INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

FBS MODELS: AN ATTEMPT AT RECONCILIATION TOWARDS A COMMON REPRESENTATION

Spreafico, Christian (1); Fantoni, Gualtiero (2); Russo, Davide (1)
1: University of Bergamo, Italy; 2: University of Pisa, Italy

Abstract

FBS is one of the most followed and studied design theories, as evidenced by the numerous investigations and rework on the subject. It is often used to provide a better understanding on existing design methods and tools in order to make them more accurate or efficient. Nevertheless the resulting methods are often loose or too heterogeneous to be easily applied; what is lacking is a scheme of collection that supports design process from the beginning to the end, while considering all possible facets.

This paper contains an attempt at reconciling many previous works on FBS, through a homogeneous and unique representation: all the elements (function, behaviour, structure, affordances, signals) have been reformulated according to the designer's and user's perspective, in terms of perception and interpretation; in this way they could be bound together in a common ontological reformulation of a more extensive scheme. In this article, we propose a bond between the various elements, using a logical-mathematical form.

Keywords: Conceptual design, Design theory, User needs

Contact:
Dr.-Ing. Davide Russo
University of Bergamo
digip- Dipartimento di Ingegneria Gestionale dell'Informazione e della Produzione
Italy
davide.russo@unibg.it

Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

Function Behaviour Structure (FBS) approach was introduced as a theoretical framework to analyse products by (Gero, 1990). One of the key points of the theory is the physical description of the behaviour with a qualitative manner, like previously explained by Hayes (1979), De De Kleer (1981) and Forbus (1984), and successively modelled as a sequence of states in (Umeda et al., 1990, Tomiyama et al.; 1993, Umeda et al., 1995, Umeda et al, 1996).
Since its inception, the Gero's FBS model has been a landmark for engineering design researchers.
Over the years, many authors have worked on Gero's FBS model, deepening time to time, different aspects, in order to improve the efficacy of the scheme or to enlarge the fields of application. Many other researcher have instead attempted to improve the theory, by exploring and defining the ontology of FBS (e.g. Rosenmann and Gero 1998, Gero 2002, Vermaas 2007, Galle 2009), others have redefined the behaviour of the device, like Cao and Tan (2007) that have explicitly dealt with Physical effects, and Del Frate et al. (2010) that introduced the possible faults of the device. As regard the relations between user and device, Brown and Blessing (2005) discusses the affordances, focused on the possible user's actions on the device, Cascini et al. (2010) and Gabelloni et al (2013) reformulated the interactions between the user and the FBS model. Cascini et al. (2013) reconciled the FBS introducing needs and better describing their links with product requirements. Several authors modelled the elements of the design process as functions and flows: Hirtz et al. (2002), Ahmed et al. (2003), Bonaccorsi et al (2007), Borgo et al. (2009) described them with hierarchical taxonomies. Keuneke (1991) and Pailhès et al. (2011) approached the problem by using a minimalistic taxonomy for describing both functions and flows in terms of material, signal and energy. The flows of the design process have also been formalized in mathematical terms by Komoto (2011) or Chakrabarti (2011) and Fantoni (2009), who in particular used a model based on vectors. Keuneke (1991) and Sasajima (1995) modelled Functions and flows by using models belonging to Artificial Intelligence schemes and Chakrabarti et al. (2011) with Sapphire or Baber et al. (1999) with Task Analysis proposed structured methodology to better decompose abstract functions in more detailed sub-functions.
While Gero and Kannengiesser (2004) situated the FBS in the three worlds of design, contributing to deepen define the field of application of the design. Other authors have also work in this field, like Deng et al., (2000) and Chandrasekaran and Josephson (2000) that have study the Environment where the device has to work and the context of use.
Nevertheless the resulting methods are often loose or too heterogeneous to be easily applied; what is lacking is a scheme of collection that supports design process from the beginning to the end, while considering all possible facets.
The idea presented in this paper is to extend Gero's FBS model (1990) and its evolution (Kannengiesser et al., 2004), covering also many aspects that are familiar to conceptual design, but never integrated in an overall FBS-based design scheme. With this aim, we have investigate the following improvements:

- The enlargement of the scheme to new elements of analysis, like affordances and manipulation;
- The definition (or redefinition) of the relation between elements, like perception and interpretation;
- The redefinition of the design context, with the introduction of the perceived dimension;
- The user perspective and his needs;
- The redefinition of the ontology in logical-mathematical terms.

