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Preface

Biomimicry is captivating. It evokes and attracts the interest of people around the globe, from various disciplines, ages, and professions. It is made of the right ingredients: colorful images, nature, inspiration, innovation, and success stories. In technology, biomimicry provides us with amazing materials and structures and suggests solutions beyond our regular thinking patterns. It is a promising path to address some of the major sustainability challenges of humanity today. In science, biomimicry is a fascinating area for study. It is still in formation and therefore leaves ample space for creation and contribution. It involves many disciplines that should be integrated wisely and consequently challenges the disciplinary nature of science.

I (Yael) was exposed to biomimicry as a child during the eighties, when I got as a present the fascinating book "Bionics-Nature's patents." At that time, the prevailing term was bionics. The book waited on my shelf for almost 25 years until it became the beginning of my new career, as biomimicry researcher and consultant. As an adult, already experienced engineer, I discovered again the biomimicry field, this time under the name biomimicry, during one of my design projects. At that time, biomimicry was brand new in Israel with zero information in Hebrew. I was captivated by the endless inspiration that nature could provide to technology. Next, I became a cofounder of Biomimicry IL, a not-for-profit organization that spread the biomimicry seeds is the industrial, academic, and educational sectors in Israel. Not much later, I associated with Prof. Yoram Reich, and we began our biomimetic journey: Yoram as a supervisor and myself as a Ph.D. candidate. This book is the result of this journey, and it is mainly based on my doctoral thesis but includes also additional insights from our backgrounds in design theories and biomimicry practice.

When we first approached the field few years ago as scientific researchers and practitioners, we realized that below the appealing magic, there was almost no scaffolding to lean on. It was not clear what knowledge bases could support the conjunction of distant disciplines and what language should be used for this purpose.

Motivated by the appeal of biomimicry, and by the lacuna of practical biomimetic design methods, we aimed to develop a new biomimetic design method. We wanted to promote the scientific understanding of the field on one hand, but to provide useful method for practitioners on the other. It was clear that we first needed to develop the missing scaffolding: some solid knowledge bases and multidisciplinary language. Inspired by the theory of inventive problem solving (TRIZ), based on identification of recurring patterns in various disciplines, we intuitively believed that patterns may be the basic words of the missing language. We went out for our patterns journey and became "patterns hunters," looking for design patterns that emerge from a large number of biological design solutions: structure–function patterns and sustainability patterns. From this moment, the patterns were the missing scaffolding and the new language to sustain the development of the new design method: the structural biomimetic design method. We invite you to join this journey and share with you our enthusiasm and insights.

Scientists in the field of biomimicry will find an extensive literature review about the biomimicry discipline including detailed review of current biomimetic design methods and tools, and a mapping of research gaps and challenges. Scientists in the field of design theories will find a unique documentation of design method formation accompanied with a detailed model for "Designing a design method."

Practitioners will find a comprehensive design algorithm and practical tools to lead biomimetic design processes, including detailed case studies. Practitioners with special interest in sustainable design will find a bioinspired sustainability tool, the ideality tool, which can be integrated within biomimetic design processes or stand-alone as a sustainability tool.

The book could be used in an undergraduate or graduate course on biomimicry, design theory, product design, or sustainability to provide in-depth material on the subject.

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I thank my parents Jacob and Dorit Helfman for providing me the seeds of curiosity; my husband Eytan for the support, confidences, and patience; and my beloved children, Maya, Gili, Aviv, Daniel, and Eyal for being my source of love and motivation.

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Yael Helfman Cohen

I thank my parents Rina and Yoseph Reich, for the strong roots and lifetime support; my children Clil (Arbol Del Amor) and Shaked (Almond), for carrying my fascination of nature in their names and personality; and my partner Nurit, for creating a nourishing, sustainable environment.

Yoram Reich

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Abbreviations

ACC	Amorphous calcium carbonate
AD	Axiomatic design
ARIZ	(English: algorithm for inventive problem solving)
ASIT	Advanced systematic inventive thinking
BID	Bioinspired design
CTO	Chief technology officer
DANE	Design by Analogy to Nature Engine
DFE	Design for the environment
E2B	Engineering to biology
FBEI	Fermanian Business and Economic Institute
GNU	Recursive acronym for "GNU's Not Unix!"
IEKG	Interdisciplinary engineering knowledge genome
ISO	International Organization for Standardization
MEMS	Microelectro mechanical system
NID	Nature inspired designs
ns	Not significant
PROSA	PRoduct Sustainability Assessment
PSI	Product, Social, Institutional
SAPPhIRE	State-Action-Part-Phenomenon-Input-oRgan-Effect
SBF	Structure behavior function
SEM	Scanning electron microscope
Su-Field	Substance-field
TRIZ	Teoriya Resheniya Izobretatelskikh Zadach (English: theory of the resolution of invention-related tasks)
VAS	Visual analogue scale
VDI	Verein Deutscher Ingenieure (English: Association of German Engineers)
WWH	What–why–how

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How to Read the Book

Chapters 1–3 provide an extensive introduction to the biomimicry discipline, including review of design processes, methods, and tools. It is recommended for both scientists and practitioners who are looking for a structured review.

