CREATIVITY TECHNIQUES FOR A COMPUTER AIDED INVENTING SYSTEM

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ABSTRACT

The development of a Computer Aided Inventing system, assisting product designers in the creative stage, is a lengthy process because of lack of any real systematization of design knowledge for software implementation. The existing development tools for knowledge-based systems offer limited support for intelligent design.
A knowledge-based architecture for intelligent product implementation is described in this paper. It is aimed at facing those problems where radical implementation is needed. Intended solutions are not based on improvement of existing inventions, but are oriented towards a new technological jump.
A modification of the function-behaviour-structure (FBS) ontology is proposed to analyze the product to be innovated.
Then an innovative behaviour oriented search aids the designer to systematically conceive a set of alternative behaviours, by means of a combination of three different creativity methods.
The identified function – alternative behaviour couple is then automatically translated into targets for an automatic patent digging activity.
Modified FBS ontology is also exploited to classify all the information collected at functional, behavioural and structural level, and a specific algorithm provides both patent search and classification in the form of a tree-like diagram.
The software can be implemented as a support for building patent technological surveys, a personal knowledge database, technological transfer and forecasting.

Keywords: Engineering Design, Technical Creativity, Knowledge Management, FBS

1 INTRODUCTION

Einstein said: “Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world” [1].
Even if it is assumed that knowledge alone will not make a person creative, it is the stuff from which new ideas are created. According to the research of Li [2], Design Creativity in product innovation needs knowledge and information to be combined with design methods and computer supporting tools (knowledge base, information resource and computer aided thinking). There are also other uncontrolled factors, such as thinking styles, environment and culture that must be added to these.
Of course, every factor influencing creativity carries a different weight, depending on the type of problem: the contribution of creativity varies according to the problem typology, such as a well-structured or an ill-defined puzzle. A deeper correlation can be developed according to a more detailed classification suggested by Getzels [3-5], based on whether the problem exists or is created, whether the problem is suggested by the solver or by somebody else and whether a known solution exists or has to be devised. According to this classification, the proposed approach is thought up specially to support designers in solving situations, such as “the problem does not yet exist but is invented or conceived, and a method for solving it is known or becomes known once the problem is formulated” (class 9), “the problem does not yet exist but is invented or conceived, and a method for solving it is not known” (class 10). The aim of this work is to support product design systematically with a radical innovation process, mainly oriented to finding alternative unconventional solutions from patent DBs".
To do this, the given technical system to be implemented is decomposed into function and behaviour , according to FBS ontology, and translated into a new problem: “How to increase a system’s performance or maintain its performance while avoiding side effects?”

A software architecture is conceived to help find information about how to move from this problem to an already known/patented solution.
In the first section, a partial revision of the "FBS design prototypes" conceptual schema adopted by Gero to represent design knowledge [6] is proposed to analyze the given product.

In the second section, an innovative method for generating unconventional behaviours based on a combination of creative methods is presented. The new alternative systems have the same function but different behaviours.
The proposed approach also involves diagrammatic and pictorial representations of data [7, 8]. In fact, tools for acquiring knowledge, if not working to externalize intermediate results of inference (such as visual tokens), may increase the memory load [9, 10].
A tree-like diagram is proposed to visualize the output of the software, and information is organized according to this modified FBS.
In the third section, an overview of the software implementation architecture is given, showing how the revised FBS is used to organize information for preparing the next applications.
A case study is introduced in the fourth section.

2 KNOWLEDGE STRUCTURING ONTOLOGY

Many directions of solution exist to innovate a product. These are different ways of achieving the same goal and are called "alternative systems" in this paper. The aim of this work is to search for these alternative systems inside patents.
Among all the information regarding a system, the authors propose to describe a system using the FBS ontology. This design ontology allows information to be selected according to a function-behaviour-structure classification and for it to be organized to provide easy software implementation.
Thus FBS has been chosen to identify the initial problem in an abstracted way, to organize all the necessary information avoiding memory load, and to build targets for guiding Knowledge Management strategies in searching useful documents to state and solve the initial problem.
According to FBS, the initial system is abstracted and decomposed into function, behaviour and structure.
From the large number of definitions found in literature [6, 11-13], the authors propose a revised version of FBS, based on 4 levels: function, behaviour, physical effect and structure. From the function to the structure, the level of specification increases and the relation between two consecutive levels is one to many (Fig. 1).

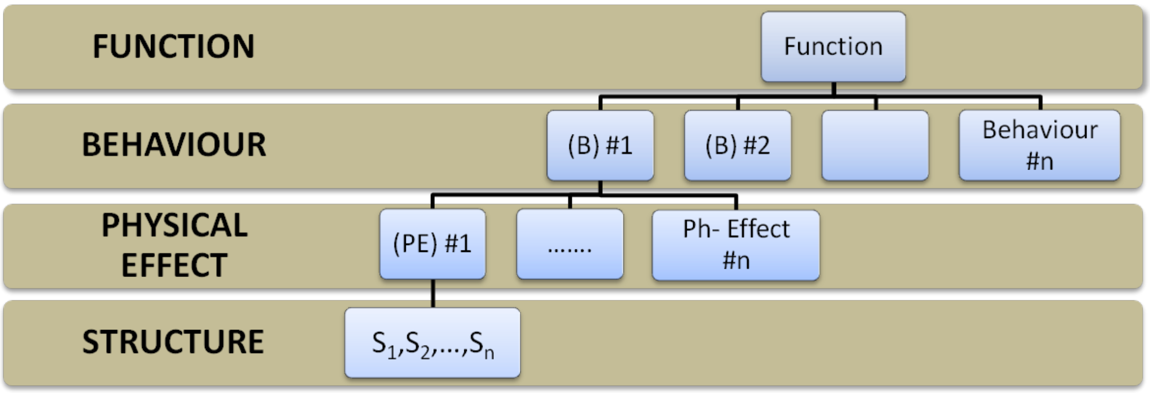


Figure 1 - Design process architecture based on a simplified version of FBS ontology.

