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X FOR DESIGN, A DESCRIPTIVE FRAMEWORK FOR MODELLING THE COGNITIVE ASPECTS OF DIFFERENT DESIGN ACTIVITIES

S. Filippi and D. Barattin

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1. Introduction

Design activities start classically from considering the functions the product will be called to accomplish and end with the definition of the product structure. The literature already offers descriptive tools to model the cognitive aspects of these activities exhaustively and effectively. The Function-Behaviour-Structure framework [Gero and Kannengiesser 2004] describes design activities by exploiting variables, processes and environments (worlds). This framework goes from the formulation of the requirements up to the definition and evaluation of the product structure. The model of March [Horvath 2004] describes design activities that begin with the productive reasoning; they draw on a preliminary statement of required characteristics to produce the first design proposal. Then, the first design proposal is deductively analysed to predict the expected performance. Finally, further design possibilities are evaluated inductively. The Matchett's model [Gregory 2013] analyses first the design situation to identify provisionally the needs the product must satisfy. Then, the primary functional needs (those that, if not satisfied, invalidate all the other achievements) and the secondary ones are identified. Alternative principles to satisfy the primary needs are searched for and the set of design solutions able to satisfy both the primary and secondary needs is defined. Then, the reviews of the outcomes are performed to evaluate both the functional effectiveness and the product quality due to materials and manufacturing processes.

Anyway, the analysis of recent design activities highlights a wide heterogeneity of starting points and goals. Different design activities can use multiple types of sources; they can start from functions, as well as from forms, materials, etc. At the same time, targets can be different, consisting in other characteristics than the mere product structure. For example, [Filippi and Barattin 2015a] describes design activities that start by considering generic forms and generate product functions as results; in [Ashby and Johnson 2014], the analysis of different materials gives indications about the most appropriate forms to relate to these materials; finally, Graziosi et al. [2014] describe the definition of the product structure starting from sounds, behaviour and forms, instead of from functions.

Unfortunately, all these characteristics make the existing tools not exhaustive in describing modern design activities effectively. This research aims at filling the gap by developing a descriptive framework to model different design activities showing any combination of sources/targets and operating in heterogeneous contexts, by considering also users' perceptions, sensations and emotions. Classic sources (functions, user needs, etc.) will be still managed, but unconventional ones like behavior, sounds, smells, etc., will be considered as well. This holds also for targets; these will be able to refer to other product characteristics than the mere structure. This framework is named X for Design - XfD. It

can be used as a reference to compare design activities and evaluate which is better in terms of variables involved, number of preformed actions, level of detail, cognitive workload, etc. The description and comparison of different design activities using a common language can help those companies that would like to change their design activities in evaluating the impact of those changes before to implement them. The document runs as follows. The background section summarizes the starting points of the research: the situated FBS framework, the framework of the product experience and the model of the seven stages of action cycle. The activity section analyses a collection of design activities, confirms the weakness of existing descriptive tools and highlights the required characteristics to be able to model those activities. After that, the description of the XfD development takes place. The definition of the models of four design activities comes afterwards. A discussion about the outcomes of the research, together with some conclusions and hints for future work, close the paper.

2. Background

This section describes the three descriptive tools exploited in the development of the XfD: the situated FBS framework, the framework of the product experience and the model of the seven stages of action cycle. These tools have been selected because of several reasons. They are generic, not referred to any specific product or situation. The situated FBS framework shows a rigorous architecture to represent at best the design activities. Both the situated FBS framework and the model of the seven stages of action cycle deal with the cognitive reasoning of designers during design activities. The framework of the product experience and the model of the seven stages of action cycle allow considering designers and users' emotions and behaviour arisen by specific situations.

