Chapter 1
Technical Biology and Biomimetics

Practicing biomimetics means learning from nature for the improvement of technology; in the various technical subject areas it is practiced with varying intensity. Of course it can be interesting or even fascinating for the engineer and the architect to dare a peek over the fence into the wealth of living nature. One must only then be cautious of a too direct interpretation. Inspirations from nature for building engineering or architecture will not function if they do not follow the in between step of abstraction. The approach of biomimetics is then a three-step process: Research → Abstraction → Implementation (Nachtigall 2010). There will repeatedly be occasions to point out this process chain, but first it is necessary to introduce some fundamental questions. How did the term “biomimetics” come into existence? Are there definitions? Why does analogue research lie at the basis?

1.1 The Term “Biomimetics”

The view that “BIONICS” is an artificial word, combined from BIOlogy and techNICS, is unavoidable. Since the 1950s this description has existed; at that time it was formulated during attempts to study the echolocation of bats for yet-to-be developed radar technology. Recently, a different terminology has been found: “BIOMIMICRY”, which literally means the “imitation of life” and does not match the goal of this book. “BIOMIMETICS” is the more recent terminology and is professionally accepted. For this reason this term will be used in this book.

The term “biomimetics” implies the understanding of biological structures and processes and their comparable technological applications, methods, or procedures.

Biomimetics is not the mere imitation of nature, neither in material and functional nor in creative regard, rather the grasping of natural principles to aid in the comprehension of analogous, technological questions, which could then be solved by the applications of optimized technologies. The term “technological application” contains all applications of the present time, be they of machine or computer technology. The term covers materials, applications, modes of operation, entities,

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design, or management. In biomimetics, it is thus about the discovering of the wealth of experience of nature to be utilized for man-made products, a practice of virtual "industrial espionage" of the most experienced researcher and developer on Earth.

In Germany, the pioneers of this field were Heinrich Hertel and Ingo Rechenberg. Werner Nachtigall performed substantial research in the areas of technical biology and biomimetics and promoted the use of "precedents in nature" for technology and economics for decades. Engineers and architects such as Richard Buckminster Fuller and Frei Otto had concerned themselves since the 1950s with "natural structures" and developed structures that have not lost any of their fascinating appeal. Otto linked "natural structures" with the aesthetic and functional expressions of buildings so that they appear logical or "natural," and with the aid of technology they accomplish similar tasks as they do in nature.

1.2 Historical and Functional Analogies

Historically, the biomimetic process developed from the comparison of results from functional morphological research with the requirements of technical constructions. Initially, this process occurred naively, as is customary when a new subject field gropingly develops. Around 1500, Leonardo da Vinci, the closest observer of bird flight of his time, developed flapping wing mechanisms, which were supposed to have functioned according to the principle of flight feathers overlapping during bird flight. One could already speak here of a "functional analogy," if the entire wing structure had not been designed so-to-speak against principles of static structure and aerodynamics. In this case and in a myriad of other "inventions" well into the twentieth century one can today remark that these inventors had paid too close attention to the *similarity of form* and neglected *functioning principles*, which represents the actual missing link for their failed or too simplified abstractions. Philosophical, epistemic approaches speak in any case of the "precedent of nature" and the "imitating technology." W.N. synthesized these issues in his 2010 book *Bionik als Wissenschaft* ("Bionics as Science"). However, earlier, more obvious attempts to integrate the analogy principle with the application of natural precedents also exist. One example is the invention of reinforced concrete.

The Parisian Joseph Monier was a "horticulturalist, paysachiste"; therefore concerned himself heavily with landscape problems. Owing to annoyance with how expensive and fragile large stone or clay planting pots were and to the clever observation that the weathered, branching sclerenchyma structures of *Opuntia* give rigidity to its leaf masses, the idea emerged in 1880 to produce pots with a multicomponent structure. A wire basket, corresponding to the sclerenchyma network in plants, gives tensile strength and simultaneously holds the pressure-resistant cement mass, corresponding to the parenchyma of plants, in shape. At the same time the cement stabilizes the wire basket form.

