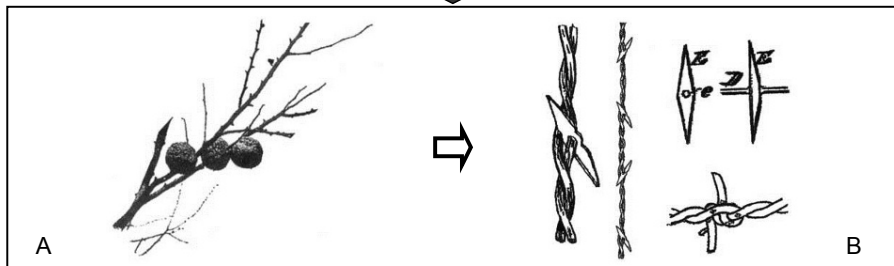




„EARLY HISTORY“

From the middle of this 19th century, there are increasingly more tendencies for a „learning from nature“, that lead into technical realizations or at least stimulate these. It is little known that barbed wire and ferro-concrete are bionic inventions. The inventor of the ferro-concrete, J. Monier, lives in the term „Moniereisen“ of the mason-guild. Besides naively appearing attempts of realization still in the 20th century, there are also more and more attempts with a firm physical basis, for example the flipper propulsions. The series reaches as far as to the zeppelins of the twenties and the war-time.

Barbed wire is a bionic invention



Sometimes, a bionic background is in an invention, that nobody has remembered any more: Barbed wire.

BIOLOGY:

Since the begin of the stock farming, the North America's farmers has known, that animals are not to be persuaded by anything to penetrate through the prickly hedges of the Osage-orange, *Maclura pomifera*. Therefore, such hedges (A) were planted as separations of the grassland and pen-fence. However, the increasing of the borders of the meadow-areas requested for engineering solutions especially since the hedges of *Maclura* only grow very slowly.

PRINCIPLE:

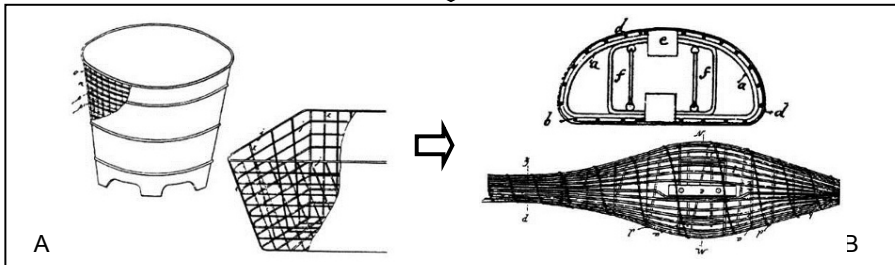
With the first patent of a „thorny wire“ (Mike Kelly, 1868), the sharp thorns close to the basis of an Osage-branch were imitated. In fact, they were built of duplicate-sharpened, thorn-like metal-platelets between two wire-strings (B). The nature model is documented in the letter of patent: „*My invention relates to imparting to fences of wires a character approximating that of the thorn hedge.*“ But the wire was still quite expensive.

DEVELOPMENT:

Since the Kelly-wire was quite extensive because of the complicated handcraft, it was replaced by automatically manufactured products. Today, it is only used in the military area where money doesn't play any role. The Glidden-wire, that was announced to the patent in 1874, was more practicable. This sharp metal-platelets, tied-in by hand, were replaced (B) by mechanically plaited double-thorns. Today, there are up to 200 barbed wire-patents.

LITERATUR: Kelly, M. (1868): Improvement in fences. US Patent No. 74379. – Glidden, J. F. (1874): Improvement in wire fences. US Patent No. 157124.

Ferro-concrete is a bionic invention



One can always speak of a bionic invention when natural models have given the essential inspiration.

PROBLEM AND BIOLOGICAL MODEL:

The Parisian „horticulteur et paysachiste“ Joseph Monier had been angry about the high costs and the risks of fracture of the ceramic or stony plant pots. On the other hand, he had observed that the linked sclerenchyma structure of a decomposed opuntia leaf gives solidity to the leaf mass. From it the ideas originated, patented in 1867, to produce flower pots in an inexpensive manner in form of multi-component constructions.

