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DESCRIPTIVE MODEL FOR INTERPRETING INNOVATIVE DESIGN

Q. Zhang, I. Deniaud, E. Caillaud and C. Baron

Keywords: innovative design, descriptive model, system

1 Introduction

The emergence of ever more technically advanced customer needs, combined with exponentially growing competition on a global range, is fuelling the demand for more innovative products. Innovative design, however, involves many variables whose characteristics and interactions are not well understood. Meanwhile, the complexity of requirements, design activities, and organization are increasing the difficulty of controlling the process. Having a comprehensive understanding of the process of innovative design through a process model is of great interest to both individuals and organizations. Therefore, “how should we describe the process of innovative design?” is defined as the main research question.

A design process can be considered as a complex set of integrated efforts. An inappropriate design process not only affects the efficiency of design phases but also increases the possibility of failure. The traditional models argue that design should advance from the general and abstract problems to the concrete and particular ones. These design activities are classed into four phases: task clarification, conceptual design, embodiment design and detail design. It would appear, due to the frequent reference and use, that the traditional representations offer designers a useful tool to design.

However, it is evident that these models do not correspond with the realities of innovative design. In the sense of the problem structure, innovative design is more to an evolving process between the design problem and the corresponding design solution [Dorst & Cross 2001]. So it is difficult to clarify design problems at the beginning of design. Moreover, these traditional models cannot make a clear distinction between routine design and innovative design. That is, there is no descriptive model to clearly reflect the creative activities. It was also recognized that these traditional representations do not adequately represent either the designer or the environment. These failings result in part from the assumption that the designer is just a passive executor, instead of an active one. Design is a process during which the designer performs actions in order to change the environment. So the designer observes and interprets what they are ‘seeing’, and then decide on new actions, instead of simply performing the recommended actions.

In order to address these limitations, we introduce a descriptive model of innovative design. The model will reflect the actual process and pattern of innovative design, will locate innovation opportunities in the design process and support a systematic perspective whose focus is on the external and internal factors affecting the success of innovative design. In section 2, we discuss the background of the descriptive model by defining innovative design and treating design process as a system. In section 3 we present our proposal for a descriptive model which is organized to achieve the stated goals. In section 4 we present our concluding remarks.

2. Background

2.1 What is innovative design?

Defining innovative design necessarily requires an understanding of the concepts of innovation and design. Design has not been adequately defined: researchers agree that it is a process, but disagree on what kind of process it is. Some have considered it as a rational problem-solving process, others as a reflective process, and still others as an evolving process between knowledge and concept. There is more agreement about innovation, namely, that it consists of two components: creativity and implementation. Creativity refers to how to generate more and better ideas; implementation concerns how to translate the ideas into product.

Looking at one of the definitions of innovative design, one could define it with design variables and forms. However, this still does not go beyond the known framework. Another definition expresses innovative design as a means to break away from the existing rules and generate new rules. The former just class innovative design into one of design categories from variable and form, and does not view innovation as the core part of it. The latter enlarges the scope of innovative design, and refers to a new form of design combining the traditional design function with new elements. However, a new form of design involves not only the product, but also organization and process.

We can define innovative design, then, as some kind of process that applies a creative idea to create a product, process, or service for a customer and market. An innovative design should break away existing forms, and demonstrate three characteristics: (1) *Novelty*. The result of innovative design is different from all previously existing products. (2) *Value*. The value of innovative design is related to a human purpose, and should be judged by the customer and society. (3) *Commercialization*. Innovative design is distinguished from the term *creative design* because it involves commercial transactions.

2.2 Treating the process of innovative design as a system

Before moving further, we need a better understanding of the term “process” and “system”. A *process* is “a set of interrelated or interacting activities which transform inputs into outputs” (IEEE Std 15288 2004). Any work done to produce a result, including creativity and innovation, involves a process. Thus, we can think of the work on innovative design as a process. Without understanding the underlying process, it is difficult to know how the results were achieved, or whether they were good or bad. A *system* is “a combination of interacting elements organized to achieve one more stated purposes” (INCOSE 2006), or “a set or arrangement of elements that are related, and whose behaviour satisfies operational needs and provides for the life cycle sustainment of the products”(IEEE Std 1220 2005).

Comparing the definition of a process with the definition of a system, we can conclude that a process is a kind of system. Thus, the process of innovative design can be viewed as a system. The process model of innovative design is a typical system model. The literature on the system model is extensive, although only a small subset of this literature focuses on innovative design. However, it is necessary to summarize some fundamental propositions which describe the modelling process of innovative design based on these models.