The plan of the paper is as follows: in Section 2 we present the state of the art about the elements involved in the design process: worlds of design, elements of FBS theory, other elements, actors involved in design processes and their actions. Section 3 presents all the steps taken to define the complete scheme: starting from a simplified representation, with only the design elements, then moving to an expanded and complex representation of the same elements according to each actor's perspectives. Section 4 outlines the conclusions.

2 STATE OF THE ART REVIEW

Our proposal is to combine some of the typical design elements in a FBS-based scheme. The scheme is not presented as a heterogeneous collage of information, but it is formalized as an algorithm of harmonically related parts. To achieve this purpose, a review of the state of the art is proposed and, at times, a logical-mathematical formalism is used to connecting the cited elements. Figure 1 shows the elements of design considered together with some modifications. Some elements (e.g. the designer's action, the goal and the function, the manipulation, and finally the perception) are reformulated in a logical-mathematical formalism that allow to link them in an algorithm for design. Another category of elements has already a satisfactory logical-mathematical form for our purposes and, therefore, do not require any modification (e.g. affordances, structure, signals and behaviour).

2.1 Designer's actions

Gero (1990) explains in general the project phases without specifying the designer's intention regarding certain characteristics. Gabelloni and Fantoni (2013) has also defined the dualism between designer and user in designing features on the device. During the design process, the features of the device can be:

- Designed (d) if the designer implements them deliberately on the device.
- Designed not to be ($\bar{d}$) if the designer designs deliberately avoid to implement them on the device. For example, an industrial power outlet can be classified as "not designed" for children safety; the children can insert objects into the holes because the cover is not present;
- Not designed (d) when the designer not deliberately implemented a feature during the device project but they are also present in the final product. For example, an airtight cover on an outlet is a safety for children as it prevents them from inserting objects into the holes, although it is not designed for this purpose.

2.2 Goals and functions

There are several definitions about goal and function. Each of them are linked starts by a behaviour (e.g. Umeda et al., 1990), others by the external environment (Gero and Kannengiesser, 2004) teach that the designer observes the external environment with the aim to modify it, still others (Cascini et al., 2010) describe the dualism between designer and user about function. If we want find relation between them into a logical mathematical formulation, we can re-formulate through logical-mathematical relations the different definitions. According to Umeda et al. (1990), and referring to Sasajima's formulation, the function is the goal that a user sees in a behaviour (B), where Goal van be find in the final state of a structure that evolves through a finite number of states S(t1), … , S(tf).

Instead Gero and Kannengiesser describe goal in other manner, involving the mental process of simulation (Sim), made by a user (U) and time-dependent. Differently to Umeda, the considered instant of time is the first one (t1). Also the environment can be described as time-dependent and the goal in this definition is a based on the observation of the environment before any possible transformation (E(t1)).

2.3 Affordances

Brown and Blessing (2005) define affordances of a device as the set of all potential human behaviours (Operation, Plans, or Intentions) that the device might allow. Also Mayer and Fadel (2009), Gaver (1991), Kannengiesser and Gero (2012) address the problem. Cascini et al. (2010) divide the affordances into designer's affordances, user's affordances, true intended affordances and false intended affordances.

