

# Bio-inspired Design Methodology

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**Abstract** The necessity to be competitive in the market pushes companies to increase the degree of innovation and at the same time to think about new products in terms of durability and efficiency. New product development is part of a strategic process called product lifecycle management, which starts with the idea generation phase. Considering this first step, for the reasons of the great impact in reduction of costs and the potential high return of investment, the goal of this research is to formulate a methodology which might be used during the idea generation phase to create innovative concepts. This methodology focuses on geometrical definition and problem solving. It takes its inspiration from biological systems to maximize durability and efficiency, and from technical systems to drive innovation. It can be used in virtual and shared environments to support designers, innovators and process developers.

**Keywords** Creativity, Innovation, Biomimicry, Biomimetics, Design Methodology, Sustainability, TRIZ

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## 1. Introduction

Design activities exert considerable influence on the well being of human life. Developments in design knowledge are expected to trigger an evolution from computer aided to knowledge-based design systems[1]. The design activity of the concept generation provides a creative forum for designer and engineers. They need to define with accuracy the problems to solve, in order to understand accurately relations, flows, and performances. Suddenly, in order to avoid pre-conceived solutions and psychological inertia, due to the finite experiences, creative methods drive designers through the problems abstraction and after through the abstraction of solutions. Different methodologies have been studied in order to combine explicit knowledge for improving this process.

The required knowledge may be of different kinds, located in different scientific areas, and derived from different sources such (people, products, processes). The efficacy of using biology as a knowledge source - often combined with other sources - has been demonstrated since the very beginnings of human history[2].

Our methodology combines biological and technical knowledge. It combines TRIZ problem solving approach with the Bio-Mimicry approach, in a way that is compatible with both (Vincent, 2005). Therefore, it is important to think in terms of using information related with biological functions, and then translate those in terms of technical functions to solve design related problems. With the aim to give more

importance to the spatial variable, the reordering will give top priority to the most important variable of the space. Connections among different domains provide logic reasoning abilities that can be visualized and analyzed in a CAD environment. This is important because currently designs are created and visualized in CAD systems.

CAD environment is a connection ring between the Product Lifecycle Management functions and other manufacturing functions. This provides the possibility to create an integrated functional structure. It might be useful to underline here that PLM technology has emerged from the growing interest and dependency of companies on CAD and PDM systems; and, that ever more knowledge has been embedded into the CAD environment using PDM technology. The modern CAD systems are constraint-based models in which every element may be connected by means of parameters, relationships and references[3].

## 2. Purpose of the Study

The concept generation is connected with companies' strategic thinking, and with the future impacts in terms of return of investments that it may produce. How the concept definition may influence all parameters related to a future product and subsequent outcomes can be easily understood.

Hansen presented a comprehensive procedure, for the concept generation (Hansen, 1965), based on the specific problem definitions, in which the definition of internal and external relations is mandatory before any decision can be made. Improvements in information technology systems allow designers to enjoy greater freedom and to enhance the creative process, and research activities to generate new concepts. Information technology can improve the capacity of humans to understand and solve problems, making shorter

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the transition among different type of knowledge belonging different disciplines. Methods for the concept generation may be more intuitive (such as brainstorming, morphological maps) or logical (step-by-step guided). The present research will focus attention on the latter, in particular on TRIZ, the Russian step-by-step guided theory of inventive problem solving.

The objective of this paper is to create a new methodology that can build a bridge between technical and biological systems. It will concentrate on the geometrical structures and principles that may be introduced to the CAD environment, which offers a useful link with the Product Lifecycle Management (PLM).

### 3. Problem Solving

Problem solving is a characteristic of human research activities, engineers are looking for answers that can be utilized by designers in the definition of new tasks. In Biology appends the opposite: the initial state is represented by the answer, and one is trying to find out the problem.

Problems present an unwanted initial state, a desirable end state and obstacles to get from one to the other. Problem definition involves a formal description of the initial state and end state- sometimes there are intermediate states as well. Problem solving essentially means removing those obstacles, which are often characterized by varying degrees of complexity and uncertainty.

Access to formalized knowledge is vital to define formally the state of the problem. The problem solving process involves a step-by-step analysis that starts from a comparison of the problem with what is already known. Available knowledge related with possible solution principles is useful to clarify the nature of the requirements. Automated problem solving and generic problem solving have been described also by Simon and Newell (1972)[4]. They state that generic problem solving has to focus on the description of the current situation and the desired one in order to change the system acting to be closer to the goals.

### 4. TRIZ

The TRIZ, theory of inventive problem solving claims that inventive problems can be codified, classified, and solved methodically with a process of abstraction, of the contradictions, and inventive principles of solutions[5].

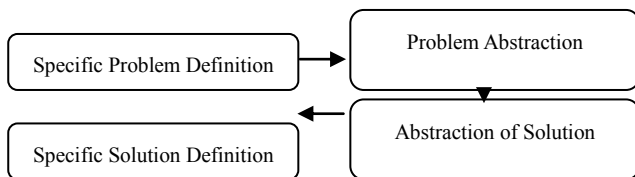


Figure 1. TRIZ method in Inventive Problem Solving Process.