Some original definitions are improved with the aim of creating targets for the following patent extraction while the structural level is further specified to better classify results.

Function (F): function (F) of a technical system is the motivation/purpose of its existence, i.e. what it is for [14]. The designer specifies the requirements in terms of functional concepts. Therefore, function (F) should represent the designer's intention, given as the requirements [15].

Every product has a main function. According to Umeda and Chakrabarti [11, 13], it is difficult to clearly distinguish this function (F) from behaviour (B). Their definitions do not represent function (F) independently of the behaviour (B). Both function (F) and behaviour (B) of a system describe what the system does, but function (F) is intentional and is identified at a higher level of abstraction than its behaviour ("open the nut instead of crack it").

Behaviour (B): according to Gero, the behaviour (B) describes the attributes that are derived or expected to be derived from the structure (S) variables of the object, i.e. what it does. This definition is difficult to turn into target keywords and use in a patent digging activity. For this purpose, it is preferable to consider behaviour (B) as a sequential change of states [13].
The behavioural level is based on the network of alternative behaviours (B) all deriving from the same functional concept. Our B level is built starting from the identification of the system function (F) and generating all possible ways by which it is possible to achieve the design purpose defined by the function (F). For example, a razor is conceived to cut hair (F), but can work with many behaviours (B), such as hair extraction, hair breaking, hair killing, hair growth inhibiting, etc.

Physical effect: to better understand this level, the concept related to the physical phenomenon must first be introduced. A physical phenomenon is the cause of a state transition from a state one to a state two. Thus a behaviour can be described by its initial state and a set of physical phenomena [13]. The physical effects (PE) are the laws of nature governing change, so a physical phenomenon is associated with a given PE. Activation of a PE is necessary to create physical phenomena and changes of state [11].
The PE can be described quantitatively by means of the physical laws governing the physical quantities involved. Thus the friction effect is described by Coulomb's law, $F_F=\mu * F_N$ and the expansion effect by the expansion law $\Delta l=\alpha * l * \Delta\theta$. [12]. If we take into account systems for noise abatement (F), the keywords identifying PE are the sound absorption, the sound insulation index or the dynamic rigidity, etc.
All PE and laws are related with physical/experimental coefficients or quantities. Thus the specification of keywords for the patent digger can be collected a priori in a specific library regardless of the context in which they are used. Then a list of potentially related PEs is identified for each behaviour .

Structure (S): describes the components of the object and their relationships, i.e. what it is [16]. The authors further specify this level by adding the concept of design parameters.
All transformation provided by behaviours (B) by means of PE in order to achieve the design task (F) are realized thanks to the system structure (S). This transformation is made by modifying at least one design parameter. For example, in order to increase cutting efficiency in a razor, many design parameters can be changed, such as the blade sharpening, or its inclination, the number and the distance of blades, etc.
In order to better classify and specify all the workability directions, the authors have created a further classification of this level based on modified design parameters [17]. Thus the design parameters are divided into three different types, as follows:

- **Type 1**: parameters/variables concerning the interaction between the selected object and the other elements of the system.
- **Type 2**: parameters/variables describing the object regardless of the context (system in which it is placed) and concerning design choices for manufacturing and dimensioning.
- **Type 3**: parameters/variables concerning physical properties of the object, i.e. constituting material, physical state, density, etc.

This version aims at creating targets (keywords) for patent search. The function-behaviour oriented search is conducted by generating keywords related to behaviours by means of a procedure based on a combination of 3 creativity methods, and a pre-built DB of physical effect as shown in sections 3 and 4.

3 A CREATIVE DESIGN METHOD FOR GENERATING THE BEHAVIOURAL LEVEL

Beginning with the early experimental studies of Duncker [18] in the 30s, and continuing through the 1960s and early 1970s, researches on design and problem solving have followed one upon another, especially in the area of creativity methods to stimulate innovative engineering solutions. Design process comprises 4 major phases: analysis of task, conceptual design, embodiment design and detailed design. According to Gero's classification, the design can be described in 5 basic steps [16], (from function to documentation) and each step can be linked to the design process phases [19].
This paper will concentrate on the conceptual design, which, for FBS ontology, corresponds to the so-called “formulation” process, i.e. the transformation of the posited functions (F) into behaviour (B) that is expected (Be) to enable these functions (F→Be).

Gero assumes that a theory that relates design requirements (F) to behaviour (B) does not exist, hence the formulation step F→Be should be supported by experiential knowledge (past design experience) [20]. Designers carry out this formulation step bringing their experience of F,B,S together in schemas called design prototypes. Creativity methods can contribute to improving design prototypes, supporting the generation phase of new functions (F), behaviours (B) or structures (S).

In particular, this paper focuses on generation of new behaviours (B), systematizing this formulation phase by combining several creativity methods in a software framework.
Creativity methods are selected to be integrated in a method for patent digging. Results can be used to extend past designer experience to all designers' experience (i.e. patents).

