

# Contents

<b>1</b>	<b>Biomimetics: Its Technological and Societal Potential .....</b>	<b>1</b>
	Herbert Stachelberger, Petra Gruber, and Ille C. Gebeshuber	

## Part I Material Structure

<b>2</b>	<b>Bionic (Nano) Membranes .....</b>	<b>9</b>
	Jovan Matovic and Zoran Jakšić	
2.1	Artificial Nanomembranes .....	10
2.2	Biological Nanomembranes .....	12
2.3	Functionalization of Artificial Nanomembranes Toward Bionic Structures at ISAS: TU Wien .....	13
2.3.1	Nanomembrane-Based Bionic Structures for Energy Harvesting .....	13
2.3.2	Nanomembranes as Bionic Detectors of Electromagnetic Radiation .....	19
2.4	Conclusion .....	22
<b>3</b>	<b>Biomimetics in Tribology .....</b>	<b>25</b>
	I.C. Gebeshuber, B.Y. Majlis, and H. Stachelberger	
3.1	Introduction: Historical Background and Current Developments .....	26
3.2	Biology for Engineers .....	28
3.3	Method: The Biomimicry Innovation Method .....	30
3.4	Results: Biomimetics in Tribology – Best Practices and Possible Applications .....	32
3.4.1	Application of the Biomimicry Innovation Method Concerning Mechanical Wear .....	33
3.4.2	Application of the Biomimicry Innovation Method Concerning Shear .....	35

3.4.3	Application of the Biomimicry Innovation Method Concerning Tension .....	35
3.4.4	Application of the Biomimicry Innovation Method Concerning Buckling, Fatigue, Fracture (Rupture) and Deformation .....	35
3.4.5	Application of the Biomimicry Innovation Method Concerning Attachment .....	37
3.5	Summary and Outlook .....	40
<b>4</b>	<b>Reptilian Skin as a Biomimetic Analogue for the Design of Deterministic Tribosurfaces .....</b>	<b>51</b>
	H.A. Abdel-Aal and M. El Mansori	
4.1	Introduction .....	52
4.2	Background .....	56
4.2.1	The Python Species .....	56
4.2.2	Structure of Snake Skin .....	58
4.2.3	Skin Shedding .....	59
4.3	Observation of Shed Skin .....	60
4.3.1	Initial Observations .....	60
4.3.2	Optical Microscopy Observations .....	62
4.3.3	Scan Electron Microscopy Observations .....	63
4.4	Metrology of the Surface .....	69
4.4.1	Topographical Metrology .....	69
4.4.2	Bearing Curve Analysis .....	70
4.5	Correlation to Honed Surfaces .....	73
4.6	Conclusions and Future Outlook .....	77
<b>5</b>	<b>Multiscale Homogenization Theory: An Analysis Tool for Revealing Mechanical Design Principles in Bone and Bone Replacement Materials .....</b>	<b>81</b>
	Christian Hellmich, Andreas Fritsch, and Luc Dormieux	
5.1	Introduction .....	84
5.2	Fundamentals of Continuum Micromechanics .....	85
5.2.1	Representative Volume Element .....	85
5.2.2	Upscaling of Elasto-Brittle and Elastoplastic Material Properties .....	86
5.3	Bone's Hierarchical Organization .....	88
5.4	Elastic and Strength Properties of the Elementary Components of Bone: Hydroxyapatite, Collagen, Water .....	88
5.5	Multiscale Micromechanical Representation of Bone .....	91
5.6	Experimental Validation of Multiscale Micromechanics Theory for Bone .....	93
5.7	How Bone Works: Mechanical Design Characteristics of Bone Revealed Through Multiscale Micromechanics .....	96
5.8	Some Conclusions from a Biological Viewpoint .....	98

<b>6</b>	<b>Bioinspired Cellular Structures: Additive Manufacturing and Mechanical Properties</b> .....	<b>105</b>
	J. Stampfl, H.E. Pettermann, and R. Liska	
6.1	Introduction .....	105
6.2	Fabrication of Bioinspired Cellular Solids Using Lithography-Based Additive Manufacturing .....	107
6.2.1	Laser-Based Stereolithography .....	108
6.2.2	Dynamic Mask-Based Stereolithography .....	108
6.2.3	Inkjet-Based Systems .....	110
6.2.4	Two-Photon Polymerization .....	111
6.3	Photopolymers for Additive Manufacturing Technologies .....	112
6.3.1	Principles of Photopolymerization .....	112
6.3.2	Radical and Cationic Systems in Lithography-Based AMT .....	114
6.3.3	Biomimetic, Biocompatible, and Biodegradable Formulations .....	115
6.4	Mechanical Properties: Modeling and Simulation .....	118
6.4.1	Linear Elastic Behavior .....	118
6.4.2	Nonlinear Response .....	119
6.4.3	Sample Size and Effective Behavior .....	119
6.5	Conclusion .....	121

