ración entre esta relación y la obtenida en la etapa anterior se podrán detectar las áreas de interés, o incluso productos concretos a desarrollar.

Etapa 7. Evaluación económica.

En esta etapa se debe producir una primera evaluación por parte del promotor de las ofertas innovativas que se le proponen, y, en consecuencia, bien la selección de una o varias de ellas que vayan de acuerdo con su disponibilidad económica o interés estratégico, o bien el rechazo de todas ellas, suponiendo en este caso una retroalimentación hacia etapas anteriores.

Como características más significativas de este método serían:

a) Es especialmente importante la elección del argumento biónico, ya que es el que va a condicionarnos el desarrollo de las investigaciones posteriores. En líneas generales, se trata de globalizar el problema al principio (divergencia) para particularizarlo al final (convergencia).

b) No se concentra la creatividad en una sola etapa. Hasta la búsqueda de información, tanto de mercado como de los sujetos naturales, requerirá capacidad analógica y sintética.

c) La evaluación de las ideas generadas no se produce hasta el último momento, de forma que el filtro seleccionador sea el propio mercado o los intereses estratégicos del industrial y las propuestas puedan alcanzar objetivos comerciales y productivos a corto, medio y largo plazo.

d) El estudio de mercado y de las oportunidades de intervención se puede desarrollar paralelamente a la generación de ideas. Ambos procesos requieren amplitud de criterio que propicien varias áreas de intersección entre los intereses de desarrollo y las propuestas de aplicación. Cuanto mayor sea el proceso de transformación, se podrá generar una multiconvergencia.

e) Como estrategia de diseño permite apoyarse en cualquier otra estrategia creativa o de prospección de mercado.

f) En la etapa de análisis y síntesis formales se pueden adelantar o sugerir soluciones para los subproblemas que irán surgiendo a lo largo de todo el proceso proyectual.

Nature, design and innovation: a methodological proposal

Biological models and the study of nature

The study of nature has had and still has many and varied implications for design and innovation. As a way of analysing systems and establishing biological models, Bertalanffy, from the scientific proximity of the general theory of systems, was already pointing to bionics as a factor in innovation. Others such as Pearce and Stevens have presented nature as a design strategy and others as a teaching strategy. In these pages we aim to examine in depth and propose a methodological model that will be equally valid in the didactic, projective and research fields.

In fact, we can find antecedents in the study of nature and its direct relation to basic design in the initial courses at the Bauhaus and later in the School of Ulm. These experiences have been collected and put into practice in the Department of Design of the Faculty of Fine Arts of the Polytechnic University of Valencia, and have given rise to methodological studies in the Group for Design Research and Design Management and their inclusion in the lines of action for research into design.

Establishment of analogic levels

In this section it is our intention to analyse the different project processes or methods that have been used to date, giving special attention to the transfer of information from the analysis of the natural subject to its practical or projected application.

If we study everything that man has achieved by taking nature as a point of reference, from Leonardo himself to the latest work of the Centre for Research into Natural Structures in Milan, we can group them according to the criterion of what has been the relationship between the natural reference and its materialization in the world of the artificial.

This relation is governed in some way by the grade of analogy, evident or not, between nature and the object, between the reference and the referent, establishing as a consequence four *analogic levels*:

1. Unawareness
2. Inspiration
3. Transposition
4. Imitation

Before beginning to define each of these levels it would be advisable to keep in mind certain considerations. In the first place, we have attempted to cover all those works which, in one way or another, bear some relation to nature, thereby contributing to the clarification or determination of what is considered, or could be considered, to be bionic and what is not. This consideration departs from the logical affirmation that because something has taken nature as a reference, it does not necessarily have to be seen as bionic. Such would be the example of any artistic period which might have adopted formal repertories from nature.

Secondly, analogic levels are regarded neither as watertight compartments which classify works in a categorical way nor as communicating vessels in which everything is at the same level. There will be examples in the history of design which, because of their special behaviour, fit in between one level and another.

Finally, and at the same time reaffirming the previous consideration, there will be cases when the starting point was a clear and preconceived intention of totally imitating a natural subject but when successive evaluations of the project and possible impractical elements in the proposals, in view of the results or even in the project process itself, cause a gradual descent to previous levels. Likewise, this might occur in the opposite direction; that is, after following a simple inspiration, as sub-problems arise, the designer might find the solutions in a natural subject of reference, and the result could consequently be included in later levels.