In order to support the formulation process, thereby generating all alternative behaviours (B), we need to:

- Reformulate and decompose the initial problem, improving functionality or eliminating undesired effects by working on the technical aspect of the problem. Problem solving methods are created to achieve these objectives. Among all the tools suggested by problem solving methods, the Inventive Standards [21, 22] belonging to the TRIZ theory are considered the most suitable [2].
- Call the initial conditions of the problem into question. Psychological methods are considered (such as lateral thinking [23], Why-How method, some TRIZ fundamentals and Multiscreen approach [23].
- Look at the problem from different points of view, for example changing the observer, or trying to identify yourself with the problem, or analyzing the problem by analogies. This is also useful for stimulating non obvious relations[21, 24].
- Scan the system from different detail levels. Most of creativity methods try to achieve this goal, suggesting a checklist or guidelines, or stimulating a linguistic approach. [25, 26].

The main goal of this work is to conceive a method/software to support the designer during the process of creative generation of alternative behaviours (B).
To accomplish this task, creating keywords in the form of actions representing a network of alternative behaviours, the proposed methodology suggests applying three different creativity approaches sequentially: a linguistic approach, an engineering approach and a multi-visional approach (see fig.2).

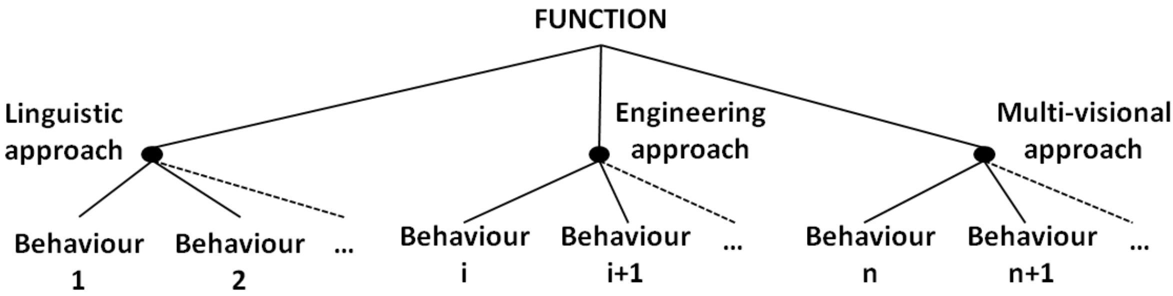


Figure 2 - The creative process for the generation of functional level based on Linguistic, Engineering and Multi-visional approach.

3.1 Linguistic approach

In the linguistic approach, a behaviour (B) oriented search can be gained by a creativity method based on semantic relationships of the function (F) (expressed in the form of action): synonymy, antonymy, hypernymy, troponymy, entailment and causal relation can be used.

In particular, troponymy of the given function (F) is used to find alternative behaviours (B): in fact, troponymy states that *the verb Y is a troponym of the verb X if the activity Y is doing X in some manner* (to walk and to run are troponyms of to move).

Hypernymy otherwise states that *the verb Y is a hypernym of the verb X if the activity X is a (kind of) Y* (to move is an hypernym of to run).

To help in finding semantic relations, dedicated knowledge bases are used, such as WordNet 3.0 [27] a lexical and semantic dictionary. These knowledge bases are very exhaustive for synonymy and antonymy relations but not for all the others.

For example, in order to open the nut (F), an alternative behaviour (B) can be represented by the verb “to crack” that is a troponym of “open”.

Among the verbs suggested by the relations, a proper selection is made in order to identify which ones indicate different directions at behavioural level. Using the semantic relations we obtain a list of verbs, but not all of which correspond to an alternative behaviour according to the definition of the FBS. In fact, a verb can describe not only a behaviour (B) but also a physical effect (PE).

In some cases, semantic relationships contain verbs used to indicate not a behaviour but a specific physical effects (PE) for changing the state of an object (i.e.to freeze or to explode). In this case the PE have to be rejected.

Therefore, to build the behavioural network through the linguistic approach, a verb describing the function (F), the purpose of the given system, at a very general level, has to be identified, then a list of semantic expansion is automatically generated. At present, manual filtering of verbs related to PE is conducted. The selected list is finally clustered into a graphical diagram where every branch clearly indicates different behaviours.

Experimental campaigns have demonstrated that the results are not complete and exhaustive using a creative linguistic approach alone.

3.2 Engineering approach

In the engineering approach, the action expressing the function (F) of the given product/process has to be recognized and classified by quality (useful or harmful), intensity (sufficient, insufficient or excessive) and application (related or not to measurement and detection).

A list of Inventive Standard Solutions (solution paths) derived from TRIZ [21, 22] is proposed for each of the typologies. This tool includes a list of conceptual solutions that are described through a textual explanation and often a comprehensive graphical schema as well. Each standard solution can suggest a list of alternative behaviours (B) to perform the function (F).

Below, the classification of the standard solutions according to the type of actions is presented, showing a revised and synthetic version. First of all, the system is reduced to a triad where a Tool acts on an Object by using a specific field (mechanical, thermal, acoustic, electrical, magnetic or electromagnetic). All the standard solutions are grouped into the following classifications:

- **Improving a system with Insufficient Action:** for an insufficient action, the Inventive Standards guide the designer to systematically think about how it is possible to intervene on the object modifying physical/structural characteristics, introducing new elements inside and outside it, modifying the environment, or the way through which the object receives the action. For the tool, some suggestions are proposed as well as more radical modifications, such as a substitution of the tool with alternative systems, its fragmentation or dynamization, modification of the interaction provided by the action (mechanical, thermal, chemical, electrical or electromagnetic), or modification of the way the action is provided over time (continuous, pulsating or resonant), during possible pauses and in its intensity.