2.4 Expected behaviour

Gero (1990) introduces the concepts of the expected behaviour as the theoretical behaviour, postulated by the designer, to accomplish the function when the structure has not yet been realized. Just like the decomposition of actual behavior (Bs) by Cascini et al. (2010), we believe that the expected behavior (Be) can be divided into two types: designer's expected behaviour (Bed) and user's expected behaviour (Beu), that could be different. In fact the designer has generally a most deepen knowledge of the device and in particular of its internal components since he had projected, while the user normally observes the device by an external point of view, grasping information about the functionality by the affordances. For this reason, the designer can know the device most intimate aspects that the user cannot seize by the affordances. Consequently, the expected behaviours postulated by designer and user can be different because depends by different level of knowledge that they have on the same device.

2.5 Manipulation

According to Cascini (2010), the term manipulation covers both direct physical manipulation and indirect user's actions, which affect the product. Since users (U) and designers (D) see a device in a different manner, they relate to it in different ways. In our opinion, the aforementioned concept of manipulation can be divided into user's manipulation (Mu) and designer's manipulation (Md). The two manipulations, respectively, depend on the user's expected behaviour (Beu) and designer's expected behaviour (Bed). Of the two, we are more interested in Mu, which is a part (expressed by " $\subset$ ") of behavior (B) and it coincides with user's expected behavior (Beu).

$$M_u \subset B;\ M_u = Be_u \quad (1)$$

Furthermore, we can summarize the determination of user's manipulation (Mu) as the result of a process (explained by "→") of mental simulation (Sim), which involves the structure (S), the affordances (A), and the user's expected behaviour (Beu), all focused on the achievement of the goals (G).

$$Sim(G, S \to A \to Be_u) \to M_u \quad (2)$$

The simulation is a mental process that gives the user an idea of the manipulation (Mu) that he has to play on the device. To do this, the user imagines the expected behaviour of the device (Beu), based on the understanding of affordances from the structure (S→A). Similarly, the user grasps the expected behavior from the goal he/she wants to achieve. Sometimes, as for example in case of alternative uses (Keuneke and Allemang, 1989), the sequence can become as follow, because the user learn the affordances by the structure and, according to them, he hypothesizes the function of the device starting from the structure

$$Sim(G \to M_u \to Be_u \to S \to F) \quad (3)$$

Actually under a certain goal (e.g. holding paper sheets on a table), every object with a certain weight (Beu) on the table can be located (Mu) on top of the paper sheets. The structure of the object exerts a behavior that holds the paper on their location.
The last formulation explains also the idea of "guess" introduced by Keuneke and Allemang (1989), the assumption of context for making use of a device (Kuipers, 1981) and the "mode of deployment" by Chandrasekaran and Josephson (2000) (Figure 2): the user of a device can imagine the context it is intended for based on its general usage.

2.6 Perception

According to Hirtz et al. (2002) signals provide information on a material, energy or signal flow, as an output signal flow. They represent the perceptible evidences of behaviours. If we look at the model of the four worlds, we can assert that a signal (Sign_e) (Hirtz et al., 2002) (described above) is initially in the external world. The signal is then perceived by the observer, which internalizes it in the perceived world. Afterwards, the perceived signal (Sign_p) will be interpreted.
Many authors such as Gero and Fujii (2000) and Shea (2010) contributed to a general definition of perception. The perception (P) of an external signal (Signe) generates a perceived signal (Sign_p), which is correct only if it coincides with the external signal.

$$Sign_p = P(Sign_e) = \begin{cases} = Sign_e \\ \neq Sign_e \end{cases} \quad (4)$$

When the operation of perception depends on the observer (the designer or the user), subjectivity is introduced in the method. The perception here is considered only from a physical point of view: the receptors of the user/designers are activated and decoded into internal signals. The external signals when conveyed from the external world into the internal one are ready to be interpreted (=processed).