Even so, the first level, which we have called *unawareness*, includes all those works which by using conventional design methods unknowingly arrive at solutions that are found in nature. We do not mean by this that if they had followed a bionic method they might have reached the solution earlier, since many of nature's solutions are, from the constructional aspect, elementary and a process of logical thinking would have led to similar solutions. This is, in fact, the aim of basic design.

Perhaps the most representative example of this level, and the most anecdotal, is Buckminster Fuller's design for the double spacial reticle geodesic domes, which when constructed seemed to him to be «astonishingly similar» to diatoms or to the geometry of spherical cacti.

One more thing should be added as far as this level is concerned: it contemplates a large number of works carried out to date, but works which cannot be regarded as being completely bionic, even though the results are similar to those arrived at by nature, since there was no previous intention and therefore no specific analogic methods employed in order to arrive at such similarities.

Coineau and Kresling would include in this category those systems in which the analogies have been established *a posteriori*, considering the natural models to be a means of perfecting the human inventions.

A second analogic level would be that which we have called *inspiration*, based as it is on a partial conception of the totality of the natural subject referred to, which could lead to a lack of respect for, if not a contradiction of, the basic principles implicit in such a totality. This means that this level would be characterized by an anecdotal seizure of some of the aspects with which nature manifests herself, without taking into account that these aspects are the result of an evolutionary-functional process and are conditioned by each other, since there is, as in any biological system, an interrelation between the whole and its parts.

This level would also include all those works which have been based gratuitously on biological or organic forms without considering the functional causes such forms respond to. Nevertheless, it must be acknowledged, just as the psychology of perception affirms, that it is precisely because of this formal aspect, reasoned or not, that we can begin to recognize an object as being based on some natural thing, and if indeed it were a reasoned form near to nature, it could give rise to what could be called an example of bionic aesthetics.

Thus, as we mentioned above, those artistic movements which exalted nature as a fount of inspiration for generating forms, both bidimensional and tridimensional, cannot be considered bionic.

The third analogic level would be characterized by the *transposition* of basic principles observed in the natural system which are applied onto the artificial object and which, in general, define the result. In this case, unlike the previous, the acquisition of aspects from the reference can be partial but at no moment will this contradict its agglutinating harmony, or at least this partial transposition will have a functional justification. For this reason, from this level onwards we can speak of bionics in the strictest sense within widely accepted definitions:

> It is the science of systems, whose operation is based on that of natural systems or which present specific characteristics of natural systems or show analogies with them (Steele, 1960).
>
> Bionics is not only a question of engineering but also of finding ideas which permit the most varied mechanisms to be constructed, whose living prototypes have existed for centuries within reach of men. The basic process would be to ask oneself how such mechanisms function and then how to reproduce the principle.
>
> It is the utilization of biological prototypes in the design of synthetic systems created by man. In other words, it is a matter of studying the fundamental principles of nature and succeeding in applying the principles and processes to human needs.
>
> It is the study of living systems in order to apply their technical principles and processes to technologies. It is particularly suitable for stimulating the ability to capture the three-dimensional details and formal principles which give them their structure and, at the same time, for increasing the capacity for transformation, that is, when we examine and analyse an analogous object.
>
> Under the denomination «bionics» two types of scientific work are generally studied: one, more closely related to design, studies the equilibrium in nature between form, material and function while trying to find solutions that can be used by man in his environment; the other mainly investigates the neurophysiological problems of living forms with the object of reproducing them artificially.
>
> The aim of bionics is to discover the secrets of nature, whether of plants or of animals, and to deduce therefrom constructive principles on which to base technical creations.

This level would include the work carried out by the Centre for Research into Natural Structures of the European Institute of Design in Milan and part of the work of the Institute of Light Structures of the University of Stuttgart, this being the criterion followed in their methods of work, as we will see later.

For Coineau, an example of partial transposition would be Paxton's Crystal Palace, in which it is only the principle that is taken, while the technical realization appears to have nothing to do with its living model, the floating circular leaf of the Amazonian Victoria water lily, which is clearly quite different from the rectangular windows proposed by the engineer.

Finally, the total IMITATION of nature would be the fourth analogic level which is proposed. This would suppose the transposition of all the most important aspects of a natural subject, such as function, structure and form, onto the artificial subject.

We could find examples of this level throughout the course of the history of techniques and, more specifically, in the latest research into the flight of insects with a view to its application in propellers and turbines carried out by Werner Nachtigall of the Saarbrücken Institute of Zoology.