#### 4.1. Figure Captions

The sequence of steps belonging to the TRIZ method is represented in Figure 1.

TRIZ is based on the existence of patterns of innovation based on principles. The theory comes from the Altshuller’s study of thousands of patents. The value of the invention is given from the main goal to reach an ideal value in design without harmful functions and overcoming any contradictions.

$$Value\ of\ ideality = \frac{Useful\ functions\ or\ effects}{Harmful\ functions\ or\ effects}$$

TRIZ is based on the on the transformation of specific problems into generic ones, it relates functions with potential structures or shapes, and specifies the principles that should be used. TRIZ offers the possibility to consider physical and technical contradictions for the concept definition. Nevertheless, since we need to focus on the geometrical definitions related to CAD modeling, we are only considering the physical contradictions in order to use those in during a CAD modeling definition[6].

Table 1. Separation Physical Principles.

Triz Principles Separations Related With The Physical Contradictions		
in SPACE	In TIME	Upon CONDITIONS
1, 2, 3, 4, 5, 6, 7, 8, 11, 13, 14, 15, 17, 23, 24, 25, 26, 27, 29, 30, 31, 32, 33, 35	9, 10, 11, 15, 16, 18, 19, 20, 21, 26, 34, 37	28, 29, 31, 32, 35, 36, 39

#### 4.2. Table Captions

Altshuller identified administrative, technical and physical contradictions and organized them in 39 parameters[7]. He found that to detect solutions there are 3 separations among physical principles that are divided by the time, space, conditions.

This paper will focus only on the principles related with space, with some exceptions that have been also included. The exceptions are related with the principles 11 Beforehand Cushioning, 15 Dynamics, 26 Copying, 29 Pneumatics and Hydraulics, 31 Porous material, 32 Colors changes, 35 Parameter changes.

### 5. Innovation and Efficiency

Innovation is driving the lifecycle of products to make it become shorter, pushing for a premature obsolescence. Additionally, innovation is a key factor that is adopted by companies to ensure improved product performance on the market. Innovation could be characterized as the capability to define new solutions, new relations, and the further they are from previous solutions and the field in which they are operating, the higher the degree of innovation[8]. In order to produce innovation, companies must make use of different sources such as people, products, and processes. *The idea of collaborative and open innovation through the use of teams is a dominant trend.* Exchanging collective knowledge

within the team promotes collaborative imagination[9].

Since computer applications are used heavily during the concept generation. Consequently, developers need to support the use of formalized knowledge to support the team's capacity to create new relations and solutions. Intelligent network systems are available to support people during this process and semantic processors are used to achieve this. The formalization of knowledge can simplify the connection of information with tasks of the design workflow. A commonly used formalization technique is a semantic net in which we can visualize these relations as connections and knowledge as nodes for the representation. The vocabulary follows rules of a formal semantics to facilitate the computer processing of information. One can also represent knowledge formally using ontology. Numerous languages have been developed to do this. One of the most commonly used languages is OWL. The basic elements of the OWL are classes, properties, and instances of classes, also known as individuals. Knowledge is encoded using axioms to describe the elements and their relationships. Taxonomies are used to classify hierarchically classes and properties.

Visualizing relations is often helpful for checking the complexity, the qualitative state of a system, and where the problem is located. TRIZ, the theory of inventive problem solving proposed by Altshuller is based on the view that innovation is guided by principles that are repeated with different relations, in different areas, providing different solutions. For these reasons, they can be learned. Considering the consumption of energy and materials like the problems to solve, we can use TRIZ and all the parameters and principles from the efficiency point of view in order to solve the big contradiction of innovation that often seems to be in opposition with that of durability.

Considering the evolution of product efficiency on the temporal axis, we can realize that the efficiency for every individual product is increased. At the same time the number of products present on the market also increases, on the other hand the lifecycle becomes shorter (Jevons' Paradox).

If the goal is to create more efficient product systems, it is important understand what similarities are present among the areas that we want to relate together. The common aspects and differences among design, biology, and innovation may allow us to create a common language that could constitute the basis for achieve this goal. Considering Life Cycle Assessment, Bio mimicry and TRIZ, the concepts of functions, flows, and relations is commonly used and in particular the "Main Function" is defined as one without which the system loses its meaning. A system is complete if every function is directly connected with the principal one. The notion of "Flow" consists in an amount of material, energy and information with a dominant path. An important role is also covered by "Relations", relevant for the fulfillment of function and to exchange the flow. Information is generally given by signals that are the physical way in which it is supplied. Information provides the internal decision making capability. Signals are received, prepared, compared or combined,

transmitted, displayed, recorded[10].

To summarize, the definition of the functional model leads us to understand the complexity and quantity and state of interactions among the elements; relational boundaries to allocate or exchange resources, energy and information; decomposition of problems, enhancement of abstraction.

