Chapter 7
Biomimetics in Architecture [Architekturbionik]

Petra Gruber

Abstract This chapter presents an overview of this emerging field, investigating the overlaps between biology and architecture. A brief description of historic developments and classical approaches such as analogy research sets the stage for a strategic search for a new methodology of design. Different methods of biomimetic design are compared with regard to information transfer. Application fields in various scales and successful examples in architecture are presented to illustrate the use of basic biological phenomena such as emergence, differentiation, intelligence and interactivity in a technological as well as designed environment. Own projects as case studies in biomimetic design are described and compared to derive success factors for future projects.

7.1 Introduction

Biomimetics in Architecture [Architekturbionik] is an emerging field that is currently being defined and explored. The application of observations made in nature to architecture has always been a challenge for architects and designers. The strategic search for role models in nature is what discerns biomimetics from the ever-existing inspiration from nature. While bioinspiration may be limited to a morphological analogy, biomimetics makes use of functional analogies, processes, mechanisms, strategies or information derived from living organisms.

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The term “biomimetics” appeared in the 1960ies, at about the same time as “bionics” was coined, that found its reinterpretation in the German “Bionik”, the combination of the first and last syllables of the words “Biologie” (biology) and “Technik” (technology) [1]. Meanwhile Bionik/Biomimetics is widely accepted as an interdisciplinary science that delivers innovation in a wide range of application fields. Architecture, design and building are promising fields for biomimetic innovation.

7.2 History: Different Approaches

The overlaps between biology and architecture are manifold, and observation of interactions is based on the western culture of opposing nature and technology, often ignoring the dialectic perspective of interactiveness and mutual influence. As Portoghesi puts it: “Being an integral part of nature ourselves, we shall never be able to talk about it from the outside but only from the inside, uncertain whether to consider something created and produced by man as being ‘outside’ nature” [2].

Current developments as described in the following increasingly use a biological paradigm to overcome this separation.

Many movements in the history of architecture have taken their own approaches to nature, and famous architects such as Alvar Alto, Frank Lloyd Wright and Le Corbusier have laid emphasis on this connection. A chronological discussion of the history of architecture is beyond the scope of this chapter, but some important examples of the last century will illustrate the diversity.

A defined starting point in time for biomimetics in architecture cannot be stated. Inspiration from nature in architecture has existed at all times. The first human dwellings were natural shelters, and archetypes such as caves and trees have been used as models for architectural design throughout the history [2]. Biomorphic designs mimicking formal aspects of biological models were extensively used in many architectural styles, for example anthropomorphic floor plans in vernacular building traditions. Natural materials were used to build shelters and houses, and technologies to harvest and process materials were invented and are being continuously developed further until today. Technology is one of the main driving forces for architectural development. The formal transfer of constructions out of ephemeral building materials to durable building materials such as stone is a well-known phenomenon in architecture history, and is a source of information on historical building technology. In Egyptian temples, phytomorphic analogies, forms relating to plants, found in stone columns indicate the use of reed bundles and trunks of palm trees as construction elements, and many other examples refer to symbolic as well as pragmatic use of natures models [2].

The Renaissance genius Leonarda da Vinci, who strategically used nature as a model, is often presented as first biomimeticist. The historical analysis of patents derived by natural models revealed that reinforced concrete, one of the most common modern building materials, was invented by the French gardener Joseph Monier. He experimented with wire mesh to make plant pots more durable after having noticed the sclerenchymatic fibre structure, the strengthening tissue, of decaying parts of opuntia, the prickly pear [1]. This very influential biomimetic invention enabled architects and designers in the last century also to reform nature in organic designs.

Hence in the 1950s, Pier Luigi Nervi, Gio Ponti and Oscar Niemeyer exploited the structural potential of concrete, while others like, for example, Eero Saarinen with his TWA Terminal and Jørn Utzon with the Opera house in Sydney took a more biomorphic direction. The asymptote of design of organic space was Frederic Kessler's so-called Endless house [3].

Findings in natural sciences strongly influence architecture and arts, as can be shown among many other examples by the work of biologist Ernst Haeckel [4] that has been cited and reinterpreted from the turn of the twentieth century until today, for example by the designer Luigi Colani [5]. Representatives of biomimetics in architecture and theorists having researched the overlaps between nature and architecture will be presented in the following.

7.2.1 *Analogy and Convergence*

The work of Frei Otto and his group in Germany was focused on "natural constructions", a concept encompassing many interesting properties, both in nature and architecture [6]. The concept of "natural constructions" is ambiguous and can include:

- Constructions and structures observable in nature, at all scales and levels of hierarchy, from the nanosurface of the lotus leaf over materials, cells, tissues, organs, populations and ecosystems to the universe itself (if non-living phenomena are included)
- Buildings of animals that have evolved over a long time
- Traditional human building typologies that have developed over a long time
- Architecture showing any natural aspect, for example sustainable design

Frei Otto used an experimental approach that he called "synthetic analogy research" to gain understanding of natural structures and processes like, for example, minimal surfaces and the geometry of soap bubbles and foam. Principles of self-organisation in nature were investigated to be used for form finding. Decades of research and experimental development of methods, structures and materials brought about many very inspiring publications on natural constructions and the development of a novel building technology and typology: modern membrane constructions. The same approach – but with less influence on building technology – was used by the famous Antoni Gaudi and Heinz Isler, who developed a refined technology to build ephemeral shell structures [7, 8]. All three experimented with hanging models to find optimised forms – gravity and self-organisation were used to develop efficient building structures with the least possible amount of material. The search for light constructions culminated in the discovery of the so-called tensegrity structures by Buckminster Fuller and Kenneth Snelson in the 1960s [9]. Tensegrity structures are self-stressing and have remarkable mechanical capacity compared to the amount of material needed. The structures consist of tensioned elements, ropes that create a continuous subsystem and elements under compression, which create a discontinuous subsystem. The construction of vertebrates and the cytoskeleton of cells seem to follow the same construction principle – an interpretation that was found by Donald Ingber, who was inspired by Fuller and Snelson's discoveries [10], and one of the many examples of reverse information flow.

