Conclusiones

Se ha intentado, a partir de la redacción de diez tesis y su complementación a través de ejemplos, desarrollar la definición del concepto de diseño en un ambiente empírico, teniendo en cuenta las formas biológicas.

El «diseño» es un concepto definido técnica y artísticamente: esto es, no es un concepto biológico. Para la descripción de las formas desde el punto de vista filogenético y ontogenético, los biólogos se ayudan de las disciplinas clásicas, como la morfología o la morfología funcional.

Bajo esta perspectiva, la aplicación del concepto de diseño al mundo animado de la biología no aporta un valor especialmente innovador.

El concepto de diseño se puede aplicar análogamente al mundo de la técnica. De esta manera se intentará que las disciplinas técnicas, artísticas y artesanales sigan el ejemplo y vayan más allá de su propio campo.

Así, se pueden distinguir puntos en común. Definitivamente, del canon de formas de la naturaleza podemos aprender todavía mucho más, sobre todo en el mundo práctico del diseño.

Nadie jamás copiará la naturaleza de manera subyugada. Partiendo de la base de una biónica y una técnica bien entendidas, la naturaleza es una gran fuente de inspiración. Esta orientación hará que la técnica de la humanidad se convierta en una técnica para la humanidad.

El estudio de las «construcciones de la vida» y de la «fantasía de la creación» puede ser, en términos generales, muy significativa para un ejercicio de creatividad biónica, y conducir así a una actitud anímica que permita, por un lado, la contemplación de la vida y, por otro lado, reconducir la actitud interna de la humanidad frente al ambiente, sea biológico o no.

Form creation and bionics: biologic design

Introduction

In this first exposition, I will show to what point the concept of «biologic design» plays an important part in biology and in design-fixed techniques, and also, I will try to establish the interrelationships that exist between the world of biology and the technical world. Toward this end, I will expose ten theses with their complementary examples.

1. The concept of design can be analogous to the concept of technical design in biology

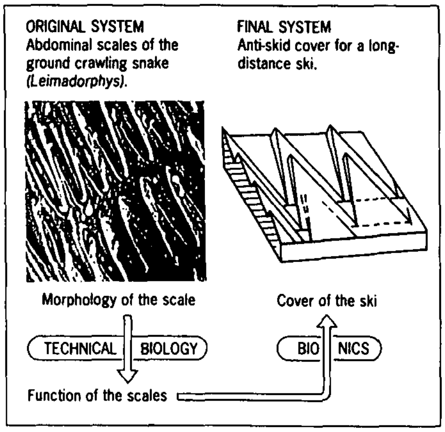
The word «design» comes from the latin verb *designare* (to design). By design we can understand concepts like project, sample, plan, model, or the cooperation of the artist in the creation of a form. But perhaps the most exact formula is, according to my criterium: «creation of the product in the field of a practical esthetic»; this was found by the Ulm Superior School of Design.

Accordingly, we see design as a realization of the projection and creation of a product, inasmuch as the practical and esthetic aspects play a very important role.

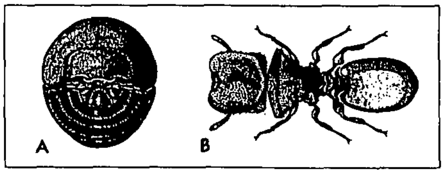
We have no recognized designer for the products of biology, but even so, evolution is responsible for evolution (development of the tribe or group) and onthogenesis (individual development), giving a form to animals and plants and giving them a concept of design. For this reason, we can also speak of biologic design and say that its concept of design can be analogous to the concept of design. The esthetic aspect would mean an exception, though: biology can make affirmations toward concepts of natural science such as form or function, but it cannot do so outside this field, as would be the case in esthetics.

Once we have made the introduction, we can now give a definition of what biology is in itself. By biologic design we understand the organic creation of form in the field of action of the diverse functional demands in phylogenesis and onthogenesis.