The fundamental idea of this application appears typically biomimetic: A principle of nature is abstracted; however no forms were slavishly copied. The natural principle would be: *Mechanical synergy of a tension-resistant cylindrical network of sclerenchyma with a pressure-resistant parenchyma matrix.* The technical principle would be accordingly: *Mechanical synergy of a sclerenchyma-analogous steel reinforcement with a parenchyma-analogous cement medium.* A new industrial branch had thus been invented, the reinforced concrete structure. Incidentally, the imaginative gardener lives on in the expression “Monier iron.”

1.3 The Form–Function Problem

However, the above-sketched fundamental concept of “functional analogies” was later lost. In 1905, C. Lie gave his mechanically driven “pilot fish” (which was supposed to have hauled one line) the form of an actual fish, with all the corresponding fins at the “biologically correct” locations. An actually efficient hauling device with the fish as precedent would look different in its essential details. The form–function problem is depicted in two well-known examples, the Sony robot dog AIBO and Frei Otto’s tree columns (1988).

Behind the popular Sony robot dog, though looks cute, wags its tail, and can pee, lies no biomimetic concept. It is simply the technical copy of a natural form (which is not a negative critique; it sells well, but it is not biomimetic). Otto’s “tree columns,” as one can observe in form in the Stuttgart Airport and under some highway bridges, do *not* look like trees yet comprise nonetheless an analogous biomimetic concept of the “structural tree.” Before their design, studies were performed on branching angles, thickness proportions, and other aspects of tree branches. Also observed was the structure of such a column, which should support a given load over a given area while having least possible mass—the functional goal of the dimensions to be optimized.

1.4 Biomimetics and Optimization

The development of the so-called “tree columns” represented an optimization problem. A further possibility to apply biomimetics for solving such problems, the evolution strategy, also exists. I. Rechenberg and his colleagues had already shown in the 1960s that one can translate the principles of biological evolution for optimizations in technology, by integrating accidents (mutation, recombination) and subsequent testing strategies (selection) in design development. The arithmetic techniques of their “evolution strategy” (Rechenberg 1973) have since been used in an increasingly important manner in the area of technology, in particular when theories for application are impedingly complex or if no basis for the optimization of certain systems exists at all. C. Mattheck (1993) also used the principles of accidents and biological optimization for his processes of “computer-aided design” (CAD) and “computer-aided optimization” (CAO). He had gained inspirations for the development of these very successful and much-used computer processes from his observations of the functions of tree forms.

1.5 From Accidental Discoveries to the Entry into the Market

Sometimes taking the dog for a walk in the forest pays off, or at least that is what happened to Swiss engineer and inventor G. de Mestral. In 1980, the journalist D. Dumanowsky described in the *Boston Globe* the invention of hook and loop fasteners as the outcome of one such walk through the forest in 1941, after de Mestral and his Irish setter had been coated in burs: “It was barely possible to get them out of his wool pants and his dog’s fur. Out of curiosity, de Mestral looked at one of the burs under the microscope. Hundreds of fine hooks appeared when enlarged. As such the bedrock for the idea of hook and loop fasteners was laid. With the use of modern production techniques arose eventually the product “Velcro”. (The name comes from two French words, “velour” (wool) and “crocher” (hook).” Although barely out on the market, the distributor made a yearly profit in the tens of millions in America alone.

Today it is almost impossible to imagine everyday life without Velcro. But one should not forget that, as a rule, a thorny path lies between a patentable idea and market implementation. With de Mestral it lasted 20 years and initially cost him a lot of money, before the product was established and became financially worthwhile. With their discovery of the Lotus effect, W. Barthlott and Ch. Neinhuis (1997) had to similarly learn the hard way, or at least over a similar timespan. Likewise, it had lasted 20 years from the first microscopic studies of the nub structures on the lotus leaf to the successful façade coating “Lotusan,” which has now been provided for hundreds of thousands of houses.

Biomimetic ideas and biomimetic products are simply two different things. Who attempts such an endeavor requires patience, a good patent attorney, and some money. In recent history, interested firms have been unwilling to stick money into the development of a nature-based concept, which is patented and made ready for the market for a high cost, only for the idea to be quickly stolen after a few years. They develop something instead in concealment and throw it onto the market, where it can redeem its cost over maybe 2 years, before cheap(er) copies flood the market.