7.2.2 Strategic Search for the Overlaps Between Architecture and Nature

In spite of the obvious importance of the connection between nature and architecture, few attempts to strategically investigate the topic were made. Smaller fields such as zoomorphic and anthropomorphic architecture were explored, the focus lying more or less on the morphological aspect [11, 12].

Paolo Portoghesi compiled the encyclopaedic book "Nature and Architecture", which is not only the most extensive collection of analogies between nature and architecture, but also discusses structural and functional parallels [2].

The first book on "Architekturbionik" was published by the Russian Juri Lebedew in the 1970s and presents a comprehensive collection of then up-to-date architectural developments worldwide, which relied on principles derived from nature, even if their creators did not think of themselves as biomimeticists [13]. Werner Nachtigall published a book on "Bau-Bionik" focusing on analogies in construction, and using structural categories to order natural constructions like fibre reinforced structures, shells, folding structures or membranes [14]. Nachtigall also refers to vernacular architecture as a source of solutions especially concerning climatisation and building physics, and presents current projects that integrate principles like natural ventilation.

Christopher Alexander has described in his life's work "The Nature of Order" an architectural interpretation of life and convergent pattern emergence in nature and architecture, stating the importance of living structures as surrounding for human existence [15]. Alexander is convinced of the necessity of a paradigm shift, from the mechanised processes to widespread overall living processes that involve unfolding wholeness and fundamental differentiation. He defines a living process as any adaptive process that generates living structures, step by step, through structure-preserving transformations. Alexander's approach is not biomimetic, but investigates and applies the topic of life and aliveness in an architectural context.

The "Design and Nature" conferences were launched in 2002, providing a forum for a broad approach exploring nature and its significance to design and architecture [16, 17]. The book "Nature Design" focuses on the relation between nature and the broad field of design, and presents current as well as historic examples. Four essays trace the historical changes in the relation between nature and design from the nineteenth century until today and establish connections to the respective political and economic developments [18].

The author's Ph.D. thesis on "Architekturbionik" [19] is the first strategic search in biomimetics in architecture carried out since Lebedew's groundbreaking work. The use of the so-called criteria of life as an ordering system to categorise current architectural developments is a new approach to investigate the overlaps between nature and architecture. Imposing the life sciences terminology to a technical realm delivers insights that could not be made otherwise and suggests future fields for experimental development. The exploration of the signs of life in architecture has shown that many of our current developments in architecture are based on one or more aspects related to life, for example sensing and reaction, growth, locomotion and others. Morphogenetic and evolutionary design strategies are still key issues in the current architectural discourse and implemented into architectural design by many research groups.

7.3 Strategies: What is Transferred and How is it Done?

7.3.1 *What is Transferred?*

The transfer of information from one discipline to the other is the most interesting part of the biomimetic process. The transfer of form, the application of morphological characteristics is most common in architecture and design and cannot be excluded from discussion. Furthermore, the symbolic meaning is important, as Sachs puts it *...that forms inspired by nature become topical when modern society finds itself in crisis, and that the use of organic forms is intended to bring about harmonization and reconciliation with an external world perceived as hostile or uninhabitable* [18]. Even more general than the investigation and transfer of "natural constructions" is the transfer of qualities that can be found in nature. Talking about interesting "natural phenomena" would include for example the play of light falling through foliage, emerging from a complex interplay of different parameters in animate as well as inanimate nature. Nature's phenomena can include surfaces, materials and/or structures, functions, constructions, mechanisms, principles (e.g. self-organisation) or processes (e.g. evolution), delivering models to be analysed, abstracted and applied to architectural solutions on all scales and levels of design (Fig. 7.1).

7.3.2 *Methods*

The following methods are used in biomimetics in general. Two different approaches to biomimetic information transfer can be discerned according to the direction of information flow respectively starting point of the search.

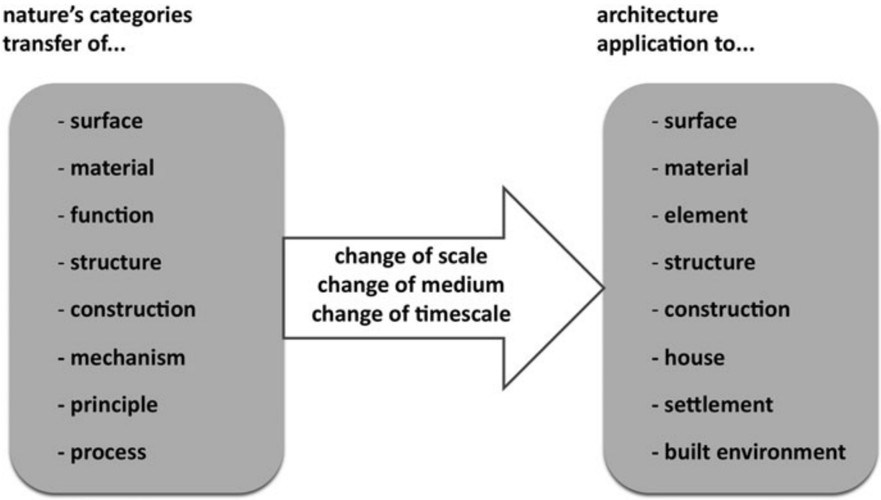


Fig. 7.1 Scheme of nature's categories, information transfer and application, based on [19]