However, Coineau does not distinguish between this level and the former when he affirms: «In a fair number of cases it is a question of a copy of nature in accordance with a typical bionic process: a study of a natural system, interpretation of the principle, and then transposition to a creation of an industrial type» and gives as classic examples artificial dolphin skins, which would belong to the fourth level, and the constructions of Le Ricolais, inspired by the radiolarians, which would correspond to the second or third level.

This last level is possibly the most controversial for various reasons which are worth examining. On the one hand, the intention to imitate nature in the belief firstly that it was possible, and secondly that it would bring the best solutions, has been shown throughout history, from Leonardo to the present day, to be not always feasible or successful. This statement can be illustrated by the history of aviation, where man has succeeded in flying when he gave up attempting to lift himself with mechanical principles, as Leonardo thought, and began to experiment on the basis of gliding.

On the other hand, progressive understanding of the neurophysiological systems of living beings and the parallel development of microelectronics and technology permit a multitude of meeting points between certain sciences and others with the names of cybernetics, robotics or biomechanics and with the limits between one and another perfectly permeable. For this reason perhaps, it is this level that lends itself to a dual recognition; on the one hand, as being most easily assimilable into the area of bionics, as there is a greater equivalence between the natural reference and the artificial;

and, on the other, as a door that is open to other areas of scientific knowledge that might lead to confusion.

With the establishment of the analogic levels we have at our disposal an instrument for measuring and for providing access to the methodological models which bionics involves.

This tool has served us in the first instance for clarifying the creations considered to be inside the field of bionics and which could be characterized by the following attributes: firstly, a previous intention to approximate to nature; secondly, a specific methodology for the transformation of information; and thirdly, the materialization of the results within the levels contemplated.

In the same way, in a second instance, it is going to be of use to us in isolating those levels which deserve a study in depth of the methods of analysis, synthesis, evaluation and application which their respective *transpositions between the natural and the artificial* have required.

If we follow this criterion it is then obvious that the third level and a large number of the cases that can be included in the fourth are those we are to study, because it so happens, moreover, that they are precisely those that are best documented or, at least, have been more widely disseminated or have permitted easier access to the information generated by investigators or designers.

We will concentrate, then, on the study and discussion of the methods of those centres that are most representative of both levels, that is to say, the Centre for Research into Natural Structures of the European Institute of Design in Milan and the Institute of Light Structures of the University of Stuttgart.

Discussion of the method followed by the CRSN, Milan

The contributions made by Bombardelli in the study of the methods and applicable cases examined in the Centre for the Investigation of Natural Structures constitute a first valuable step towards an understanding of possible ways of gaining access to bionics as far as it relates to the project.

He also refers, although not in depth, to what investigation and bionic analysis consist of.

In cases 1 and 2 he includes a specific analysis which would consist of:

- Differentiation of the mechanisms of the natural subject.
- Study of the formal relations between them.
- Comprehension of the nature and organization of the materials.
- Study of the functional structure.

Method 1

Natural subject ⟶ Integral bionic analysis of the natural subject ⟶ *Definition of a project problem* ⟶ Project

Method 2

Project problem ⟶ Specific bionic investigation ⟶ *Project*

This analysis could well be applied to an individual subject, that is to say, to an isolated case; or equally to observing how the same problem is solved in different ways in different natural subjects. Such would be the examples of animal and vegetal architecture.

The next step in this project process, and the interest of these methods, lies in the moment when the synthesis of the information obtained from the natural subject by means of sketches, diagrams, photographs and, above all, from models (understood as the three-dimensional materialization of an analysis in a synthesis) begins to emit information and suggestions about analogic transposition for application to specific *solutions, materials and production processes.*

Once this information has been obtained we go on to the first selective filter, which will be defined by the requirements of the specific case in question. In this step, as in the previous one, it is advisable to be generous with the number of ideas that they might suggest to us and not to be too strict in our selection, since they can create a store of valuable information for other cases if we are able to preserve them. Even so, either consciously or unconsciously, we classify the information into three categories:

– Utopian solutions.

– Solutions that have already been put into practice or that already exist.

– Solutions for immediate application.

In accordance with the schemes of methods 1 and 2, from the choice of solutions we move on to the definition of a project problem and/or the development of a specific project.

Method 3 would enter perfectly well into the second analogic level with all the considerations previously mentioned.