– **Improving a system with Harmful Action:** Inventive Standard Solutions guide the designer to modify the system, allowing useful action and, at the same time, only avoiding the harmful actions. This can be realized by introducing a new element between the tool and the object (as shown in figure 1), introducing a modification of the tool and/or object, modifying the interaction provided by the action (mechanical, thermal, chemical, electrical or electromagnetic) and adding new actions.

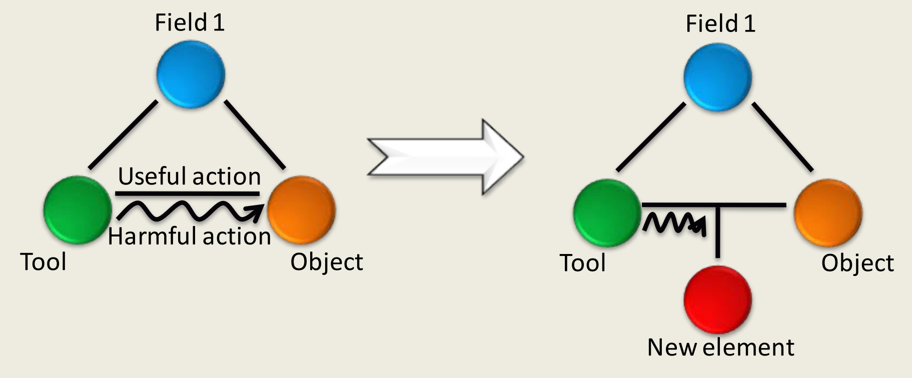
ELIMINATION OF HARMFUL INTERACTION BY A FOREIGN SUBSTANCE	
TEXTUAL DESCRIPTION	**SCHEMA EXPLANATION**
If useful and harmful effects appear, and there is no need to maintain direct contact between the substances, a third substance should be introduced between them.	

Figure 3 - A practical example of one of the 76 Inventive Standard Solutions. The straight line between Tool and Object indicates a useful action while the wavy line stands for a harmful action.

– **In the case of Excessive Action**, the designer can solve the problem by introducing an element that interacts with the excessive action in order to limit it, or by removing the excess.

– **In the case of Measurement or Detection**, the designer can change the problem in order not to need to perform detection or measurement. They can detect properties of a copy of the object, transform the initial problem into a set of successive detections of changes, measure another parameter related to the one desired, easily introduce detectable additives inside the object or in the environment (or decompose it) to change its state to indicate the state of the object. It is also suggested to improve the efficiency of the measure by using a physical effect from a knowledge effect DB (i.e. Curie point, Hopkins and Barkhausen effects, magneto-elastic effect, etc.), or by adding a ferromagnetic substance and a magnetic field inside or outside the object or in the environment, or by building a multiple system. Furthermore, it is possible to excite the oscillations (of the entire system or a part of it) at the resonance whose frequency change is an indication of the changes taking place, or to determine the state of an object changing its natural frequency or to measure the derivatives of the function.

Better exploitation of the engineering approach is offered by integration with an instrument derived directly by TRIZ, called Size-Time-Cost tool (STC). This helps to radically change the perception of the interaction we have between Tool and Object. Breaking down of psychological barriers is provided by imagining the extremes of the given system: Size and Time of the representative feature of the system are changed systematically from 0 to ∞ [28, 29].
We imagine that the object size has to be either minute (or non-existent), then think about which new behaviour (B) could realize the function (F) according to this new condition. In the same way, we imagine which new behaviour (B) there could be for an infinitely large object.

We also perform this in time (happens in no time, or takes an infinitely long time). This simple instrument is very effective in guiding one to think how the system really works, what we really want from it, and allows any false constraints to be got rid of. For our specific purpose, the tool is used as a trigger to generate alternative solution directions.

3.3 Multi-visional approach

The authors propose a final approach to be sure to have investigated all alternative situations. Here new points of view about the given problem situation are provided by abstracting the situation at higher level and changing the temporal dimension.

According to Bytheway C. [30] in his Why-How method, when addressing any behaviour (B) with the question WHY, the answer helps to abstract the purpose of the system at the higher level, thereby enlarging the number of possible solutions. The question HOW allows a specific way to achieve the purpose of the system to be identified (e.g., why do you crack a nut? To open it. How do you open a nut? By cracking it).

Tools for multi temporal scanning are known in literature as System Operators or the multi-screen method [31, 32].

The authors therefore suggest using the function (F) as the higher abstraction of behaviours (B) and changing the time to achieve the same purpose.

The multi-visional approach enriches the behavioural level simply by answering the following questions:

- *How should the object be modified in advance in order to improve or ameliorate the function (F)?*
- *Why has the function (F) been provided? How could our need be satisfied even though the function (F) cannot be partially or totally realized?*

4 DESIGN PROCESS ARCHITECTURE

The design process architecture is based on four steps: determination of the Function, Behaviour, Physical Effect and Structure levels. The steps are sequential and the levels are hierarchically linked, from an abstract level of knowledge (functions) to a very specific one (structures). The output of each step of the process is represented as a tree-like diagram consisting of nodes and branches. At least one branch departs from each node and the final framework is a pool of alternative solutions to the given product.