- Biomimetics by induction – bottom-up – solution-based
  - Takes the phenomena found in nature as a starting point, solution-based approach
- Biomimetics by analogy – top-down – problem-based
  - Takes the problem in technology as a starting point, problem-based approach

The terminology "top-down" and "bottom-up" in this respect was introduced by Speck and Harder [20], together with a step-by-step description of activities involved occurring during a biomimetic innovation process. Gebeshuber and Drack criticise that this implies a ranking between nature and technology, and suggest the use of "Biomimetics by Induction", respectively, "Biomimetics by Analogy" instead [21]. Researchers at the Georgia Institute of Technology at the Center for Biologically Inspired Design have described similar processes in detail that they name "solution-based" and "problem-based" approaches [22]. However, all groups describe similar processes, and the experiences made with designing with nature as a model seem to share similarities. The abstraction phase following profound research in the life sciences is considered crucial for the success of transfer. Reduction of complex information and identification of relevant parameters and boundary conditions are necessary for this step. In order to keep options wide at the beginning of information transfer, it is advisable to not categorise too strictly, but to follow the paths of (also very personal) interest using intuition as an important guideline.

Both methods, solution-based as well as problem-based biomimetics, involving both directions of information flow, were used in the design programmes guided by the author, and the implications and outcomes will be discussed in the case studies section (Fig. 7.2).

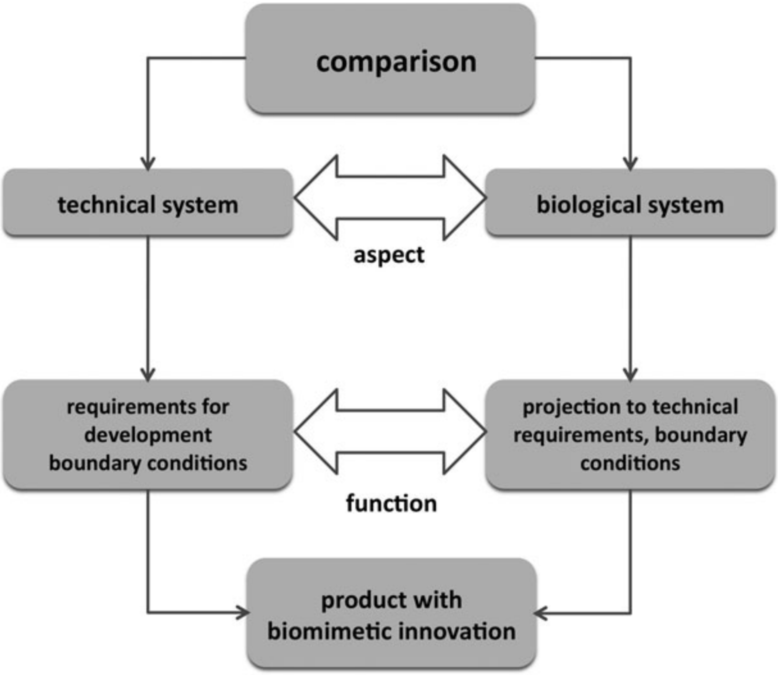


Fig. 7.2 Comparative approach to biomimetic transfer, based on [1]

In the method of Biomimcry, the transfer of functional aspects is the most favoured approach, stemming from the hypothesis that all existing constructions and structures in nature have a functional cause, and that function is the key to the establishment of suitable analogies. In contrast to biomimetics, environmental responsibility and sustainability are directly implemented into the innovation process. Innovation is understood in the notion of a necessity to push industrial developments towards a sustainable future. Biomimicry principles are used as guidelines and evaluation parameters for the innovation process [23].

BioTriz is a general biomimetics-based innovation tool, set up by a group of researchers around Julian Vincent at the Center for Biomimetics in Bath. The system is based on Altshuller's "Theory of Inventive Problem Solving" that was developed in the 1960s based on the analysis and statistical evaluation of technical patents to identify key innovation principles. A TRIZ-based analysis of problem solutions in nature has shown the profound difference of design in nature and design in technology, while technology solves problems largely by manipulating usage of energy, biology uses information and structure [24]. Only recent technologies such as nanotechnology and smart materials work in a more "biological" way. BioTriz is the adaptation of the system to "green" innovation, coming from nature rather than technology [25].

The system of BioTriz and the Biomimicry principles currently gain access to the world of architecture and engineering. One of the largest engineering companies worldwide, Arup, refers to Janine Benyus Biomimicry principles and researchers of Buro Happold that offers multidisciplinary engineering consultancy make use of BioTriz to develop innovative building technology [26, 27].

7.4 Application Fields: Successful Examples

Application fields in architecture are found on all scales, from nanoscale surface definitions over buildings and elements to urban design. The complexity of architecture, its existence on many levels is on the one hand very interesting, as many possibilities for biomimetic innovation exist, but on the other hand it is impossible that all levels are involved in a biomimetic development.

Biomimetic innovation may, for example, only concern technical aspects that are integrated into building technology, or may be limited to the use of a biomimetic surface structure, such as the "Lotusan" paint (a product with self-cleaning properties, developed by the STO company in 1999 based on the "Lotus-effect" patent of Prof. Wilhelm Barthlott).

