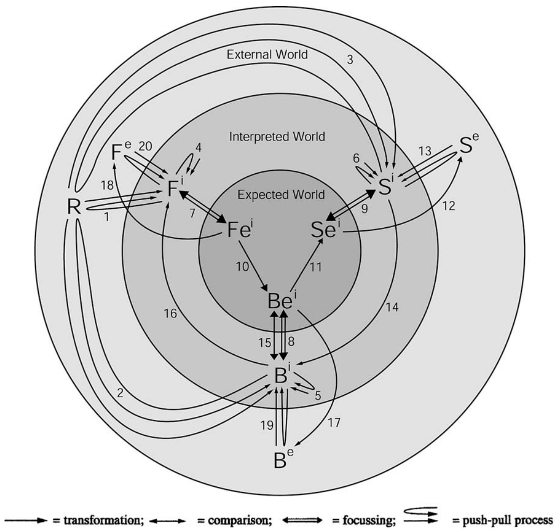


**Figure 1. The situated FBS framework [Gero and Kannengiesser 2004]**

A first consideration that clearly emerges from the analysis of the FBS framework, with respect to the scopes of the present work, is that needs identification as well as requirements definition are not fully represented.

In facts, [Gero and Kannengiesser 2004] explicitly refer to the requirements (R) of a design problem, but the description of the formulation process is limited to the statement "the design agent interprets the explicit requirements (R) by producing the interpreted representations $F^i$ and, eventually, $B^i$ and $S^i$". Compared with the careful description of the following design processes, the requirements definition appears too simplistic, probably due to the traditionally limited relevance assigned in design theory to user needs recognition.

Besides, in [Vermaas and Dorst 2007], despite the purpose of the paper is different from the present work, it is claimed that "designing starts with a client's intentional aim or desire, and produces a physicochemical description of an artefact by which the client can make the aim or desire come true", thus highlighting that the design process covers a more extended range than a translations of some requirements into a functional specification. In other terms, the first task to be accomplished by a design agent is the identification of user's intentional aims and desires and, as such, it should be properly represented into a general design framework.

Design literature rarely provide a proper distinction between needs e requirements; an accurate analysis from this perspective is reported in [Ericson et al. 2009]. In summary, needs "can be viewed as an expression of a perceived problematic situation", while requirements "are structured and formalized information about a product" and "consists of a metric and a value".

A second issue can be observed about the situated FBS framework and its related processes: an anomaly appears in the so called formulation, i.e. the use of Requirements, referred as something belonging to the External World, to produce Interpreted Functions variables $F^i$, Interpreted Behaviours variables $B^i$ and Interpreted Structures variables $S^i$.

In facts, all the other processes described in [Gero and Kannengiesser 2004] respect one of the following unexpressed rules:

variables of a certain type (i.e. F, B, S) change their reference world (i.e. External, Interpreted, Expected), e.g. as it happens in focusing steps from $F^i$ to $Fe^i$, from $B^i$ to $Be^i$ and from $S^i$ to $Se^i$;

variables of a certain type (i.e. F, B, S) are produced from a set of variables of a different kind, but still referred to the same world (i.e. External, Interpreted, Expected), e.g. as it happens in the analysis step from $S^i$ to $B^i$.

In other terms, the transition from Requirements to the interpreted variables $F^i$, $B^i$ and $S^i$ is the only process which involves both a variable change and a modification of the reference world.

In conclusions, the FBS framework appears not completely exploited to represent design activities related to user needs identification and requirements formulation. Starting from these observations, the authors have formulated a proposal for an extended FBS model, characterized by two further types of variables and their related processes as detailed in the following section.

## 3. Proposal for an extended FBS model

As mentioned above, Gero's FBS framework consists in: Function (what an artefact is for), Behaviour (what it does) and Structure (what it is).

Nevertheless, according to the goal of the present proposal, it is necessary to integrate the FBS model by means of two further explicit types of variables:

- Needs (N): the exigencies from where the existence of the artefact is originated);
- Requirements (R): a measurable property related to one or more Needs.

