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DESIGN THEORIES ANALYSIS IN FRAME OF THE DEFINITION OF INVENTIVE DESIGN EFFICIENCY

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Abstract: This paper represents partial results of our research among different design theories to make a data base of the theories components, discern inventive design activities and define an indicator for inventive design efficiency. Components that have been found and listed in this paper are in association with three approaches as C-K theory, FBS framework and TRIZ theory. Despite these three approaches have totally different structures and have been defined for different missions and applications, but comparatively against the others trace the evolution of concept during design acts and try to reformulate the originality degree of new product. This last steer us proposing a new inventiveness metric model as a combinative preliminary inventiveness assessment which is based on the three mentioned design approaches. This integrated inventiveness assessment model is represented in third section.

Keywords: *problem solving, design, inventive design efficiency, inventive design assessment, innovation*

1. Introduction

Analysing efficiency of inventive design engages with three areas that form overall efficiency of inventive design. These three areas are referred to as problem, process and product (artefact) that their interplays with actor (inventor), who has the major creative role, realize inventive design activities.

Since measuring efficiency of inventive design activities is set up to increase domination of managers on performance of R&D departments and keeping place in first level competitive markets, organization of an indicator package that monitors and measures inventive design activities seems indispensable. With this aim at first step we started among different design theories to collect design elements and parameters which have been detected in design's areas to configure the indicator.

This paper represents partial results of this collection, which have been found in association with three approaches as C-K theory, FBS framework and TRIZ theory. Despite these three approaches have totally different structures and have been defined for different missions and applications, but comparatively against the others approaches trace the evolution of concept during design acts and try to reformulate the originality degree of new product. This last steer us toward proposing a new inventiveness metric model as a combinative preliminary inventiveness assessment which is based on the three mentioned design approaches. This integrated inventiveness assessment model is represented in third section.

2. Three design approaches

This section represents a summary of our investigation regarding the three mentioned design approaches. It includes a short description of theories, fundamental structure of each one and components, elements, parameters which are listed in the tables.

2.1. C-K theory

Hatchuel and Weil in 1999 (Le Masson et al., 2010) have developed an original theory which is based on principle of Concept-Knowledge relation. It defines design as a form of reasoning where creativity is built-in its definition (Le Masson et al., 2010) to provide a better understanding of the organization and management of design in innovative projects (Le Masson et al., 2010). The main assumptions of C-K theory are concepts and knowledge spaces (Figure 1). The concepts (C) space includes a set of propositions performed by the designer without having a logical status (neither true nor false) and the knowledge space (K) is constituted by propositions that have a logical status (true or false).

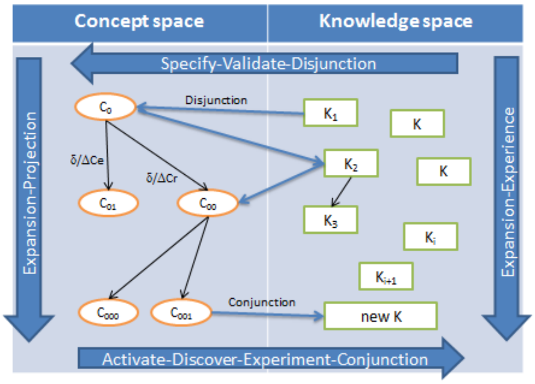

Figure 1. C-K design formalism after source model (Le Masson et al., 2010).

Furthermore, the concepts must be comprehensive in K (K-relative). In C-K theory, design seeks to extend existed concept toward a new concept which is involved with any changing (δ/ΔC) with the existing knowledge (K) and extending the knowledge (δK) with the existing concept (C) (Figure 1). For these dynamic design assumptions, it uses four operators as K→C, C→K, K→K and C→C. In the concept space, the reasoning is represented by a tree-like structure starting from initial concept (C0) and growing vertically by adding successive properties toward a better specified product and horizontally by finding different variations at a given level. C is the “starting point” for all designers having a concept which cannot be evaluated straight away and is expanded by adding attributes (Le Masson et al., 2010). Hatchuel and al. categorize concept partitioning in ‘restrictive’; if the nature of added attribute is considered as naturally related to the concept and in ‘expansive’; if the nature of added attribute is original and changes the identity of the concept as a creative process (Le Masson et al., 2010). ‘Conjunction’ is a phenomenon occurring after one or several partitioning when the resulting concept may have acquired a logical status in K. Indeed design process has been configured by generating initial concept (C0), then expanding-partitioning (C0→C) with or without disjunctions (K→C) parallel with exploring-expanding in the K space (K→K) in search of inclusion into conjunctions (C→K). An expansion of knowledge (K→K) in the knowledge space (new knowledge by parallel research) and existing knowledge is subsequently depending on exploration capacities and technological expertise. Different elements of C-K theory are listed in table 1.