2.1 The situated FBS framework

The situated FBS framework describes design activities from the cognitive point of view. Its first release [Gero 1990] uses three variables, function (F), behaviour (B) and structure (S), whose meaning is what the product is for, what the product does and what the product is, respectively. Eight processes, built on a set of sub-processes representing the atomic entities in charge of managing these variables, describe the problem solving activities of designers, the only agent involved, from the definition of the product functions to the development and validation of its final structure. The next release, described in [Gero and Kannengiesser 2004], introduces the environment to better characterize the variables, expands the number of processes and classifies the sub-processes. The environment refers to the designers' perceptive sphere and consists of the external, interpreted and expected worlds. The processes have been revised in order to better specify the relationships among the variables considering the different worlds. The sub-processes are classified against their role/aim in the environment. Sub-processes producing the interpretation of a variable in the interpreted world thanks to values coming from the external world belong to the push class (the corresponding symbol is $\subseteq$), while a further interpretation of a variable thanks to the constructive memory belongs to the pull class (the symbol is the same; they are considered together and called push-pull). The translation of an interpreted variable into its expectation is made by the focussing sub-processes ($\Leftrightarrow$). The compare sub-processes ($\leftrightarrow$) address this translation if it should appear more a comparison than a selection. An expected variable is transformed into its external representation thanks to the action sub-processes, while the transformation of a variable into a different one inside the same world is performed by the transform sub-processes. Both of them share the same symbol ($\rightarrow$). More recently, Cascini et al. [2012] added two variables - need (N) and requirement (R) - and two processes dealing with them, in order to manage the input of the design activities more finely. Figure 1 shows this release of the framework; all variables, sub-processes and worlds are present.

The situated FBS framework has been considered in several application domains and for different reasons. For example, Filippi and Barattin [2015b] started from it to generate the descriptive model of interaction design activities by considering the users of the product at the same level of designers. The situated FBS framework has been used also to describe design activities starting from forms instead of functions [Filippi and Barattin 2015a].

Just for brevity, in the rest of the paper the situated FBS framework with the extensions of Cascini et al. will be simply referred to as FBS.

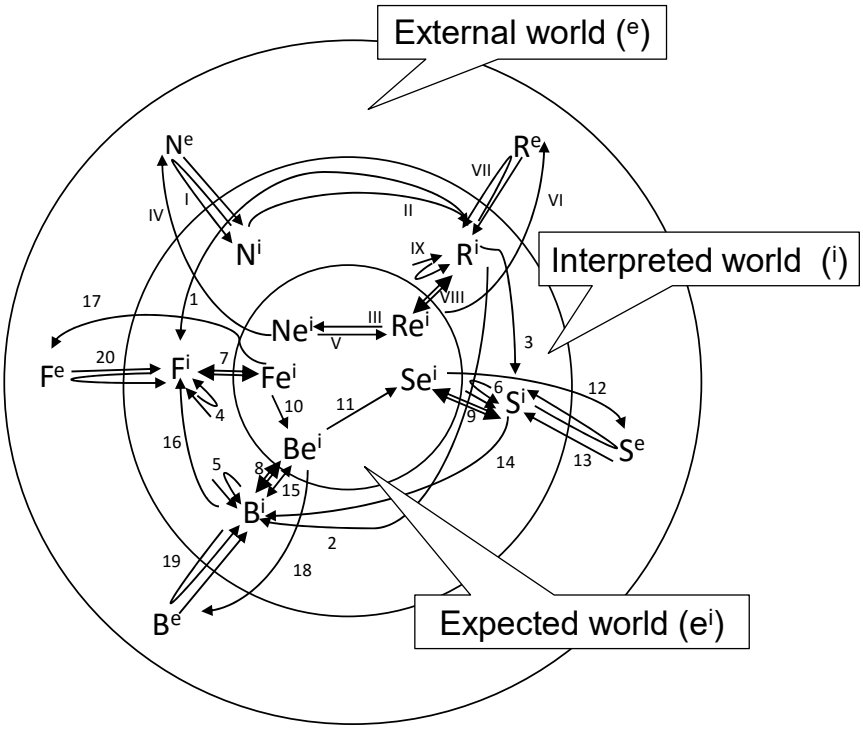


Figure 1. The situated FBS framework with extensions [Cascini et al. 2012]