More in details, Needs can be categorized according to their urgency (e.g. from physiological, to means for satisfaction), or to their universality (e.g. relevant for the whole human race, or highly based on individual judgment), but in any case they are the basic motivation for pushing people to change their situation [Maslow 1987] and, as a consequence, also to produce artefacts. Besides, Requirements are a translation of Needs into an engineering specification, i.e. a set of technical constraints such that it is possible to assess whether they are satisfied in a given context.

In marketing literature many contributions (e.g. Loudon 1988, Sheth et al. 1998 and 2004, Sandhusen, 2000) stress the importance of considering the wider customer behaviour concept (besides the customer needs one), in order to correctly define product requirements. Actually, also in this literature, last contributions (e.g., Belch and Belch 2004) mainly focused on the analysis of the customer behaviour, consider the consumer needs as an output of the consumer decision making problem. Consumer through a specific process, named "problem recognition", identifies a need and, for that, becomes motivated to solve a specific problem and will have behaviours aimed at satisfying the identified need. The extended FBS model proposed in this paper is suitable for describing what happens from the identification of a need by the user to the development of the design process.

Thus, the model suggests the introduction of two new sets of variables to describe the design process, according to its broadest meaning, since its earliest stages.

In order to take into account that the design process starts with the identification of user needs, the first step to be represented by the extended model is the *Needs Identification*. This step considers the information that the customer is able to provide, or that can be extracted by the observation of users' behaviour. The second step to be taken into account regards the *Requirements Definition*. The distinction of these two steps fits with what has been already proposed in literature [Ericson et al. 2009]. That distinction considers the customer information about desires and aims to be translated into representations of needs and formalized into requirements. Thus, the information that the customer is able to provide is elusive, and, if the expressions are not sufficiently analyzed and categorized they can mislead the development team. As an opposite, requirements must be arranged in the form of structured and formalized information about a product.
"Situating" Needs and Requirements in the external, interpreted and expected world allows to describe the needs identification and the requirements definition steps with the same formalism already proposed by Gero and Kannengiesser (Fig. 2). Similarly, *interpretation*, *focusing* and *push-pull* processes are maintained.