Table 1. Define parameters of designing in C-K theory

No.	Element	Originality	Description
1	C-K	Formal framework	Concept and Knowledge Space
2	C_0- K_0	Formal framework	Initial framework configuration.
3	C_0	Initial Concept	Initial concept. Entity x with properties $P_1 \ldots P_n(x)$.
4	K_0	Knowledge	Knowledge base
5	$P_1 \ldots P_n(x)$	Property	Properties of entity x (C_0)
6	C_0^*- K_0^*	Formal framework	Design space configuration with clear link to the initial framework configuration (C_0- K_0)
7	C_0^*	Concept	Is related to C_0 by changing the attributes of the given entity. Entity x with the properties (Pi…Pj).($P_1^* \ldots P_m^*(x)$)
8	$P_i \ldots Pj$	Property	Chosen properties among $P_1 \ldots P_n$
9	$P^*_1 \ldots P^*_m(x)$	Attribute	Chosen new attributes to support the learning process.
10	K_0^*	Knowledge	A set of knowledge that can be activated specially in the design space
11	K_0-K_0^*	Knowledge	A knowledge base that cannot be used by the designers
12	δC	Partitioning	Small expansion in C with existing knowledge
13	δK	Partitioning	Small expansion in K with existing concept [4, 2].
14	ΔC	Partitioning	Large expansion in C with existing knowledge
15	ΔK	Partitioning	Large expansion in K with existing concept
16	$\delta/\Delta Cr$	Partitioning	Partitioning restrictive. Known property in K
17	$\delta/\Delta Ce$	Partitioning	Partitioning expansive. Unknown property in K
18	$K \rightarrow C$	Disjunction operator	Transforms propositions of K into concepts (Le Masson et al., 2010)
19	$C \rightarrow C$	Expansion operator	Internal operator that controls partition or inclusion
20	$C \rightarrow K$	Conjunction operator	Seeking for properties in K that could be added or subtracted to reach propositions with a logical status (Le Masson et al., 2010).
21	$K \rightarrow K$	Expansion operator	The classical rules of logic and propositional calculus that allow knowledge space to have a self-expansion (Le Masson et al., 2010).
22	ΔC-δK	Conceptual innovation	The knowledge K used is very common to many people versus a large successive partitions in C
23	δC-ΔK	Applied science	Sophisticated knowledge with a limited conceptual development.

2.2. FBS framework

J. Gero and al. in 2006 have proposed an extension of the function-behavior-structure (FBS) framework (Figure 3), which was proposed in 1990 (Figure 2). Their proposal aimed to represent explicitly the dynamic character of designing in context (Gero, J. S. et al., 2004). In FBS framework, conceptual design is in the core of an agent-base system in order to develop computational design agents as assistance to human designers (Gero, J. S. et al., 2004). This new model tries to model the reality and emphasizes that the designer’s view of the world changes depending on what the designer does (Gero, J. S. et al., 2004). Therefore it assumes that the designer’s knowledge is grounded on his experience and his interaction with the environment. FBS framework is based on three classes; function-behavior-structure which are variables describing different aspects of a design object (Table 2).

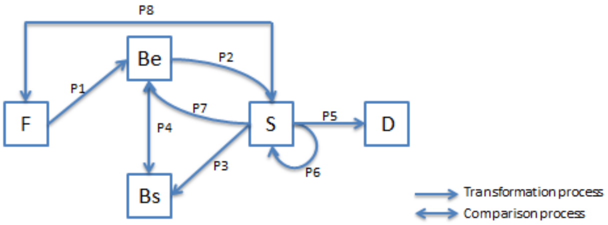

Figure 2. The basic FBS framework. Source: (Kan, J. W. T., et al. 2009)

Here the designer is making connections between these three classes through experience. Indeed designer ascribes F to B and derives B from S. Behavior was considered in two forms; expected behavior (Be) and derived behavior from structure (Bs). To portray a dynamic context of design activity, a set of process is defined, which link defined variables together. Formulation (p1), Synthesis (p2), Analysis (p3), Evaluation (p4), Documentation (p5) and Reformulations type 1 to 3 (p6 to 8) are the defined processes in FBS (Figure 2).