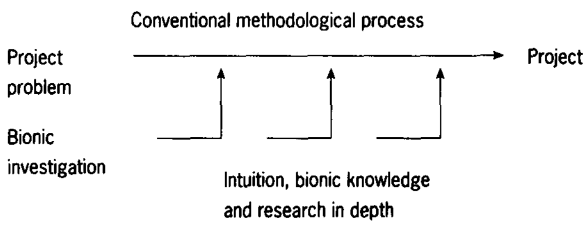
Metohd 3

However, methods 4 and 5 are those that most attract attention as they are representative of how bionics has been understood and considered up to now and of the possibilities that can be developed with the right approach.

Method 5 summarizes the utility and prevailing concept of bionics within the methodology of design; that is to say, understood as an element of support in a conventional process, as part of the creative method of synaesthesia as far as direct analogies are concerned, or as a specific methodology within the theory of methodological levels. Let us examine them separately:

The synaesthesia proposed by Gordon in 1961 consists of the examination of analogies as a means of relating spontaneous thoughts to the problem, using four types of analogies: the direct analogy, in which the designer attempts to compare the design problem with other known problems in other branches of art, technology, biology, etc.; the personal analogy, the symbolic or the fantastic. According to Jones direct analogies are the easiest to find in the search for a biological solution to a similar problem, and are at the same time the most realistic, compared with the other three.

Method 5



The Woodson methodology includes among the information resources the following list of analogies of specific problems with nature:

Tubular structural components	Canes, bamboo, bones
Hoists, fulcrums	Muscular ligaments to the bone
Doors and hinges	Trap of spider's nest
Bolt	Fins of triggerfish
Articulation	Knee
Fragile packaging	Craneum
High resistance to wind	Radial fibres of seed-pods
Lubrication	Bone joints
Refrigeration control	Surface evaporation on skin
Valve	Heart
Roller valve	Intestinal peristalsis
Filter/strainer	Whalebone
Zip fastener	Bramble and heather membrane
Automatic fastening device	Chicken legs and claws
Aerodynamics	Fishes, birds
Retractable landing system	Birds' legs
Antihumidity	Ducks' legs
Camouflage	Mimesis
Infrared tracking systems	Nasal sensor of snakes
Sonar-radar	Navigation of dolphins and bats
Electric pulse generator	Artificial pacemaker, electric eel
Ultrasonic communication	Hearing of dogs and bats
Heating insulation	Fur
Level control	Internal auditory canal
Jet propulsion	Squid siphon
Main pipes	Circulation by veins
Tools	Beaver teeth
Extruded products	Insect threads
Light-sensitive movement	Sunflower

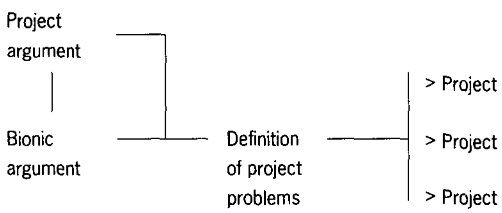
In the proposal for a theory for the project of methodological levels presented by Eliseo Gómez-Senent we observe that each project demands the use of techniques, methods and methodologies that are suited to ends in view:

The name «specific methodologies» aims to express the wide diversity of design conditions which distinguish certain projects from the others. The resources, limits and aims of the project confer on it characteristics of its own which condition the suitability or otherwise of using certain methods and techniques, the order of application and the precision with which they are to be used. The appropriate use of the techniques and project methods must lead to designing each project, that is to say, to defining its own methodology.

In this case, the contribution of the bionic component is converted into the sum of the cases in method 2; that is, for sub-problems created during the project process we resort to the study of natural subjects which solve such problems.

There is no doubt that it is method 4 that suggests and gives rise to the claim for considering the bionic method as the global design method, at least for a certain type of proposal, as well as retaining its validity as a specific method for solving particular problems. The main characteristic of this scheme is, firstly, the establishment of an analogy from the moment of the occurrence of the need, which is then converted almost directly into a bionic argument. Secondly, this fact conditions the rest of the process, which becomes the sum of the cases in method 1, requiring the study of various natural subjects and, as a result, multiplying the project proposals.

Method 4



Now, as a consequence of this new approach, a different way of tackling project problems comes on the scene, by means of the transposition we call «bionic argument». The following chart can give us some idea of the enormous possibilities allowed by the proposed approach, setting out from the common industrial sectors, and then contrasting the design problems they can originate with bionic arguments. Notice the multiplicity of proposals launched from such a limited number of problems and arguments, as against the univocal relation presented by Woodson, Alger and Hays.