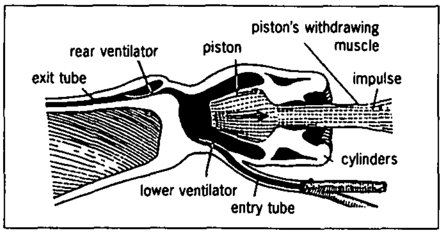
1. Example of a work method of technical biology and bionics.
2. Pill insect, *Armadillium*, seen from the front. Termite soldier *Paracryptocercus*.
3. Secretion pump of the bedbug *Dolycoris baccarum*.
4. An excentric weight after a lightning «accident» to a tree returns to its normal order.
5. Diverse degrees of skeleton mass in small and large animals, drawn to the same scale.
6. In small Reynolds number values, we find sectional and contoured wings (birds) and silk-bristle wings (and other small insects). Each wing design works in its Reynolds number field of value (black square) as is most convenient.
7. Egg-shells of the blue fly *Calliphora spp.* show the «compromise design», with the marvellous quitinous structures, which though often contradictory, come to harmonize.
8. The male of the spider *Pachygnatha clerckii* immobilizes the pincers of the female before copulation, using his own. Detail of the design of both pincers.
9. The tendon principle makes possible the accumulation of impulse muscle mass near the axle point. By means of the lessening of weight burden, energy is saved for impulse.



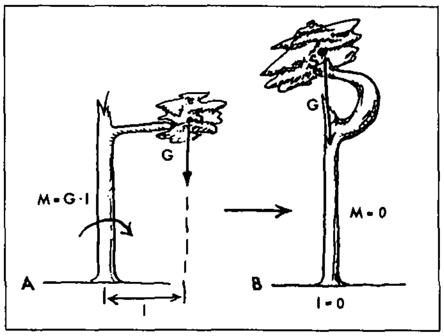
1



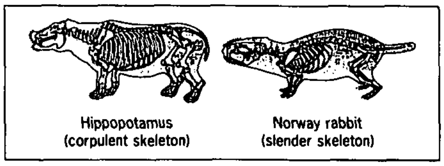
2



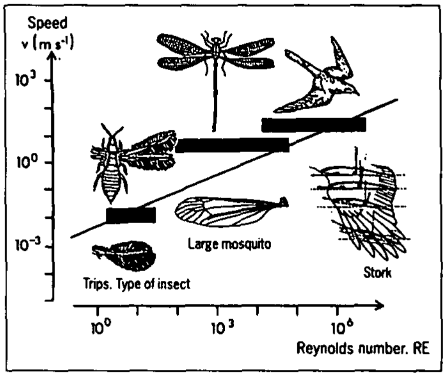
3



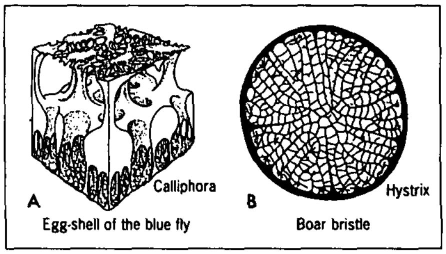
4



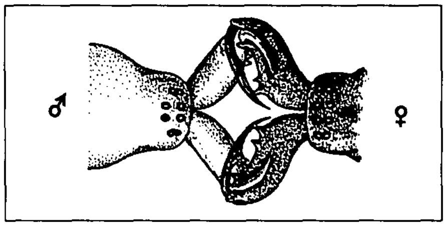
5



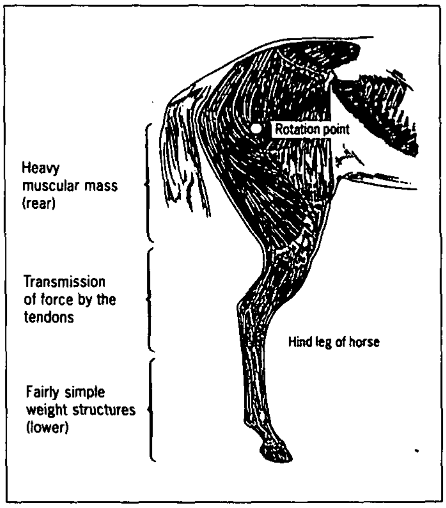
6



7



8



9

It is very important that all the processes of formation that mark organic forms also be influenced by functional requisites, and that these be, at the same time, different and often counterposed or contrary. For this reason, a biologic form will always describe a «compromise design», and it cannot allow itself an end in itself or a «luxury» self-interpretation. We often naturally perceive biologic design as «cute». This esthetic quality appears to the spectator as a secondary consequence of the process of recognition. This cannot be, however, more than a clarifying parameter. Natural science can try to explain form by the coordination of easily recognized functional requisites. From this we can establish the interrelationships between the technical world and the world of animate forms. Of what kind are they?