The tree top indicates the function (F) of the system, properly abstracted. From this father-function, all behaviours identified by creative methods come down. Every branch at behavioural level is linked to the PE extracted from a specific DB. At the end of each final branch, only related documents are identified by collecting all the keywords met by moving along the branch from the bottom to the top and combining these in a query .

4.1 Step 1 - Functional level

This level expresses the purpose (F) of the system in an abstract and general form. The function (F) can be represented by means of a very general verb.

4.2 Step 2 - Behavioural level

At the behavioural level, creativity approaches are applied to create alternative behaviours related to the given function.

All the behaviours (B) are properly translated into verbs and depurated from those containing PEs; they are then mapped on the diagram where each behaviour represents a different branch. All branches depart from the top level, so that level is the branch point.

A behavioural network is therefore created. In advanced versions of this classification, the behavioural level can be built with further sub-levels according to semantic relationships, which are not presented in this work. This means that, moving from the top to the bottom on the tree-map, the level of specification of the solutions is further detailed.

4.3 Step 3 - Physical Effect level

At the third level, each behaviour is associated with the static list of predetermined PEs.

At a general level, the PEs can be classified according to their kind of interaction: mechanical, acoustical, thermal, chemical, electrical, electromagnetic and biological. The PE database is made up of keywords in the form of a verb, adverb, adjective or of a technology suitably selected to be used for patent queries. The PEs DB is obtained by merging different commercial Knowledge DBs of effects.
A partial list of these effects indicated by the mechanical field class is shown in Figure 3:

Basic mechanical field:		
- pressure - delta pressure - compression force - tension force - torque - gravitational force - buoyancy force - forces of motion, velocity, momentum, torque, potential energy - straight line motion - projectile motion - rotation motion	- circular motion - Coriolis force - jet force - force of kinetic friction - force of static friction - restoring force - oscillatory motion, pendulum, vibration - driven oscillations - resonance - fluid motion - steady flow - Bernoulli effect	- unsteady flow - impulsive force (collision) - shock waves - surface forces - surface tension - capillary attraction - wetting - osmosis - diffusion - absorption/adsorption - Van de Waals force - mechanical force differential - …

Table 1 - An example of Field classification from DB of Physical Effects.

For a better explanation, we can consider a water purifier: the function (F) of the purifier is “to clean” (for transforming the contaminated water into clean water), one way to achieve this purpose is by “filtering the water” (B). This behaviour can be can be activated by different types of effects: mechanical, thermal, chemical, electrical, etc. Furthermore each kind of interaction can be explicated by different physical effects, so the water can be filtered mechanically by means of osmosis, centrifugation, degassing, pressure difference, buoyancy, absorption, etc.

4.4 Final step - Output level

The last step of the method, represented at the bottom of the diagram, collects all the alternative systems extracted from the patent DB, built by a query that combines the specific physical effect (PE) activating a particular behaviour (B) in order to achieve the given purpose (F).
This level can be further specified by identifying the design parameters, but in the current software implementation the design parameter level has been substituted by an Information retrieval tool. A list of target keywords can be suitably collected and combined together just by following items from the bottom to the top of a single branch, in order to prepare queries for patent and document searching automatically. A future publication will be presented to show how the algorithm works. As a result, at the bottom level, the diagram collects a set of key representative patents or pertinent documents found automatically by this retrieval tool.

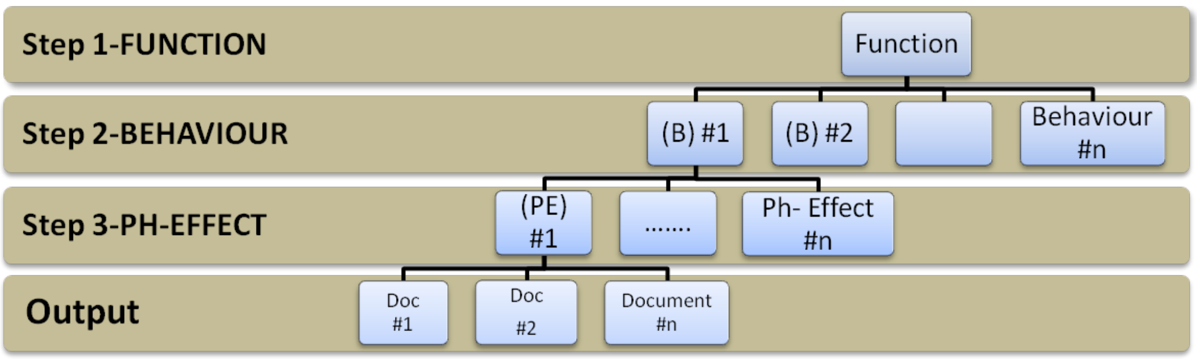


Figure 4 - Design process architecture based on a simplified version of FBS ontology.