**Table 2.** Scheme of the input-output modeling (Pahl & Beitz, 1984).

Class	Basic	Effort Analogy	Flow Analogy
Energy	Human	Force	Motion
	Acoustic	Pressure	Particle Velocity
	Biological	Pressure	Volumetric Flow
	Chemical	Pressure	Volumetric flow
	Electrical	Electromotive force	Current
	Electromagnetic, Optical, Solar	Intensity	Velocity
	Hydraulic	Pressure	Volumetric Flow
	Magnetic		
	Mechanical		
	Pneumatic	Pressure	Mass Flow
	Radioactive	Intensity	Decay flow
Material	Human		
	Gas		
	Liquid		
	Solid		
Signal	Status	Auditory	Tone, Verbal
		Olfactory	
		Tactile	Temperature, pressure, roughness
		Taste	
		Visual	Position, Displacement

### 5.1. Table Captions

In the Table 2 are shown the kinds of flows that can pass through a product system.

## 6. Functions

Depending on the complexity of a problem, the structure of functions may be less or more complex. Division into functions and sub-functions facilitates the search for solutions. The definition of the optimal (with efficient performances) functional structure is an important part of the concept definition. The meaning of functions, in a product system, is related to what the product does. That is usually expressed by an active verb with a noun. A function puts in relation, by means of a task, the available resources and the desired output as shown in Figure 4.

The system of functions can be divided into a hierarchical classification, in which each sub-function corresponds to a subtask. The so-called "If-then" relationship may clarify the concept of sub-function; if a function is performed then another one is activated[10].

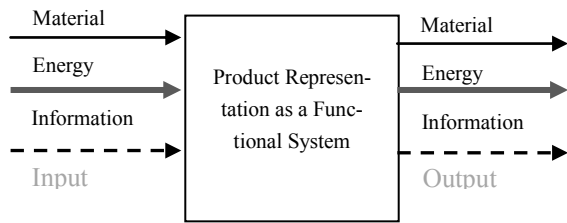


Figure 2. Generic black box model.

An elementary approach to develop a functional description is decomposing the prime functions into a tree of sub-functions. The development of functional trees can be done in several ways. The two most common are the top-down and the bottom-up approach. The top-down approach allows for a more rapid understanding of which functions require more attention - which functions give more value to the system. Typically, a side effect is introduced for

each secondary function and new functions then arise to mitigate this.

The relationship between some sub-functions and main functions is often governed by constraints. A constraint is a statement of clear criterion that must be satisfied by a product to determine the criterion value. Typically constraints can include cost, compactness, CO2 footprint, mass, reliability and so on.

Some functions may be “all time functions” or “one time functions” and they are able to support the system. Functions are generally stated in terms of measurement and mathematical relationships. The network visualization clarifies the relation among functions and the energy, material and information needed to accomplish tasks[11].

I will take into consideration the classification of functions as done by Little (1997) related with design process (see Table 3).

Table 3. Classification of functions as done by Little (1997), following the work of Pahl and Beitz (1988).

UNCTION CLASSES	BASIC FUNCTIONS	FLOW CLASS RESTRICTED	SYNONYMS	
CHANNEL	Import		Input, Receive, Allow, Form Entrance, Capture	
	Export		Discharge, Eject, Dispose, Remove	
	Transfer	Transport (M)		Lift, Move
		Transmit (E)		Conduct, Convey
	Guide	Translate		Direct, Straighten, Steer
		Rotate		Turn, Spin
Allow DOF			Constrain, Unlock	
SUPPORT	Stop		Insulate, protect, Prevent, Shield, Inhibit	
	Stabilize		Steady	
	Secure		Attach, Mount, Lock, Fasten, Hold	
	Position		Orient, Align, Locate	
CONNECT	Couple		Join, Assemble, Attach	
	Mix		Combine, Blend, Add, Pack, Coalesce	
BRANCH	Separate		Switch, divide, Release, Detach, Disconnect, Disassemble, Subtract, Valve	
		Remove (M)	Cut, Polish, Send, Drill, Lathe	
	Refine		Purify, Strain, Filter, Percolate, Clear	
	Distribute		Diverge, Scatter, Disperse, Diffuse Empty	
	Dissipate		Absorb, Dampen, Dispel, Diffuse, Resist	
PROVISION	Store		Contain, Collect, Reserve, Capture	
	Supply		Fill, Provide, Replenish, Expose	
	Extract			
CONTROL MAGNITUDE	Actuate		Start, Initiate	
	Regulate		Control, Allow, Prevent, Enable/ Disable, Limit, interrupt	
	Change		Increase, Decrease, Amplify, Reduce, Magnify, Normalize, Multiply, Scale, Rectify, Adjust	
	Form		Compact, Crush, Shape, Compress, Pierce	
CONVERT	Convert		Transform, Liquefy, Solidify, Evaporate, Condense, Integrate, Differentiate, Process	
SIGNAL	Sense		Perceive, Recognize, Discern, Check, locate	
	Indicate		Mark	
	Display			
	Measure		Calculate	

