Biomimicry: Designing to Model Nature

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INTRODUCTION

The Biomimicry Institute defines biomimicry as the science and art of emulating Nature’s best biological ideas to solve human problems. For billions of years nature—animals, plants, and even microbes—has been solving many of the problems we are still dealing with today. Each has found what works, what is appropriate, and what lasts.

Biomimicry and biomimetics come from the Greek words bios, meaning life, and mimesis, also meaning to imitate. Scientist and author Janine Benyus popularized the term biomimicry in her 1997 book Biomimicry: Innovation Inspired by Nature. Benyus believes that most of the problems that have ever existed have already been solved by nature. Benyus suggests shifting one's perspective from learning about nature to learning from nature as a way to solve human problems. Sustainability (design/sustainable.php) issues are among those that can be addressed by applying the biomimicry process to a project. Utilizing an integrated design process (wbdg_approach.php) can help open up opportunities to identify biological solutions to building problems and include the perspective of nature in the design process—as it is likely that nature already offers a solution.

DESCRIPTION

Humans have always looked to nature for inspiration to solve problems. Leonardo da Vinci applied biomimicry to the study of birds in the hope of enabling human flight. He very closely observed the anatomy and flight of birds, and made numerous notes and sketches of his observations and countless sketches of proposed “flying machines”. Although he was not successful with his own flying machine, his ideas lived on and were the source of inspiration for the Wright Brothers, who were also inspired by their observations of pigeons in flight. They finally did succeed in creating and flying the first airplane in 1903.

Left: Leonardo's design for a flying machine, c. 1488, inspired by birds in flight. Middle and right: Pigeons also influenced the Wright Brothers' design for the first airplane.

Recent success stories exist in terms of how biomimicry can be applied to building design. While buildings serve to protect us from nature’s extremes, this does not mean that they do not have anything to learn from the biological world. In fact, nature regularly builds structures with functionality that human-built structures could usefully emulate. Biomimetic research, science, and applications continue to grow and are already influencing the next generation of building products and systems as well as whole building designs.
For example, photovoltaic systems, which harvest solar energy, are a first step at mimicking the way a leaf harvests energy. Research is underway to create solar cells that more closely resemble nature. These cells are water-gel-based—essentially artificial leaves—that couple plant chlorophyll with carbon materials, ultimately resulting in a more flexible and cost-effective solar cell. (For more information see this article in Scientific American(http://www.scientificamerican.com/article.cfm?id=artificial-leaf-might-provide-mobile-energy))

The bumpy surface of a lotus leaf (computer graphic close up view on left) acts as a self-cleaning mechanism allowing dirt to be cleansed off the surface naturally by water, for instance, during a rain shower. Even the smallest of breezes on the plant causes a subtle shift in the angle of the plant allowing gravity to remove the dirt without the plant having to expend any energy. This same idea has been applied to the design of new building materials such as paints, tiles, textiles, and glass that reduce the need for detergents and labor and also reduces maintenance and material replacement costs.

Researchers have also developed non-toxic, formaldehyde-free wood glue that is now used in hardwood, plywood, and particleboard projects. The researchers discovered how to do this by understanding how blue mussels attach firmly under the water using flexible, thread-like tentacles.

The Thorny Devil, a desert lizard, gathers all the water it needs directly from rain, standing water, or from soil moisture, against gravity without using energy or a pumping device. Water is conveyed to the lizard’s mouth by
capillary action through a circulatory system on the surface of its skin. This same concept could be applied to passive collection and distribution systems of naturally distilled water which would reduce the energy consumed in collecting and transporting water by pump action (e.g., to the tops of buildings), and provide other inexpensive technological solutions such as managing heat through evaporative cooling systems, and protecting structures from fire through on-demand water barriers.

Damage to an organism naturally elicits a healing response. Bone is also known to detect damage to itself and can heal within range of its initial strength. This same concept has been applied to synthetic material design and contributed to the development of a self-healing polymer for use as building materials. Tiny capsules containing a healing agent are embedded in the polymer. When the material is damaged, the capsules rupture and release the healing agent, which repairs the cracks. The self-repairing capabilities of materials can contribute to reduced maintenance(/design/optimize_om.php) and material replacements costs as well as increased durability. Self-repairing materials can also be made lighter, resulting in reduced embodied energy and greenhouse gas production(greenhousegasemissions.php).

APPLICATION

The Biomimicry Institute(http://www.biomimicryinstitute.org/), a not-for-profit organization that promotes learning from and then emulating natural forms, processes, and ecosystems to create more sustainable and healthier human technologies and designs, suggests that the design team look at nature as “model, measure, and mentor.” There are hundreds of technologies inspired by proven design systems existing in nature. One can become more familiar with these examples by broadening and deepening an inner awareness of nature.