For this reason, the visibility of a biomimetic approach in the final design is not guaranteed, and not always aesthetic quality is involved. On the other hand, "bionic architecture" starts to be introduced in the public as a new kind of what used to be called "organic architecture", and "bionic" is increasingly used for advertising purposes. Holistic visions of a biomimetic architecture range between naïve romanticism and futuristic experimental design. The design proposals for a "Vertical Garden City", the so-called Bionic Tower of two Spanish architects, were promoted as the first existing model of a "bio-ecological urban structure", in spite of numerous less-known serious attempts to sustainable design in high-density structures [28]. Based on flexibility principles and biological structures, it is said to be adapted to the different economic, environmental and social conditions of the cities where it is built. But the definition of a "biomimetic architecture" as a new style seems as impossible as that of a "bionic car", a concept car developed using the formal analogy of the boxfish and biomimetic optimisation strategy. What can be stated in this example is valid for architecture as well as other disciplines: a biomimetic approach to novel solutions concerning a limited number of aspects of the design is used. For the different architectural scales, selected recent architectural examples are presented in the following, with regard to the qualities that have successfully been transferred.

7.4.1 Emergence and Differentiation: Morphogenesis

Emergence and differentiation are in the focus of the "Emergent Technologies and Design" masters programme at the Architectural Association in London. Michael Weinstock, Michael Hensel and Achim Menges' team elaborate refined structures in close collaboration with experts in biomimetics, mathematics, structural engineering and material science, investigating novel technologies. Material systems are developed, which integrate form, material and structure according to the structures found in nature. The projects that were developed by the students within this frame explore, for example, dynamic relations and behaviour of occupation patterns, environmental modulations and material systems, in natural as well as computational environments. Morphogenesis is investigated as a new design strategy, based on dynamic adaptation processes [29–31].

7.4.2 Interactivity

Kas Oosterhuis and his Hyperbody Research Group at the TU Delft explore what they call the “building body” [32].

Protoarchitectural projects experiment with reactivity to environmental influence and control. “Hyperbodies are pro-active building bodies acting in a changing environment. The HRG [Hyperbody Research Group] introduces interactivity not only in the process of collaborative design, but also during the use and maintenance of buildings” [33]. The biomimetic fluidic muscle finds application in architecture as easy to implement pneumatic actuation system for kinetic systems. One example is Oosterhuis’ exhibition project “Muscle”, a pressurised soft volume wrapped in a mesh of tensile Festo muscles, which can change their own length [34]. The muscles generate an apparent uncontrolled overall behaviour by moving according to programmed control, and in interaction with the visitors [35, 36]. Interactivity on a symbolic level is exploited by numerous architectural projects around the “media facade”, which may be biomimetic due to reactivity and/or control.

7.4.3 Dynamic Shape

Shape change in architecture is the result of a morphogenesis, which is not static any longer but a constant dynamic process of interaction between the building and the environment. One of the first built structures that actually changes internal space is Transformer, a temporary, shape-shifting structure designed by Rem Koolhaas in Seoul, South Korea. The pavilion consists of a steel structure wrapped in a translucent elastic membrane. The 20-m high structure has to be picked up by cranes to be rotated [37]. An unbuilt but widely published project is the “Rotating Skyscraper” by David Fisher, to be realised in Dubai. The idea of changing orientation by rotation is not new, but the dimension of the project exceeds the scale of rotating architectures that were built until today (e.g. the single family house Heliotrop in Freiburg, Germany). The Rotating Skyscraper consists of a central core, with the single floors cantilevering and rotating independently, thus changing the orientation of the floor plans and the overall form and appearance of the building [38]. Experiments for adaptive structures are carried out at the Institute for Lightweight Structures and Conceptual Design in Stuttgart. Patrick Teuffel investigated the adaptation of structures by changing the stiffness or lengths of individual elements to manipulate the flow of forces. He developed a design concept for adaptive systems, the so-called load path management, a system that dynamically adapts shape to load, thus replacing mass through energy in using a “virtual” stiffness due to actuation instead of physical stiffness [39]. These projects represent the validity of the biological paradigm in current architectural development, without directly using a biomimetic approach.

7.4.4 Intelligence

Control is also an important issue in “intelligent buildings” that are intended to provide an environment that adapts itself to the needs of the inhabitant in many ways. One way to implement smartness in buildings is the use of smart elements or materials that can react to environmental influence. Research and development in intelligent building technology is focused on integration of sensors in architecture, development of heating, cooling and ventilation systems, and on the overall control of this environment, in interaction with the user [40]. Biological models for the behaviour of integrated control systems are investigated by many research groups, also at the Vienna University of Technology, for example by the Institute of Computer Technology [41].

7.4.5 Energy Efficiency

Energy efficiency is one of the most important aspects linking biomimetic visions with living nature. As building facades represent the interface between internal space and environment, facade technology is a focus of research in energy efficiency of architecture. Biomimetic approaches are manifold and range from diverse adaptations of cacti to hot climate and intense solar radiation [42, 43] to ivy as model for a solar energy harvesting system, which can be added to an existing facade [42, 44]. Salmaan Craig developed energy-efficient building surfaces using BioTriz, and in this way working with a variety of models from nature delivering functional solutions [27]. Lidia Badarnah is part of the Facade Research Group at the TU Delft that investigates the use of biomimicry as innovation tool mainly for building envelopes [45]. Dirk Henning Braun compiled an analysis of different role models from nature for a visionary adaptive permeable skin structure [46].

Apart from facade concepts, ventilation is another key issue. Natural models like the termite mound and other passive ventilation systems in nature inspire innovative building technologies, even if the phenomena may not yet be fully understood [47].