Discussion of the method followed by the IL, Stuttgart

It is worthwhile making a few observations about the method followed by this centre. Firstly, we might say that it is characterized by a recognition of basic building elements in nature. This encounter is produced as follows: considering that the Institute is centred on the study and application of light structures in the fields of architecture and engineering, its fields of research and action are therefore limited and the search for the principle of lightness is very much in evidence.

The first step in the method, then, is implicit in the centre's working premise, which defines the structural models to be applied to the project. The next step is to find those principles of lightness which are displayed in whatever natural environment, be it dead or living, of animal architecture, popular architecture or of the history of technology. It is at this moment that there occurs the recognition of the fulfilment of these principles of lightness in natural environments.

In other words, therefore, it is a question of an *a posteriori* encounter, not intended or forced from the beginning; but this does not mean that we are to consider it as belonging to the first analogic level, that of unawareness, since Frei Otto's group has precisely experienced and proved on numerous occasions that the principle of lightness and economy in materials is a premise that is amply demonstrated in nature. It would be, rather, at this first moment a process that could be included in the third analogic level, but in an opposite direction since the transposition is the result of building principles detected during its verification not only in nature but in any other structural environment.

Secondly, after this inspection of the basic building principles has been produced, there then follows an exhaustive analysis of different manifestations which fulfil these premises. It is here precisely that they coincide with and exceed in rigour the studies carried out by the Italian centre: an understanding of the whole, of the parts that constitute it, of their relationships and functions; giving, moreover, material shape to all the information which is being produced by means of photographs, models and, above all, publications, thereby generating a valuable archive for subsequent investigations.

It would be interesting, in a way, to establish a parallel between the method followed in the Institute of Light Structures and method 4 of the Milan centre,

SECTORS	ARGUMENTS			
	Light constructions	*Articulations*	*Locomotion*	*Structured surfaces*
Furniture	Light furniture Structures Shelves	Elements for loocks: Hinges Handles Straps	Bearings	Rigidity of laminated materials
Toys	Construction games Architecture	Mobiles Puppets	Mechanical games Robots	Tactile games Jigsaw puzzles
Building systems	Structural systems: Stands Scaffolding	Unions Joints Seams	Light planes Deltas Chassis Bodywork	Panels Sections Roofs
Packaging	Containers Nets Bags Composites	Folding items Hooks Fasteners	Sistems of transport fragile items	Rigidity of poor materials: cardboard, plastics
Building materials	Bricks Lattices Wrought-iron Meshes	Joints Glues Adhesives	Light high-resistant materials	Tiles Paving Coverings
Textile	Light fibres	Hooks Clasps Buttons Fasteners	Transpirable fabrics	Articulated meshes Composites Smooth, rough, soft types

since the principle of lightness followed by some is what others call «bionic argument» and which they apply directly from the beginning of the project process.

An example to illustrate this process would be that followed by the design and construction of the Olympic stadium at Munich, where inspection and study in depth of spiders' webs was not carried out until the best solution to the specific problem of covering large surfaces was considered to be recourse to tensile structures, and constructional models equivalent to those required were found in this animal architecture. From that moment on, as information pertaining to spiders' webs increased, so did greater possibilities of the transposition of this data to construction solutions become apparent, to such an extent that, in view of the final results and our knowledge of the process, we could attribute them to a fourth analogic level with a higher degree of similarity between the natural reference and the final construction.

As a result of the rigour applied to the method followed and a concentration on a horizontal field, that of light constructions, as opposed to the verticality of the fields dealt with by the Milan centre, it is essential to mention the significant contributions made, which become, in their turn, converted into part of the method of working. On the one hand, the classification of constructions in any of the possible environments constitutes a valuable area for the grouping of bionic-related themes. On the other hand, we have already mentioned the significant generation of information by means of publications, which would be impossible without the momentous work carried out by multidisciplinary teams and the charismatic guidance of their leader, Frei Otto.

Likewise, with the passage of time and experiments, this project method has been reinforced by the development of its own know-how, which goes from the calculation of structures, both from scale models and by computer, to the development of photographic equipment that can be adapted to the specific needs of any research, taking in on the way the development of a programme for calculating patterns for tensile structures or the development of specific technology for construction with pretensed mesh applied in the Institute's own central building.

Bionics as a design methodology

The closeness between the methods of the institutes of Stuttgart and Milan and the creative and investigatory interest of their results are the phenomena which come to the fore if bionics can be regarded as a method of design derived from and, at the same time, native to conventional methodologies.

To present bionics as an overall design method which is neither a highly specific methodology only applicable to a few projects nor a general method which does not manage to define specific aspects which make it operative is one of the objectives and the main corpus of this thesis.