**Table 4.** Main database of biological and technical samples.

NAME DATA-BASE	COUNTRY	DESCRIPTION	RESEARCH APPROACH
<i>Bio-mimicry Database</i> [18]	Rocky Mountain Institute	It contains biological information	The research can be done looking for challenges, strategies, organisms, people, citations, and products
Design Spiral Methodology[19]	Biomimicry Guild	It's a process for bio-inspired design	It includes 6 interactive steps (identification of problem to solve, translation of how the Nature performs the function, observation of champions in Nature, abstract ion of the strategy or patterns, application of solutions or models, and evaluation and comparison of the new solutions or principles)
<i>Bio-TRIZ</i> [16]	Bath University	It's a systematic method to do a parallelism between natural and engineering systems	Users can search on base of contradictions or functions present in the design problem
<i>Functional Keyword Search</i> [20]	University of Toronto	It uses a natural language to locate biological phenomena	It uses function key words search, and a language called WorldNet® that organizes words relations. The words are ordered for frequency within a 50 words window.
<i>Cognitive modeling and SBF modeling in BID</i> [21]		Cognitive modeling of the bio-inspired design process and representation of biological behavior.	The studies in bio inspired design are conducted using a problem-driven, and a solution-driven approach
<i>IDEA-INSPIRE</i> [22]	Indian Institute of Science at Bangalore	Contains natural and technical systems organized for behaviors described from a generic causal behavioral model, called SAPPHERE	Behaviors described for means of nouns, verbs, and adjectives. The variables are connected in a weighted way giving more relevance to the verbs

The previous classification summarizes typical classes of engineering functions. If we want to compare biological with technical resolutions, it's important convert the identified bio-function in standard design functions and inventive TRIZ principles[12]. Once that conflicts and functions have been defined, it easier looks for abstract solutions, and next for specific definitions. Every company has its own store of knowledge related to best practices and optimum solutions to use as a base to develop new products. But, when a designer or engineer is looking for radical innovative solutions to a specific problem, the process of abstraction becomes essential to emphasize the main innovative task. After, the design may be described as a progression from the abstract to the concrete or as a goal directed heuristic problem solving process[13]. Starting from the concept definition, designers determine layout and forms; in line with this, my purpose is to define a net of relations (among efficient functions, shapes, spatial principles of innovation and sustainable principles, on the abstract level) that could be used for a first geometrical definition of a product.

## 7. Integration between Biology and Other Fields

Biological systems are being studied by different fields in order to construct useful models and simulate possible reactions, performances and so on. Some examples include biomechanics which is the application of mechanical principles to living organisms; biotechnology which is the study of applied biology, using living organisms in engineering, technology, medicine; mathematics which has developed models that describe the biological model formation; com-

puter sciences, creating simulation to understand the growth of biological cells and so forth.

Biology is more descriptive than engineering which is prescriptive, but they share the same prime goal: problem resolution. The major reason of bio-mimicry is to look at nature to find technical solutions.

### 7.1. Bionic, Bio-mimicry

Bionic (Schmitt, 1969) is a bio-inspired field that involves engineering and science. Bionic is a multi-disciplinary science based on the properties, processes, functions, organizations, and relationship of biological systems. The term bionic was introduced by Major John Steel of the Aerospace Division of United States Air force in the 1960. Bionics sees nature as an answer for building sustainable or not man-made creations[14]. The most recent term of Bio-mimicry was coined by biologist Janine Benyus (1997) and it comes from *bios* that means life and *mimesis* that means imitation. This new field represents an inspiration for human methods, processes and designs to study examples and material in nature to apply them in the man-made environment in order to reduce the environmental impact[15]. Evolution in Nature has already done a great number of inventions that may be used to find solutions for the technical problems. In nature the classification can be hierarchical, parametric or combinatorial. Several books, published from the 1870 onwards, have examined the subject, among these: "Homes without hands" and "Nature's Teaching: Human Inventions anticipated by Nature" written by J.G. Wood; "Natural Theology", published by Paley's, was filling the examples from the structural and mechanical point of view; "Design in Nature", by J. Bell Pettigrew's published in the 1908 shows the handiwork of the systems in the animal

body.

## 8. State of the Art, Integrations between Biology, Design and Innovation

Several researches have tried to collect biological information with the aim of using those in the problem solving process, often the efforts are focused on the creation of comprehensive repositories that are collecting data related with several fields. An interesting research has been conducted by the department of Mechanical Engineering, Centre of Bio-mimetic and Natural Technologies University of Bath, has developed a BIO-TRIZ matrix that derives from PRIZM (reduced versions of the standard 39X39 Matrix of Contradictions)[16].

Bio-TRIZ is the methodology that has been developed analyzing 500 biological phenomena covering more than 270 functions; they analyzed more than 2500 conflicts and their resolutions in biology ranked by level of complexity. They established six operational fields in which every object is put in relation by means of an action with a subject. They underlined that only principles of spatial composition are similar in both the biological and technical systems[16]. They further clarify the distinction between the meanings of cause and effect in the technical system and in the biological one. In technical systems for instance the ambient pressure is the *cause* of the boiling point of pure water which is the *effect*. In biology an *effect* is the problem to be solved by the organism and the *cause* is the method of solution. The department reorganized the matrix using a condensed version of the TRIZ principles[17].