PRINCIPLE:

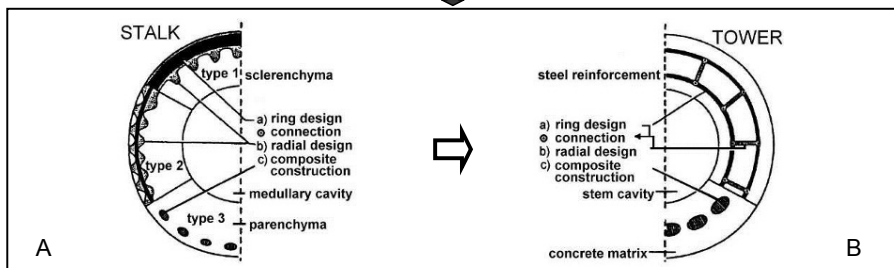
In the plant world the parenchyma mass consist of cells standing narrowly side by side, which are stabilized by the turgor pressure, but still sensitive to traction. On the other hand, the connected structure of the sclerenchyma, forming multiple lignified, long-stretched bundles of cells, is not very stabile against lateral pressure; however, it is insensitive against fraction forces. The combination of the two materials combines in an ideal way compression- with tensile-strength.

TECHNOLOGY:

The pressure-proof parenchyma mass keeps the tensile-proof network of sclerenchyma at distance. For the last one, a wire-skeleton is analogue in the technical range, for a flower pot a wire-basket (A), for a sleeper an accordingly formed winding of wire (B), for the first one the matrix of the poured, solidifying cement. Therefore, a sleeper or a bucket of cement with wire-matrix-filler combines compression with tensile strength: Ferro-concrete.

LITERATUR: Monier, J. (1867): Nouveau système de caisses et bassins mobiles et portatifs au fer et ciment applicable à l horticulture. Prevet Français Nr. 77165. – Monier, J. (1880): Verbindung von Metallgerippen mit Cement. Kaiserliches Patentamt Nr. 14673, Kl. 80.

Importance of analogy considerations: ferro-concrete



The importance of an analogy-research was highlighted the first time by W. Rasdorsky at the example of the ferro-concrete.

TECHNICAL DESCRIPTION AND BIOLOGICAL UNDERSTANDING:

W. Rasdorsky, who critically regarded S. Schwendener's vision of double-T-beams, got the idea „from lectures, heard in the years from 1906 to 1907, about the iron concrete structure“ that the plant is to be understood as a composite construction, „in which the rows of sclerenchyma correspond to the iron armouring, the cells of parenchyma to the concrete matrix“ (probably it was meant: the cement matrix): the right way to a functional understanding.

PRINCIPLE OF ANALOGY-RESEARCH:

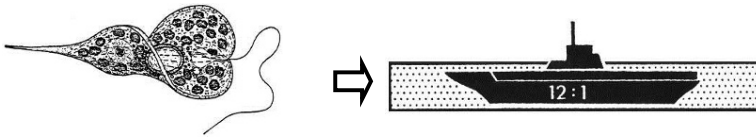
With the above-mentioned quotation from the year 1911, the heuristic role of the analogy-research, so important today, already had been shown very early: „Therefore, between the technical composite constructions and the plant-organs, there is an extensive analogy“ of the whole construction-principle. Giesenhagen notes in 1912 that leaves „with their strengthening tissues form a grid like the iron insert in a ferro-concrete mass (A, B)“.