In principle, it could be accepted as a design method since it deals with a compendium of the technique of creative thought, the technique of design and the investigatory process, as could be shown in all its known practical applications. It is, therefore, not a question of contradicting the present consideration of bionics as a method of support for solving sub-problems during the project process. This role can continue to be played in those cases that require it. What is proposed is that bionics, adjusted by the methods we have so far studied, can encompass everything from the initial presentation of the project problem up to its productive realization, contemplating from the presentation the withdrawal and recycling of the developed product.

For this approach to be accepted in its totality we should revise the considerations of project theorists and methodologists, which in this case will become the absolute essentials for evaluation as a design method.

To this end we will turn to the two authorities expressly recognized among theorists, methodologists, historians and planners and which have served at the same time as a point of reference for all these investigators. They are, on the one hand, Morris Asimow who, since his *Introduction to Design* (1962) and the establishment of a project philosophy, by including constant feedback among the methodological phases and separating, moreover, these phases into stages which he calls those of feasibility, preliminary design, design of detail and planning, has constituted a conceptual model followed by most authors.

On the other hand, we have John Christopher Jones, who years later (1970) in *Design methods. Seeds of human futures* analyses the problem of the evolution of design towards new parameters prompted by the progressive complexity of projects, which was increased by the introduction of the concept of system into design considerations.

Methodological requirements

We have stated from the beginning that a design method can be considered to be a compendium of the technique of creative thinking and the technique of design. If this second part is corroborated by the application of Asimow's requirements, the first part can be verified by the observance of the objectives of any creative process: these are

- Direct the thinking.
- Facilitate the processes of analysis-synthesis.
- Look for new relationships at the subconscious level.
- Make possible the step from the subconscious to the conscious.
- Verify and test the value of the solutions.

As far as the technique of design is concerned, according to Asimov, any method must take in the following requisites:

- There must exist a project philosophy based on consistent principles and logical derivatives, an operative discipline which leads to action and a critical feedback mechanism.
- It must respond to certain factive and ethical principles that take form in a morphology of the project, which should develop by following an iterative process of problem-solving.

For Jones, every design process is formed by three stages or categories which he calls divergence, transformation and convergence. Divergence is the act of extending the limits of the design situation and obtaining a space for investigation will be sufficiently ample and fruitful for the search for a solution. Transformation is the stage in which an exact model is defined and thus allows convergence towards arriving at a single design.

From then on it is a matter of continuous scrutiny of these requisites and a rational check of how, point by point, they are being satisfied or are taking form by means of one or various illustrative examples. At the end of this chain of rigorous demands, necessary for any validation of the aim of this thesis, we will have succeeded in clarifying the pattern of another design method that is perfectly articulated in all its different phases.

It is perhaps worth beginning this process by checking the objectives as aspects of creative thinking:

1. Directing the thinking. With the establishment of a first analogy in the presentation of the problem, which is translated into a bionic argument, the areas of interest for the project are already defined.

2. Facilitating the processes of analysis-synthesis. This is one of the objectives which we showed to have been satisfied when we were studying the investigatory methods on which the centres of Milan and Stuttgart are based, whose aim is no other than that of providing information that can be synthesized and applied to the project.

3. Looking for new relationships at the subconscious level. The fact that the selected bionic argument can appear in very divergent environments not only in nature but also in technology allows, in a first stage of free, unconditioned searching, for analogies between different areas of knowledge and individual or collective experience.

4. Making possible the conditions which generate the leap of new solutions from the subconscious to the conscious. This objective is a consequence of the previous since, if we have achieved a good analogic situation with an interdisciplinary basis and the possibility of any kind of connection, by giving material form to such assimilation through graphics, diagrams and, above all, models, we are creating tools that are none other than those proper to design, which awaken the transfer from the subconscious to the cognitive world.

5. Verifying and confirming the value of the solutions. This object is achieved from the moment when, even though many of the ideas that have emerged in this analogic process have to remain in the archives, there is always one idea, or a symbiosis between several, that prospers and determines the final characteristics of the project.

Once this first aspect, which refers to the techniques of creative thinking, has been validated, we can pass on to the merely methodological or technical aspects.

We begin, then, by checking the ideological context of the project which accommodates the bionic component and verifying the existence or not of a philosophy of its own. In this respect, there is use for all the ideological antecedents that have favoured and shaped a clear, definite line of thought, which we mentioned at the beginning of this article, with consistent principles and their corresponding logical derivatives, among which we could list the constructional principles of lightness, of economy in material, of optimization of forms, respect for the environment both in the technology used and also in the ability to recycle the materials or the biodegradable possibilities of the substances used.