### 8.1. Table Captions

In Table 4 we can see the main database that have tried to collect biological and technical samples in order to provide useful references for new products developments.

## 9. PLM and Knowledge Management

The concept of relational database is strictly connected with that of Semantics. Semantic Network is a net in which the arcs are the meaningful relations between nodes that represented objects. Connections among data enable analysis and conclusions to compute information in a logic reasoning process. Knowledge belonging to different disciplines could be integrated and available, and ontology based collaborations are possible. Tools such as PDM (Product Data Management) have been developed for data accesses and collaboration during the new product development process. PLM enables users to search the repository models for information related with the best practices, functionalities in order to reduce time losses and costs. Constraints are extracted from CAD environments such as NX to define the ontology in order to interpret them in a computer language.

Standards for the Exchange of Product Information provide for instance the Application Activity Model that qualifies the Product Design Ontology. The CAD Model can also contain the geometrical features connected with the metadata. Once the modeling is completed, several simulations could be processed with the aim to understand physical properties or engineering specifications.

One example that has been developed for the Methodology for product Family Ontology using the formal concept analysis in order to reduce complexity, lead time and development costs (Nanda et al. 2006)[23].

Product Design Ontology has been modeled in conformity with On-To-Knowledge (Sure et al. 2003). OTK may be defined for the ontology design as an interactive process composed of four phases:

- The concepts and the hierarchy of relations are established;
- The modeling of the product design ontology is expressed;
- The ontology is validated in comparison with the goals;
- The evolution of the ontology is maintained in line with scenarios.

The core components of Products Design Ontology are shapes representations, shapes processing tools (algorithm), tasks, conditions (geometric) and groups.

## 10. Proposal of Methodology

The present methodology will focus mostly on the domain of the bio inspired formal features taken by Nature in order to solve problems connected with an efficient use of energy, resources and information. The aim of this methodology is to select the most used and effective geometrical features from biological systems, that can exceed in performances, and connect those with part of TRIZ principles and WBCSD requirement of sustainability.

Before to introduce the methodology is important make a brief survey in the method of classification, introduced in natural history. The quality of wholeness (of integrity of a unity in structure, in which parts contribute in composition and functions) was a central concept in the natural history of Aristotle.

Much of the eighteenth-century natural history was devoted to the question of classifications culminating with the work of Buffon and Linnaeus. Aristotle formulated the idea that variety of animal species derived from an exhaustive recombination of limited number of different kind of component organs. This suggested the idea of archetypes[24]. Aristotle, simultaneous, adopted also the idea of harmonious and coherent relations between all the parts and the whole, even if the idea of permutation is in contrast with that of harmony[25]. In Germany Goethe made an abstraction of the idea of archetype creating a permutation model of plant structure. Goethe's followers pursued the idea of similarities not only in the structural plan but also in different parts in the

same body. In England Richard Owen abstracted an archetypal skeleton from all the vertebrates, underlining that life on the other planets, with different conditions, might manifest other possible modifications[26]. Goethe was one of the first using the term of “morphology” in *Zur Naturwissenschaft überhaupt, besonders zur Morphologie* (1817), as study of form and structure, and geometrical factors, and he indicated his conviction that mineralogy, botany and zoology were governed by general and universal laws of spatial structure.

From this brief survey we can turn to the modern movements that has been looking to the work of nature to produce biological analogies and mechanical analogies, (terms suggested in “Biological and Mechanical Fallacies by Geoffrey Scott) such as the series of comparisons of mechanical structures with plant stems and with animal skeletons of D’Arcy Thompson[27]. The relevance of the work of Zeising (that tried to prove as the Golden section is the Key of all morphology) comes in relations with the botanical observation of the arrangement of leaves and stems in plants, and other patterns of petals and flowers whose dimensions lie in Fibonacci series[28]. Considering that a certain fixity exist in forms and size of biological entities, and that it is related with functional reasons that are governing proportions and dimensions (principle of similitude[29]), there are some important differences between the technical and the biological systems that are relevant to considerate before starting:

- technical systems are bigger in size and faster in time than biological;
- refined technical systems are the results of decision making, biological systems are the results of an evolutionary process[30].

The methodology is based on four axioms that are the Bio-inspired formal features, the WBCSD principles, the TRIZ spatial principles, and the functions of efficiency. The selected axioms will provide a part of knowledge focused on the management of geometrical, functional, and inventive information in order to reach the goal of a more efficient design.

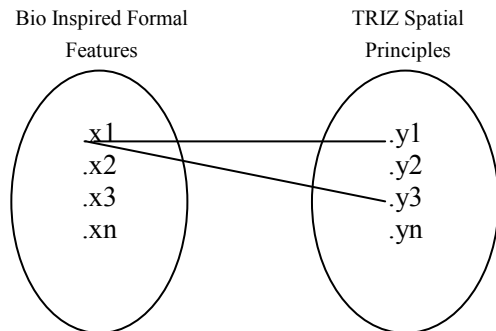


Figure 3. Example of Relations between Domain and Range.