- Design is something of an art but with many consistent patterns. Similarly, while innovative design seeks to design something innovative, the designer or the design team tends to follow a pattern. That is, the process of innovative design has some repeatable structures.
- The process model of innovative design is to plan and control the process, and determines design activities. Structured methods are valuable for managing these design activities.
- The innovation cannot be fully mechanized. Despite the advances in understanding of innovation, artificial intelligence and techniques, we still cannot accurately prescribe a comprehensive mechanism for innovation.

Although these propositions cannot ensure our success in the modelling process, they provide us with the theoretical basis for a descriptive model of the innovative process.

3. Descriptive model

Based on the propositions in Section 2, in designing the model, we have had three goals in mind.

- (1) The model should represent the fundamental processes of innovative design to be useful in understanding the patterns involved in the process.
- (2) The model should involve all the necessary elements in the innovative design process, so that we can know when and where the innovations could emerge, proceed and grow.
- (3) The model should be comprehensive enough that it will be useful to the designers when discussing different factors affecting the success of innovative design.

We believe that the model addresses these goals reasonably well and can, therefore, be useful in interpreting innovative design. Therefore, according to the three goals, the main question of a descriptive model becomes “How should we describe the process of innovative design.” This question can be divided into two sub-questions: “What processes should be performed”, and “How should we structure these processes.”

As for the first sub-question, we construct the basic framework of innovative design based on the FBS(Function-Behaviour-Structure) model (Section 3.1). However, the basic framework is not able to take into consideration the entire innovative design process. Referring to the chained-linked model of innovation, the basic framework is extended by considering the innovation process (Section 3.2.1).

Because the structure of innovative design is not linear, and inspired by the model of the CPS(creative problem process), we solve the second sub-question by placing the basic framework into a circular form (Section 3.2.2). Further, we introduce the designer and the environment space into the model (Section 3.3). Section 3.4 integrates the two aspects, and finally proposes the descriptive model of innovative design.

3.1 Constructing the basic framework of innovative design

John Gero proposed his FBS model of design as a theoretical base for understanding design, and as a conceptual basis for computerized tools intended for supporting the designer [Gero 1990]. According to the FBS model, design consists of eight elementary steps, which are defined in terms of the key concepts of function, behaviour and structure. Five of them transform the desired functions of the artefact into the design descriptions in sequence. And the designer carries out these steps on the basis of knowledge stored in and retrieved by design prototypes.

Vermaas and Dorst [Vermaas & Dorst 2007] identify two problems with the FBS model: the absence of a stable definition of function, and the model’s double aims of describing the actual design and prescribing improved design. Because the second problem involves explaining how descriptive and prescriptive modelling could be distinguished and connected, it goes beyond the scope of this paper. So we focus on a solution to treat the first problem. Vermaas and Dorst’s solution involves a redefinition of the three basic concepts (Table 1), and a reformulation of the eight elementary processes (Table 2). These proposals and analyses are considered as useful ones for understanding and developing the FBS model [Per 2009], particularly in (1) ensuring the stable conceptual framework over time, and (2) a clear separation between the internal concept (purpose) and the non-internal concept (function, behaviour and structure).

The new FBS model modified by Vermaas and Dorst has been chosen as constructing the basic framework of innovative design, because:

1. The new FBS model can be very useful in integrating the design process and the creative process [Howard et al. 2008]. The creative process is an integral part of the innovative design. Three creative process elements (analysis, generation and evaluation) can be mapped onto a view of the design process (Table 2). Tables 2 shows that Processes 1, 2, 6, 7, 8 correspond with the generation stage of the creative process, which results in the generation of new function, new behaviour or new structure. The representation linking the creative process and design process provides us with a way, by which it is possible to judge whether the design stage properly corresponds to an innovative process. It will enable us to focus on the creative activities that the designer is actually performing.
2. The new FBS model accords with the system view of innovative design in Section 2.2, and it appears to be very appropriate to describe the main characteristics of innovative design. A

foundational concept of the FBS model is the concept of “design state”. A design state is defined as a representation of all possible states which also can be seen as a representation of all possible solutions at a certain moment in time. Because the design states are transferred with time, the state-transition reflects directly the evolving process between design problem and design solution in innovative design. Moreover, the transitions of these design states include a series of design activities.