2.7 Interpretation

The process of interpretation, also cited other times in the paper, is contextualized in this paragraph on the signals. The perceived signal (Sign_p) becomes an interpreted signal (Sign_i) through interpretation (I) and is then going to be part of the interpreted world. The interpretation is a subjective task, since it depends on an evaluator and his yardstick. The outcome of the interpretation is described with a positive signal (logic state = 0) if the evaluator judges it favourably, on the basis of pre-established standards of value; otherwise the outcome is described with a negative signal (logic state = 1):

$$Sign_i = I(Sign_p) = [0,1] \tag{5}$$

Given the signal, we believe that interpretation is always differential respect to a comparison signal ($\overline{Sign}$).

$$Sign_i = I(Sign_p - \overline{Sign}) = [0,1] \tag{6}$$

In fact, if the perception (P) is not distorted, the interpretation (I) compares the external signal (Signe) with the comparison signal ($\overline{Sign}$). With regard to the comparison signal we can make some observations about its form:

- The comparison signal may represent an ideal signal that the device should produce: if we consider the example of a lawn mower, the external signal may be the length of the grass obtained while the comparison signal is the desired length.
- The comparison signal may be a previous external signal, recorded before the action of the device. In this case, the comparison signal is the length of the uncut grass.
- The comparison signal may represent the signal obtained from an alternative device: we compare the length of the grass obtained with a lawn mower, with the length of the grass obtained with a brush cutter.
- The comparison signal may be obtained from another device and does not affect the same characteristic. So far, the external signal (Signe) and the signal of comparison ($\overline{Sign}$) are referred to the same feature. However, we could work with an innovative device that realizes a new function, and consequently a new feature. In this case the interpretation could compare an external signal (Signe) that is read from a feature of the device, with a comparison signal ($\overline{Sign}$) that is read from a feature of the device. For example, if a device bends the grass instead of cutting it, we could compare, during interpretation, the bent grass with the cut grass.

2.8 Interpretation and perception

The result of the interpretation asserts whether the device realizes its functions and it depends on external signals that explain the status of the device:

$$Sign_i = 0 \rightarrow not\ realized\ functions; \quad Sign_i = 1 \rightarrow realized\ functions \tag{7}$$

Referring to previous work of Gabelloni and Fantoni (2013), the following table (Table 1) describe the possible scenarios between kind of signals and user's perception. For the moment, Interpretation is valuated only by two logical level (0 and 1), the model can be complicate including a range of intermediate levels.

Table 1. Spectrum of combinations between user's perception and user's interpretation

	Negative external signal (Sign_e ≠ $\overline{Sign}$)		Positive external signal (Sign_e = $\overline{Sign}$)	
	Negative interpretation (Sign_i = 0)	Positive interpretation (Sign_i = 1)	Negative interpretation (Sign_i = 0)	Positive interpretation (Sign_i = 1)
Wrong perception (Sign_p ≠ Sign_e)	No	Ok	Ok	Ok
Correct perception (Sign_p = Sign_e)	Ok	No	No	Ok

2.9 Interpretation and goals

The user's evaluation of a device can be investigated by crossing the interpretation of the signals with the expected goals of a specific device. Some simple remarks can be made: if the user interprets positively a signal and his goals coincide with those of the designer, the user is satisfied with the device while if user's goal goals do not coincide with designer's goals, the user is unsatisfied. If the user perceives a negative signal and his goals coincide with those of the designer, the user is dissatisfied with the device. Finally, if the user interprets negatively a signal but his goals do not coincide with those of the designer, the situation is uncertain. The following table (Table 2) summarizes the aforementioned possibilities.

Table 2. The satisfaction representation according to the User's interpretations and the goal coincidence.