IMPORTANCE OF ANALOGY-RESEARCH:

The early analogy-research led not only to a correct understanding of the morphological structure, but also influenced the manner of view of the following generation of researchers. Bachman compared in 1922 the configuration of the tensile fibres within the bamboo with „a reinforcement of the mainly stressed outer layer during flexion (like the ferro-concrete). Bower referred in 1923: „Ordinary herbaceous plants are constructed on the same principle.“

LITERATUR: Rasdorsky, W. (1911): Bull. de la Société des Naturalistes de Moscou, Sect. Biol. 4, 351–405. – Rasdorsky, W. (1928): Ber. d. Dtsch. Bot. Ges. 46, 48–104. – Giesenhagen, K. (1912): Handwörterbuch d. Naturwiss. 2, 1–35. – Bachmann, F. (1922): Jb. Wiss. Bot. 61, 372.

Naive suggestions for realizations lead into a void



A

B

One must give up suggestions for realizations, which don't include the physical-technical bases.

BIOTECHNICAL COMPARISON CAN LEAD TO IDEAS, BUT ...

R.H. Francé, one of the early proponents of a „learning from nature for technology“, for example, already tried in his 1919-work „Die technischen Leistungen der Pflanzen“, to overcome borders of disciplines. So, he proposed to build a „rotating submarine“ after the model of the „water-screw-form“ of a unicellular green-alga. Representatives of the type *Phacus* and others actually move helically.

... BIOLOGY AND TECHNOLOGY ARE NOT ALWAYS COMPARABLE:

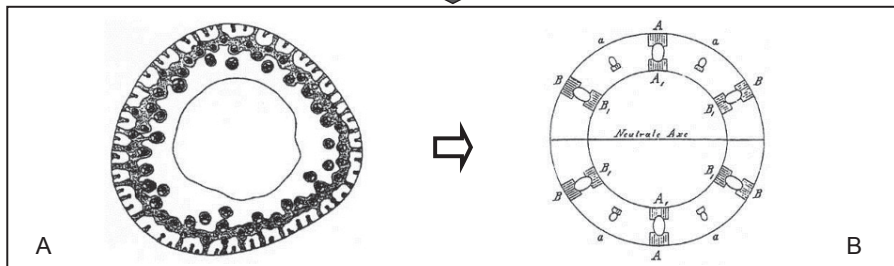
A comparison is sense-empty in this case since the physical prerequisites for the movement of a 1/10 mm long green-alga (A) and a 30 m long submarine (B) are completely different. Not only the lengths have differed about the factor $3 \cdot 10^5$ also the speeds differ in similar manner. So the Reynolds-numbers, which mark the characteristics of the water flow, differ approximately in the relation of $1:10^6$.

TECHNOLOGY:

A submarine cannot rotate screw-like together with its team through the water. One cannot transfer the mechanism of movement of the small green-alga to a 30 m long submarine either. So, the proportions of pressure - and friction drag are example-wise completely different. A submarine could not swim in such a way. The same is valid vice-versa: Small algae with submarine-form and -drive would not make progress in the water.

LITERATUR: Francé, R. H. (1919): Die technischen Leistungen der Pflanzen. Veit & Co, Leipzig.

Technical and physical principles as basis



New or rediscovered technical or physical knowledge was already used for early principal explanations.

BIOLOGY:

Cross-sections through plant-stems or -stalks, for example of the guts-reed, *Cladium mariscus* (A), normally are marked by annular load-bearing structures of merged sclerenchyma. These often form centrifugal and centripetal bulgings. Such structures show common enough cross-section-forms that resemble technical double-T-steel-profiles. Accordingly, then they were also described as „biological double-T-profiles.“

PRINCIPLE:

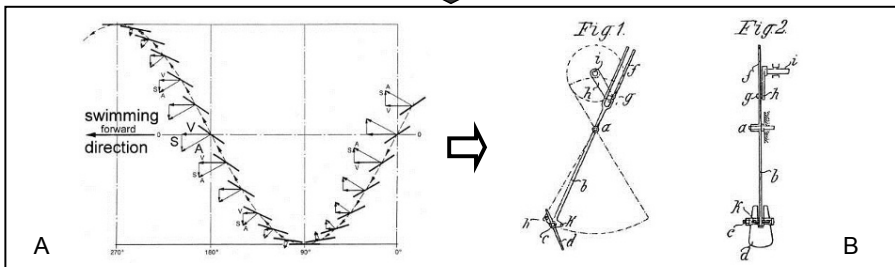
One knows about technical double-T-beams since their introduction into the concrete- and railroad-constructions of this 19th century, that due to their typical cross-sections they show an especially high moment of inertia and are relatively resistant to bending and torsion (B). This is especially true if they are combined to radial complexes: So technical biology can explain the so-being of biological structures by analogue conditions.