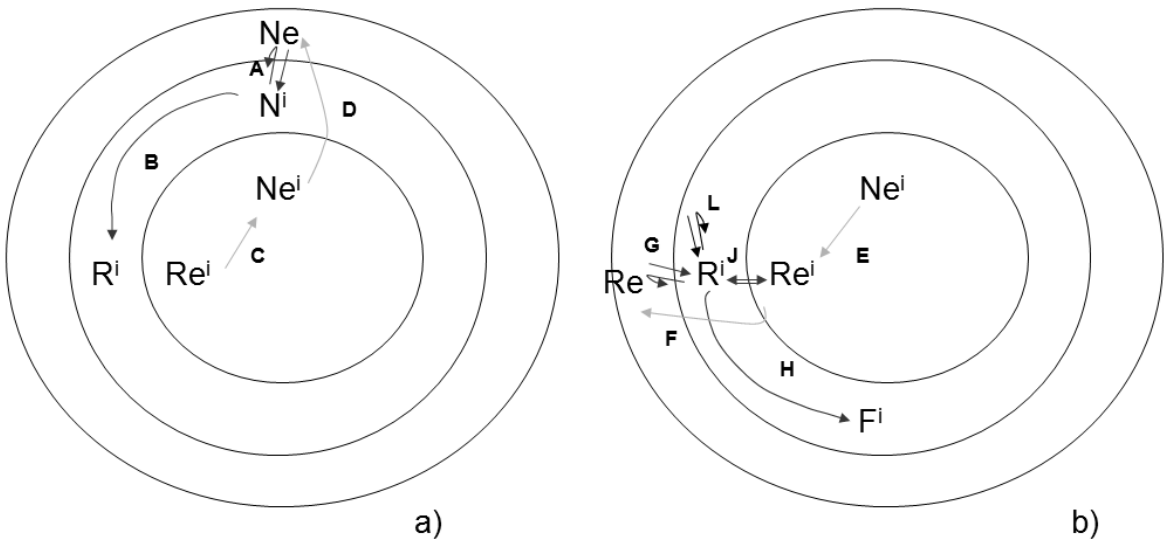


**Figure 2. Extended FBS model: Need identification (a) and Requirement definition (b)**

As shown in figure 2a, the proposed extended model describes Needs identification as constituted by the following elementary processes:

- Process A: uses Ne collected from customers to produce $N^i$ variables (interpretation)
- Process B: transforms $N^i$ into $R^i$ variables (transformation). These $R^i$ are a preliminary set of requirements, useful to better categorize the provided needs.
- Process C: transforms the initial expected requirements $Re^i$ into $Ne^i$ variables (transformation). This step ensure that needs not provided by customers, but necessary, have the chance to be taken into consideration.
- Process D: transforms $Ne^i$ into Ne variables (transformation) to validate the expected requirements with the customers.

Here it is assumed that constructive memory doesn't play a direct role on the interpreted Needs in the way of reasoning of a designer, since at a cognitive level the interpretative scheme is represented (and consequently filtered) by the Requirements.
By analyzing these four processes it is possible to recognize two of the main macro-processes proposed in [Gero and Kannengiesser 2004]: analysis and synthesis. Analysis occurs in the definition of variables in the interpreted world from information collected in the external world and in the transformation of the variable type within the interpreted world. Besides, synthesis occurs in the transformation of the variable type within the expected world and in the transformation of expected variables into homologous external ones.

In the proposed Needs identification step, A and B processes correspond to analysis, while C and D to synthesis. That means, in general, that Needs identification is composed initially of an analysis process that creates a mental link between the expressed needs and possible requirements in a sort of feasibility analysis. The process of synthesis produces a list of needs that can be deducted by the expectations of the designer (in the form of requirements) and to be validated by the customer. Therefore, according to these alternative paths, the identified Ne can be directly provided by the customer and/or can be deducted by the expectations of the designer which proposes them to the customer.

The Requirement Definition process (Fig. 2b) starts from the complete list of expected needs $Ne^i$ previously identified and it is composed of:

- Process E: transforms the initial expected needs $Ne^i$ into a complete set of $Re^i$ (transformation).
- Process F: expands the $Re^i$ set into a bigger or equal number of Re variables (transformation).
- Process G: uses Re to produce $R^i$ variables (interpretation).
- Process H: transforms the subset of $R^i$ implying any kind of action into $F^i$ variables (transformation).
- Process J: focuses on a subset ($Re^i \subseteq R^i$) of $R^i$ to produce an initial requirement state space (focusing) .
- Process L: uses constructive memory to produce further $R^i$ variables.

Again it is possible to recognize the two main macro processes of analysis and synthesis. A synthesis process (E+F) that transforms the expected needs into external requirement, an analysis process (G+H) that derive $F^i$ from external requirement in order to better comprehend the requirements.

Besides, process J must be carefully considered because it is the process in which decisions take place. In the focalizing process, actually, designer intentionally decides which subset of variables consider and this decision represents a real “design choice”.

By considering the two need identification and requirement definition steps as integrated in the extended FBS model, the formulation step proposed by Gero changes at least for those parts which involve requirements. In particular the revisited formulation step can be represented as in figure 3.

The focal difference between this revisited step and the formulation step proposed in the original FBS framework mainly consists in two kinds of processes which definitively substitute the direct processes from the external word of R variables to the interpreted word of Fi, Si, and Bi variables:

- Process M: reuses Re to produce definitive $R^i$ variables (interpretation). This step is oriented to the creation of definitively validated interpreted requirements that can be correctly transformed.
- Processes Ni: transforms $R^i$ into $F^i$, $S^i$ and $B^i$ variables (transformation). These $F^i$ are not a preliminary set of functions anymore, but constitute, together with the other interpreted variables $S^i$ and $B^i$, a detailed comprehensive set of design variables.