5 CASE STUDY: THE STATE OF THE ART OF A NUTCRACKER

In this case study, methodology is applied to build a state of the art of a nutcracker. In fact, the state of the art of a product contains all the alternative systems.
STEP 1: The first step starts with the identification function of the nutcracker. A general description of its purpose is "to open the nut". This is an abstract level to indicate the more specific function of cracking a nut.
STEP 2: Use of the creative approach to generate Behaviours.
- Linguistic Approach. Starting from the verb "to open", and examining all the semantic relationships by means of the WordNet 3.0 dictionary, different ways (B) to perform the opening function can be evaluated: *nut cutting*, *nut levering*, *nut drilling* and *nut cracking.*
- Engineering Approach. By systematically using the Inventive Standard Solutions related to the insufficient action (to crack a nut), other directions can be found. Some Standards suggest modifying the nut, solutions such as a *nut weakening* or a *nut pre-cutting* process are generated.
The force intensity used to perform the action can be modified, so from cracking we can generate the direction related to *nut disintegrating* or *destroying*.
Changing the force in time, for example by performing a pulsating action, may suggest to *hit a nut repeatedly*.
- Multi-visional approach. Finally, it is possible to complete the search of the alternative directions using the Multi-visional approach. Here below are questions and the relative answers:

– How should the nut be modified in advance in order to improve or ameliorate its opening?

Answering this question we can think *of a nut without the shell, a shell already open or an ultra-thin shell*.

– Why has the opening been provided? How could it satisfy your need even if the nut cannot be partially or totally opened? In this case, unusual solutions can be generated, for example an *edible or digestible shell*.

Merging all the behavioural alternative provides a synthesis of the network of the directions of solutions obtained starting from "to open" in a tree-map (Fig. 6):

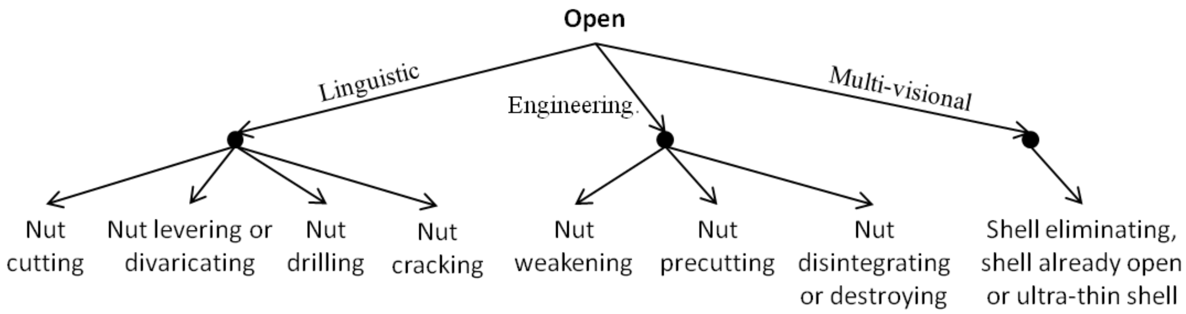


Figure 5 - Starting from the function "to open", the tree-diagram represents the behavioural level of directions of solution identified by the three proposed approaches.

Every direction can be translated in one or more characterizing verbs, depurated of effects, and each verb can be expanded using semantic relations.
In table 2 an exemplary case is provided dealing with linguistic expansion of cracking.

Direction of solution	CRACK
Synonym	break, check
Hypernym	separate, split up, fall apart, come apart
Troponym	shatter, fracture, dash, burst, split, puncture, burst, bust, smash, ladder, snap, fragment, fragmentize, crush, etc.
Causal relation	wear, wear out

Table 2 Linguistic expansion of the direction: nut cracking.

This Step is completed by overall expansion of all behaviours identified and mapped on the diagram. This expansion allows a structured organization of keywords related to functional and behavioural level (see fig.7).

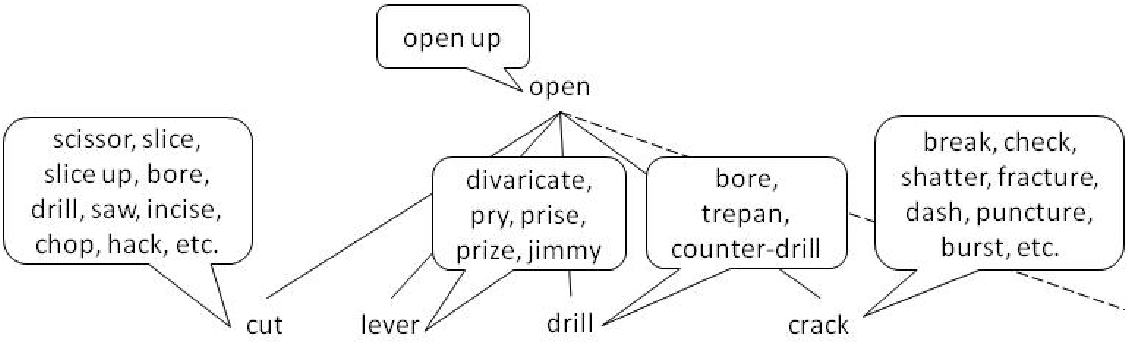


Figure 6 - Representation of the Linguistic expansion related to characterizing verbs of some directions of solution.

STEP 3: Combining Behaviours (B) with Physical Effects (PE)

After alternative ways for opening a nut are found at the behavioural level, a specification of these directions is possible, by adding information about which PE can be used with them.

Using the effects DB it is possible to specify these directions according to the typology of interaction with the nut. Therefore, at general level, the behaviour of cracking can be performed mechanically, acoustically, thermally, chemically, etc.

Every branch of the tree is finally composed of a list of keywords containing behaviours at different levels of specificity, an expansion of these behaviours and a list of keywords related to the effect used.

An algorithm automatically elaborates a complex query for each branch, combining the target keywords belonging to the same branch in order to obtain the most pertinent results by means of a patent search.