7.4.6 Material/Structure/Surface

The differentiation between material, structure and surface is no longer valid when working with nature as a model, which is important also for biomimetic approaches to energy efficiency of facades. Research and development takes place on more than one scale; so the topic of energy efficiency is strongly connected to the influence of nanotechnology in architecture. Nanotechnology is the discipline of researching and manipulating materials on the scale of molecules and atoms, providing entirely new possibilities for the development of materials with desired properties. The use of smart materials that can react to changing environmental conditions has already become common in building industry. Self-cleaning and easy-to-clean surfaces are applied in the glass industry and as coatings of construction materials and products. Other functions of already available nanotechnological surface coatings include anti-reflectivity, switchable transparency and darkening in photochromic glass, anti-fingerprint, fire protection, antibacterial, scratch proofness, air cleaning and microcapsules for fragrances [48]. Self-healing, self-repair and autonomous energy supply are functions that already require nano-stucturing beyond surface coating. Self-organised healing and repair of elements are especially interesting in cases where local failure would lead to a total system breakdown, as in airplanes, space technology or in pneumatic structures, which rely on air pressure to maintain structural integrity. Self-repair according to natural self-repair mechanisms in plants is explored by the Plant Biomechanics Group in Freiburg and applied to polymer materials and membranes for pneumatic constructions [49]. Self-organised crack polymerisation is experimented with for use in space applications and in concrete. Hollow glass fibres filled or microspheres with polymer matrix are integrated into composite materials. The breakage of the containers and the following release of the sealing matrix fulfil the tasks of detection and solution at the same time [50]. Biological models for effective reversible and high adhesion like the gecko foot and seashells are experimented with [51] also for expected implementation in building industry.

7.4.7 Integration

The topic of integration has a diversity of notions in the context of biomimetics in architecture. Integration of material, structure and surface is not a new idea, but new micro- and nanosystems production technologies boost developments in this field. The goal of a research project at the Massachusetts Institute of Technology in the USA that explores hierarchical combination of Carbon nanotubes is to generate a material architecture that governs a combination of structural, optical and fluidic behaviour. "Construction *in vivo*" is a novel approach to designing, fabricating and maintaining building skins by controlling the mechanical and physical properties of spatial structures inherent in their microstructure. This material can be differentiated and adapted according to local and global context [42, 52]. On a macro-scale, fibre composite materials lend themselves for the production of hierarchical material and the integration of functional elements. Research at the ITV Denkendorf in Germany explores the production of differentiated fibre composite structures with pultrusion technology, following principles derived from plants [53]. The technology of pultrusion (a synthesis of the terms pull and extrusion) that produces composite fibres with continuous cross section is combined with a braiding technology to create three-dimensional structures.

Integration of nature into architecture seems to increase with the density urban structures are populated – developments towards integrative concepts come from countries with very high population density: Ken Yeang's concepts of green skyscrapers, which intend to enhance quality of life and integrate architecture into a cycle of resource and energy flow, were designed for urban areas in southeast Asia. The architecture firm MVRVD's world expo 2000 project of a stacked landscape came from the Netherlands, one of the most densely populated countries in Europe. Building with nature is another integrative concept, which is used by the so-called Baubotanik group in Stuttgart, which makes use of living trees for architectural structures like bridges and pavilions, together with a biotechnological approach concerning the connections and integration of technical elements [54].

7.5 Case Studies

The author has more than 8 years of experience in biomimetics in architecture, comprising guidance of students projects at the architecture faculty of the Vienna University and Technology, design programmes, workshops and academic studies [19, 55, 56]. The outline of the programmes and a selection of resulting projects will be presented and analysed in the following.

7.5.1 Biomimetics Design Exercise

Biomimetics was introduced at the "Department for Design and Building Construction" at the Vienna University of Technology as part of a special education in membrane constructions. Within this frame, a combination of lectures and design exercises were carried out, using a thorough inductive approach, based on the personal fascination for a natural phenomenon [55]. Approximately 60 students per year attended the course, and about 25% of the design exercises were successful in delivering innovative architectural concepts (even if far from being realised). Challenges for the students ranged from selection of an appropriate model to finding of scientific information, interdisciplinary scientific research, understanding and abstraction of a principle to the identification of an application field and scenario. In many cases, scientific information about the selected phenomenon was not

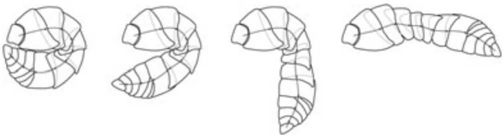


Fig. 7.3 Geometrical analysis of pill bug [57]

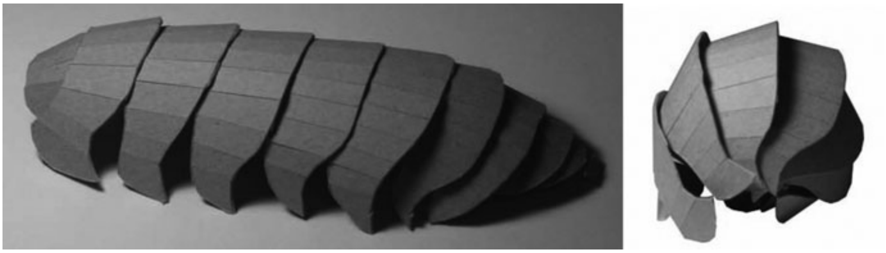


Fig. 7.4 Model of pill bug shell, open and coiled up state [57]

accessible. In particular, when spatial issues in tangible scale were of interest, the students themselves carried out research. In some cases, this basic research exhausted the timeframe of the programme, but delivered surprising insights for further studies. The examination of the geometrical characteristics of the pill bug, for example, delivered insights about the functional morphology of the segmented outer shell. The geometry of the segments and the position of the pivot points lead to the almost spherical form of the coiled up animal [19, 57]. This is a very interesting system considering the efforts of mathematicians and designers to define patterns for the tiling of spheres and curved shapes in general (Figs. 7.3 and 7.4).

Interest in spatial development or dynamics was characteristic for many natural phenomena that were selected by the students. A successful translation of crystal growth was carried out by Kieser/Oberndorfinger, who developed a pneumatic structure that could change its overall shape [19, 58]. The system could be applied to create a flexible space (Figs. 7.5–7.7).