Such a revised formulation step not only describes with a higher level of detail the relationship between requirements and design variables, but also results coherent with the two implicit rules to be respected by the design elementary processes mentioned in section 2, i.e. a change of the reference world is applied only to a fixed type of variable and vice versa a change of the variable type is performed referring to the same world.

The other processes from the $4^{th}$ to the $10^{th}$ are kept as in the original model. They correspond to:

- Process 4: uses constructive memory to produce further $F^i$. These $F^i$ variables result from the history of all $F^i$ variables that have been constructed in current and previous design experiences.
- Process 5: uses constructive memory to produce further $B^i$ variables. These $B^i$ variables result from the history of all $B^i$ variables that have been constructed in current and previous design experiences.

- Process 6: uses constructive memory to produce further $S^i$. These $S^i$ variables result from the history of all $S^i$ variables that have been constructed in current and previous design experiences.
- Process 7: focuses on a subset ($Fe^i \subseteq F^i$) of $F^i$ to produce an initial function state space.
- Process 8: focuses on a subset ($Be^i \subseteq B^i$) of $B^i$ to produce an initial behaviour state space.
- Process 9: focuses on a subset ($Se^i \subseteq S^i$) of $S^i$ to produce an initial structure state space.
- Process 10: transforms $Fe^i$ into $Be^i$.

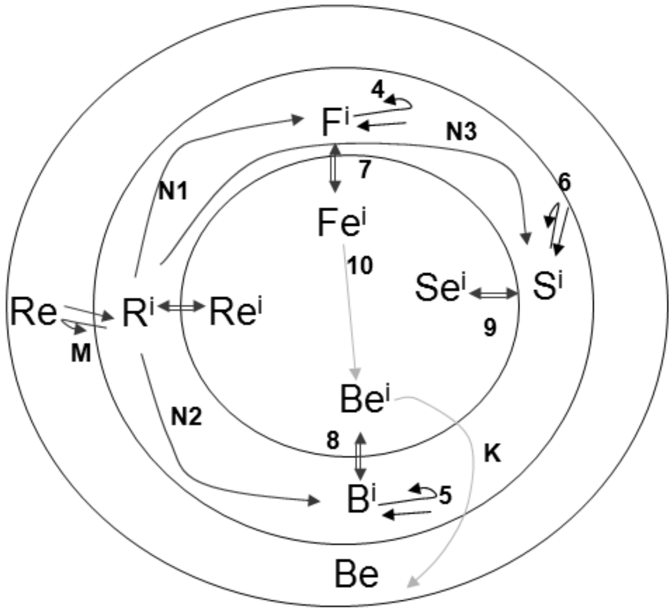


**Figure 3. Extended FBS model: the revisited formulation step**

Once more, the processes 8, 9 and 10, as the process J, can be considered as real choice activities.
The last difference in the formulation step is represented by the process K, whose meaning is a preliminary validation of the behaviours. This validation is not explicitly represented in the original model, but in the authors' opinion it should be considered, because in the following synthesis step the structure is produced starting from these individuated behaviours.
The following steps (synthesis, analysis, evaluation and the three reformulation typologies) proposed by Gero don't involve needs or requirements and respect the above mentioned rules, therefore the authors have fully kept their original formulation.
It is worth to notice that some processes in this reviewed framework assume the role of basic routines inside each specific step (keeping out evaluation and documentation). In particular, the analysis, synthesis and choice processes constitute the fundamentals as shown by colours in figures 2 and 3 (analysis in red, synthesis in green, choice in blue).
The overall design process thus results constituted by the followings:

- Needs identification = analysis + synthesis;
- Requirements definition = analysis + synthesis + choice;
- Formulation (reviewed ) = analysis + synthesis + choice;
- Synthesis (as proposed by Gero) = synthesis;
- Analysis (as proposed by Gero) = analysis;
- Reformulation Type 1 = analysis + choice;
- Reformulation Type 2 = analysis + choice;
- Reformulation Type 3 = analysis + choice.