2.2 The framework of the product experience

The framework of the product experience [Desmet and Hekkert 2007] describes the cognitive activities involved in different types of affective product experiences and the relationships among these activities. The product experience is defined as a change in core affect attributed to user-product interaction. It is a multi-faceted phenomenon composed by three elements: the aesthetic experience, experience of meaning, and emotional experience. The aesthetic experience represents the ability of a product to delight one or more human sensorial modalities. The experience of meaning allows the personal or symbolic significance of a product to be set. Thanks to this experience, people recognize metaphors and highlight expressive product characteristics; consequently, precise meanings are assigned to that product. Of course, this experience is influenced by individual and cultural differences. The emotional experience represents the interpretation of a product based on events considered as potentially beneficial or harmful. This experience is influenced by users' personality and past experiences. The three components are conceptually separated; anyway, it is difficult to distinguish them in an everyday product experience; the emotional experience is directly influenced by the others because emotions come from the evaluation of an event sensed through the aesthetic experience or derived from the experience of meaning.

2.3 The model of the seven stages of action cycle

The seven stages of action cycle proposed by Norman [2013] is an approximated model of human cognition and behaviour. It is composed by three levels, hierarchically ordered against the consciousness degree in the human mind, that work together. The first level is the visceral level, unconscious, that expresses the basic protective mechanisms of the human affective system by making quick judgments about perceived stimuli and generating automatic actions as answers to these stimuli. The second level is the behavioural one, partially conscious, that represents the home of the behavioural skills triggered by situations that match specific patterns. The third level is the reflective level, conscious, where reasoning and decision-making processes occur in a deep and slow way; these often occur when the events have already happened. The seven stages of action take place in these three levels. As soon as a stimulus comes from the external world, the human being perceives (I stage) it through the senses at the

visceral level. Then, the stimulus is interpreted (II) and it becomes internal information at the behavioural level. Now, the human being compares (III and IV) this information with the goals established before to start the interaction at the reflective level. Starting from the results of the comparison, the human being plans (V) the next action to do (always at reflective level), specifies (VI) his/her behaviour (at behavioural level) and performs (VII) the action, before in its mind (at visceral level) and in the external world afterwards.

3. Activities

3.1 Analysis of design activities

The analysis of four design activities showing different starting points and goals allows for highlighting those distinctive characteristics that will help in defining the requirements for the development of the XfD.

3.1.1 From functions to structure

The design of a CNC milling machine can be considered a good example of those classic activities that define the product structure starting from the functions the product will be called to accomplish. The materials to mill and the types of processing lead the selection of the functions to implement; this selection is strongly influenced by the designers' skills and knowledge. Functions are analysed and transformed into product behaviour first and structure of it afterwards. Design solutions are then exploited to build a first prototype. The prototype is used to check and validate the design solutions and to highlight possible improvements.

3.1.2 From sounds, behaviour and forms to structure

The optimization of the structure of a dishwasher [Graziosi et al. 2014] is an example of these design activities. The testers consider the sounds, behaviour and visual appearance (forms) of a specific dishwasher door while it is opened and closed; these sources are implemented thanks to a mixed prototype. Then, the testers express the desired behaviour the door should have and compare it against the ones generated by the prototype. This feedback allows the designers modifying the structure of the dishwasher door to match the desiderata. After the modifications, the tests start over if required.

3.1.3 From forms to functions

The design activities of Alessi, an iconic Italian company producing home appliances, start from the analysis of fashionable forms [Alessi 1998], [Alessi 2015], [Filippi and Barattin 2015a]. This analysis exploits testers' touch and sight to define the product behaviour first, and the related functions afterwards, considered as the goal to achieve. These functions are then compared with the ones obtained from the analysis of the user needs. This comparison allows for the definition of the ultimate goals to achieve and a first prototype is built on them. The prototype is evaluated and the design solutions optimized.