The research of adaptive systems and the transfer to architectural applications were issues that many students were interested in, obviously also inspired by the current architectural discourse. Smart, reactive and interactive elements were designed inspired by biological mechanisms investigated in a variety of plants and animals. The inspiration for the experimental design project "aero dimm", a pneumatic facade with colour change option, came from the colour change of cephalopod skin: Between two layers of a facade, elastic membranes change volume by pneumatic pressure, creating dark parts on the surface. The ventilation tubes can be integrated into the inside membrane of the system. "Aero dimm" could be used for facade darkening as well as colour change (Fig. 7.8) [19, 59].

Reasons for failure in achieving a biomimetic transfer were manifold – simple disinterest in nature, limited knowledge, selection of unexplored phenomena,

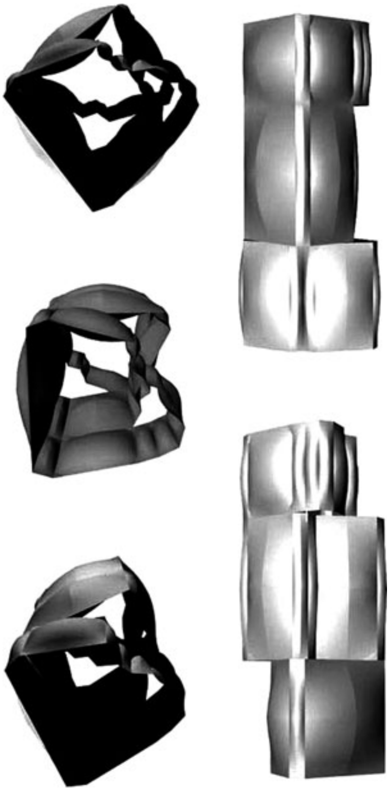


Fig. 7.5 Pneumatic structure, inspired by crystal growth processes [58]

superficial examination, inability to identify abstract principles, misinterpretation of the phenomenon and scaling problems to name a few. Successful transfers were characterised by a focused research phase and precise abstraction of a principle to be applied in architecture.

7.5.2 Biomimetics Design Programmes, Workshops and Studies

The design programmes were carried out at the Department for Design and Building Construction at the Vienna University of Technology. The introduction of biomimetics in larger design programmes required the introduction of a problem-based method, as given architectural tasks had to be dealt with. The usual timeframe for a design programme is one semester. In all programmes, the approach taken in was a combination of problem- and solution-based approach that included the following steps.

First, a broad search for interesting phenomena was used, which identified groups of organisms and aspects that were assumed to be in some way interesting for the given task. A research phase delivered scientific information on these phenomena.

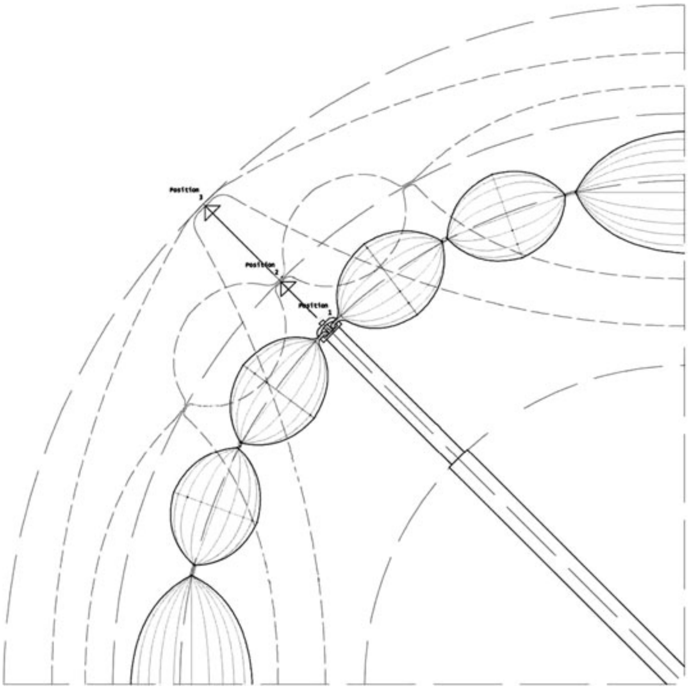


Fig. 7.6 Construction detail [58]

The many options were then gradually narrowed down using evaluation systems that were based on the boundary conditions of the architectural task. The selected examples were explored in depth, effective principles identified and applied to a specific architectural assignment.

Two projects aimed at the development of architectural solutions for outer space: “Transformation structure/space” (2004) and the study “Lunar Exploration Architecture” (2006), a study for the European Space Agency [60,61]. Biomimetics was used to find innovative designs for deployable structures for a lunar base.

The workshop “Bioinspired facade design” was carried out in 2007 in collaboration with the London-based architecture firm Horden Cherry Lee Architects and a British surfboard company, Beach Beat surfboards. A team of architects and engineers accompanied the programme from the Vienna University of Technology. In contrast to other case studies, the task was clearly defined: the scope was to design a specified part of facade cladding for a high rise building, with a specific material technology that was taken from the sports industry, where high-performance materials are commonly used and developed. Based on investigations on repetitive structures in nature, for example locomotion rhythms of earthworm [62], bark of trees, fractal structure of human lungs, etc., and on fibre composites technology, four different design projects were developed until prototype stage (Figs. 7.9–7.11).