2. Technical biology and bionics complement one another like the image and its reflection

Technical biology tries to better understand and describe constructions and types of procedures in the animate world through the contribution of physical and technical know-how. Bionics is based on the criteria of technical biology. It intends to take them as a suggestion for other technical creations of its own. Its own creations will, however, have to observe some laws, according to the kind of accredited engineering procedure. A pure copy of nature could be a non-scientific fakery.

Example: snake-skin and the cover for a long-distance ski.

The scales from the abdomen of certain South American snakes of the group *Leimadorphys* (representatives of which drag themselves along the ground of humid forests by a back and forward peristaltic movement of their scaly skin) have a scale structure on one of their sides which is particularly parabolic. By basic technical and physical know-how (technical biology) about the effects of friction, the structure of the scales can be explained and given a morphological function. The scales are «direction-dependent friction generators». With them the snake slides forward perfectly, but not backward. The translation of this principle to technique (bionics) has made us think of the cover of a long-distance ski, even though this is technically simpler. It permits the long-distance skier to slide forward, but allows a saving of back-sliding on a slope (fig. 1).

3. The organism forms a functional whole

Form and function are inseparable in an organism. The one conditions the other. We cannot often tell what has been more important for giving the form: if the form has been created as a response to functional requirements or if the organism has begun to use a given form as a response to a convenient function.

Example: kugelassel (pill-insect).

The insect *Armadillium vulgare* looks like a normal beetle when it is sliding along. In case of danger, it can curl up into an impenetrable pea-sized pill. The adaptation is so detailed and precise that the abdomen and antennae fit into already foreseen places. In this way the animal is unassailable, and in front of an enemy, it rolls away. In a normal situation, however, the diverse parts that can curl up and transfigure the animal into a pill-shell have «normal» and diverse functions (fig. 2). The heads of the termite *Paracryptocercus* also act in the same way. With their heads, the «soldiers» of this group close their constructed entrance from within.

4. Biologic constructions follow the principle of highly-integrated construction

Biology, unlike the technical world, seldom constructs from individual parts, finished separately, and combined later. Quite often, almost regularly, the constituent elements of the form are created by adaptation and adjustment, and fuse slowly together into an integrated whole. Very interesting examples of this are to be found in the insect world, and in the bug order.

Example: secretion pump of dolycoris.

Bedbugs sting their prey, injecting a secretion through the sting. This substance impedes the coagulation of the liquid sucked in from the sting, and avoids the obstruction of the absorption canal. For this, they use a minute (2/10 mm) but efficient secretion pump. The secretion pump has all those elements «technically necessary» for its function, such as the spadix, the cylinder, or ventilators. But the elements cannot be totally delimited among one another. In a configuration in which the elements are totally integrated, the secretion pump creates a functional design in a highly integrated type of construction (fig. 3).

5. The organism compensates for harmful loads

Interior and exterior forces influence every organism. Some forces are «desired», and are therefore used. As an example, we have the use of the various forces of friction in the snake *Leimadorphys* when it drags itself along. Other forces are «not desired». These can overburden the support properties of an organism. If the organism cannot remove these forces, what it does is try to compensate their negative repercussions.

Example: shattering of a treetop and decrease of the tension on the trunk by compensatory growth.

Imagine a tree which loses its top because of lightning, and only keeps a solid lateral branch alive. Through its centre of gravity, the mass of gravity G produces an important flective force $B = M \cdot I$ on the branch. This force cannot be compensated by contrary forces (as it could be before the lightning-bolt), and means a strong burden on the trunk. The tree regulates this lack of compensation of forces by provoking the biased growth of the branch, over a period of time, above the rest of the trunk. If the centre of gravity is above the trunk, then the distance I, and therefore the flective force are equal to zero (fig. 4). The excentric and harmful burden disappears.