1.6 Nature and Technology—Antagonistic?

W.N. has, since he began concerning himself with biomimetics in the 1960s, always differentiated between “Technical Biology” and “biomimetics in the actual sense,” which he demonstrated in numerous publications; a selection can be found in the literature appendix. Fundamentally, they are only two different perspectives that connect nature and technology. Both belong inseparably together.

Technical Biology investigates the structures, processes, and evolution principles of nature from the viewpoint of the technical physicist and related disciplines. *Biomimetics* attempts to project these base results backwards to technology and to give inspirations for modern solutions better suited for people and the environment.

As already mentioned in the foreword, there is no reason today why nature and technology should be considered so separate, as before. Exactly the opposite: Only when we overcome the boundaries with a meaningful integration, when we realize that the biology-oriented and the technology-oriented disciplines can learn from one another, progress can be achieved.

The engineer should no longer only simply take note of an entire world of structures, processes, and development principles, but use the wealth of knowledge found in nature, wherever it is suitable and meaningful.

The biologist, on the other hand, should no longer be content with simply collecting data and letting himself disappear behind the books in a library. He should be empowered to engage with the structural engineer and offer him insights and perspectives. This encounter should be allowed to reach the limits of reasonableness: Only then can we break out of gridlocked, seemingly unalterable, predefined paths.

G.P., since he began his work on biomimetics as a young architect in the late 1980s, has been deeply influenced by Frei Otto and his ideas when they met each other as teacher and student at the University of Stuttgart. G.P. has worked as an architect since then, using biomimetic inventions when the benefits promise a positive outcome for his building designs. Biomimetics functions as one design tool among other various possibilities of gaining knowledge within a holistic design process.

1.7 Classical Definitions of Biomimetics

The discipline of “bionics” or “biomimetics” is established within the realm of nature sciences, and the term should be therefore scientifically and clearly definable. Particular definitions always reflect the zeitgeist; they gain, however, more precision through the ongoing process of knowledge, as to be found in the following three definitions.

From the beginning of the 1970s W.N. defined bionic/biomimetic work as follows**:** “Learning from nature for self-sufficient, engineerable design.” Nature provides inspirations that the engineer should not simply copy, but incorporate into the structural design—in the art of his or her science. One can also state, “Nature delivers no blueprints for technology,” and therefore underline the viewpoint that general stimuli from the most diverse sources can have influence on technical design. However, direct copies never lead to the ultimate goal.

In a convention of the Association of German Engineers (VDI) for the “analysis and evaluation of future technologies,” Düsseldorf 1993, which stood under the motto “Technology Analysis Bionics,” the attending technical biologists and biomimetics scientists agreed on the clause, quoted earlier in the foreword (Neumann 1993):

> Bionics/Biomimetics as scientific discipline is concerned with the technological implementation and application of structural, procedural, and developmental principles of biological systems.

Bionics is then accordingly a discipline of applied science. The profit of insights and each aspect of biomimetic interpretation always have their bases in the essence of biological systems.

In recent years, the understanding has been established that the VDI definition from 1993, which was intentionally narrow on the grounds of precision and differentiation, should be broadened. In particular, it could not bear one important fundamental aspect of biomimetics, namely influencing technology, so that it can provide a stronger connection between humans and environment. W.N. then suggested the following condensed alternative:

> Learning from structural, procedural, and developmental principles of nature to form a positive network of man, environment, and technology.

This formulation then also encompasses interactions between environmental influences and living beings.

The German VDI set up a work group that further considered such questions and developed specifications for standards of the biomimetic process. However, science can by definition never reach an end point. The current insights from the work on the VDI guidelines, on which G.P. had collaborated, can be found in Chap. 3.

1.8 Biomimetic Disciplines

The subjects of biomimetics can be summarized by the three fundamental disciplines of structure biomimetics, process biomimetics, and development biomimetics.

Structure biomimetics pertains to issues of substances, materials, prosthetics, and robotics.

To *process biomimetics* belong the corresponding viewpoints of climate and energy, construction and possibly architectural design, sensor technology, and ultimately kinetics and dynamics of machine construction.