EXPLANATION BY AN OTHER FIELD:

S. Schwendener, botanist and biomechanics in the late 19th century, was stimulated „by the viewing iron bridges and railway stations with their numerous double-T-profiles“ to understand rigid plant-stalks as systems of such profiles. In the year 1888, he wrote in a book: „The plant undoubtedly constructs after the same rules like the engineers only that their technology is a very much finer and more perfect.“

LITERATUR: Schwendener, S. (1874): Das mechanische Prinzip im anatomischen Bau der Monocotylen ... Engelmann, Leipzig. – Schwendener, S. (1888): Über Richtungen und Ziele der mikroskopisch botanischen Forschung. Naturwiss. Wochenschrift, Berlin.

„Fish-propellers" of the tail fin-type



The reference „prototype nature“ is often given in older patent-writings, but not in newer once.

BIOLOGY:

The efficiency of the tail fin-drive of fishes has been regarded as outstanding since ages ago. In the patent-writing of Zdenko Knight of Limbeck is written: „Object of the present invention is a fin-propeller for ships, which is mounted instead of a screw-propeller on the rear-ship and includes an onward driving movement corresponding to the tail fin of fish, through deflections to star-board and port side.“

PRINCIPLE:

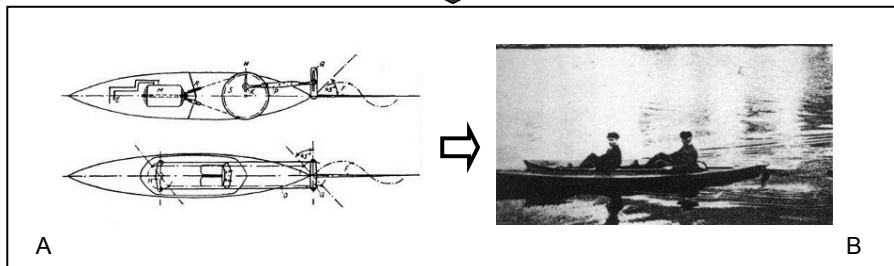
The thrust-production in a to and fro swinging fin (A) happens in the way that it is put at a positive angle of attack relative to its path through the water. So a lift component A is created at a right angle to the direction of the beat in addition to a drag component in the beat-direction. This one can be separated into a thrust-component V in swimming direction and a lateral force-component S vertically to it.

TECHNOLOGY:

The drive consists of an eccentric-fork-system (B), that lets a driving-rod b swing to and fro. At the end of the rod, a fin is fixed, that is eccentrically built, so that its surface is always orientated against the water pressure d. It beats against the block h and the opposite block and regulates itself in such a way, that it always generates thrust, at the reversion-points the side of attack changes.

LITERATUR: Ritter von Limbeck, Z. (1903): Fischpropeller für Schiffe. Kaiserliches Patentamt Nr. 153810, Kl. 65 f.

„Wave-propeller" with an elastic fin



There are few examples in the area of early bionic realization from the step of idea / model to full-scale-implementation.

BIOLOGY AND TECHNOLOGY:

After the study of the propulsion-mechanisms of fishes, the engineer H. Schramm, who had given his book „The undulation as propulsion-factor in nature and technology“ the apodictic subtitle „Thoughts of an engineer about the problem swinging propulsion in technology and biology“ took a chance for realization of models into full-scale-implementations. Men carrying boats with undulating stern-fins were built and tested.