The individuated three basic routines, analysis synthesis and choice have many similarities with the three decisional processes identified by [Simon 1960]. He individuated three main fundamental decisional processes: intelligence, design and choice. Intelligence is that activity which alerts us to the need for an intervention in order to change the current state of something. It is the process of sensing and conditions that require action, or that signals a change is required in order to achieve the desired goals. Design, for Simon is the definition of possible courses of action that can respond to the current situation in a way that makes it better able to achieve goals. Choice, in turn, is the process of selecting the design alternative which is most efficient and effective in achieving our goals. These three are thoroughly interdependent and always take place in a way that finds them intertwined. In the proposed model, actually the analysis represents the activity that define the conditions for design actions or changes, synthesis produces specific design solutions and might require a preliminary activity of choice in determining focal conditions.

## 4. Exemplary application of the proposed extended FBS model

In order to clarify the proposed extended FBS model, it is here proposed the design of a kettle. In general, customers provide several unstructured external needs such as reduced heating time, no maintenance, transportability of the device, volume capacity in order to make tea for four people, etc. These different needs feed the Need Identification step, in particular:

- Process A: uses Ne provided by customer to produce $N^i$ variables such as “avoid formation of deposit” or “avoid impairing the following usages”
- Process B: transforms $N^i$ into $R^i$ variables such as “subsequent usages do not create variations of the boiling time, as well as in the chemical/physical or organoleptic features of water”.

Indeed, the designer progressively attributes a metric and a target value to each $R^i$; eventually (through the synthesis E and/or by choosing a subset of $R^i$ in the process J) the expected requirements $Re^i$ are expressed by means of measurable technical features of the device and they constitute design constraints. In this case, it is possible consider requirements such as “boiling time <3 min”, “Δ water hardness < 10 mg/l after the use”, “water without deposit (< 0.2 mm) in the mug”, etc. The other design processes regard:

- Process C: transforms the initial expected requirements $Re^i$ into $Ne^i$ variables such as “short time for preparing hot water”, “invariant water taste and healthiness”, “no visible deposit inside the poured water”.
- Process D: transforms $Ne^i$ into Ne variables: the interpreted Needs are proposed to candidate users to verify their appeal.

The processes which constitute the Requirement Definition process consider the complete expected needs $Ne^i$ previously identified (such as “short time for preparing hot water”, “invariant water taste and healthiness”, “no deposit visible inside the structure”):

- Process E: transforms the initial expected needs $Ne^i$ into a complete set of $Re^i$ (such as “boiling time <3 min”, “Δ water hardness < 10 mg/l after the use”, “deposit < 0.2mm in the mug”, “volume capacity = 1 liter”, etc.).
- Process F: transforms $Re^i$ into Re variables. The Re set is a bigger set of variables. It can contain variables directly referable to a specific $Re^i$ such as “Volume capacity = 1 liter” or other variables not explicitly considered in $Re^i$, such as “height of the kettle < 300 mm”
- Process G: Re are interpreted to produce $R^i$ variables, such as .
- Process H: transforms $R^i$ into $F^i$ variables such as “increasing water temperature until boiling status”, “contain water”, etc.

In parallel, a process which concerns mainly the $R^i$ set and which derive the subset $R^i$ can be conducted and consequently processes M and N1, N2, N3 definitively transform variables from the external word to the interpreted word of $F^i$, $S^i$, and $B^i$ variables. The other processes from the 4th to the 10th are maintained as in the original model. Table 1 presents a partial list of exemplary processes of each of the above mentioned transformations. It is worth to notice that the purpose of the table is not providing an exhaustive specification for the design of a kettle, but just to clarify the meaning of the added and revised processes occurring according to the proposed extended FBS model.