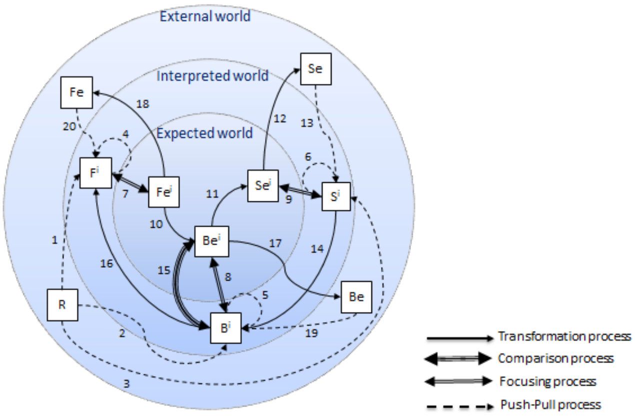

Figure 3. The situated FBS framework. Source: (Gero, J. S. et al., 2004)

Gero and al. also define designing as an activity during which the designers perform actions in order to change the environment. They presented three different kinds of environment as; the external world, the interpreted world and the expected world (Figure 3 and Table 2) that interact with one another by separated links as; Interpretation, Focusing and Action (transformation) (cf. Table 2) (Gero, J. S. et al., 2004). These worlds and their processes are ascribed to designer which trace new concept. Gero and Fujii detailed the interpretation links as a push-pull process, which represents the interaction between the expected world and the external world via interpretation (Table 2). Then they merged the basic variations of design object with the nested worlds and defined corresponding variables (Fei, Bei, Sei, Fi, Bi, Si, Fe, Be, Se and R) and twenty situated processes between them (Figure 3 and Table 2).

Table 2. Defined parameters of designing in the situated FBS framework

No.	Element	Originality	Description
1	External world	Environment	Represents outside of designer
2	Interpreted world	Environment	Builds inside of designer in term of sensory experiences, percepts and concepts. (Internal world)
3	Expected	Environment	Imaged actions of designer from object

	world		
4	Interpretation	Process	Transforms variables, which are sensed in the external world into the interpreted world.
5	Focusing	Process	Focuses on some aspects of the interpreted world.
6	Action	Process	An effect, which brings a change in the external world according to the expected world.
7	Comparison	Process	Comparing process
8	Push process	Interpretation Process	A data-driven process where the production of an internal representation is pushed by sensed data.
9	Pull process	Interpretation Process	An expectation-driven process which the original data are based to match the current expectations.
10	Fe^{i}	Variables	Expected function resulted from focusing on F^{i}
11	Be^{i}	Variables	Expected behavior derived from expected function or interpreted behavior which results from requirement or interpreted structure either from external structure or from requirement.
12	Se^{i}	Variables	Expected structure sometime without depiction
13	F^{i}	Variables	Interpreted function either derived from requirements or ascribing meaning to depicted structure
14	B^{i}	Variables	Interpreted behavior from depicted structure or requirements
15	S^{i}	Variables	Interpreted structure either from external structure or form requirement
16	F^{e}	Variables	External function, usually in term of written words
17	B^{e}	Variables	External behavior, usually in term of written words
18	S^{e}	Variables	Depiction that indicates structure
19	R	Variables	Requirements derived from the given brief
20	P 1	Process	uses R to produce Fi variables such as ‘enhancing winter solar gain’ or ‘controlling noise’
21	P 2	Process	Uses R to produce Bi variables such as ‘thermal conduction’ and constraints on them.
22	P 3	Process	Uses R to produce Si variables such as ‘glazing length’ and ‘glazing height’ and constraints on them.
23	P 4	Process	Uses constructive memory to produce further Fi variables such as ‘providing view’ or ‘providing daylight’. These Fi variables result from the history of all Fi variables that have been constructed in current and previous design experiences.
24	P 5	Process	Uses constructive memory to produce further Bi variables such as ‘light transmission’. These Bi variables result from the history of all Bi variables that have been constructed in current and previous design experiences.
25	P 6	Process	Uses constructive memory to produce further Si variables such as ‘type of coating’. These Si variables result from the history of all Si variables that have been constructed in current and previous design experiences.
26	P 7	Process	Focuses on a subset (Fe*i*_F*i*) of Fi to produce an initial function state space.
27	P 8	Process	Focuses on a subset (Be*i*_B*i*) of Bi to produce an initial behavior state space.
28	P 9	Process	Focuses on a subset (Se*i*_S*i*) of Si to produce an initial structure state space.
29	P 10	Process	Transforms Fei (e.g. ‘enhancing winter solar gain’) into Bei (here ‘direct solar gain’).
30	P 11	Process	transforms Bei into Sei
31	P 12	Process	Transforms Sei into Se, for example, by producing an iconic representation of a rectangular window and/or symbolic representations of structure variables.
32	P 13	Process	Uses Se as well as the current analysis goals to produce Si. For example, a thermal analysis ‘pulls’ different Si variables than a structural analysis does. Different representations of Se can also ‘push’ this process to emerge Si variables that have not been