Innovative design needs appropriate knowledge, and level of abstraction for the realization of new physical descriptions. Mapping connections between sustainable functions and bio-inspired formal features makes explicit the aided decision space, and emphasizes the conception of the product as

a system of functions and also involve the concept of meta-knowledge. With the objective to reduce the consumption of energy, materials and optimize the transfer of information, relations/properties have been designed between:

- Individuals of the bio inspired geometrical features and individuals of functions performed (using patents applications and biological examples to solve specific problems);
- Individuals of bio inspired geometrical features and individuals of TRIZ principles;
- Individuals of bio inspired geometrical features and individuals of WBCSD eco principles;
- Individuals of efficient functions (considering the differences between the natural and the technical language).

The present research has considered 10 samples from the population of biological area, and 10 samples from the population of technical patents for every bio inspired geometrical feature, in order to create functional and formal analogies, to validate their choice. The key words have been selected with reference to the biological features, and the technical functions taken from the matrix in Table 3.

The structure of the methodological design approach is showed in the following diagram.

Taking into consideration the literature[31-34] related with the patterns used by Nature to design biological products, and using the filter of efficiency, the following bio-inspired geometrical features classification emerges:

- Symmetry;
- Spirals;
- Sinuous and undulations;
- Radial dimensions;
- Grouping, Pure Geometries, and Divisions;
- Boundaries;
- Fractals, Ramification.

A brief introduction will be done about all the afore mentioned features, to better explain in a following moment the feature of symmetry. Property of symmetry gives more stability to the system against gravity, reducing the consumption of energy when the system is in movement; undulations are related with efficiency in use of energy in propagations (waves); spirals give strength to the object, reducing stress, and transferring rhythms; radial dimensions connect the outlying points directly with the center, improving the system stability; groupings, pure geometries give more compactness, reducing the vulnerability, facilitating the fitting and coming out; boundaries optimize the exchange of resources with the eternal systems; fractals and ramifications organize in different levels of hierarchy the optimization of flows distribution.

From these we will take the Symmetry, as example, to show how to use our methodology.

### 10.1. Symmetry

The design process is characterized by the search for meaningful space definitions generate by knowledge. Con-

sidering the feature of symmetry, we can immediately understand that the concept in itself is closely related to the CAD concept of copy, reflection, rotation, translation or combination of these and with the natural concept of create.

Symmetry acts to balance and ensure stability in relation with the center. We can find different examples in the (1) animal kingdom, where this configuration reduces the use of energy during the movement of objects in motion; (2) vegetal kingdom where the development of shapes starting from a fixed point constitutes the best criterion for the structural disposition against gravity, tending to be more stable, using a smaller quantity of material; (3) minerals, where there is a reduced scale of movement. Symmetry is the only one way to develop an ordered growth starting from the regular geometrical structures. In the biological area we encounter principally four kinds of symmetry: axial, bilateral, radial and crystalline. Symmetry prevails more in radiating and concentric arrangements, otherwise the relation is established from the side, or from above or below in the case of spirals. This property is frequently observed in crystals, plants and animals.

10.1.1. Table Captions

Table 5 shows two examples. In the first, we show the analogy between the bio inspired formal feature used by the Jellyfish and the patent n. 5603277. The improvements in relation with the previous patents are supplied by the reduction in size and weight, which are inconvenient for carriage and storage and have a high cost. The structure is stronger, more stable, durable and reliable. On the right side we can see the patent 3899953 that uses a tube and a plurality of fins to stabilize the rotation; by arranging the rocket composition around the center, the rocket maintains the correct course, coiling and with unimpeded flight.

10.1.2. Table Captions

Table 6 has been developed analysing data, from a number of 10 patents (selected from a group of 30 per BF Feature), and 10 bio-samples to establish relations among functions, sustainable and innovative spatial principles and so on.