3.1.4 From materials to functions

As reported in [Ashby and Johnson 2014], the forms of chairs, buildings, etc. are strongly conditioned by the characteristics of the materials they are made of. This would suggest the design activities that can be represented by the paradigm "from materials to forms". Anyway, this research goes one step forward, by considering materials as the starting point for the definition of product functions. The design activities run as follows. First, a sample case of materials is proposed to the testers. They are asked to touch the materials without involving any other sense; moreover, there are no clues about possible forms, etc. The testers express their sensations and emotions while touching the materials. The results are analysed and transformed into functions by designers. For example, one material could suggest the function "easier and safer handling of a cell phone", while a different one the "grasping of a ball while running". These functions could lead to the development of cell phone covers and basketballs respectively.

3.2 Definition of the requirements for the XfD development

The description of the different design activities highlights the multiplicity of elements they could start from (sources), as well as that of the characteristics of the product they aim developing at (targets). This research means sources as always referred to the product; references to other subjects, e.g. the users of the product, are considered as future development. Sources refer to results of sensorial perceptions, like in the case of forms, sounds, materials and structures, as well as to immaterial elements, like product functions and behaviour. Nevertheless, it is straightforward to note that targets show the same characteristics (they always refer to the product and they can be the results of sensorial perceptions as well as immaterial elements). Therefore, the two concepts (source and target) are considered here the same thing. Being able to collect all sources and targets in the same set entails some advantages. A unique set allows avoiding information redundancy and/or misalignment, as well as simplifications of the XfD structure. All of this suggests the first requirement to consider for the development of the XfD; the framework must consider this set of sources/targets and be able to manage their characteristics. Moreover, the obvious dependence of the design activities from the nature of the sources and targets requires high flexibility and updatability of the XfD structure (second requirement). Finally, the analysis of the design activities highlights the importance of the involvement of the users of the product, mainly regarding emotional matters. The XfD must address and manage this involvement as well (third requirement).

3.3 Development of the XfD

Some existing descriptive tools can satisfy the single requirements highlighted in the previous paragraph but none is able to answer to them altogether. This is why this research aims at making descriptive tools work in synergy in order to exploit their specific abilities in answering to the requirements as a whole. The tools described in the background section can satisfy the requirements if used in synergy. What follows is the description of the XfD development; it highlights which tool is used and how this happens time by time.

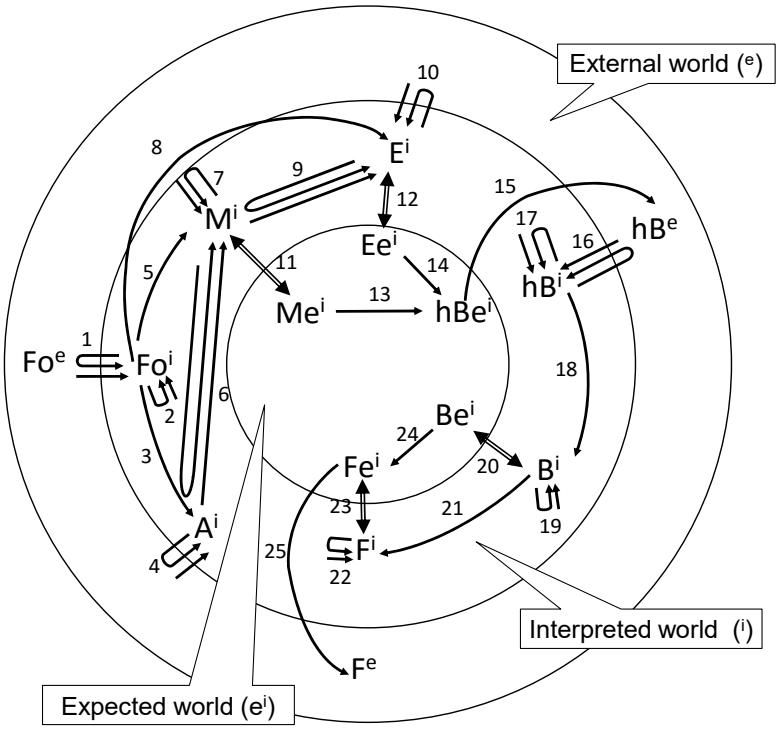
The core of the XfD structure traces the FBS one; specifically, the FBS components exploited here are the variables, the environment (worlds) and the structure of the sub-processes - the building blocks for defining the models of the design activities. These components could help in fulfilling the first requirement because new variables (sources and targets) and new cognitive activities can be easily considered in the framework. The second requirement could benefit as well, thanks to the generic definition and generation of the FBS components that allow gaining the right flexibility to be easily updated due to the different design activities to model. Along with the FBS, the framework of the product experience and the model of the seven stages of action cycle give their contribution to the XfD. Three components of the product experience are exploited: the levels (the aesthetic experience, experience of meaning and emotional experience), the relationships among them and the conditions (personality, cultural and social differences and past experiences) that influence them. All of this is of great help in representing and managing perceptual, behavioural and emotional matters in design; therefore, this helps in fulfilling the third requirement about the involvement of the users of the product regarding emotional matters. The model of the seven stages of action cycle is exploited to make the cognitive mechanisms explicit. It well explains how the human mind generates a reaction starting from a perceived stimulus. By comparing Gero's and Norman's descriptive tools, both of them start from the external world, collect and cognitively elaborate pieces information to reach a precise goal, and express this goal again outside the cognitive sphere. Apparently, the two tools describe the same things. The difference consists in the point of view. The Gero's framework emphasizes variables, worlds and sub-processes, and considers them as atomic entities, building blocks; on the contrary, the Norman's model focuses on the processing, on how the elaboration of the pieces of information takes place. The structure of the three levels - the visceral, the behavioural and the reflective, as well as their meaning and relationships will be of great help in covering the lacks of consideration regarding the "how" the human reasoning takes place and the human behaviour and emotions (third requirement).