6. The absolute size of an organism determines its static design

The size of an animal is important for the exterior —and even more for the interior (weight, skeleton)— configuration of the animal. Statistically observed, large animals have more problems than small ones. The larger size of their exterior has to increase more than its length. In this way, the animal's skeleton is stronger and more resistent. In the case of large animals, their aspect visibly reflects on their exterior form, and on the visual impression the observer will have. Due to the earth's forces of gravity, animals larger than the dinosaurs we know could never survive. Even with their large skeletons, their systems would disappear under their own weight.

Example: proportion of the skeleton.

In a classic of biologic literature, Hesse and Doflein, first published in 1919, we find the sketch of a hippopotamus and a Norway rabbit, drawn to the same scale (fig. 5). We can immediately see that the skeleton of the hippopotamus is much heavier than the Norway rabbit's. This is because the diameter (D) of the bone does not increase according to the length of the body (L), or with the length itself of the bone (D L). It does so according to the relation between D L L $L^{1.50}$. It has been possible to arrive at this conclusion after many tests. In the antelope family, the exponent found empirically for the forearm reaches 1.52.

7. The organism makes contact with the environment

The environment marks the design of the organism. This design is extremely important. This does not happen directly. Properties won from the environment are not transmitted (*lamarckism*). Evolution depends more on wide palettes of small, spontaneous changes, so that there will always be beings that will have more possibilities for survival and reproduction because of their optimum physical conditions. In this way, the «ecologic niches» are filled.

The ecologic niches are also physical. The conditions of the environment are also determined by physical laws. We also get the feeling that the configuration uses the «physical niches»: the adequate physical form is confused.

Example: insect wing forms.

We have already explained that small animals are, compared to large ones, subject to other static conditioners. In the same way we can say that air offers other conditions of resistance to small animals. The smaller an insect is, and the slower it flies, it will find more air resistance. The smaller insects «row» through the air, like small «water fleas» with different resistance.

The form of the wing adapts to the properties and state of the air. We speak of its dependence on the biologic form with the name of Reynolds number (RE). This corresponds to the length of the body (L) and the speed (V) of the observed animal's wings, as well as the air capacity and its kinetic resistance. The result is: RE = VL/. The smaller Reynolds number will be characteristic of smaller, slower flying animals.

At higher Reynolds numbers, sectional and contoured wings are physically more appropriate (birds' wings). At medium Reynolds numbers, wings which are not so contoured are more appropriate, but rather those formed by flatter and longer layers (mosquito and dragonfly wings). The smaller insects, with wings of a length of only a few millimetres (beetles and large inoffensive mosquitos, with a wing length no more than tenths of a millimetre), which do not have the two types of wings we have mentioned, have silk-bristle wings.

Nature adapts perfectly and precisely to environmental conditions, in which the design of the wing will develop (in the case which we study in the field of Reynolds measurement) (fig. 6).

8. A Form must Satisfy Multiple Demands

We have already defined biological design as an organic configuration which adjusts to the force field of diverse functional demands. There are many and diverse requirements, and these can act either in a negative or positive way. They are often counterposed. Thus a boar bristle must be long to act as a «war weapon», but flexible at the same time. A long bristle is stronger, for fighting, but a shorter one is more flexible. Somewhere we will find a compromise that will provide the final configuration of the image. Each and every one of these biological designs is finally a kind of compromise in the force field of dozens of these environmental conditioners.

Example: blue-fly egg-shells.

The egg-shells of fly larvae must be light, so as to produce many eggs from one single use of material. They must be elastic, to assume different forms. They must also permit the interchange of gases like any other texture, to allow for the intake of oxygen from the exterior and the exit of carbon dioxide produced in the interior. And, finally, they must be impermeable to water and permit the interchange of water vapour. We could formulate many more conditioners for a fly egg-shell.

In the field of action of these diverse and often contradictory conditions (lightness of construction, stability, resistence to gases and impermeability, etc.), evolution has played a supporting role by providing a quitinous substance formed by multiple tentacles and a shell which by the effects of its structure makes water run to the edges (fig. 7*a*). In this complex way, the boar also combines lightness and stability (fig. 7*b*).