			looked for initially.
33	P 14	Process	transforms Si into Bi. For example, a thermal analysis transforms glazing properties into thermal conduction properties, while a structural analysis transforms frame properties into properties related to the resistance to certain loads.
34	P 15	Process	Compares the interpreted and the expected value of a particular behavior variable,
35	P 16	Process	Transforms Sei into Se to be used as a design description for construction or manufacture.
36	P 17	Process	Transforms Bei into Be to be added in the design description produced by process 12.
37	P 18	Process	Transforms Fei into Fe to be added in the design description produced by process 12.
38	P 19	Process	Constructs new Bi from Be. It represents the same class of processes as described for the construction of Si
39	P 20	Process	Constructs new Fi from Fe. It represents the same class of processes as described for the construction of Si

2.3. Triz five levels of inventiveness

After a large investigation of technical and psychological researches in order to understand the technique of the inventive process, G. Altshuller and his colleagues 1956, considered six stages for the creativity process respectively; ‘Problem identification’, ‘Problem formulation’, ‘Problem abstraction’, ‘Searching for analogies within generalized knowledge bases’, ‘Solution Concept formalization’ and ‘Practical implementation’. The underlying steps that define the TRIZ process stages can be named ‘Heuristics’ and seen as systematic ways of solving inventive problems (Altshuller G. et al., 1999). The general goal investigated by Altshuller and his colleagues was to find universal rules, which are applicable in every area of human activity for solving any inventive task (Altshuller G. et al., 1999). They also recognized that the inventive activity implements at multiple levels. TRIZ is thus proposing five levels that classify inventions from low to high (Table 3).

Table 3. Defined parameters of designing in the five levels of TRIZ

No.	Element	Solution area	Description
1	Level one	A profession (a specific section of an industry)	Utilization of one existing object without consideration of other objects
2	Level two	An industry (by methods known within same industry)	Choosing one object out of several
3	Level three	A science	Making partial changes to the selected object
4	Level four	Outside the boundary of the science where the problem originated	Development of a new object, or the complete modification of a chosen one.
5	Level five	Outside the boundary of contemporary science (need to make a new discovery based on new science data)	Development of a completely new complex of systems.

The first and second levels include only classical or routine design tasks. Therefore they are not considered as inventive since a contradiction exists but nothing new is brought to the problem space and either a compromise or an already existing knowledge within the problem domain is sufficient to solve the task. Therefore every engineer can individually reach these two levels by classical use of their know-how or simple creative tools to trigger this know-how like brainstorming. According such a description, the real inventive jump of results is obtained by one or the last three levels. Altshuller claims that for the first and second level, already developed techniques or methods that propose thinking mechanisms are suitable, but about the higher levels, they are unusable. To be solved, the higher levels need the use of new knowledge/discoveries for the solution to emerge. Altshuller and al. express that when a problem appears, problem solving is conducted by the solver along the five levels starting from the most evident one (level 1) to the last one (level 5). Solutions to problems found within the first levels generate confidence even in excess (Altshuller G. et al., 1999) while the higher the level is the more risky the solving task is (from the solver's viewpoint). Also psychological inertia is harder to break since on the last 3 levels, an external resource or knowledge necessary to solve exists but is distant from the solver's expertise. Altshuller also characterized differences between the levels by the amount of trials-and-errors which are made by an average engineer in search of a solution.

3. Inventiveness assessment model

This section represent our proposition as a preliminary inventiveness assessment model which is based on three mentioned above models. It is a qualitative assessment model within the product area that classifies a new/improved product after design acts in accordance with two assessment blocks.

The first block observes solution methodology involved in final product and second one analyzes the FBS final product. According to this, it includes two integrated steps as is named 'Solution Methodology Assessment' (SMA) and 'Evolutionary Result Analysis' (ERA) to evaluate the inventiveness degree (Figure 4). The solution methodology assessment (SMA) relies on the five levels of TRIZ theory that recognizes the inventiveness conditions of problem solving. Between these technical problem solving (TPS) conditions, the first level cannot take place in our assessment model because this level includes routine problem solving with a 'routine design output' (Howard, T. J. et al. 2008) without considering contradictions. In this block, following concept tree-like structure of C-K theory let us to evaluate and clarify the solution methodology by properties and attributes which are applied in problem solving and categorize among the four levels (Figure 4). In this model we supposed initial concept (C_0) (in C-K theory) as the first imagination of design question which is putted on the table for design project team, and has been derived respectively from function (F in FBS framework) and expected behavior of new product (Be) (Figure 4). Along concept tree-like structure and its relative knowledge space (Figure 4), design process is in technical problem solving (TPS) phase that results new/improved product structure (S in FBS framework).