## Part II Form and Construction

<b>7</b>	<b>Biomimetics in Architecture [Architekturbionik]</b> .....	<b>127</b>
	Petra Gruber	
7.1	Introduction .....	127
7.2	History: Different Approaches .....	128
7.2.1	Analogy and Convergence .....	129
7.2.2	Strategic Search for the Overlaps Between Architecture and Nature .....	130
7.3	Strategies: What is Transferred and How is it Done? .....	131
7.3.1	What is Transferred? .....	131
7.3.2	Methods .....	131
7.4	Application Fields: Successful Examples .....	134
7.4.1	Emergence and Differentiation: Morphogenesis .....	134
7.4.2	Interactivity .....	135
7.4.3	Dynamic Shape .....	135
7.4.4	Intelligence .....	136
7.4.5	Energy Efficiency .....	136
7.4.6	Material/Structure/Surface .....	137
7.4.7	Integration .....	137
7.5	Case Studies .....	138
7.5.1	Biomimetics Design Exercise .....	138

7.5.2	Biomimetics Design Programmes, Workshops and Studies .....	140
7.6	Future Fields, Aims and Conclusion .....	144
7.6.1	Aims .....	144
7.6.2	Considerations About Future Developments .....	145
<b>8</b>	<b>Biomorphism in Architecture: Speculations on Growth and Form .....</b>	<b>149</b>
	Dörte Kuhlmann	
8.1	Introduction .....	149
8.2	The Essence of Nature .....	150
8.3	Nature as a Source for Form .....	152
8.4	Natural Processes .....	153
8.5	Organic Versus “Mechanical” Form .....	156
8.6	Bionics and Cyborgs .....	159
8.7	Ecology .....	162
8.8	From Fractals to Catastrophies .....	165
8.9	Form Follows Function .....	167
8.10	The Concept of Organic Unity .....	171
8.11	Conclusion .....	174
<b>9</b>	<b>Fractal Geometry of Architecture .....</b>	<b>179</b>
	Wolfgang E. Lorenz	
9.1	Fractal Concepts in Nature and Architecture .....	179
9.1.1	From the Language of Fractals to Classification .....	179
9.2	Fractals: A Definition from a Mathematical and an Architectural Point of View .....	182
9.2.1	Roughness and Length Measurement .....	182
9.2.2	Scale Range and Distance .....	184
9.2.3	Self-Similarity: An Important Attribute of Fractals .....	184
9.2.4	Architectural Examples .....	186
9.2.5	Developed Through Iteration .....	187
9.2.6	Differences Between Architectural and Mathematical Fractals .....	189
9.2.7	Fractals as a Design Aid .....	189
9.2.8	Fractals Are Common to Nature .....	190
9.2.9	The Factor Chance .....	191
9.3	From Simulation to Measurement .....	192
9.3.1	Curdling .....	192
9.3.2	Fractal Dimension .....	194
9.3.3	Perception and Distance .....	196
9.4	Fractal Dimension and Architecture .....	196
9.4.1	Fractal Dimension and Approaching a Building .....	197
9.4.2	Results of Measurement .....	198
9.5	Conclusions and Outlook .....	199

### Part III Information and Dynamics

#### 10 Biomimetics in Intelligent Sensor and Actuator

<b>Automation Systems</b> .....	203
Dietmar Bruckner, Dietmar Dietrich, Gerhard Zucker, and Brit Müller	
10.1 Research Field .....	204
10.2 Automation .....	204
10.3 Intelligence and Communication .....	206
10.4 Open Problems: Challenges in Research .....	207
10.5 Intelligence of Bionic Systems .....	209
10.5.1 Hierarchical Model Conception .....	209
10.5.2 Statistical Methods .....	210
10.5.3 Definition of Intelligence .....	211
10.5.4 Choice of the Right Model .....	212
10.5.5 Top-Down Methodology .....	212
10.5.6 A Unitary Model .....	213
10.5.7 Differentiation Between Function, Behavior, and Projection .....	213
10.5.8 Indispensible Interdisciplinarity .....	214
10.6 The Psychoanalytical Model .....	214
10.7 Conclusion .....	217

#### 11 Technical Rebuilding of Movement Function Using

<b>Functional Electrical Stimulation</b> .....	219
Margit Gföhler	
11.1 Introduction .....	219
11.2 Principle .....	220
11.3 Actuation .....	220
11.3.1 Stimulation Signal .....	222
11.3.2 Electrodes .....	223
11.4 Stimulators .....	224
11.5 Control .....	225
11.5.1 Modeling/Simulation .....	225
11.5.2 Control Systems .....	227
11.6 Sensors .....	229
11.6.1 Artificial Sensors .....	229
11.6.2 Natural Sensors in the Peripheral Nervous System .....	229
11.6.3 Volitional Biological Signals .....	230
11.7 Applications for the Lower Limb .....	231
11.7.1 Cycling .....	231
11.7.2 Rowing .....	239
11.7.3 Gait .....	241
11.8 Applications for the Upper Limb .....	242
11.9 Outlook .....	243
References .....	244

**12 Improving Hearing Performance Using Natural Auditory Coding Strategies ..... 249**  
Frank Rattay  
12.1 The Hair Cell Transforms Mechanical into Neural Signals ..... 249  
12.2 The Human Ear..... 251  
12.3 Place Theory Versus Temporal Theory..... 253  
12.4 Noise-Enhanced Auditory Information ..... 253  
12.5 Auditory Neural Network Sensitivity Can be Tested  
with Artificial Neural Networks ..... 257  
12.6 Cochlear Implants Versus Natural Hearing ..... 258  
12.7 Discussion ..... 259  
12.8 Conclusion..... 260  
References..... 260

**Index ..... 263**