**Table 1. Exemplary processes occurring in the early stage of design of a kettle, classified according to the proposed extended FBS model**

| Design Phase | Process | Basic role | From (exemplary variables) | To (exemplary variables) |
|---|---|---|---|---|
| Needs Identification | A: $Ne \rightarrow N^i$ | Analysis | No maintenance | Avoid impairing the following usages<br>Avoid formation of deposit |
| | B: $N^i \rightarrow R^i$ | Analysis | Avoid impairing the following usages | Subsequent usages of the kettle do not create variations of the boiling time, as well as of the chemical/physical or organoleptic features of water |
| | C: $Re^i \rightarrow Ne^i$ | Synthesis | The hardness of water boiled in the kettle should not increase more than 5 mg/l, nor the poured water should contain particles bigger than 0.2 mm | Invariant water taste and healthiness<br>No visible deposit inside the poured water |
| | D: $Ne^i \rightarrow Ne$ | Synthesis | Invariant water taste and healthiness | Boiled water should not impact the taste of the tea/coffee<br>Safety of boiled water after years of usage |
| Requirements Definition | E: $Ne^i \rightarrow Re^i$ | Synthesis | Kettle capacity sufficient to prepare four cups of tea/coffee | Volume capacity = 1 litre |
| | F: $Re^i \rightarrow Re$ | Synthesis | Volume capacity = 1 litre | Volume capacity = 1 litre<br>Height of the kettle < 300 mm |
| | G: $Re \rightarrow R^i$ | Analysis | Height of the kettle < 300 mm | Height of the kettle < standard scaffolds height |
| | H: $R^i \rightarrow F^i$ | Analysis | Volume capacity = 1 litre | Kettle contain water |
| | J: $R^i \rightarrow Re^i$ | Choice | Subsequent usages of the kettle do not create variations of the boiling time, as well as in the chemical/physical or organoleptic features of water | After 1000 usages of the kettle the boiling time to heat 1 litre of water should remain less than 3 minutes<br>The hardness of water boiled in the kettle should not increase more than 5 mg/l, nor the poured water should contain particles bigger than 0.2 mm |
| FBS Formulation | M: $Re \rightarrow R^i$ | Analysis | Boiling time < 3 min | Heating time of 1 litre of water from 15°C to 100°C < 3 min |
| | N1: $R^i \rightarrow F^i$ | Analysis | Heating time of 1 litre of water from 15°C to 100°C < 3 min | The kettle increases water temperature from 15°C to 100°C |
| | N2: $R^i \rightarrow B^i$ | Analysis | Heating time of 1 litre of water from 15°C to 100°C < 3 min | The kettle supplies through an electric resistance 356 kJ to water (by Joule effect) in less than 3 minutes |
| | N3: $R^i \rightarrow S^i$ | Analysis | Heating time of 1 litre of water from 15°C to 100°C < 3 min | The kettle parts in contact with water must be made with materials capable of working at 100°C |
| … | $4^{th}$ – $10^{th}$ | Standard processes as already presented in [Gero and Kannengiesser 2004] | | |

Once again it is worth to highlight that the elementary processes summarized also in Table 1 are not necessarily followed in the presentation order. For example, the needs identification phase can start either with an analysis of users' behaviour, from where a list of interpreted requirements is produced, or from a list of expected requirements postulated by the designer, to be validated through a synthesis of needs potentially relevant for some users. In the specific case of the kettle design, the first path (processes A+B) means translating the expressed user need "No maintenance" into the interpreted requirement "Subsequent usages of the kettle do not create variations of the boiling time, as well as of the chemical/physical or organoleptic features of water". The second path transforms postulated requirements as "The hardness of water boiled in the kettle should not increase more than 5 mg/l, nor the poured water should contain particles bigger than 0.2 mm" into potentially relevant user needs as "Boiled water should not impact the taste of the tea/coffee" and "The water boiled in the kettle should remain safe even after years of usage". Similar considerations can be done also for the Requirements Definition stage.