Development or evolution biomimetics ultimately encompasses areas of neurophysiology, the already implied aspects of biological evolution, and also corresponding viewpoints of procedural and organizational methods.

Therefore, building and architecture biomimetics can be sorted in the broader framework of biomimetic disciplines. However, these subdisciplines must not be strictly held under the banner of "process biomimetics," although there they have their main position, as building and design are processes. Naturally, they encroach into structural biomimetics, especially when it comes to building and insulating materials. Ultimately, they also play an important role in development biomimetics, when a building structure—which in view of drastically more complex structures such as sport halls happens increasingly often—must be processed again and again to produce new variations with a trial-and-error method on a computer.

1.9 Biomimetics for Architecture and Design: Basic Aspects

Biomimetics offers no methods with which one can directly implement into our technical processes. Biomimetics for architecture and design may be translated from the German expression "Bau-Bionik" to "building biomimetics," meaning biomimetics that aims on aspects of architecture and/or design. "Building biomimetics" will then still not be a method to directly build houses or design Items. However, the large range of natural precedents certainly offers the potential of finding new ideas. The difference lies in the fact that the idea generating process in this field can both lie away from the technical paths, more with the natural precedents, and still lead to concepts based on synthetic and technical aspects. In the end, both methods are often mixed. It will be therefore difficult to find a pure "biomimetic" structure, and often only parts of structures are biologically inspired (thus "biomimetic"). If the defining components of a building or building part are biologically inspired, then the building as a whole can then be designated as "biomimetic."

Architects, building engineers, and designers use the research results of biomimetics as a design approach; they actively employ biological insights as design methods or design tools. Biomimetic work itself is defined by its methods; biomimetics is then actually not to be seen as a discipline of the sciences.

Certainly, biomimetics broadens the horizon and offers an incomparably detailed basis for the abstraction of natural precedents, which could or does already enter into the creative design processes of building engineers and architects in various modes. Chimney structures of termites for example have provided inspiration—and also more broadly and to a larger extent—for solar-driven thermoregulating ventilation systems in Europe and Africa. One recent, well-known example is the ventilation system designed by the firm Arup for the East-Gate Hall in Harare, Zimbabwe.

With the translation of inspirations from the living world into technology world must—and we will always be referencing and are addressing here once again the foreword from the first edition—be cautious and cannot expect the impossible. A direct copy never leads to the goal. If, however, a fundamental idea from nature is grasped, for example, the environmentally neutral thermoregulating ventilation from solar effects, then the inspirations can provide for stronger technological–biological handling of these aspects and their biomimetic application in the engineering sciences. One must only understand that nature delivers no blueprints and that their structures and processes are not easy to appreciate or behold much less implement. However, they are present in multitude.

Of course, it cannot hurt to remember once again the principle of biological–technological and technological–biological analogies. Ventilation systems of termites and those of technology are *analogous systems*. Such systems can always be developed in principle in two manners. Either nature provided the driving stimulus, in which case technical structures are further developed under the umbrella of the engineering science disciplines or the development occurred without the knowledge of the nature to such structures. In this instance, one establishes a posteriori a functional consistency, inventing analogous structures. On this basis of comparison nature can be more subtly observed.

With the insertion of technical know-how, natural structures can often be much better understood than under biological viewpoints alone. A better understanding of this kind in turn offers a more advantageous basis for implementation and so forth.

Thus, a discipline is then able to learn from the other.

1.10 Nature and Technology as Continuum

In the end, all research activities mean nothing other than chipping away at a large continuum, even if it is at different corners and with different tools. Natural evolution has lead to fantastic structures, processes, and developmental principles long before there were humans on this planet. Ultimately, evolution is also the source for the human physiological–mental capacity and only from that could the idea of human technology even be conceived.

Thus, technology is nothing other than the continuing of natural evolution with another means. Therefore for us technology is, epistemically speaking, not something "principally different." We see, aside from pragmatic needs for differentiation, no compelling reason why nature and technology should then be considered as opposites, as it has occurred in the past.

Rather, technology and nature form parts of a continuum. This fact can either be statically understood, or it can be further developed and used. The tool for that is biomimetics. Not the only and surely not the most important.

But in many aspects the best.