PRINCIPLE:

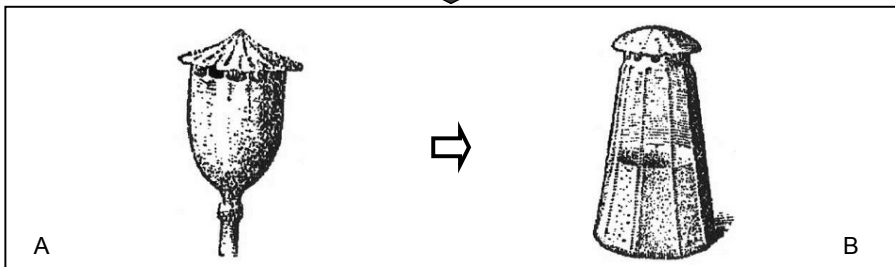
Long stern-fins (A) were put into horizontal-swinging. It was recognized on that occasion, „... that the elasticity of the fin should not be continuously the same but that, at the point of attack of the fin-pressure-force, the front part of the fin, flexible connected to the boat-stern, should be strong and of little elasticity and to its rear end it should be continuously soft and flexible.“ - An analogy to the fish.

TECHNOLOGY:

Five such fins were tested. The best one showed efficiencies that were higher than those of ship-propellers. Within certain boundary conditions, a screw-propeller attains efficiency of 0.52 and contrary to this, the undulating propeller 0.78. The basic approach was enlarged to a two-men-canoe (B). With the best fin, coming like a fish-fin to a hair-sharp edge at the end, especially high static thrust has been achieved.

LITERATUR: Schramm, H. (1927): Die Schwingung als Vortriebsfaktor in Natur und Technik. Gedanken eines Ingenieurs über das Problem der schwingenden Propulsion in Technik und Biologie. De Gruyter, Leipzig.

Test for the patent-office: Francé's salt shaker



Will the patent-office consider an „invention, which the nature has already made,” patentable? The test was positive.

PROBLEM:

Raoul H. Francé, the discoverer of the microscopic life in the soil („Edaphon”), tried to multiply microorganisms from an even inoculation of a soil area. So he looked for a method for even inoculation, „strewing quite evenly, each square millimetre with one dozen of the smallest life-germs.” However, all the spreading devices usual in the 20-er years like conventional salt shakers (A), powder-shakers for small children, atomizers or strainers, scattered quite unevenly.

PRINCIPLE:

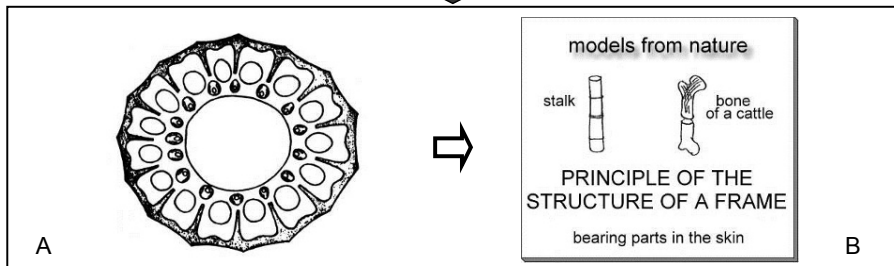
„I found the solution of the problem in the capsule of the poppy. Everyone knows them, everyone knows, that the holes, grouped in circles below their covers, are used for scattering the small poppy-grains, but never somebody has thought that here an invention of the plant is given, which surpasses the our ones. A poppy-capsule, filled with the grains of the earth, scattered very much more evenly as I had succeeded with other devices until then.”

PATENT:

„With a bold decision, I wanted to have certainty. I drew a shaker for salt, for powders or other medical purposes after the model of the poppy-capsules (B) and declared this as invention to the pattern-protection. One didn't deny me the protection; an invention was done. After short, I got confirmed that by the patent-office...” Francé held himself only, sympathetic modest, for a „miserable copier of the nature.”

LITERATUR: Francé, R. H. (1919): Die technischen Leistungen der Pflanzen. Veit & Co., Leipzig. – Francé, R. H. (ca. 1929): Deutsches Patentamt Nr. 723730.