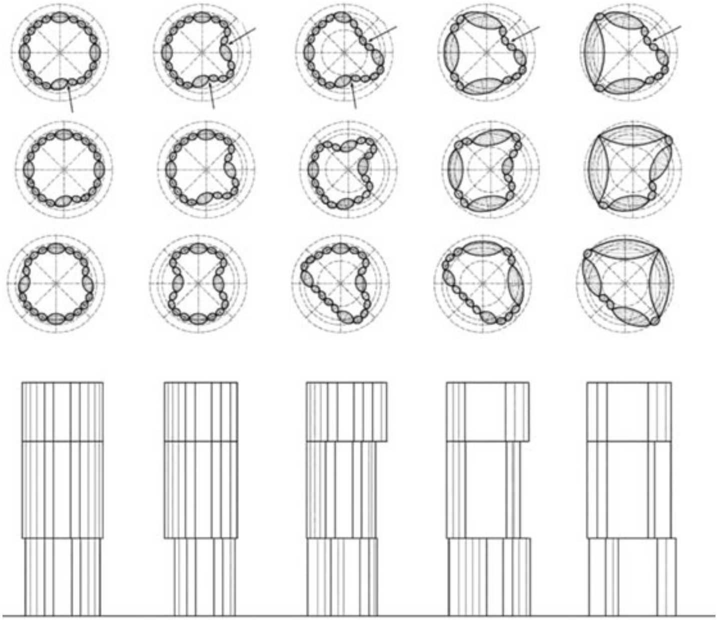


Fig. 7.7 Possible variations of the pneumatic space, sections and elevations [58]

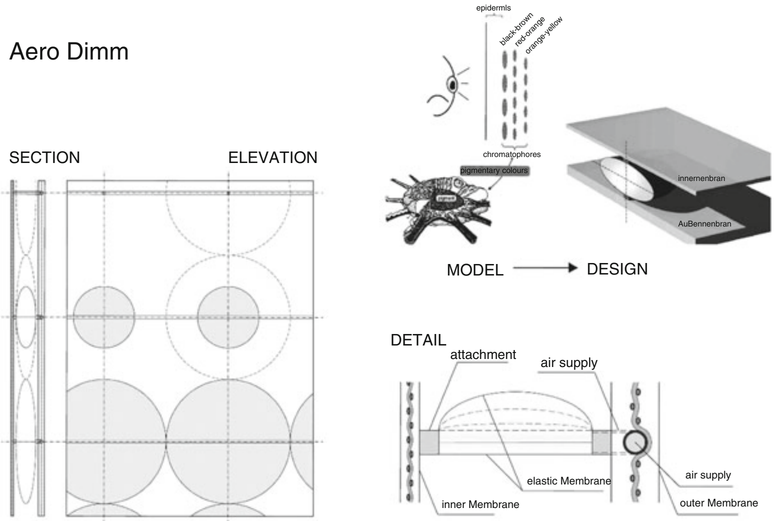


Fig. 7.8 "Aero Dimm" – inspired by cephalopods, pneumatic facade darkening [59]

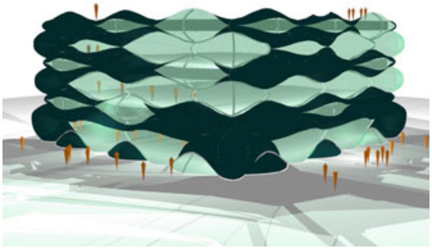


Fig. 7.9 “Worm” project, bioinspired facade design workshop, visualisation [62]

Fig. 7.10 Prototype model of facade element, fibre composite material [62]

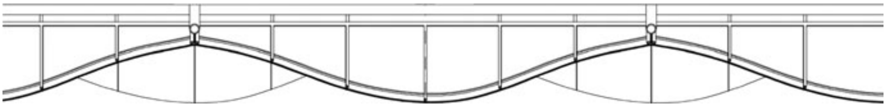
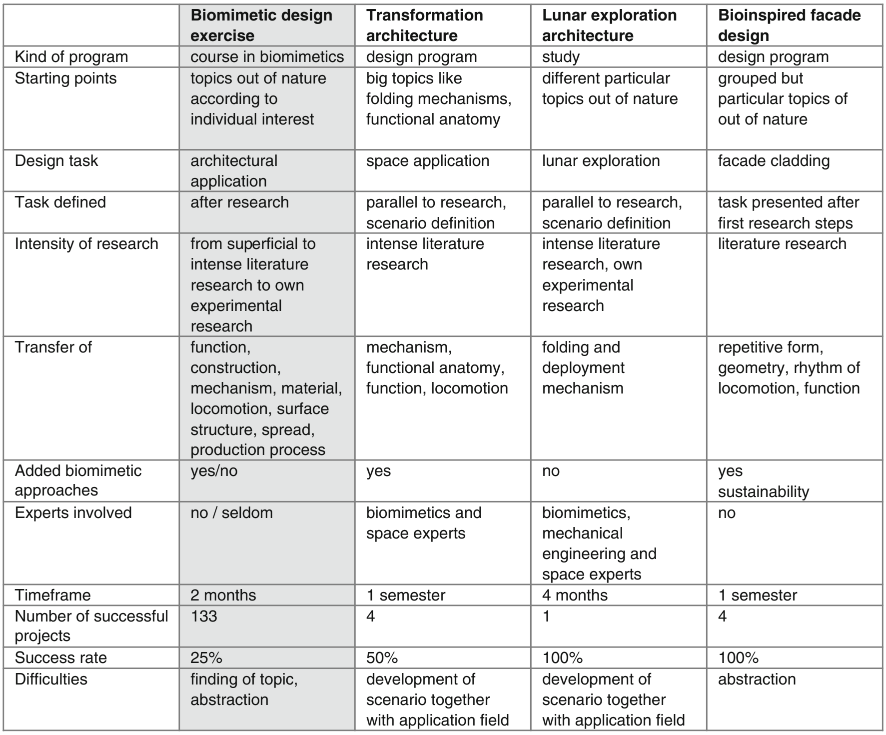


Fig. 7.11 Horizontal section of “Worm” facade [62]

A comparison of all design exercises and programmes mentioned is presented in the following table. For the comparison, the starting points, the transfer and the endpoints of the four different studies are considered. The kind of programme relates to the design task, intensity of research, availability of experts and duration of work (Fig. 7.12) [56, 63].