	Coincidence of the goals (Gu = Gd)	Non-coincidence of the goals (Gu ≠ Gd)
Positive interpretation (Sign_i = 1)	Satisfaction	Dissatisfaction
Negative interpretation (Sign_i = 0)	Dissatisfaction	Uncertainty

2.10 Interpretation and time dependence

So far, user's interpretation and designer's interpretation have been evaluated with signals at the same instant in time, but a signal can change its value over time; thus the perception of the signal can also change over time and thus, in the same manner, also the perception. For this reason, the perception and the interpretation are time-dependent.

$$Sign_e = Sign_e(t) \quad (8)$$

$$Sign_p = P(Sign_e(t)) = Sign_p(t) \quad (9)$$

$$Sign_i = I(Sign_p(t) - \overline{Sign}) = Sign_i(t) \quad (10)$$

Thus, two interpretations, performed by the same observer on two signals, in two different instants in time, are equal only if the signals and their perceptions do not change.

$$Sign_i(t_1) = Sign_i(t_2) \quad if \quad Sign_e(t_1) = Sign_e(t_2) \quad with \quad t_1 \neq t_2 \quad (11)$$

2.11 Interpretation and different evaluators

If we consider the presence of two evaluators (the user and the designer or two users), the interpretation of the first (I1) may not be equal to the interpretation of the second one (I2), at the same instant in time. This is because the interpretation is, as we have previously stated, rooted in psychology/memory of past experiences of the evaluator.

3 COMPLETE SCHEME

The representation in fig. 3 summarizes all the process of the design during design process, with all the elements of the original theories, which have to be considered time-dependent. The starting point for the designer is the analysis of the functions (F), defined by the customers. By them the designer decide which affordances (A) implement on the device so that the user can understand the correct functions of the device. Gero and Kannegiesser (2004) call this process "memory". Then, the designer simulate the expected behaviour of the device (Be). to do this, the designer has to consider that the user in turn imagine an expected behaviour starting of the device that has in front, starting from the affordances that he comprehend. For this reason the process of the implementation of the correct affordances on the device is crucial since it influence the designer idea of the expected behaviour of the device. In turn the user's idea of the expected behaviour determine his manipulation (M) on the device. For this reason the next step of the designer in design process is the definition of the correct manipulation on the device, obviously consider who the user can interpret them by the expected behaviour. According to manipulation, designer project the structure (S) as a part of the external environment (E). By the test on the structure the designer observes the actual behaviour (Bs) that is the same that the user can observes if he act in proper manner on the structure. By them the designer has to think how the user perceive the actual behaviour: we call it perceived behaviour (Bp). At last the designer has to consider how the user can interpret (Int) the functions and the affordances of the device from the perceived behaviour and evaluate the design process in this optics, eventually rethinking them.

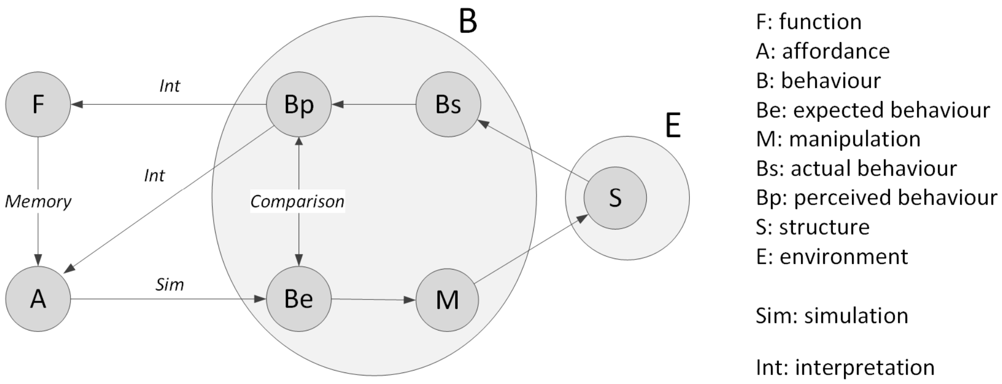

Figure 1. Simplified scheme.

Let introduce now the user's perspective into this representation. The result is a more complex framework, as shown in figure 2.