Focusing on variables, the XfD uses the FBS ones, all of them referred to the sources/targets set. Anyway, the set can be integrated every time a different product characteristic should need to be represented. For example, variables like sound (So) and material (Ma) will be added in the following.

Three more variables are added to allow the product experience to be described at best. They are the aesthetics (A), meaning (M) and emotion (E); they refer to the product as well. Finally, the introduction of one more variable is required by the involvement of the model of the seven stages of action cycle; this is the sole variable referred to the users of the product instead of to the product itself. It is named human behaviour (hB).
The environment in which the variables are considered is the same of the FBS; therefore, the three worlds (the external, the interpreted and the expected worlds) are present here, along with their relationships and the rules to elaborate pieces of information within one world or to make transformations from one world to another.
The processes in the XfD vary due to the specific design activities to model; however, the components of every model have the same structure as that of the FBS sub-processes. The classes remain the same, with a little add-on. The pull class, as well as identifying sub-processes allowing a further interpretation of a variable thanks to the constructive memory, is meant here as the way to classify sub-processes where the interpretation of a variable can be influenced by a different one. The sub-process $Me^i \rightarrow hBe^i$, referred to the new variables introduced during the development of the XfD, is proposed as an example to explain how the sub-processes are composed and how they work. The expected meaning (Me^i) - achieved thanks to the analysis of a specific stimulus - is transformed (→) into expected human behaviour (hBe^i) to be used in later sub-processes.
Once finished the description of the components of the XfD (structure, variables, environment and processes), the following section reports a first exploitation of the XfD in modelling the design activities "from forms to functions". This description shows in detail how the framework works.

3.4 XfD exploitation

This section starts with the description of how the "from forms to functions" design activities are modelled thanks to the XfD. Figure 2 shows the complete model. The graphical language is the same used in Figure 1, representing the classic "from functions to structure". The sub-processes are orderly listed in a table to allow the description to be followed at best.