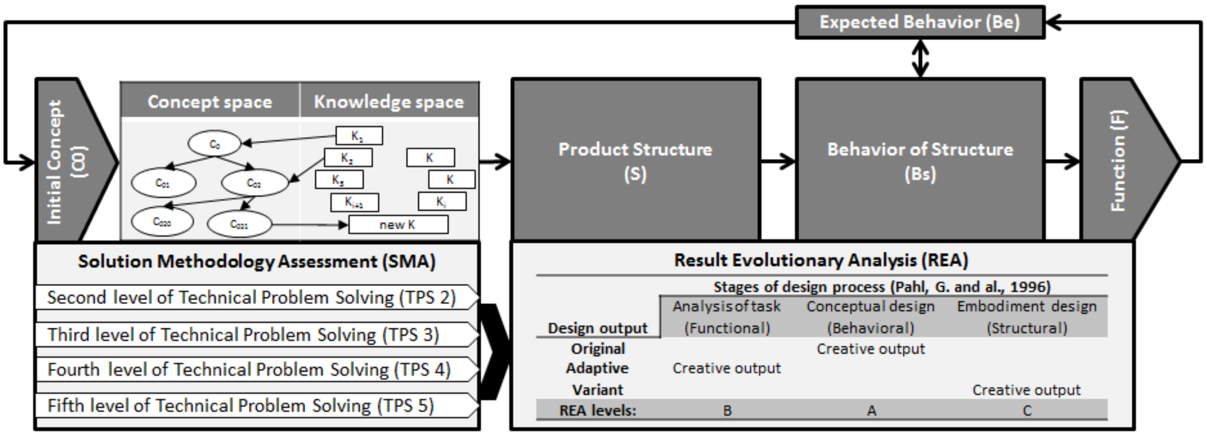

Figure 4. Inventiveness assessment model

From here we are in the second assessment block which is proposed by Howard, T. J. et al. 2000 (Table 4, Figure 4), where the evaluation leans on final design product as a 'creative design output' (i.e. design output containing at least one creative output at the systems' level under study (Howard, T. J. et al. 2008)). According to Howard, T. J. et al. 2008, a creative design output which are defined from an engineering/technology perspective, is defined as an 'original design output' if there is a ‘creative output’ (i.e. an idea that is both original and appropriate (Howard, T. J. et al. 2008)) at the behavioral level (Be). It will be an ‘adaptive design output’ if there is a creative output at the functional level (Fe). And it can be considered as a ‘variant design output’ if there is a creative output at the structural level (Se) (Howard, T. J. et al. 2008).

Table 4. Evolutionary Result Analysis. Source: (Howard, T. J. et al. 2008)

Design output	Stages of design process (Pahl, G. and al., 1996)		
	Analysis of task (functional)	Conceptual design (behavioral)	Embodiment design (Structure)
Original		Creative output	
Adaptive	Creative output		
Variant			Creative output
ERA levels:	B	A	C

Combining these two assessment blocks (SMA and ERA) (Table 5), characterizes new/improved products within twelve inventiveness classes as the first class introduces the highest inventiveness of design output and the twelfth one represents the lowest level of inventiveness.

Table 5. Inventiveness assessment classification

ERA levels **SMA levels**	**A**	**B**	**C**
TPS 5	1	2	3
TPS 4	4	5	6
TPS 3	7	8	9
TPS 2	10	11	12

The above assessment could be useful for categorizing new/improved product features for analyzing efficiency of inventive design purposes and intellectual property issues within the product area.

4. Conclusion

This paper represented partial results of our research among different design theories to make a data base of the theories components, discern inventive design activities and define an indicator for inventive design efficiency. These partial results are in association with three approaches as C-K theory, FBS framework and TRIZ theory. These three approaches trace the evolution of concept during design acts and try to formulate the originality degree of new product. This last steer us toward a new inventiveness metric model as a combinative preliminary inventiveness assessment which is based on the three mentioned design approaches. Our preliminary integrated inventiveness assessment model is useful for categorizing new/improved product features for analyzing efficiency of inventive design purposes and intellectual property issues within the product area.

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