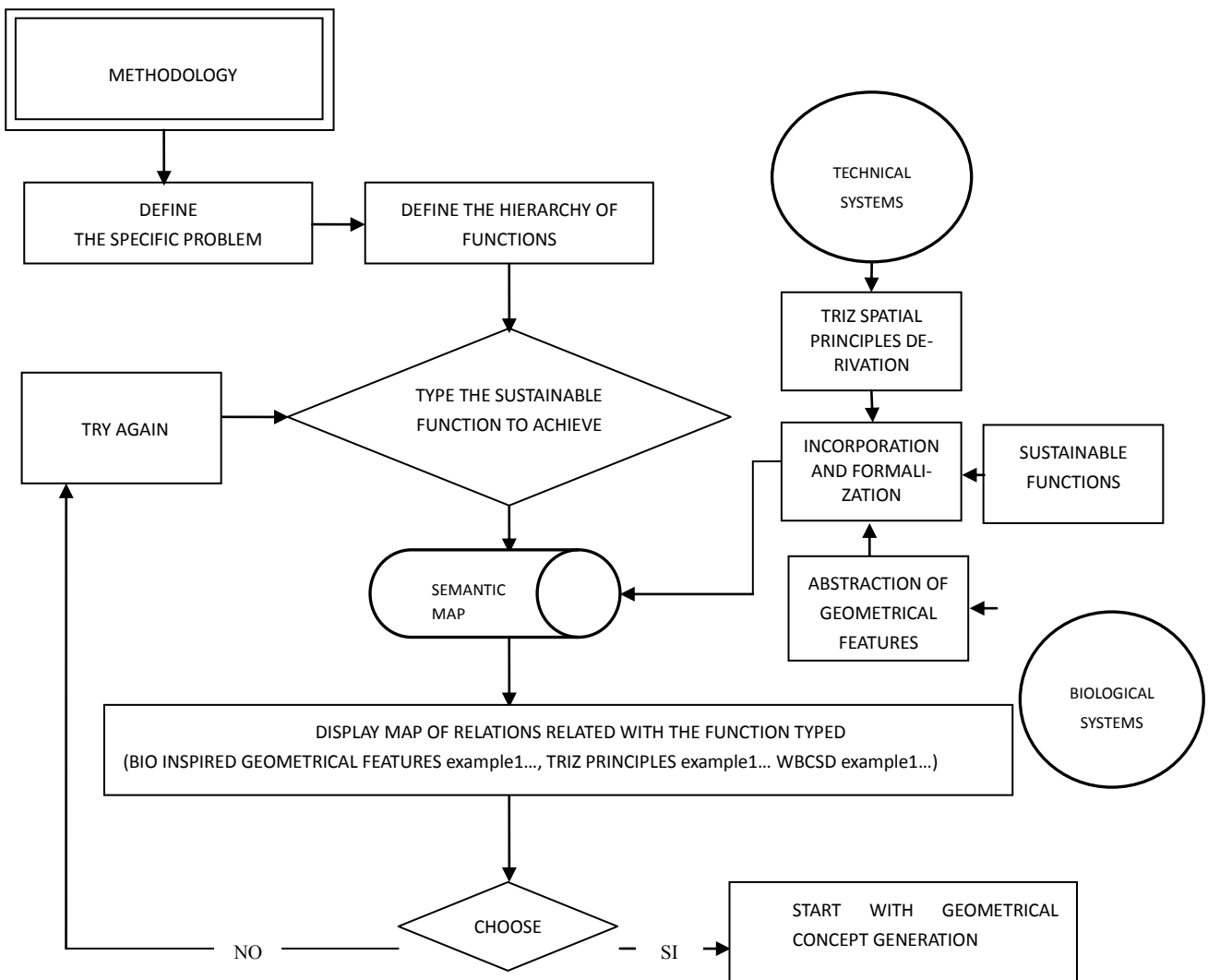
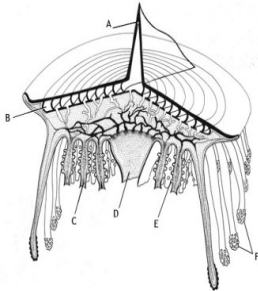
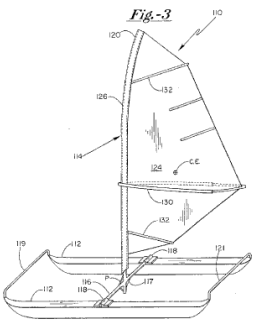
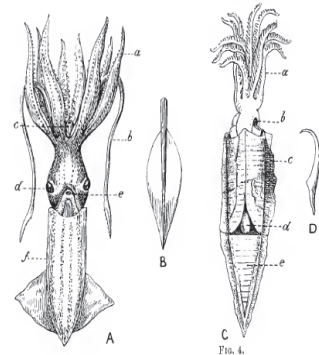
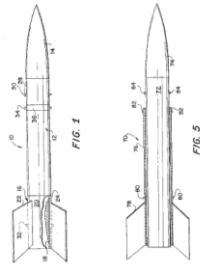


Diagram 1. Diagram of the methodology's structure.



**Table 5.** Association between the biological application and the technical one.

SYMMETRY			
BIOLOGICAL AREA	TECHNICAL AREA	BIOLOGICAL AREA	TECHNICAL AREA
<b>NAME:</b> VELELLA ( <i>Jellyfishes</i> )	<b>NAME:</b> Tack aback sailboat, <i>PATENT:</i> 5603277, <i>INVENTOR:</i> William B. Webb	<b>NAME:</b> SQUID	<b>NAME:</b> SELF-PROPELLED FIN STABILIZED, <i>PATENT:</i> 3899953, <i>INVENTOR:</i> Jean Edmond Labruyere
			