1	$Fo^e \subseteq Fo^i$
2	$Fo^i \subseteq$
3	$Fo^i \rightarrow A^i$
4	$A^i \subseteq$
5	$Fo^i \rightarrow M^i$
6	$A^i \subseteq M^i$
7	$M^i \subseteq$
8	$Fo^i \rightarrow E^i$
9	$A^i + M^i \subseteq E^i$
10	$E^i \subseteq$
11	$M^i \Leftrightarrow Me^i$
12	$E^i \Leftrightarrow Ee^i$
13	$Me^i \rightarrow hBe^i$
14	$Ee^i \rightarrow hBe^i$
15	$hBe^i \rightarrow hB^e$
16	$hB^e \subseteq hB^i$
17	$hB^i \subseteq$
18	$hB^i \rightarrow B^i$
19	$B^i \subseteq$
20	$B^i \Leftrightarrow Be^i$
21	$B^i \rightarrow F^i$
22	$F^i \subseteq$
23	$F^i \Leftrightarrow Fe^i$
24	$Be^i \rightarrow Fe^i$
25	$Fe^i \rightarrow F^e$

Figure 2. Model of the "from forms to functions" design activities

The model starts with the interpretation (1) of the external form (Fo^e). The resulting interpreted form (Fo^i) is further interpreted thanks to the constructive memory (2). After that, the interpreted form generates a precise product experience in the designers and in the users of the product and this sets the values of the aesthetics (A^i) (3), meaning (M^i) (5) and emotion (E^i) (8) variables. The interpreted aesthetics (A^i) is further interpreted thanks to the constructive memory (4); successively, it influences (6) the meaning (M^i). Now, the meaning (M^i) is further interpreted (7); after that, along with the aesthetics, it influences (9) the emotion (E^i). This happens because emotions are influenced by aesthetics and meanings as described by the product experience framework. Finally, also the emotion (E^i) is further interpreted (10). The final interpreted meaning (M^i) (11) and emotion (E^i) (12) focus on the definition of the expected meaning (Me^i) and emotion (Ee^i) that must be designed into the new product. The sequence of sub-processes performed up to now corresponds to the first four stages of action of the Norman's model. The designers or users of the product perceive a stimulus (here coming from the sight and maybe also from touching the form), they interpret it through the product experience, compare the results with their expectations and choose the most suitable goals. Now, the expected meaning (Me^i) and emotion (Ee^i) are transformed (13-14) into expected human behaviour (hBe^i), the actions that the designers or the users of the product plan to do to achieve those meanings and emotions (fifth stage in the Norman's model). The expected human behaviour (hBe^i) is transformed (15) into external human behaviour (hB^e) to specify and perform the human thoughts. This corresponds to the sixth and seventh stages in the Norman's model. Now, the external human behaviour (hB^e) is interpreted (16) and the result (hB^i) is further interpreted (17) to be transformed (18) into the interpreted product behaviour (B^i). Thanks to this sub-process, the interpreted product behaviour (B^i) is further interpreted (19) and successively focused (20) on the definition of the expected behaviour (Be^i) to be designed into the new product. Then, the interpreted behaviour (B^i) is transformed (21) into interpreted functions (F^i). These functions (F^i) are further developed (22) thanks to the constructive memory and focused (23) on the definition of the expected functions (Fe^i) to be designed in the new product. Finally, the expected behaviour (Be^i) is transformed (24) into expected functions (Fe^i) to be added to those derived from the sub-process 23. In the end, the expected functions are transformed (25) into external ones (F^e). All of this should make clear that the XfD allows modelling the "from forms to functions" design activities.

Table 1 reports the models of all the design activities considered in this research. To be precise, the classic "from functions to structure" design activities are described more finely than in the FBS because the XfD allows considering also behavioural and emotional matters related to designers and users of the product. In order to address the design activities easily, each model is coded using the formalism sources>>targets. For example, the model of the design activities "from forms to functions" is labelled as Fo>>F.