Airship-constructs of the 20er years



The light construction of biological stalks with far outside lying supporting frame supplied stimulation for airship frames.

BIOLOGY:

Grass-stalks and horsetails (A) carry their sclerenchyma stiffening-system far peripheral in form of interconnected ring-structures. Support elements especially surround the vascular bundles, so that they become stiff tubes. These are interconnected by sclerenchyma with their neighbouring tubes. So a type of a ring form results. From time to time effective, radial geared double-T-beams occur, too.

PRINCIPLE:

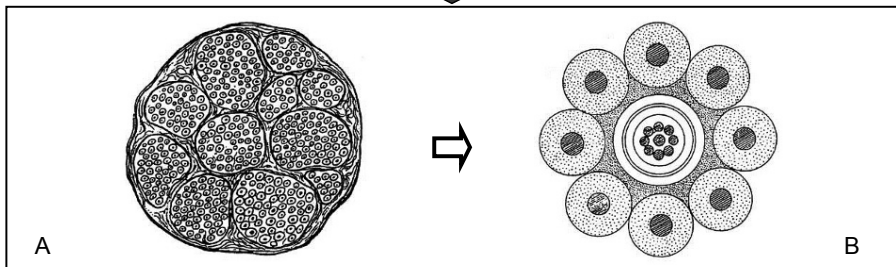
Through the described arrangement, a big second moment of inertia of these girder structures occurs, an essential reason for their considerable bending and distortion-stiffness. There are numerous types, from the horsetails up to the bloom-plants, which work all after the same principle. Through the outside displacement the supporting system doesn't become so very much died out, so that it would become sensitive against local buckling.

TECHNOLOGY:

For the conception of the aluminium made beam-frames of airships, one studied both stalks and bones „after the model of the nature (B).“ Concerning the „principle of the carrier-body-construction“ one was interested to localize „bearing parts in the outside-skin.“ A direct realization of these studies is not verifiable. The qualitative proof however, that already Graf Zeppelin or his followers carried on bionics, is secured.

LITERATUR: Zeichnung aus einer technischen Publikation über Messungen und Rechnungen an Zeppelinmodellen (Bauweisen, Strömungsverhalten, Antriebe etc.) in einem Museum. Nicht näher eruierbar. Skizze B ist eine direkte Nachzeichnung des Ausstellungsblatts.

Bionics in totalitarian systems



Even dictatorial systems as the national socialism and communism had accepted the „prototype nature.“

NATIONAL SOCIALISM:

Into the blood-and-soil-ideology of the third empire, the natural was embedded, though in emotionally exaggerated revaluation. 1939, Alf Gießler, a then „Gauleiter“, set natural and technical realities opposite to each other in his book „Biotechnology“, for example nerves and cable-cross-sections (A, B): „The high technical proficiency of the northern human being ... has its unequalled model in the processes of the nature itself.“

COMMUNISM:

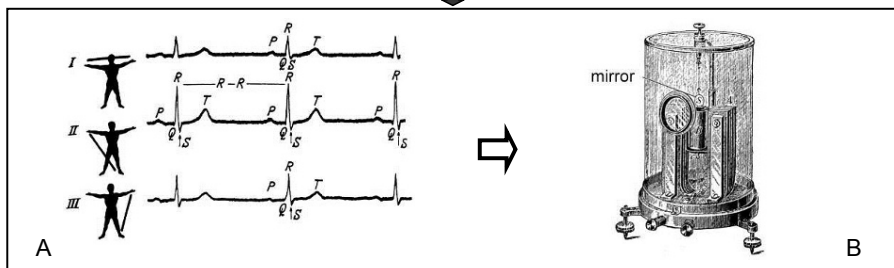
Marx, Engels as well as Lenin referred many times and desiderated on principles of the biosphere: „... that there is our entire reign over the nature ... to recognize her laws and, to be able to apply them right.“ „Morphological and physiological appearances, form and function, stipulate each other reciprocally.“ „Darwin has drawn attention to the natural technology“ „From the living view to the abstract thinking“

CRITICISM:

In both cases, applicable statements were turned into the goal of the fulfilment of political demands. This admittedly doesn't devaluate the comparisons, but it relatives them. For example A. Gießler tried to find groups of prototypes in the nature (A) for each technical line from the construction-statics up to the electro-technology (B). He therefore compared already whole areas to find similarities between nature and technology: early analogy research.