## 5. Conclusions

In this paper the Function Behaviour Structure model of designing proposed in [Gero and Kannengiesser 2004] is critically analyzed and extended. Three reflections in particular are taken into account. First, in the FBS model the Need Identification and the Requirement Definition are not sufficiently considered. Second, in the original model an anomaly appears: the reference world and variable changes are made during the first step in a different way if compared with the rest of the model. Third, applying a decisional perspective on the FBS framework, some observations can be made by considering the Simon's model proposed in 1960.

For these reasons, in the paper, while maintaining the formalism adopted by Gero, the Needs Identification and the Requirements Definition steps are explicitly defined and modelled. By introducing these two steps, the formulation phase proposed in the original FBS framework must be reviewed in those processes which definitively substitute the direct processes from the external word of R variables to the interpreted word of $F^i$, $S^i$, and $B^i$ variables. This revision allows also to eliminate the above mentioned anomaly. What emerges from this study is that some processes in this reviewed framework assume the role of basic routines inside each specific step. These individuated three basic routines, namely analysis, synthesis and choice, have many similarities with the three decisional processes individuated by Simon (1960). That constitutes a further relevant outcome of the paper, because it links two important models in literature and makes explicit the decisional meaning of the design processes.

In this paper, the proposed extension of the FBS model has been clarified through a simple example not related to a real design task. Indeed, the authors are experiencing the application of the model to industrial case studies and will share the results of this activity into a next publication.

### References


*Belch, G.E., Belch, M. A., Advertising and Promotion: An Integrated Marketing Communications Perspective,6 th Edition, McGraw-Hill: New York: NY, 2004.*

*Büyüközkan, G., Feyzioğlu, O., "A fuzzy-logic-based decision-making approach for new product development", International Journal of Production Economics, 90, 2004, pp.27–45.*

*Cavallucci, D, "Integrating Altshuller's development laws for technical systems into the design process", CIRP Annals - Manufacturing Technology, vol. 50(1), 2001, pp. 115-120.*

*Ericson, Å., Müller, P., Larsson, T., Stark, R., "Product-Service Systems: From Customer Needs to Requirements in Early Development Phases", Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS2) Conference, Cranfield University, 1-2 April 2009, pp.62-68.*

*Gero, J.S., Kannengiesser, U., "The situated function-behaviour-structure framework", Design Studies 25(4), 2004, pp. 373-391.*

*Krishnan, V., Ulrich, K.T., "Product development decisions: A review of the literature", Management Science, 47 (1), 2001, pp.1–21.*

*Loudon, D.L., Consumer Behaviour: Concepts and Applications, McGraw Hill, London, 1988.*

*Maslow, A. H., "Motivation and Personality", Harper & Row Publishers Inc. NY, USA, 3rd edition, 1987.*

*Sandhunsen, R.L.. Marketing, 3rd edition, Barron's Educational Series Hauppauge, New York, 2000.*

*Sheth, J.N., B. Mittal, B. Newman, Customer Behavior: A Managerial Perspective, Dryden Press, 1998.*

*Sheth, J.N., B. Mittal, Customer Behavior: A Managerial Perspective, 2nd edition, Thomson/Southwestern Publishing, 2004.*

*Simon, H.A., "The New Science of Management Decision", New York, NY: Harper and Row, 1960.*

*Urban, G.L., Hauser, J.R., "Design and Marketing of New Product", 2nd Edition, Prentice-Hall Inc.,Englewood Cliffs, NJ, 1993.*

*Vermaas, P.E., Dorst, K., "On the conceptual framework of John Gero's FBS-model and the prescriptive aims of design methodology", Design Studies, 28, 2006, pp. 133-157.*

*Wan, Z., He, W.P., Zhang, D.H., Cai, H.M., Yu, S.H., "Creative design research of product appearance based on human–machine interaction and interface", Journal of Materials Processing Technology, 129, 2002, pp. 545–550.*

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