But these principles, according to Asimow, would have no value if they were not brought into action by means of an operative discipline. In this context we should remember that the antecedents of bionics, before being understood as a design method, were scientific-investigatory or, at least, were immersed in project methodologies and that, therefore, such discipline was inherited or borrowed from conventional design methods. We should also remember, on the one hand, the project antecedents known by the nature-artifice relationship, and also the large number of examples of products from one centre and another, which in some way have experimented with these methods.

Finally, returning to the inclusion of bionics in project processes, which have brought to it an evaluating criterion, we will recognize a constant feedback process in their phases, as in those cases where work has been paralyzed by an evident lack of viability or by other imperatives, or those investigations which have had to be constantly redirected before arriving at a successful solution.

As far as the factive and ethical principles of Asimow's second group of requirements are concerned, it was said that these should take form in a morphology of the project and that this should develop by following an iterative process of problem-solving.

In order not to reiterate the affirmations and confirmations, we will first of all study morphology and the project process so that later we will gradually come to recognize the fulfilment of each of these principles which we are, nevertheless, going to list. Among the ethical principles will be those for satisfying needs, physical economic and financial feasibility, optimization of the alternatives, the project criterion, the economic value of the evidence and a minimum commitment. Among the factive principles we will find the existence of a morphology and a project process, subproblems, a reduction of uncertainty, bases for the decision and communication.

Proposal for the method

In accordance with what we have analysed in earlier parts of the article, we could deduce a generic application method for the basic principles of bionics.

This method would correspond to a plan such as that on the following page.

In each of these stages there is a series of tasks to be developed and objectives to be achieved before passing on to subsequent stages.

Such tasks and objectives are as follows:

Stage 1. Establishment and analysis of needs.

The need will be presented in the form of a statement that is sufficiently generic to be transferred to a bionic argument. It must demonstrate an economic need and resources with which to satisfy it.

Stage 2. Identification of the problem.

With the preceding data and with technical information, the problem is identified and the bionic argument is established which in the natural world can offer solutions to the same problem. The establishment of the bionic argument will maintain a balance between the generic and the specific, so that the theme to be investigated can be clearly focused without arriving at the point of giving or suggesting concrete solutions.

Stage 3. Concept of the project.

This consists of looking for possible solutions revealed in nature. It is a stage which requires an ability to synthesize the statement, an ability to observe and recognize this statement in different aspects of reality in the natural world. It is really an analogic ability that can be complemented in some cases by the availability of much visual information from different natural environment. A selection will be made of those natural subjects which best represent the stated argument. This leads to more than one conception of the project.

Stage 4. Analysis of natural subjects.

An analysis is made of each of the natural subjects selected in the previous stage. The specific analysis will consist of:

- A differentiation of the mechanisms of the natural subject.
- A study of the formal relationships between them.
- An understanding of the nature and organization of the materials.
- A study of the functional structure.

The information will be preserved by means of photos, graphics, diagrams and models which synthesize the observed formal proposals.

Stage 5. Proposals for application.