LITERATUR: Gießler, A. (1939): Biotechnik. Quelle & Meyer, Leipzig. – Marx, K.; Engels, F. (Gesammelte Werke, ed. 1962): Dialektik der Natur. Bd. 20, 496 und 611–620. – Lenin, W. I. (Gesammelte Werke, ed. 1964): Bd. 29, 229; Bd. 38, 160. Dietz, Berlin.

Transition to the functional aspects



The consideration of function in biology challenges the technically-physical disciplines as far as at their borders.

BIOLOGY RANGES AMONG THE MEASURING DISCIPLINES:

Nature-enthusiasm or politically motivated super elevation of nature, to early and uncritical transferring and partly naive view-manners have contributed, approximately as far as to the middle of this 20th century, only here and there something to the deepening of the cross-relationships. This changed as soon, as the measuring biological disciplines were able to offer questions and results that were equal to those of the technical sciences.

BIOLOGY BEGINS TO ASK BORDERLINE QUESTIONS:

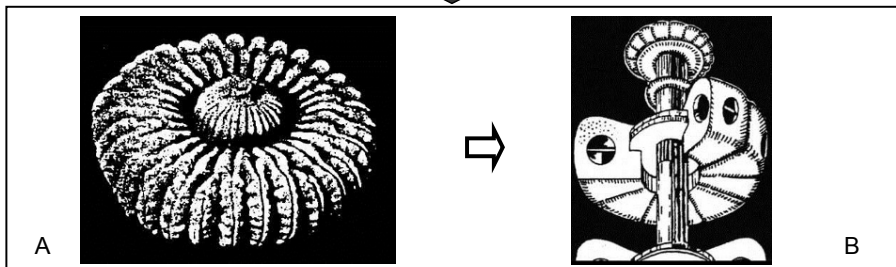
If biology hardly was capable previously to fit in suitably suggestions from technology, the medal now turned back quickly. The questions, which the biologists and human-physiologists asked the technicians and physicists, became gradually so difficult, that the physical-technical disciplines had to resign at first. Their interest awakened this on the other side, they became interested and this led to continuing developments.

EXAMPLE:

As in the late 19th century, human-physiologists began to examine the electrocardiogram of the human heart (A) and to appraise it already clinically, the sensitivities and time-functions of the used measuring instruments (e.g. mercury-drop-galvanometer) were inappropriate. The demand for fast indicators without intolerable phase-shift led to the construction of sensitive rotating-mirror-galvanometers (B).

LITERATUR: Rein, H.; Schneider, M. (1971): Einführung in die Physiologie des Menschen. 16. Aufl. Springer, Berlin. – Lueger, O. (Hrsg.) (1904): Lexikon der gesamten Technik und ihrer Hilfswissenschaften. 2. Aufl. Deutsche Verlags-Anstalt, Stuttgart/Leipzig.

In the architecture especially the function counts



Architecture-bionics is at risk to be lost in form-similarities („biomorphic constructions“). However, the function counts.

FORM-SIMILARITIES IN BIOLOGY AND TECHNOLOGY:

That pure form-similarity doesn't have anything to do with bionics can be seen in the Russian architecture of the post-war era, that sometimes exhausts itself in nature imitation and so has little to do, with the new Russian architecture of the twenties. 1985, J.S. Lebedev writes in his book: „In the last two to three decades, we became eyewitnesses of a new creative impulse in the architecture.“ But which one?