Figure 8 shows the results of the algorithm: a list of representative patents that contain inventions to open a nut by cracking, using different effects.

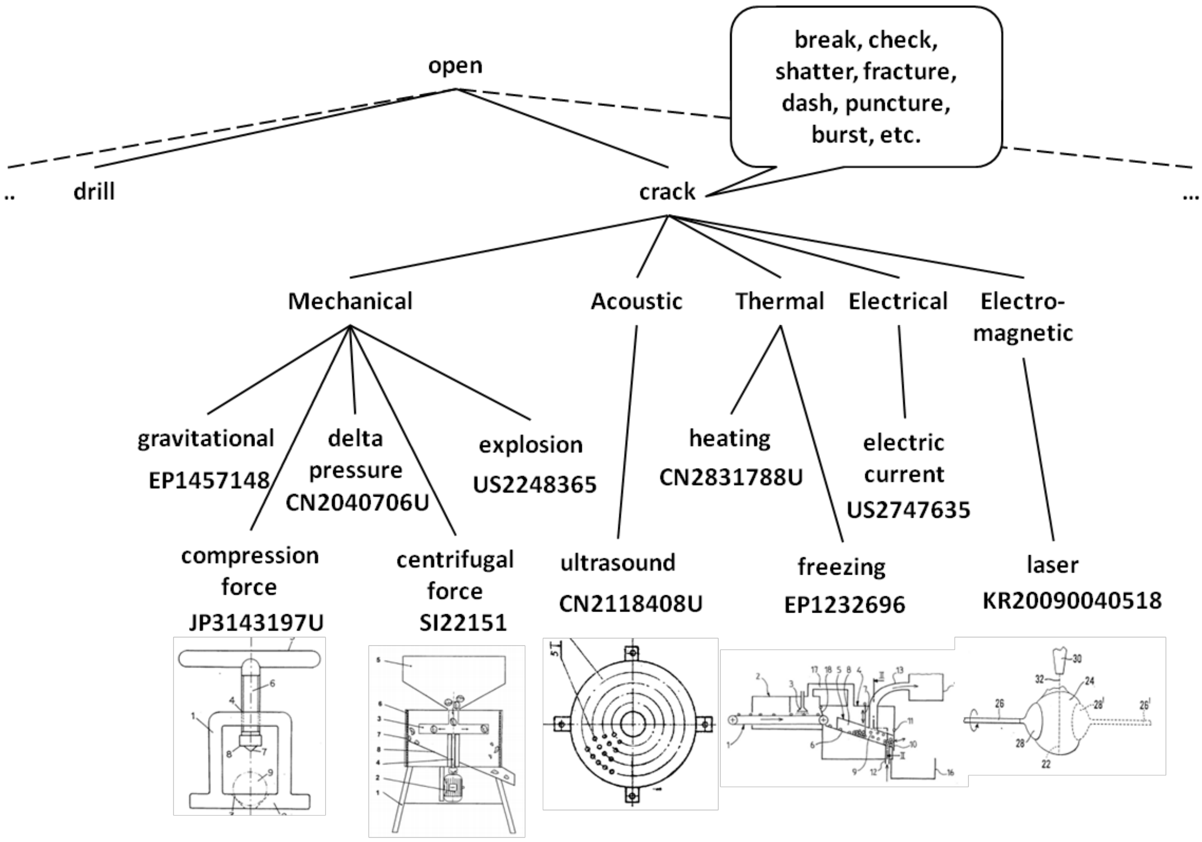


Figure 7 - A partial list of representative patents that grant inventions to use effects (e.g., gravitational, compression, delta pressure, etc.) for cracking a nut in order to open it.

5 CONCLUSION

This work aims at developing a methodology for systematic idea generation in product design based on a patent search. The approach is based on two main phases, (1) the generation of alternative behaviours using a combination of creativity methods, and (2) an information extraction activity from the knowledge DB such as Patent literature. The systematic generation of alternative systems starts from the identification of the design purpose/intention (F) of a given product and suggests three creative approaches as a systematic way to find alternative behaviours for the same function.

These behaviours are suitably translated into keywords and combined with other keywords coming from a Physical Effects DB. A specific algorithm manages all these keywords, creating a pool of queries for identifying crucial documents/patents to make a concise state of the art of the given product .

Results are then organized in a tree-like diagram according to an adapted version of FBS ontology.

FBS is also used both for organizing patent digging and for clustering results. In fact, the authors propose a new definition of structure (S) in order to gain new criteria to classify products.

The “Behaviour oriented patent search” presented allows:

- systematization of past design experience (i.e. patents) in order to improve the Function to Behaviour (F→Be) formulation step [33]. Creativity methods are applied to generate a huge amount of different behaviour solutions to be found in every technological domain, including those far from the given designer’s knowledge
- operation of selectively in every knowledge DB, extracting only crucial documents even from a huge quantity of data. Furthermore, the current search algorithm makes an automatic patent classification possible
- easy interpretation of results thanks to a very concise graphical representation. The hierarchical tree-like diagram offers a rapid overview of the state of the art of the given product and allows the designer to evaluate results according to 4 classification levels: (F), (B), (PE), (S)
- support for automatic construction of the state of the art of a system. The core of the method is a versatile module that can easily be implemented for supporting different purposes, such as a building knowledge database, prior art searches, technology transfer and forecasting.