The implementation phase often brought about new challenges and problems, which was again handled in a biomimetic approach by the students, without being instructed to do so. In this way, added biomimetic ideas were implemented in the designs, which is being referred to as “added biomimetic approaches” in the comparison table. This phenomenon was also observed in the studies of the “Center for Biologically Inspired Design” at the Georgia Institute of Technology in the USA and integrated into the method of the so-called compound analogical design [64]. Consultancy of experts in the life sciences and/or biomimetic transfer was experienced as very important and always stimulating. Growing abstraction of a natural phenomenon increases applicability and transfer, but can remain superficial when research was not profound enough.



	Biomimetic design exercise	**Transformation architecture**	**Lunar exploration architecture**	**Bioinspired facade design**
Kind of program	course in biomimetics	design program	study	design program
Starting points	topics out of nature according to individual interest	big topics like folding mechanisms, functional anatomy	different particular topics out of nature	grouped but particular topics of out of nature
Design task	architectural application	space application	lunar exploration	facade cladding
Task defined	after research	parallel to research, scenario definition	parallel to research, scenario definition	task presented after first research steps
Intensity of research	from superficial to intense literature research to own experimental research	intense literature research	intense literature research, own experimental research	literature research
Transfer of	function, construction, mechanism, material, locomotion, surface structure, spread, production process	mechanism, functional anatomy, function, locomotion	folding and deployment mechanism	repetitive form, geometry, rhythm of locomotion, function
Added biomimetic approaches	yes/no	yes	no	yes sustainability
Experts involved	no / seldom	biomimetics and space experts	biomimetics, mechanical engineering and space experts	no
Timeframe	2 months	1 semester	4 months	1 semester
Number of successful projects	133	4	1	4
Success rate	25%	50%	100%	100%
Difficulties	finding of topic, abstraction	development of scenario together with application field	development of scenario together with application field	abstraction

Fig. 7.12 Comparison of programmes at TU Vienna regarding important aspects of transfer and conditions

The development of an application scenario (e.g. in the space projects) was experienced as an obstacle, and took much time and effort. On the other hand, can a specified task result in oversimplified transfers?

As a result, the strategy to only roughly define an application field delivers the most innovative results, but cannot be applied to particular tasks. Respective time has to be allocated to the development of the application scenario.

Gradual differentiation of the design with respect to starting points and application may deliver an applicable method for biomimetic architectural design.

7.6 Future Fields, Aims and Conclusion

7.6.1 Aims

Even if the biomimetic approach is not carried out thoroughly from analysis in the life sciences to technical application, the use of models taken from nature meanwhile seems to be a commonly used approach in current architectural design.

Within the last decades, the use of biology's paradigm in architecture has increased. *... it is now becoming evident that a new strand of biomorphism is emerging where the meaning derives not from specific representation but from a more general allusion to biological processes... [Biomorphism] signifies the commitment to the natural environment... is apt to be considered more environmentally responsible (or responsive)...* [11]. There seems to be a general belief that the use of biological models will help to develop a more sustainable and ecologically responsible future, which leads to a better quality of life in built environment.

It is beyond controversy that the discussion of nature and natural technologies delivers increased knowledge and consciousness about ecological interconnections, but biomimetics as a sole innovation tool can also deliver unsustainable products and is not a panacea for all global problems [65]. The efforts of biomimetic architectural development should be targeted to sustainability and energy and resource efficiency, but application of a biomimetic innovation method does not guarantee an ecological solution. Even if the investigation of nature's principles imply increased consciousness of natural processes and complexity, the aim to design environmentally responsible has to exist independently from the innovation method. Current developments in biomimetics in architecture and design also include networking on an international level.

Scientific and commercial interests in biomimetics have led to the founding of several organisations, such as the Bionc Engineering Network BEN in Germany [66], BIOKON international based in Germany [67] with a group focusing on architecture and design, BIONIS in the UK [68] with a focus on engineering and the Biomimicry group in the USA [69].

7.6.2 Considerations About Future Developments

The one to one modelling, the creation of prototypes of new architectural solutions is still important – the virtual modelling capacities and qualities do not yet reach a stage where sole digital development would be sufficient to grasp the future qualities of a new architectural solution. Until now, limited factors of buildings or projects are investigated digitally, for example the influence of the sun, acoustics, internal stresses due to loads and environmental forces. Moreover, consultants work on these factors separately, considering different scales and different computer modelling tools.

Digital models, on the other hand, allow the introduction of design algorithms from nature: optimisation processes, growth processes, evolutionary processes for example can be applied. The processes are relocated from the real world to a digital model space. New production processes influence and determine the creation of architecture. In the same way design and production will be modified by the biological paradigm, when biomimetic principles are applied.

Marcos Novak, investigating actual, virtual and mutant intelligent environments states: *One of the fundamental scientific insights of this century has been the* *realization that simulation can function as a kind of reverse empiricism, the empiricism of the possible. Learning from the disciplines that attend to emergence and morphogenesis, architects must create generative models for possible architectures. Architects aspiring to place their constructs within the nonspace of cyberspace will have to learn to think in terms of genetic engines of artificial life. Some of the products of these engines will only be tenable in cyberspace, but many others may prove to be valid contributions to the physical world* [70].

The future of biomimetics in architecture is the creation of visions with the strength to establish innovation for the improvement of the quality of our built environment.

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