FORM-PROTOTYPES IN NATURE:

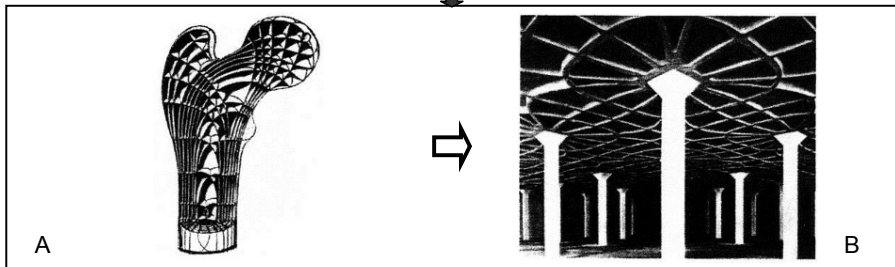
Continuing Lebedev: „Forms of the nature, like ocean mussels, petals, turtle-tanks, bended and pleated plant-leaves became converted into *Mefcg* (highlighting by the authors) of the built environment.“ If the hollyhock-fruit (A) was the model for a „hollyhock-high-rise“(B) on the basis of a pure form-similarity, this is pure architecture-*.gaPd*. If however, one compares the possibilities of the arrangement of the part-fruits, function comes into play.

CRITICISM OF THE PURE FORM-MODEL:

Nature-forms are always functional, then however only with reference to their respective tasks. The intestine has a series of functions, from the transportation up to the re-absorption. If one shapes a „biomorphic“ building in intestine-form (F. Kiesler, an American architect of the 60th years, s. p. 91), such functions don't play any role, and new technical functions are not deducible from the form. The building therefore is not bionic.

LITERATUR: Lebedev, J. S. (1983): Architektur und Bionik. Verlag für Bauwesen, Berlin. – Nachtigall, W. (2003): Bau-Bionik. Springer, Berlin.

Trabeculae of bone-spongiosa and isostatic ribs



The formation of stress-trajectories in small spongiosic trabeculae leads to analogue frame structures in buildings.

BIOLOGY:

The spongy structure of trabeculae for example in neck and head of a femur (Femur) is not oriented randomly. The single trabeculae orient themselves in relation to the trajectories of stress that is in direction of the main pressure- and tension-stresses. The lines of the same stress are at right angles to each other. In space the lines form areas (A) of the same stress, which, in each case, also are vertically to each other (comp. p. 119).

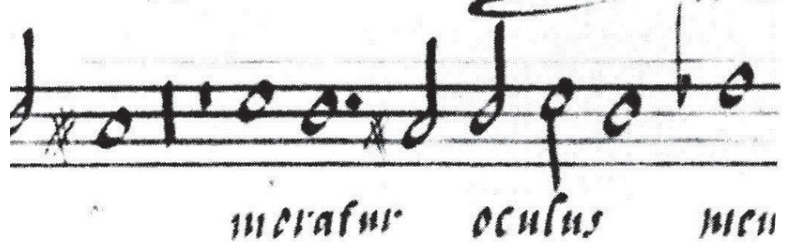
PRINCIPLE:

Frame elements which run in line with the trajectories of stress in the plain or in space, so line-shaped or shell-like, relieve themselves mutually of bending stresses which may become highly dangerous. Biological or technical materials endure pressure-forces to a certain extent, but also traction-forces to a high extent. Therefore, it makes sense to accept higher pressure- or also tension-stresses for the benefit of reduction of bending stress.

TECHNOLOGY:

One can dissolve a bearing area, for example a floor-blanket, into girders, that follow the directions of trajectories of pressure- and of traction-stresses in each case. Altogether, the frame system (B) then can become lighter than a normal-blanket. The architect P. Nervi comments in his patent-writing about concrete-elements with isostatic ribs: „One frequently finds examples in the nature, and that of the bone trabeculae ... is classic.“

LITERATUR: Kummer, B. (1962): Funktioneller Bau und funktionelle Anpassung des Knochens. Anat. Anzeiger 110, 261–293. – Nervi, P. et al. (1950): Perfezionamento nella costruzione di solai, volte ... Italianisches Patent Nr. 455678.



Bionics by Examples

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Nachtigall, W.; Wisser, A.

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