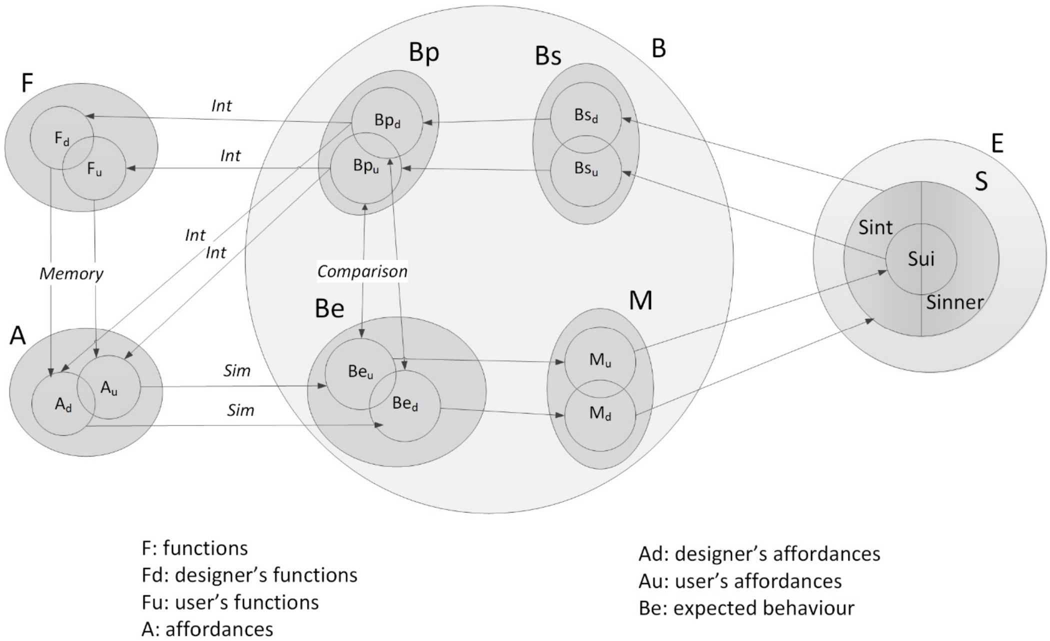

Figure 2. The scheme with the subdivisions of the elements.

Unlike the previous one, in this representation the elements are replaced by sets of elements. First of all, functions set (F) that are divided into functions intended by the designer (Fd) and functions assessed by the user (Fu), which are two distinct sets: Fd represent the collection of the device functionalities, designed by the designer, while Fu represent the device functionalities expect by the user before and after the use of the device. Fd and Fu can be different because the user might expect some functionalities which have not been designed or he do not see others present. The intersection between Fd and Fu symbolizes the user's ability to expect the functionalities of the device provided by the designer or by other side the user's capability to transmit the designer functionality to user through the structure of the device.

The affordances set (A) are divided into designer's affordance (Ad) and user's affordance (Au) that respectively represents the affordances implemented by the designer on the device and the affordances learned by the user. Also in this case the intersection between Ad and Au represent the success of the designer. This operation clearly underlines the process of memory in a more complex definition: Au and Ad respectively retrieve Fu and Fd.
Even behaviour (B) is divided into subsets: designer and user starting from different affordances can simulate (Sim) different expected behaviour of the device: Bed for the designer and Beu for the user.
Following the same order of the scheme in figure 2, also the designer idea about manipulation on the device (Md) can be different from user’s manipulation (Mu).
The structure set is divided into tree subsets: the designed interface (Sint), user’s interface (Sui) and the inner interface (Sinner). According to designer’s view, the user can directly interface only with a part of the structure (Sint) and not with the other (Sinner) but it is probably that the user do not interface with entire Sint and interact with the Sinner.
Experimenting the behaviour of the structure, user and designer obtain two different actual behaviour, respectively Bsd and Bsu because they manage the structure of the device in different manner and they obtain different answers by it. Also observing the actual behaviours the designer and the user can perceived them in two different manner, respectively Bpd and Bpu.
The last step is to check if the structure is able to help user to achieve his/her goals. The comparison is twofold: Fd and Ad are interpreted from Bpd, while Fu and Au are interpreted from Bpu.
Though of the scheme in figure 2 seems complete, it does not represent the arrival point of our work, because it misses to represent the operational context of the design process.