3. The degree of innovation depends on the distance from the existing design output with the variables and the goals of design, the new FBS model clearly represents these parameters. According to the definitions in Table 1, the ‘variables’ of design can be assigned to the ‘behaviour’, the ‘structure’ and the ‘function’, while the ‘goal’ of design corresponds to the ‘purpose’. The greater the difference between these parameters, the higher the innovation degree.

Table 1 The definitions of the key concepts on Vermaas and Dorst’s view

Purpose(P)	The design intention
Function(F)	Those physical dispositions of an artefact that contribute to the purpose for which the artefact is designed
Behaviour(B)	The physical disposition of the artefact
Structure(S)	The materials of the artefact, the dimensions and geometry of these materials, and their topological relations

Table 2 The eight elementary processes of the FBS model

The eight elementary process [Vermaas & Dorst 2007]			Activities in the creative process [Howard et al. 2008]
Process1: Formulation	$P \rightarrow F$	Transformation of the client’s purposes into functions (physical dispositions) expected to contribute to these purposes	Generation
Process2: Synthesis	$F \rightarrow S$	Transformation of these functions (these physical dispositions) into a structure of the artefact that is to exhibit the functions	Generation
Process3: Analysis	$S \rightarrow B$	Derivation of the actual behaviour (all the physical dispositions) of the artefact from the description of the structure	Evaluation
Process4: Evaluation	$B \leftrightarrow F$	Comparison of the actual behaviour and the functions	Evaluation
Process5: Documentation	$S \rightarrow D$	Production of the design description	N/A
Process6: Reformulation type1	$S \rightarrow S'$	Choice of a new structure	Generation
Process7: Reformulation type2	$S \rightarrow F'$	Choice of new expected behaviour	Generation
Process8: Reformulation type3	$S \rightarrow P'$	Choice of new functions	Generation

Therefore, the new FBS model can provide us with a framework to describe the process of innovative design. Based on the definitions and the processes of Tables 1 and 2, the basic framework for innovative design is constructed, as showed in Figure 1.

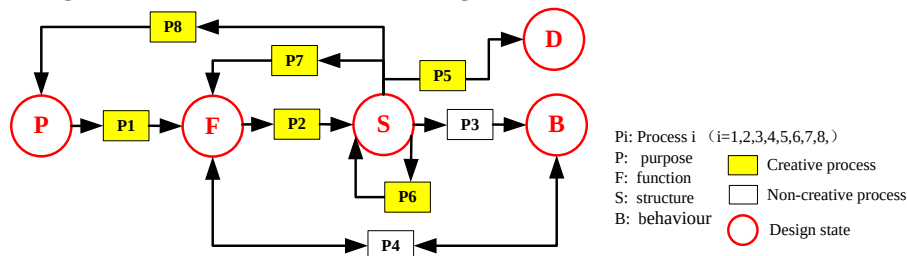


Figure1. The original basic framework of innovative design based on the FBS model

Although the new FBS model provides us with a framework, it lacks relevant elements necessary to completely describe the entire process system. Reflection is an important concept for design and

innovation, by which the designer can interact with the internal and external environments and when appropriate propose new or even innovative solutions. The sources of information for innovation include internal factors, external/commercial factors, education /research establishments, generally available information and other external factors. However, in its current state, the new FBS model can simply focus on the internal innovation of design process, but cannot consider other possible innovation opportunities associated with the external. The next two sections introduce the relevant elements (namely innovation, the designer and the environment space) which are not taken into account in the FBS model, but these elements are essential and necessary. After defining these elements, we consider how to incorporate them into the descriptive model we propose.

3.2 Modifying the basic framework by considering the innovation process

As we have discussed in Section 2.1, an innovative design should break away from existing forms, and demonstrate three characteristics: *Novelty*, *Value* and *Commercialization*. These characteristics are relevant with innovation process. Therefore, the importance of an understanding of how to combine innovation process with design shapes the ways in which we model innovative design. The innovation process concerns why and how innovation emerges, proceeds and grows. There is not a widely agreed upon model of a firm-level process of innovation that incorporates all the requirement of different disciplines. In practice, innovation is a coupling and matching process, and involves many iterations and much feedback. Numerous recent works recognize these characteristics, and propose more complex, variegated and interactive models. In the section, we will modify the basic framework to adapt to these characteristics.