At present, the patent classification according to structures (S) is done manually. Future developments concern automation of this process. The software has been tested with an academic experimental campaign and is now usually used in consulting services. The results of this work have encouraged the authors to further develop this method. The algorithm is patent pending for this reason.

REFERENCES

[1] A. Einstein and L. Infeld, *The evolution of physics*. New York: Simon and Schuster, 1961.

[2] Y. Li, J. Wang, X. Li, and W. Zhao, "Design creativity in product innovation," *The International Journal of Advanced Manufacturing Technology,* vol. 33, pp. 213-222, 2006.

[3] J. Getzels, *Creative thinking, problem solving, and instruction*. Chicago: University of Chicago Press, 1964.

[4] J. Getzels, "Problem finding: A theoretical note," *Cognitive Science*, vol. 3, pp. 167-172, 1979.

[5] J. Getzels, "The problem of the problem," in *Question framing and response consistency*, R. Hogarth, Ed., ed San Francisco, 1982, p. 37.

[6] J. S. Gero, "Design prototypes a knowledge representation schema for design," *AI MAGAZINE,* vol. 11, 1990.

[7] Z. Bilda and J. S. Gero, "The impact of working memory limitations on the design process during conceptualization," *Design Studies,* vol. 28, pp. 343-367 2007.

[8] M. Suwa and J. S. Gero, "The Roles of Sketches in Early Conceptual Design Processes," 1988.

[9] A. Newell and H. A. Simon, *Human problem solving*: NJ: Prentice Hall, 1972.

[10] P. Sachse, W. Hacker, and S. Leine, "External Thought-Does Sketching Assist Problem Analysis?," *Applied Cognitive Psychology,* vol. 18, pp. 415–425, 2004.

[11] A. Chakrabarti, P. Sarkar, B. Leelavathamma, and B. S. Nataraju, "A functional representation for aiding biomimetic and artificial inspiration of new ideas," *AI EDAM: Artificial Intelligence for Engineering Design, Analysis, and Manufactoring,* vol. 19, pp. 113-132, 2005.

[12] G. Pahl and W. Beitz, *Engineering Design: A systematic approach*: Springer Verlag, 1977.

[13] Y. Umeda and T. Tomiyama, "FBS Modeling: Modeling Scheme of Function for Conceptual Design," *Workshop on Qualitative Reasoning about Phys.'Systems*, pp. 271–278, 1995.
[14] J. S. Gero and M. A. Rosenman, "A conceptual framework for knowledge based design research at Sydney University's Design Computing Unit," *Artificial Intelligence in Engineering,* vol. 5, pp. 65-77, 1990.
[15] Y. Shimomura, M. Yoshioka, H. Takeda, Y. Umeda, and T. Tomiyama, "Representation of Design Object Based on the Functional Evolution Process Model," vol. 120, pp. 221-229, 1998.
[16] J. S. Gero and U. Kannengiesser, "The situated function-behaviour-structure framework," *Design Studies,* vol. 25, pp. 373-391, 2004.
[17] D. Russo, "Knowledge extraction from patent: achievements and open problems. A multidisciplinary approach to find functions," in *CIRP Design Conference*, Nantes, France, 2010.
[18] K. Dunker, "On Problem-Solving," *Psychological Monographs, Whole No. 270,* vol. 58, 1945.
[19] T. J. Howard, S. J. Culley, and E. Dekoninck, "Describing the creative design process by the integration of engineering design and cognitive psychology literature," *Design Studies,* vol. 29, pp. 160-180, 2008.
[20] J. S. Gero, K. W. Tham, and H. S. Lee, "Behavior - a Link between Function and Structure in Design," *Ifip Transactions B-Applications in Technology,* vol. 4, pp. 193-220, 1992.
[21] G. S. Altshuller, *Creativity as an exact science*: Gordon and Breach Science, 1998.
[22] V. Petrov, "History of Standards System Evolution. Information materials," First edition ed. Tel-Aviv, 2003.
[23] E. De Bono, *Lateral thinking: creativity step by step*: Harper & Row, 1970.
[24] E. De Bono, *New think: the use of lateral thinking in the generation of new ideas*. New York: Basic Books, 1967.
[25] R. Horowitz. (2003, Introduction to ASIT.
[26] B. Eberle, *Scamper: Creative Games and Activities for Imagination Development*: Prufrock Press, 1996.
[27] C. Fellbaum, Ed., *Wordnet: An Electronic Lexical Database*. Bradford Books, 2010, p.^pp. Pages.
[28] G. S. Altshuller, *And Suddenly the Inventor Appeared*, 2nd edition ed. Worcester, MA: Technical Innovation Center, Inc., 1996.
[29] D. Russo, T. Montecchi, and D. Regazzoni, "A systematic exploration for conceiving function and behaviour of a new technical system," in *IDMME - Virtual Concept'10*, Bordeaux, France, 2010.
[30] C. W. Bytheway, "FAST: An Intuitive Thinking Technique," *VaLue WORLD,* vol. 28, pp. 2-4, 2005.
[31] D. Mann. (2001, System Operator Tutorial. 9-Windows On The World. *TRIZ Journal*.
[32] G. Schuh and M. Grawatsch, "TRIZbased Technology Intelligent," in *ETRIA Conference TRIZ Future, TFC,* 2003.
[33] P. Vermaas and K. Dorst, "On the conceptual framework of John Gero's FBS-model and the prescriptive aims of design methodology," *Design Studies,* vol. 28, pp. 133-157, 2007.