Table 1. XfD models of the design activities considered in the research

Sources / Targets	Material (Ma)				Source
	Sound (So)		Source		
	Behaviour (B)		Source		
	Form (Fo)		Source	Source	
	Structure (S)	Target	Target		
	Function (F)	Source		Target	Target
Design activities		F>>S	(So+B+Fo)>>S	Fo>>F	Ma>>F
Model	1	$F^e \subseteq F^i$	$Fo^e \subseteq Fo^i$	$Fo^e \subseteq Fo^i$	$Ma^e \subseteq Ma^i$
	2	$F^i \subseteq$	$B^e \subseteq B^i$	$Fo^i \subseteq$	$Ma^i \subseteq$
	3	$F^i \rightarrow M^i$	$So^e \subseteq So^i$	$Fo^i \rightarrow A^i$	$Ma^i \rightarrow A^i$
	4	$F^i \rightarrow E^i$	$Fo^i \subseteq$	$A^i \subseteq$	$A^i \subseteq$
	5	$M^i \subseteq$	$B^i \subseteq$	$Fo^i \rightarrow M^i$	$Ma^i \rightarrow M^i$
	6	$M^i \subseteq E^i$	$So^i \subseteq$	$A^i \subseteq M^i$	$A^i \subseteq M^i$
	7	$E^i \subseteq$	$Fo^i \rightarrow M^i$	$M^i \subseteq$	$M^i \subseteq$
	8	$M^i \Leftrightarrow Me^i$	$Fo^i \rightarrow E^i$	$Fo^i \rightarrow E^i$	$Ma^i \rightarrow E^i$

	9	$E^i \Leftrightarrow Ee^i$	$B^i \rightarrow M^i$	$A^i+M^i \subseteq E^i$	$A^i+M^i \subseteq E^i$
	10	$Me^i \rightarrow hBe^i$	$B^i \rightarrow E^i$	$E^i \subseteq$	$E^i \subseteq$
	11	$Ee^i \rightarrow hBe^i$	$So^i \rightarrow A^i$	$M^i \Leftrightarrow Me^i$	$M^i \Leftrightarrow Me^i$
	12	$hBe^i \rightarrow hB^e$	$So^i \rightarrow M^i$	$E^i \Leftrightarrow Ee^i$	$E^i \Leftrightarrow Ee^i$
	13	$hB^e \subseteq hB^i$	$So^i \rightarrow E^i$	$Me^i \rightarrow hBe^i$	$Me^i \rightarrow hBe^i$
	14	$hB^i \subseteq$	$A^i \subseteq$	$Ee^i \rightarrow hBe^i$	$Ee^i \rightarrow hBe^i$
	15	$hB^i \rightarrow B^i$	$A^i \subseteq M^i$	$hBe^i \rightarrow hB^e$	$hBe^i \rightarrow hB^e$
	16	$B^i \subseteq$	$M^i \subseteq$	$hB^e \subseteq hB^i$	$hB^e \subseteq hB^i$
	17	$B^i \Leftrightarrow Be^i$	$A^i+M^i \subseteq E^i$	$hB^i \subseteq$	$hB^i \subseteq$
	18	$B^i \rightarrow S^i$	$E^i \subseteq$	$hB^i \rightarrow B^i$	$hB^i \rightarrow B^i$
	19	$S^i \subseteq$	$M^i \Leftrightarrow Me^i$	$B^i \subseteq$	$B^i \subseteq$
	20	$S^i \Leftrightarrow Se^i$	$E^i \Leftrightarrow Ee^i$	$B^i \Leftrightarrow Be^i$	$B^i \Leftrightarrow Be^i$
	21	$Be^i \rightarrow Se^i$	$Me^i \rightarrow hBe^i$	$B^i \rightarrow F^i$	$B^i \rightarrow F^i$
	22	$Se^i \rightarrow S^e$	$Ee^i \rightarrow hBe^i$	$F^i \subseteq$	$F^i \subseteq$
	23		$hBe^i \rightarrow hB^e$	$F^i \Leftrightarrow Fe^i$	$F^i \Leftrightarrow Fe^i$
	24		$hB^e \subseteq hB^i$	$Be^i \rightarrow Fe^i$	$Be^i \rightarrow Fe^i$
	25		$hB^i \subseteq$	$Fe^i \rightarrow F^e$	$Fe^i \rightarrow F^e$
	26		$hB^i \rightarrow B^i$		
	27		$B^i \subseteq$		
	28		$B^i \Leftrightarrow Be^i$		
	29		$B^i \rightarrow S^i$		
	30		$S^i \subseteq$		
	31		$S^i \Leftrightarrow Se^i$		
	32		$Be^i \rightarrow Se^i$		
	33		$Se^i \rightarrow S^e$		