3.2.1 Extending the basic framework by introducing the requirement

One alternative to the linear model, called the “chained-linked model”, is proposed by Kline and Rosenberg [1986]. They describe how feedback and loops allow the potential innovator to seek existing inter-firm and intra-firm knowledge in the innovation process. Figure2 is a redrawn version of the chained-linked model. The chained-linked model presents a great advance in explaining the necessary interaction for successful innovation. According to the model, a key element in determining the success of innovation is the extent to which a firm manages to maintain effective links between these phases of innovative process.

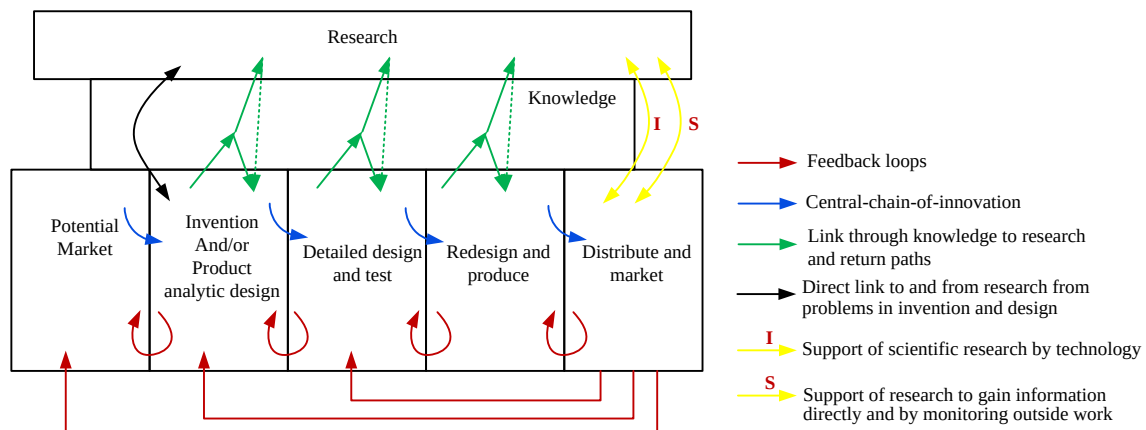


Figure 2. The chained-linked model

As for innovative design, these effective links and feedback loops provide the probable sources of innovation. These could include, for example, the feedback from the market, technical advances, and the accumulated knowledge. Recall that the basic framework of innovative design that was shown in Figure 1. The original framework, due to the lack of a comprehensive representation of the sources of innovation, is restricted to the internal process of innovative design. According to the descriptions of these elementary processes, these creative processes (Processes 1, 2, 6, 7, 8) result in the innovative outputs, namely new functions (by Processes 1, 7), new purposes (by Process 8) and new structures (by Processes 2, 6). In terms of an innovation process, these creative processes that produce the

innovative outputs are not comprehensive. In light of the chained-linked model, the new purposes do not only result from the process $S \rightarrow P$ (Process 8), but also from technical push and market pull. Technical push describes the scientific and technological advances that push a new idea into the design process, while market pull places more emphasis on market needs.

To better and comprehensively exploit this process, we add requirements (R) into the original framework of innovative design. First, the designer analyzes the requirements (R), which come from the technical advance and the market needs, leading to the interpreted purposes (P). Then the purposes (P) are augmented by the designer's own experience or the firm's accumulated knowledge. Therefore, the new basic framework of innovative design is shown in Figure 3. An initial design state space is built up by the requirements (R). Because the transformation from R to P (Process 0) brings on a new purpose, the process 0 is also the generation stage of the creative process.

