Chapter 1
Biomimetics: Its Technological and Societal Potential

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Abstract This introductory chapter contains a short discussion of the topic of biomimetics with special emphasis on background and goals together with an overview of the book. Biomimetics is described as information transfer from biology to the engineering sciences. Methods and preconditions for this interdisciplinary scientific subject are mentioned briefly focusing on the educational issues and the pathway to product development. To provide the reader with a preliminary information, an overview of the book is given devoted to a brief description of the remaining chapters which are allocated to three main sections "Material & Structure", "Form & Construction", and "Information & Dynamics".

The process of evolution on earth during the last approximately 3.4 billion years resulted in a vast variety of living structures. Most recent findings suggest that multicellular organisms could have been around for 2.1 billion years [1, 2]. At any time, organisms were able to adapt dynamically to various environmental conditions. It is therefore the principal goal of biomimetics to provide an in-depth understanding of the solutions and strategies having evolved over time and their possible implementation into technological practice. Very often biomimetics must reach down to the microscopic and ultimately to the molecular scale. Some of nature's best tricks are conceptually simple and easy to rationalize in physical or engineering terms, but realizing them requires machinery of exquisite delicacy [3].

The routes of technology transfer from biology to the engineering sciences are normally not too clearly drawn. There is no doubt about the outstanding innovative

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potential of the biomimetic approach. Yet there is no guarantee that a technical solution based on biomimetics will be ecofriendly. This has to be proven separately in any case.

There is a tremendous scope of research topics in the field of biomimetics (bionics) that – according to Rick [4] – could be roughly assigned to either construction bionics (e.g. materials, prosthetics, and robotics), procedural bionics (e.g. climate/energy, building, sensors, and kinematics/dynamics), or information bionics (e.g. neurobionics, evolution bionics, process bionics, and organization bionics).

Biomimetics is therefore an innovation method being applied in a multitude of technological fields. The realization of biomimetic innovation can be done either from the technological point of view (problem-oriented) or from the biology point of view (solution-oriented). These basically different approaches are therefore called top-down (biomimetics by analogy) or bottom-up (biomimetics by induction) approaches. They can also be distinguished by their differing time of development and other requirements.

To some extent biomimetics as an interdisciplinary scientific subject is thought to contribute to sustainable innovation [5]. Complex systems and patterns arise out of a multiplicity of relatively simple interactions in a hierarchically structured world. This phenomenon is called *emergence*. According to systems theory, it is necessary to go well beyond the frontiers of classical disciplines, thought patterns, and organizational structures in order to accomplish sustainable innovation.

Comprehensive knowledge as an asset is one of the most important preconditions for innovation within knowledgeable societies (Lane 1966 cited by Jursic [6]). Applied curiosity about everything's working principles requires a profound preoccupation with the technical foundations. Biomimetics is thought to facilitate the approach to technological developments and to foster scientific basics.

Advanced training in the fields of interdisciplinary research and development is a challenge that has to be met using novel concepts of teaching and training. Training is therefore a key to the expansion of biomimetics. It should be included in the training syllabus of engineers and designers to make them aware of the potential of the approach. The biological sciences should be made aware of the commercial applications of their knowledge. In order to introduce innovation principles into societal practice, there is need for ingenious and well-educated people and a proactive environment. For the education of highly qualified scientists and engineers, open access to scientific fields and domains is indispensable. Interdisciplinary activities in research units such as universities need to be initiated and supported internally (executive level) and externally (research grants). Close cooperation is necessary between R&D units and industry and economy in order to promote inventions. The formation of biomimetics networks currently taking place in Europe can be seen as the core event in the formation of a dynamic developmental area [7, 8].

The main aim of this book is to provide the reader with a collection of chapters that review the actual R&D activities at Vienna University of Technology with respect to topics in biomimetics. The three main sections "Material & Structure", "Form & Construction", and "Information & Dynamics" cover a wide range of topics.

"Material & Structure" contains five chapters. Matovic and Jakšić start this section with a chapter on "Bionic (Nano)Membranes" [9]. The authors offer a concise and clear picture of the most important artificial nanomembrane-related procedures and technologies, including those for fabrication and functionalization, and present the main properties and potential applications, emphasizing recent results in the field contributed by the authors. Bionic nanomembranes have a potential to improve environmental protection, to bring breakthroughs in life science, to enable the production of clean energy, and to contribute in numerous other ways to an enrichment of the overall quality of life.