9. The organism enters into contact with other organisms

Here, design bumps up against design, because constructive formations participate perfectly together as to their functional task, even though this contact may only appear once in the life of the two organisms. The most representative examples are to be found in the field of genitive or similar organs, which play a very important part in the field of fecundation attitudes. From this we draw the next example.

Example: impeding pincer movement during spider copulation.

Male spiders are at risk during copulation. Female spiders (usually a great deal larger) often see them as objects of attack, and attack them with their pincers. In these cases the males must avoid the pincer attack by the females till the coupling can be carried out peacefully, thanks to diverse techniques used. A very useful defence possibility is the immobilization of the female's attack weapons.

Males of the spider *Pachygnatha clerckii* have a specialized design in their own pincers. These fit into a geometric configuration, and have long and very flexible claws at the base of their legs. During the approach, the male attacks the female's pincers, trapping them between his own and immobilizing the tips with his own (fig. 8).

There are a great variety of copulatory mechanisms in the animal kingdom.

10. The organism lives subject to the energy dilemma. Energy must be saved everywhere

We can say that if an organism is not careful about the energy it has about it, it will not be capable of living or of survival. Available energy is limited. We can also say that the energy yield (energy by time, measured in Joules per second = Watt) is limited. If a female bird has to invest a great energy yield in flight to feed herself on a normal spring day (perhaps because the wings do not have an aerodynamically optimum form), then in this time interval she has less energy for the synthesis of her eggs, and that will negatively affect their reproduction.

All biologic processes are energetically optimized to the last detail. (Human civilization could take an example from natural strategies for each biologic process: the saving of as much energy as possible.)

With all the adaptations discussed till now, we can assume a positive balance of energy. A biologic design would also suppose a use of energy parting from a savings base.

Example: an ideal configuration saves movement energy.

Horses and other fast mammals like gazelles have a very well-developed pelvic zone, and their legs, on the contrary, are so delicate that we sometimes have the feeling that they are made only of skin and bone.

The majority of muscles are found in the upper quarters, near the rotation point, and thus transfer the fixation points of the movement force (attack) to the tendons, which are longer at the ends, increasing their power.

The more developed the muscular mass of the leg is, the more force has to be used in each step, when, from the rest position, it is taken up again. The equivalent for this use of energy for the momentum of leg movement is the calculation based on the sum of the units of mass (M_i) and the potential of the rotation distances (r_i^2) in respect to the axle. If the muscles were all along the leg, the momentum of the weight of the leg would be very high, given the high values of r_i^2. But in this way, the momentum of the mass of the leg is kept low, because the disposal of the muscles along the axle keep the r_i^2 values low. Thus the acceleration capacity diminishes, and also the capacity for movement in general. In this way, there will be less excess of energy per unit of time, and it will be available for other biologic processes.

The elements of construction necessary for this tactic, that is to say, the long, light, and resistent tendon, have been developed by Nature in an ideal manner. In the configuration of the horse's leg, the principle of the tendon, already mentioned, is also applicable. There is also an added advantage: energy can be stored in the stretched tendons. Thus a good part of the energy applied to the leg in movement can be stored in the tendon, and be available for the next phase of movement. This «trick» also saves energy (fig. 9).

Conclusions

We have tried, in the exposition of ten theses and their complementary examples, to develop a definition of the concept of design in an empiric environment, taking biologic forms into account.

«Design» is a technically and artistically defined concept; that is to say, not a biological one. To describe forms from the phylogenetic and onthogenetic points of view, biologists help themselves to classic disciplines such as morphology or functional morphology.

From this perspective, the application of the concept of design to the animate world of biology does not bring an especially innovative value.

The concept of design can be applied, by analogy, to the technical world. In this way, it will intent that the technical, artistic, and artesan disciplines follow the example, and go beyond their own camps.

Thus, points in common can be detected. Quite definitely, we can learn much more from the canons of Nature, especially in the practical world of design.

No-one will ever copy Nature abjectly. If we begin from a well understood bionic and technical basis, Nature is a great font of inspiration. This orientation will make human technique a technique for humanity.

The study of «life constructions» and the «fantasy of creation» can be, in general terms, very significant for an exercise in creative bionics, and lead to an attitude that allows, on one hand, the contemplation of life, and, on the other, a reconduction of humanity's inner attitude toward the environment, be it biologic or not.