4 CONCLUSIONS

This paper organizes in a single FBS based design model all the additional aspects developed over the years from Gero’s model (1990) and it has been developed to support all steps of the design process. The scheme goal is to regulate the designer and user duality, in order to help the designer in considering the user’s needs. Firstly, the paper outlines the elements involved in this study; then, an ontological revision brings to a logical-mathematical definition of the elements, possibly adding new aspects. Finally, we proposed the overall pattern, explained with the help of intermediate forms.
The scheme could be used to trace the steps for a thorough conceptual design that does not omit any aspect of the design process.
Through it, we offer to the designer a greater awareness about the user’s device perception and interaction; in this manner the design implements on the device all the features that the user needs and the necessary affordances to convey the user to a proper use. A possible integration between the proposed scheme and the world of design (Gero and Kannengiesser, 2004) is currently under development.

REFERENCES

Ahmed S., Wallace K. M., (2003), Evaluating a Functional Basis, Proceedings of ASME 2003 Design Engineering Technical Conferences, DETC2003/DTM-48685, ASME.
Baber C., Stanton N. (1999). Analytical prototyping. In J. M. Noyes & M. Cook (Eds.), Interface technology (pp. 175–194). Baldock UK: Research Studies Press.
Bonaccorsi, A., Fantoni, G., (2007), Expanding the functional ontology in conceptual design, Proceedings of ICED 2007, DS 42.
Borgo S, Carrara M, Garbacz P, Vermaas P, E. (2009) A Formal Ontological Perspective on Behaviors and Functions of Technical Artifacts, AI EDAM 23, 3-21.
Brown D C, Blessing L. (2005). The relationship between function and affordance. DETC2005-85017, Long Beach, California, USA.
Cao G, Tan. R. (2007). FBES model for product conceptual design. Journal of Product Development.
Cascini G, Del Frate L, Fantoni G, Montagna F. (2010). Beyond the Design Perspective of Gero’s FBS Framework.
Cascini, G., Fantoni, G., Montagna, F., 2013. Situating needs and requirements in the FBS framework. Design Studies, 34(5), pp. 636-662.
Chandrasekaran B, Josephson J. R. (2000). Function in device representation. Engineering with Computers 16: 162-177.