Tribology, the science of friction, adhesion, lubrication, and wear, is the focus of the next two chapters. Tribology is omnipresent in biology, and various biological systems have impressive tribological properties. In "Biomimetics in Tribology" [10], Gebeshuber, Majlis, and Stachelberger investigate a large hitherto unexplored body of knowledge in biology publications that deals with lubrication and wear, but that has not before been linked extensively to technology. Best practices presented comprise materials and structures in organisms as diverse as kelp, banana leafs, rattan, diatoms, and giraffes.

In "Reptilian Skin as a Biomimetic Analogue for Design of Deterministic Tribo Surfaces" [11], Abdel-Aal and El Mansori investigate the multiscale structural features of reptilian skin. Shed skin of a Ball Python is chosen as the bioanalogue. Snakes have surface features that contribute to excellent wear resistance and tunable frictional response in demanding environments. The results are translated to enhance the textural design of cylinder liners in internal combustion engines.

Hellmich, Fritsch, and Dormieux subsequently investigate multiscale homogenization theory, an analysis tool for revealing mechanical design principles in bone and bone replacement materials [12]. Multiscale poromechanics recently became a key tool to understand "building plans" inherent to entire material classes. In bone materials, the elementary component "collagen" induces, right at the nanolevel, the elastic anisotropy, while water layers between stiff and strong hydroxyapatite crystals govern the inelastic behavior of the nanocomposite, unless the "collagen reinforcement" breaks. Mimicking this design principle may hold great potential for novel biomedical materials and for other engineering problems requiring strong and light materials.

In the final chapter in the section on materials and structure, Stampfl, Pettermann, and Liska report on "Bio-inspired cellular structures: Additive manufacturing and mechanical properties" [13]. Many biological materials (wood, bone, etc.) are based on cellular architecture. This design approach allows nature to fabricate materials that are light, but still stiff and strong. Using finite element modeling in combination with additive manufacturing, it is now possible to study the mechanical properties of such cellular structures from a theoretical and experimental point of view. Stampfl, Pettermann, and Liska give an overview of currently available additive manufacturing technologies, with a focus on lithography-based systems.

Additionally, numerical methods for the prediction of mechanical properties of cellular solids with defined architecture are presented.

The section on “Form & Construction” contains three chapters. Gruber introduces the emerging field “Biomimetics in Architecture” [14] and presents various case studies that exemplify the innovational potential of structures, materials, and processes in biology for architecture and emphasize the importance of the creation of visions with the strength to establish innovation for the improvement of the quality of our built environment.

Kuhlmann deals in her chapter “Biomorphism in Architecture – Speculations on Growth and Form” [15] with the essence of nature, nature as source for form and ecology, touches upon cyborgs and the concept of organic unity, and reaches the conclusion that despite many authors’ claims of producing something radically new, many of the design strategies applied by the current architectural avant-garde can be traced back to one of the oldest and most influential ideas in architectural history: the concept of organicism in its various guises.

In the final chapter of this section, “Fractal Geometry of Architecture – Fractal Dimension as a Connection Between Fractal Geometry and Architecture” [16], Lorenz introduces fractal concepts in nature and architecture, and defines them from mathematical and architectural points of view. The fractal concept of architecture means that details of different sizes are kept together by a central rule or idea: avoiding monotony by using variation. The author concludes that this concept is the reason why Gothic cathedrals and examples of the so-called organic architecture are so interesting and diversified.

The three chapters in the section “Information & Dynamics” deal with sensors and actuators, electrostimulation of muscles, and improved strategies for auditory coding in cochlear implants. Automation, dealing with the utilization of control systems and information technology to reduce the required human intervention, mostly in industrial processing systems, but more in all kinds of daily human activities for instance driving a car in the near future, faces the problem of increasing complexity through the incorporation of dramatically increasing amounts of details in sensory systems.

In “Biomimetics in Intelligent Sensor and Actuator Automation Systems” [17], Bruckner, Dietrich, Zucker, and Müller present an approach to use biomimetics as the promising method for overcoming this problem. They argue for careful application of the biomimetics approach in various respects in order to develop a technically feasible model of the human psyche and hence redeeming one of the big promises of artificial intelligence from the early days on.