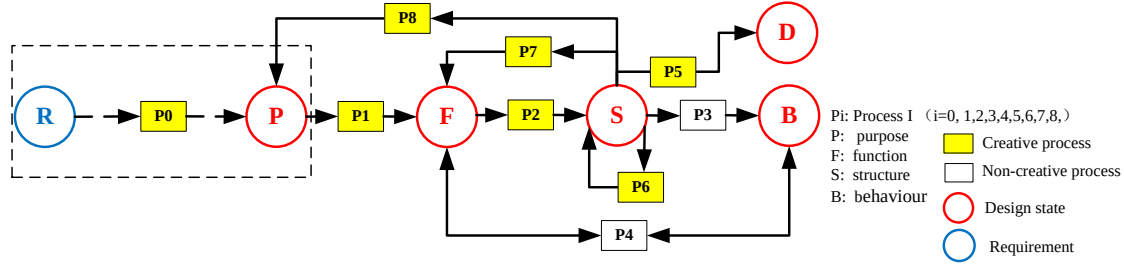


Figure 3. The new basic framework of innovative design

3.2.2 Circularity in the basic framework

In fact, the new version is still a logical development of the innovative design shown in Figure 3. A design process proceeds through the Processes 0-8. However, most practitioners do not follow these separate steps in their daily practice, and very few of them can draw straightforward steps in any given process. Some researchers consider the process as an example of CPS (creative problem process), in which the entire process can be considered a spiral type. In the CPS domain, it places these processes on a circle and connects these processes with each other. Moreover, it indicates that all these processes are necessary, but the sequence can be varied. Based on these views and the experiences of consultants, Buijs[2003] proposes the circular version of the innovation model, as shown in Figure 4. All four stages of innovation (product launch and use, product development, strategy formulation and design brief formulation) are executed in the circular style. Leadership, culture, emotion, motivation, risk-taking and passion are the elements of the term “heart”. Thus, we rely on the “heart,” the competitive environment and the thinkingway the innovation team, as a way to start with out of the four stages.

Inspired by these analyses of Buijs, we conclude that the new version of the framework (Figure 3) similarly should be adapted as a circular style. Here, we see two reasons for the circular configuration in which we visualize our basic framework. Firstly, there is not any iteration in the basic framework. Referring to the theories of innovation and the chained-linked model, we have already recognized innovation process is neither smooth nor linear, nor often well-behaved. Iterations and feedbacks are inevitable elements in the process. Secondly, due to the complexity and the uncertainty of innovative design, it is impossible to finish the tasks we requested of each individual. So innovative design is by necessity compulsory teamwork, and different team members can perform these elementary processes at the same time. In other words, these processes are carried out in a parallel fashion.

Therefore, our conception of a circular model with three layers provides an initial setting, into which we put these elementary processes of the basic framework. Figure 5 shows the circular process model. It consists of three layers: (1) Mapped onto in the middle layer are the nine elementary processes (described by Table2), with the iterations between these processes shown as dotted lines. The yellow parts denote that these processes are creative processes as in Figure 3, while the blue ones are not. The solid black lines represent the transformation and comparison between these design states (described by Table1). (2) In the central layer, we transform the term ‘heart’ into ‘designer’, which drives these

situatedness. Gero and Kannengiesser [2004] describe situatedness as the interaction of the external world, the expected world and the interpreted world, see Figure 6. The external world, namely the environment space, is composed is represented as outside of the designer, while the interpreted word and the expected world are built up on the inside of the designer world. The interpreted world refers to sensory experiences, precepts and concepts of the designer. In the expected world, the actions that the designer will perform are imagined. These three worlds are dynamically coupled with each other through three types of processes: interpretation, focusing and action.

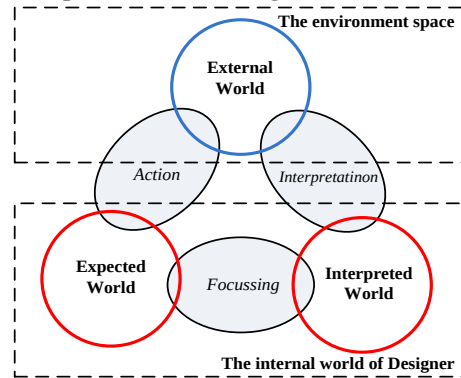


Figure 6. Situatedness as the interaction of three worlds

Although Gero and Kannengiesser reconstruct these elementary processes of the FBS model based on the new framework, the external world is not clearly demarcated. That is to say, which elements does the external world include? According to the definition of the external world, the representations of these elements should be able to describe an external influence on the designer's interpretation, and moreover, these are objective and independent of the designer. Furthermore, because the external world is dynamic with time, it should be seen as a time dependent variable. Reyman *et al.* [2006] develop a concept called *design situation* to model design which defines the state of the combined concepts at a certain point in time. Here, we adopt the basic framework of the concept "design situation" to describe the external world, including the state of the design context, the state of the stakeholders, the design state and the state of the design process, as showed in Figure 7. The definitions of relevant concepts are listed in Table3.

Having described situatedness and the concrete elements of the external world, we are now able to develop a more detailed framework of innovative design. In Figure 8, we show the three worlds of described situatedness, similar to Figure 6. Comparing with the initial circular model (Figure 5), the central layer "designer" is decomposed into the interpreted world and the expected world, and the middle layer and the outer layers consist of the external world. Through the pertinent definitions of Table 3, the design state and the state of the design process are located in the inner part of the external world, while the state of the design context and the state of the stakeholders are put into the outer part. In Figure 8, we represent more explicitly the process of innovative design as a dynamic environment, and also clearly depict the influencing elements.