**Table 6.** Relations among functions, eco-efficiency parameters and innovative spatial principles.

BIO-MIMICRY FEATURES	FUNCTIONS	WBCSD FEATURES	TRIZ PARAMETERS	TRIZ PRINCIPLES	Material Energy Information
<b>SYMMETRY</b>  <i>(axial, bilateral, radial, crystalline)</i>	STABILIZE POSITION TRANSFER GUIDE SECURE REGULATE DISTRIBUTE	Reduce Material Reduce Energy	12 Shape of the object; 8 Volume of a stationary object. 14 Strength; 26 Quantity of matter. 13 Stability of object composition; 26 Quantity of matter. 19 Energy spent by a moving object; 5 Area of stationary object.	1 SEGMENTATION; 4 ASYMMETRY (Length of stationary object); 8 ANTI WEIGHT (Volume of stationary object); 14.SPHEROIDALITY 29 PNEUMATICS AND HYDRAULICS; 35 PARAMETERS CHANGES.	M E I

The purpose is to introduce a semantic map of formalized information to make easily visible all the possibilities, to analyze, and help decision making during the concept generation. Computer Aided Innovation tools have been developed to help innovators in their creative performances. These tools are characterized from being a support for desktop engineering, from technological and cognitive aspects, from evaluative tools and theoretical foundations[6]. Considering representation, reasoning and syntax, and constructing axioms with the purpose to connect bio-inspired geometrical features with innovative principles in CAD, on the base of the work that is shown in Table.6 we have designed a semantic map based on a common language of nouns and verbs.

The relations between verbs and objects are powerful enough to provide a level of understanding of the knowledge. There may be different ways to represent the map and logical connections between facts. Logic thereby serves as a

meta-language for describing operations. The map has been constructed creating class hierarchy in Protégé, where for each class there is a group of individuals connected with other individuals by means of properties. If the designer is looking for some sustainable functions/problems, the net of relations with the pictures connected emerges to allow them to improve their creativity in finding solutions. Relations among individuals of different classes as BFF (Bio-inspired Formal Features), SDF (Sustainable Design Functions), TP (TRIZ Principles), and WBCSD Eco Principles (World Business Council for Sustainable Development) have been set as follows:

```

<!--
http://www.semanticweb.org/ontologies/2011/5/Ontology13
08844901478.owl#Symmetry -->
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rdf:about="http://www.semanticweb.org/ontologies/2011/5/
Ontology1308844901478.owl#Symmetry">
    
```

```

<rdf:type
rdf:resource="http://www.semanticweb.org/ontologies/2011/5/Ontology1308844901478.owl#BFF_BioinspiredFormalFeatures"/>
<BFF_to_SDF
rdf:resource="http://www.semanticweb.org/ontologies/2011/5/Ontology1308844901478.owl#DistributeWeight"/>
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rdf:resource="http://www.semanticweb.org/ontologies/2011/5/Ontology1308844901478.owl#ReduceEnergyConsumption"/>
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>
<BFF_to_TP
rdf:resource="http://www.semanticweb.org/ontologies/2011/5/Ontology1308844901478.owl#TP1Segmentation"/>
<BFF_to_TP
rdf:resource="http://www.semanticweb.org/ontologies/2011/5/Ontology1308844901478.owl#TP4Asymmetry"/>
<BFF_to_TP
rdf:resource="http://www.semanticweb.org/ontologies/2011/5/Ontology1308844901478.owl#TP8AntiWeight"/>
<BFF_to_WBCSD
rdf:resource="http://www.semanticweb.org/ontologies/2011/5/Ontology1308844901478.owl#WBCSD6Durability"/>
</owl:NamedIndividual>

```

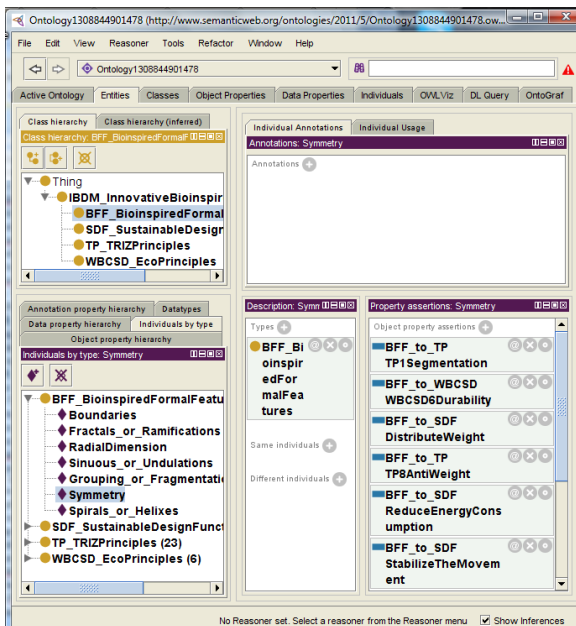


Figure 4. Classes, individuals and properties used in the methodology.

## 11. Conclusions

The present methodology is based on the use of simplified

bio inspired geometrical features as source of innovation in order to integrate those in our products. One advantage to use simplified geometries is that they can be computationally examined for following refinements.

Computer aided information, innovation and design can create generative social environments that team work can expand to collaborate reducing efforts. Create all the relations, in order to push the innovation towards efficiency, makes more visible new and useful connections to stimulate creativity.

My research is in development and the idea is to connect all the analogies with images to support, and to better explain the meanings related with.

Further studies are required in order to expand the map, considering also the bio-geometrical risks related with time (speed) and space (size).

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