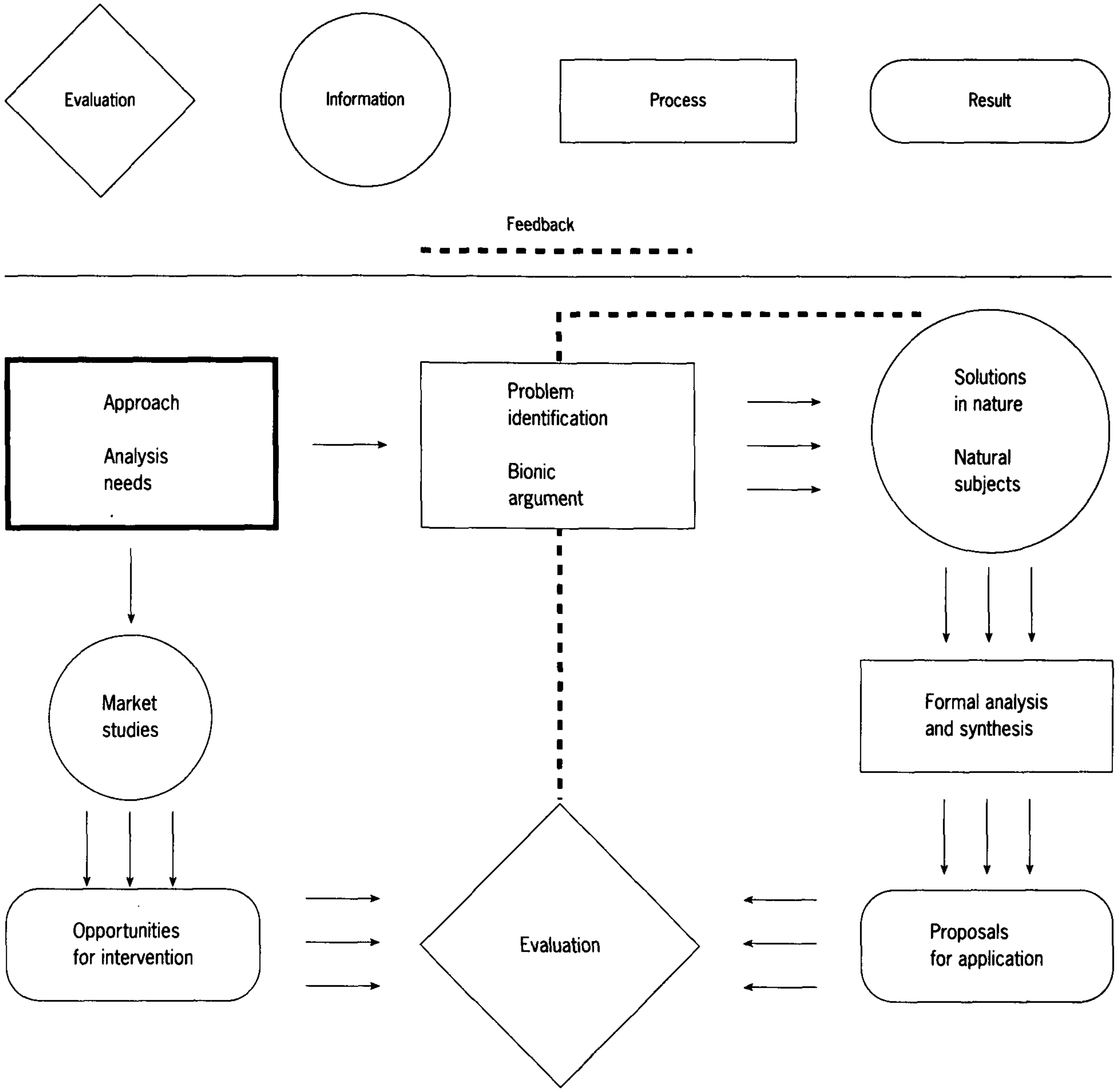
The previous analyses will enable an exhaustive list of possible applications to be drawn up, not even ruling out those that might appear to be absurd, utopian or unattainable.

Stage 6. Market studies and economic feasibility.

This is a study of what is already existing on the market both with reference to the project process and also concerning manifestations of the bionic argument in products that have already been created. An exhaustive list will be made of possible areas for intervention, not only for possible new products but also for competitive improvements on those already existing. A comparison of this list with the one obtained in the previous stage will make it possible to detect areas of interest or even specific products to be developed.

Stage 7. Economic evaluation.

In this stage the promotor must make an initial evaluation of the innovatory offers proposed and, consequently, either the choice of one or more of these which suits his economic possibilities or strategic inter-



est, or the rejection of all of them, which would then suppose feedback to previous stages.

The most important characteristics of this method would be:

a) Of special importance is the choice of the bionic argument since it is this that is going to decide for us the development of later investigation. In general terms, it is a question of generalizing the problem at the beginning (divergence) in order to particularize it at the end (convergence).

b) The creativity is not concentrated in one sole stage. Even the search for information, both about the market and of natural subjects, will require analogic and synthetic ability.

c) The evaluation of the ideas that have been generated does not occur until the last moment, so that the selective filter is the market itself or the strategic interests of the manufacturer, and the proposals can achieve commercial and production objectives in the short, medium or long term.

d) Studies of the market and of opportunities for intervention can be developed parallel to the generation of ideas. Both processes require a breadth of criteria that is favoured by the various areas of intersection between the industrial interests of development and the proposals for application. The greater the process of transformation, the greater the likelihood of the generation of a process of multi-convergence.

e) As a design strategy it can be supported by any other creative strategy or market survey.

f) In the formal analysis and synthesis stage solutions can be advanced or suggested for the sub-problems which will go on arising during the whole of the project process.