Table 3. The relevant definitions and reasons of the external world

Concept	Definition	Why should it consider these concepts?
Design context	It is described by the sets of factors influencing the design state and the design process at a certain time.	An innovation process is an adaptive system which evolves by reacting to its context. The contextual factors are one of the determinants of innovation.
Stakeholder	A party that has an interest in innovative design.	The stakeholders play a key role to evaluate the value and novelty of an innovative solution by communication with the designer.
Design state	It refers to the key concepts of the FBS model, including Purpose Function, Behaviour and Structure(see Table 1)	The four state variables are the temporal solutions of design. On the basis of the perceptions of these state variables, the designer makes expected actions. Therefore, according to the definition of the external world, design states are one of parts of the environment.
Design	It is defined as a series of design	The designer learns which activity were not successful

process	activities that have been performed by the designer before the current design state.	from the accomplished design activities, and grounds them on previous knowledge. It can be seen as the external information of the designer.
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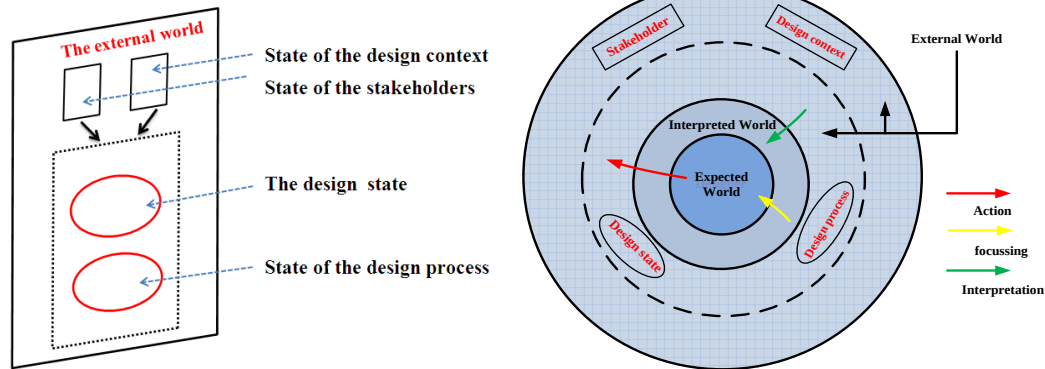


Figure 7. The external world of the designer **Figure 8. The situated model of innovative design**

3.4 Integrated descriptive model of innovative design

In the section we will attempt to map these elementary processes of the basic framework onto the situated model of innovative design. That is to say, it combines the Figure 5 and Figure 8 into an integrated descriptive model, as shown in Figure 9.

As can be seen, the **III** layer shows the enhanced version of Vermaas and Dorst's model based on the FBS model. The solid lines completely represent the different elementary processes (transformations and comparisons between these design states that are described in Table 1) and which can be found listed in Table 2. The Vermaas and Dorst' model focuses on the internals of the design process, but does not treat the innovative process, e.g. the process from requirement to purpose.

Another change of the basic framework can be viewed as the adoption of the viewpoint of circularity in the basic framework. Because the complexity and uncertainty of innovative design, these elementary processes are impossible to be performed in sequence rather than in parallel fashion. Moreover, the feed forward loops and feedback loops incorporate the source of innovation. The circularity of these processes has been included in the structure in order to reflect these characteristics of innovation process.

Additionally, the integrated model consists of four layers, in which the **I** and **II** layers respectively correspond to the expected world and the interpreted world of the designer, and the **III** and **IV** layers represent the external world of the designer. This is a consequence of introducing the designer and the environment space in order to deal with the designer's interaction process with the external world and within oneself. In practice, the designer takes command of what he is 'seeing' and 'doing' in the design process, and communicates this information to the stakeholders, then makes actions in the current design context. The basic framework in Figure 3 is not able to reflect these interactive activities.

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Qiang Zhang
INSA de Strasbourg, LGECO, Design Engineering Laboratory
LGECO, 24, Boulevard de la Victoire, 67084 Strasbourg Cedex, France
Tel. +33(0)3 88 14 47 00, Email: qiang.zhang@insa-strasbourg.fr