Scientists/researchers who are looking for research directions and ideas may find interest in Chap. 4, a mapping of the research gap and challenges, as well as in the summary of future research in Chap. 13. Researchers in the field of design theories or biomimetic design will benefit from Chap. 5, a presentation of a research model: how to design a design method. They may also benefit from Chap. 6, a review of theories, knowledge bases, and conceptual frameworks that may serve as a foundation for biomimetic design scaffolding. Detailed description of the research methodology, process, and results appears in Chaps. 7–9. Chapter 12 has value for researchers who are interested in assessing design methods by field and class experiments. Innovation researchers may find interest in innovation assessment, criteria, and rubric, presented in Chap. 11, as well as in a review of the innovation aspects of this research, in Chap. 13.

Practitioners who want to gain practical tools should first focus on Chaps. 7–9 in order to understand the knowledge bases of the structural biomimetic design method. The core of the practical knowledge is located in Chap. 10, presenting in details the design algorithm and tools to support the structural biomimetic design process. Some of these tools stand-alone and may be used during general biomimetic design processes, not only with the structural design process. Special attention should be devoted to Chap. 11, which includes four detailed case studies from biology to an application and vice versa. Engineers may find special interest in this design method as it is based on the TRIZ knowledge base and views biological systems as if they were technological systems.

Sustainability researchers and practitioners of sustainable design will find interest mainly in Chap. 9. This chapter elaborates on sustainability patterns in nature and presents the ideality bioinspired tool for sustainable design.

Part I
Introduction

Chapter 1
The Biomimicry Discipline: Boundaries, Definitions, Drivers, Promises and Limits

1.1 The Origins of the Biomimicry Discipline

Since the dawn of history, human beings have observed nature and applied its lessons. The significant modeling advances of recent decades and the ability to examine natural solutions by technological means such as scanning electron microscope (SEM), have promoted the expansion of study and practice of nature. In the middle of the 20th century, the idea that new technologies can benefit from biological knowledge pervaded the scientific community and began to consolidate as a distinct domain of research and application: Biomimicry (Bio = life, Mimicry = imitate/mimesis).

Biomimicry is an intended emulation of nature life solutions for solving contemporary challenges. It is based on viewing 3.8 billion years of evolution as a "design lab" and observing its results. Nature serves as a model, mentor and measure for promoting sustainable innovation designs [1], rather than only a source of materials.

1.2 The Biomimicry Discipline—Boundaries, Terminologies and Research Scope

Biomimicry is part of a general trend of convergence between biology and engineering. This convergence is becoming a source of innovation of the twenty-first century. It offers opportunities for mutual knowledge transfer, potential emergence of a new body of knowledge, as well as transfer of actual substances between the domains.

Focusing on the biomimicry discipline, there are also various definitions including biomimetics, bionics, bio-inspiration and bio-inspired design (BID). In some countries, all these terminologies are considered synonyms, but in others, these terminologies are understood differently. The distinction between these bio-terms is not always clear and may confuse both newcomers and experienced researchers or practitioners.

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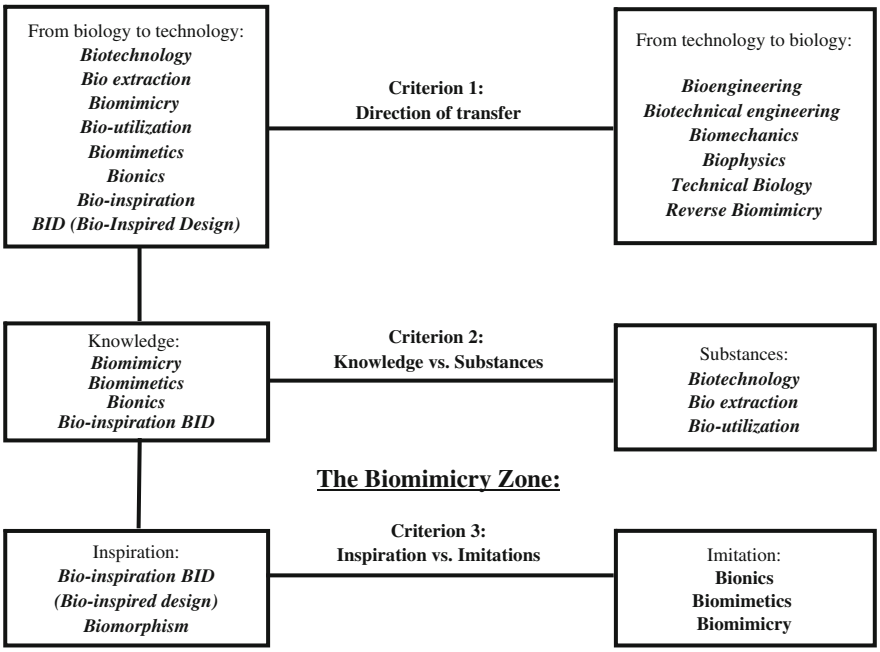

Fig. 1.1 Road-map for the bio-terms

The purpose of this section is to delineate the borders of the biomimicry discipline in relation to closely related disciplines. Based on literature definitions, we suggest three distinctive criteria between the bio-terms. In Fig. 1.1 we present how each criterion narrows the space of bio-terms by excluding several bio-terms, till we reach finally the biomimicry zone.

1.2.1 Criterion 1: Direction of Transfer

We distinguish between transfer from biology to technology or vice versa [2]. We exclude from the biomimicry zone bio-terms that refer to transfer of knowledge from engineering or technology to biology including:

- *Bioengineering*, which is based on the application of engineering knowledge to the fields of medicine or biology; it is also called *biomedical engineering* (Webster's Dictionary). A similar definition is *Biotechnical engineering* that involves the application of engineering principles and tools to solve problems in life sciences [2].
- *Biomechanics*, which is the application of mechanical principles to study and model the structure and function of biological systems [2].