4. Discussion

The successful modelling of the design activities highlights the compliance of the XfD with the requirements set at the beginning. First, sources/targets are considered homogeneously and the set containing them appears managed in a correct way; the pieces of information describing the sources/targets are represented by variables without losing any meaning and/or detail. Second, the XfD structure seems to be easily updatable thanks to the addition of new variables and the related sub-processes to manage them; moreover, the XfD structure is flexible enough to model design activities belonging to different scenarios. At the same time, it is clear that if the same design activities should change over time because of addictions or changes, their XfD model can be easily updated in an incremental way without the need to restart from the beginning. Third, the involvement of the users of the product is kept into consideration thanks to the management and exploitation of specific variables related to product experience and to the human behaviour and emotions. These variables have a great importance because their expected values affect directly the generation of the targets.

It must be pointed out that, since the framework still needs to be tuned up, these early experiences in adopting the XfD have been conducted by the developers and by experts in cognitive matters and process modelling. Therefore, if from one hand the modeling activities performed up to now go towards the expectations, from the other hand it is too early to say the ultimate world about the effectiveness, the usability, the completeness of the XfD. Anyway, since the XfD is mainly the result of a synergy among well-known and long-exploited descriptive tools and much attention has been paid in making them working together as smoothly, efficiently and effectively as possible, there is quite confidence about positive outcomes also from further adoptions in the future.

The first modelling experiences start to highlight the existence of a direct connection, a tight relationship between the sources/targets and the design activities (and, consequently, the cognitive processes

involved). This relationship allows for a sort of "reverse design" concept to be introduced. Available information/knowledge about the cognitive processes of specific design activities, along with their temporal sequence, can allow making a better selection of the right input to consider (sources) and of the best points of view for representing the product-to-be (targets). For example, consider a company developing user interfaces for office automation software packages. The design activities could likely focus on the interface structure (buttons, icons, widgets in general). On the contrary, the analysis of the cognitive processes provided by the XfD suggests considering the user behaviour in the face of specific needs. Designers should derive the product behaviour starting from the analysis of the user's one. This way, the product will likely offer the best support (cognitive compatibility) to user behaviour and to the problem solving processes. Therefore, the definition and implementation of the interface structure (old goal of the design activities) would be more correctly considered as the simple implementation of the much more important analysis and development of the product behaviour (new goal).

5. Conclusions

The research described in this paper aimed at developing a descriptive tool to model the cognitive aspects of different design activities. Starting from some existing tools focused on human cognition, behaviour and emotions, the X for Design descriptive framework has been defined. Based on a common set of sources/targets, it allows describing design activities that generate different product specifications starting from a heterogeneous collection of pieces of information. Once the requirements have been set and the development of the framework has taken place, four different design activities have been modelled to highlight the compliance with the initial requirements. The first ones define the product structure starting from the functions to implement; the second ones define the product structure starting from sound, behaviour and form; the third design activities define the product functions starting from forms; finally, the fourth ones define the functions the product will be called to accomplish starting from materials.

In the near future, other design activities as well as other existing descriptive tools will be considered, in order to update/integrate the framework and check its validity. Future work will also focus on the "reverse design" concept; its possible exploitation has been spotted in the discussion section but it deserves a deeper reasoning. Another important hint for future developments refers to the sources/targets set. Now, this set is fully product-related. It would be interesting to extend the coverage to human aspects like personality, etc., as well as to external aspects like environment and culture.

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Prof. Stefano Filippi, Associate Professor
University of Udine, DIEGM
Via delle Scienze, 206, 33100 Udine, Italy
Email: filippi@uniud.it