De Kleer, J. and Brown, J.S. (1981), Mental models of physical mechanisms and their acquisition. In Cognitive Skills and Their Acquisitions, ed. by J.R. Anderson, Erlbaum, Hillsdale, New Jersey, Chapter 9, pp. 285-309.
Del Frate L, Franssen M, Vermaas P E. (2010). Towards defining technical failure for integrated product development. Proceedings of the 9° ETRIA/CIPR TRIZ Future Conference, Timisoara, Romania 4-6: 26-34.
Deng Y M, Britton G A, Tor S B. (2000). Constraint-Aided Design 32: 889-899.
Erden MS, Komoto H, van Beek TJ, D'Amelio V, Echavarria V, Tomiyama T (2008) A Review of Function Modeling: Approaches and Applications. Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 22: 147-169.
Fantoni, G., Apreda, R., Bonaccorsi, A., (2009), Functional Vector Space, ICED'09, 24 - 27 August 2009, Stanford university, Stanford, CA, USA.
Forbus, K.D. (1984), "Qualitative process theory". Artificial Intelligence 24 (3): 85-168.
Gabelloni, D.; Fantoni, G., (2013) Designers' promises or users' expectations?, 19th International Conference on Engineering Design ICED2013, Seul
Galle P. (2009) The ontology of Gero's FBS model of designing.
Gaver (1991) Technology affordances.
Gero J. S. (2002) Technological Knowledge: Philosophical Reflections, Boxmeer, the Netherlands, June 13e15, 2002).
Gero J. S., Fujii H., (2000) A computational framework for concept formation for a situated design agent, Knowledge-Based Systems 13(6): 361-368.
Gero, J. S. (1990) 'Design prototypes: a knowledge representation schema for design', AI Magazine.
Gero, J. S., Kannengiesser, U. (2004) 'The situated function–behaviour–structure framework', Design Studies Vol. 25 No. 4 July 2004.
Hayes P.J., (1979), The naive physics manifesto, D. Michie (Ed.), Expert Systems in the Micro-Electronic Age, Edinburgh University Press, Edinburgh, pp. 242–270
Hirtz JM, Stone RB, McAdams DA, Szykman S, Wood K (2002), A functional basis for engineering design: reconciling and evolving previous efforts. Res Eng Des 13:65–82. doi:10.1007/s00163- 001-0008-3.
Kannengiesser, Gero (2012) A Process Framework of Affordances in Design.
Keuneke, A. (1991) Device representation: the significance of functional knowledge, IEEE Expert, 24, 22-25.
Keuneke, A. and Allemang, D. (1989), "Exploring the no-function-in-structure principle". Journal of Experimental & Theoretical Artificial Intelligence, 1 (1): 79 – 89.
Komoto, H, Tomiyama, T, (2011), A theory of decomposition in system architecting, ICED11, 15 - 18 August 2011, Technical University of Denmark, Copenhagen.
Kuipers, B. (1994), "Qualitative Reasoning: modeling and simulation with incomplete", Artificial Intelligence XX
Mayer, Fadel (2009) Affordance based design a relational theory for design).
Pahl G., Beitz W., Feldhusen J., Grote K H (1984) Engineering Design, Springer.
Pailhès, J., Sallaou, M, Nadeau, J.P., Fadel, G. M., (2011) Energy Based Functional Decomposition in Preliminary Design, Journal of Mechanical Design, Vol. 133
Rosenman M A, Gero J S.(1998). Purpose and function in design: from the socio-cultural to the techno-physical. Design Studies.
Sasajima, M., Kitamura, Y, Ikeda, M., Mizoguchi, r., (1995), FBRL: A Function and Behavior Representation Language, Expert Systems With Applications, Vol. 10, No. 3/4, pp. 471—47.
Shea, K., Ertelt, C., Gmeiner, T., Ameri, F. (2010). Design-to-fabrication automation for the cognitive machine shop.
Srinivasan V, Chakrabarti, A, Lindemann, U, (2012) Towards an Ontology for Engineering Design Using SAPPhIRE Model, CIRP Design 2012, Bangalore India, 28-30 March 2012
Stone R. B., Wood K. (2000) Development of a Functional Basis for Design, Journal of Mechanical Design, 122(4): 359- 370.
Tomiyama T., Umeda Y. and Yoshikawa H., "A CAD for functional design," CIRP Annals - Manufacturing Technology, vol. 42, no. 1, pp. 143-146, 1993.
Umeda, Y., Takeda, H., Tomiyama, T., Yoshikawa, H. (1990) 'Function, Behaviour, and Structure', In Applications of Artificial Intelligence in Engineering (Gero, J.S., Ed.) pp. 177–193. Southampton0Berlin: Computational Mechanics Publications/Springer–Verlag.
Umeda, Y., Tomiyama, T. and Yoshikawa, H. (1995) FBS Modeling: Modeling scheme of function for conceptual design, Proceedings of the 9th International Workshop on Qualitative Reasoning. Amsterdam, Netherlands, 11-19 May 1995: 271-8.
Umeda Y., Ishii M., Yoshioka M., Shimomura Y., and Tomiyama T., (1996) "Supporting conceptual design based on the function-behavior-state modeler," Artificial Intelligence for Engineering Design, Analysis and Manufacturing, vol. 10, no. 4, pp. 275-288.