The next chapter is “Technical Rebuilding of Movement Function Using Functional Electrostimulation” by Gföhler [18]. To rebuild lost movement functions, neuroprostheses based on functional electrical stimulation (FES) artificially activate skeletal muscles in corresponding sequences, using both residual body functions and artificial signals for control. Besides the functional gain, FES training also brings physiological and psychological benefits for spinal-cord-injured subjects. Current stimulation technology and the main components of FES-based neuroprostheses including enhanced control systems are presented. Technology and application of

FES cycling and rowing, both approaches that enable spinal-cord-injured subjects to participate in mainstream activities and improve their health and fitness by exercising like able-bodied subjects, are discussed in detail and an overview of neuroprostheses that aim at restoring movement functions for daily life as walking or grasping is given.

In the final chapter of this book, “Improving Hearing Performance Utilizing Natural Auditory Coding Strategies”, Rattay deals with cochlear implants, the most successfully applied neural prostheses [19]. Cochlear implants have still deficits in comparison with normal hearing. The author argues that in contrast to nature, spiking patterns generated artificially in the auditory nerve via actual implants are based on the frequency information alone, whereas the natural method makes use of two additional principles. One of these principles, based on stochastic resonance, is especially spectacular as it uses noisy elements of the sensory system in order to amplify weak auditory input signals. The design of the next generation of cochlear implants should therefore include noisy elements in a concept similar to that shown by nature.

Not surprisingly, the Section “Material & Structure” by comparison is more extensive than “Form & Construction” and “Information & Dynamics”. This reflects a big focus on material science and related fields. But nevertheless one can find true international reputation and competence also in the other areas cited here.

References

1. A. El Albani et al., Large colonial organisms with coordinated growth in oxygenated environments 2.1 Gyr ago. Nature **466**, 100–104 (2010)
2. Ph.C.J. Donoghue, J.B. Antcliffe, Origins of multicellularity. Nature **466**, 41–42 (2010)
3. P. Ball, Life’s lessons in design. *Nature* **409**, 413–416 (2001)
4. K. Rick, Economy and bionics, http://pgamb.up.edu.br/arquivos/pgamb/File/SummerSchool/Rick%20-%20Economy%20and%20Bionics%20.pdf [3/16/10]
5. E. Jorna (contr. ed.), Sustainable innovation. *The Organisational, Human and Knowledge Dimension* (Greenleaf Publishing Co., 2006) Sheffield, UK
6. N. Jursic, http://sammelpunkt.philo.at:8080/797/2/wimo/node4.html [07/08/10 21:31:50]
7. bmvit (Bundesministerium f. Verkehr, Innovation u. Technologie). BionIQA – Bionik Innovation und Qualifikation Austria. Wien (2010)
8. DTI (Department of Trade and Industry). Biomimetics: strategies for product design inspired by nature – a mission to the Netherlands and Germany. Report of a DTI Global Watch Mission (January 2007)
9. J. Matovic, Z. Jakšić, Bionic (nano)membranes. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron, 2011)
10. I.C. Gebeshuber, et al. Biomimetics in tribology. in *Biomimetics – Materials, Structures and Processes, Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron, 2011)
11. H.A. Abdel-Aal, M. El Mansori, Reptilian skin as a biomimetic analogue for design of deterministic tribo-surfaces. in *Biomimetics Materials, Structures and Processes, Examples,*

Ideas and Case Studies, ed. by P. Gruber et al., Series: Biological and Medical and Medical Physics, Biomedical Engineering, (Springer Publishing, Series Editor Claus Ascheron, 2011)
12. C. Hellmich, A. Fritsch, L. Dormieux, Multiscale homogenization theory: An analysis tool for revealing mechanical design principles in bone and bone replacement materials. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron, 2011)
13. J. Stampfl, H.E. Pettermann, R. Liska, Bio-inspired cellular structures: Additive manufacturing and mechanical properties. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron, 2011)
14. P. Gruber, Biomimetics in architecture [Architekturbionik]. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron, 2011)
15. D. Kuhlmann, Biomorphism in architecture – speculations on growth and form. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron, 2011)
16. W.E. Lorenz, Fractal geometry of architecture – fractal dimension as a connection between fractal geometry and architecture. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron, 2011)
17. D. Bruckner, D. Dietrich, G. Zucker, B. Müller, Biomimetics in intelligent sensor and actuator automation systems. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron, 2011)
18. M. Gföhler, Technical rebuilding of movement function using functional electrical stimulation. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron 2011)
19. F. Rattay, Improving hearing performance utilizing natural auditory coding strategies. in *Biomimetics – Materials, Structures and Processes. Examples, Ideas and Case Studies*, ed. by P. Gruber et al., Series: Biological and Medical Physics, Biomedical Engineering (Springer Publishing, Series Editor Claus Ascheron 2011)

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