Ask Nature(http://asknature.org/), developed by the Biomimicry Institute, is a free, open source, online project designed to inspire innovation and technologies that create conditions conducive to life. To accomplish this, Ask
Nature is organizing the world’s biological literature by function along with providing access to biological blueprints and strategies, bio-inspired products and design sketches, and access to experts to talk with and collaborate with to solve problems. To utilize the tool and apply this broader method of thinking into a building project, begin by asking:

- How would nature solve green building challenges?
- How does life make things?
- How does life make the most of things?
- How does life make things disappear into systems?

The Biomimicry Guild, in collaboration with other organizations, developed a practical design tool called the Biomimicry Design Spiral that uses nature as a model. This tool outlines guidance using the following steps to apply the tool effectively and systemically to the creative process. Below are listed the basic steps in that process. (For more detailed information on this process, see the Biomimicry Design Spiral[http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html].)

- **Identify**
  - Develop a Design Brief of the human need.
- **Interpret**
  - Biologize the question; ask the design brief from Nature’s perspective.
    - Ask "How does Nature do this function?" "How does Nature NOT do this function?"
- **Discover**
  - Look for the champions in nature who answer/resolve your challenges
- **Abstract**
  - Find the repeating patterns and processes within nature that achieve success
- **Emulate**
  - Develop ideas and solutions based on the natural models

Nature as measure: is embedded in the evaluate step of the Biomimicry Design Spiral.

- **Evaluate**
  - How do your ideas compare to Life’s Principles, the successful principles of nature?
- **Identify**
  - Develop and refine design briefs based on lessons learned from evaluation of Life’s Principles

As noted by the Biomimicry Guild[http://www.biomimicryguild.com], since nature works with small feedback loops constantly learning, adapting, and evolving their environments and processes, building design professionals can also benefit from this way of thinking. This would enable designs to evolve in repeated steps of observation and development, uncovering and/or seeing new lessons, and applying these constantly throughout the exploration of a design.

By applying this process, it is possible to create buildings, products, and/or processes that are inherently more sustainable/[design/sustainable.php], perform better/[design/func_oper.php], use less energy/[design/minimize_consumption.php], eliminate or create less waste[cwmgmt.php], reduce material/materials.php) costs, and open up opportunities to create new products and potentially new markets by spawning innovation.

**Examples**

*Esplanade Theater*
The Esplanade Theater(http://en.wikipedia.org/wiki/Esplanade_%E2%80%93_Theatres_on_the_Bay) and commercial district in Singapore, designed by DP Architects and Michael Wilford, hosts an elaborate building skin which influenced the look and function of the interiors, inspired by the multi-layered Durian plant with its formidable thorn-covered husk. The Durian plant uses its semi rigid pressurized skin to protect the seeds inside, just as the building exterior is part of an elaborate shading system that adjusts throughout the day to allow sunlight in but protects the interiors from overheating.

Eastgate Centre

A termite mound (left) which inspired the design of the Eastgate Centre in Zimbabwe (right).

Termites have an amazing ability to maintain virtually constant temperature and humidity in their termite mounds in Africa despite outside temperatures that may vary from 35°F to 104°F (3°C to 42°C). Researchers initially scanned a termite mound and created 3-D images of the mound structure, which revealed construction that can influence human building design. The Eastgate Centre, a mid-rise office complex in Harare, Zimbabwe, uses a form of passive cooling(psheating.php) similar to how the termite mound works and stays cool without air conditioning and uses only 10% of the energy(/design/minimize_consumption.php) of a conventional building its size.

Dives in Misericordia Church

In the early 1990s, scientists at the Italcementi Group in Bergamo, Italy, produced a self-cleaning concrete that keeps buildings from tarnishing from pollutants in the atmosphere. Photocatalytic particles in the cement oxidize the pollutants coming into contact with the hardened concrete surface, that help to maintain the original surface appearance, a very white concrete, over time. The idea was inspired in part by self-cleaning plants and contributes to the reduction of maintenance and repair costs to the building.

EMERGING ISSUES
Research and analysis continues to grow in this field with more species documented from which to draw inspiration. Below are a few of the recent studies that are continuing to influence design, engineering, science, and technology.

Spiders can create web silk as strong as the Kevlar used in bulletproof vests. Engineers could potentially use such a material—if it had a long enough rate of decay—for suspension bridge cables, artificial ligaments for medicine, and many other purposes. (See The Biomimicry Institute for more information and the latest research at www.biomimicryinstitute.org)

Other research has proposed adhesive glue from mussels, solar cells made like leaves, fabric that emulates shark skin, harvesting water from fog like a beetle, and more.

Recently, researchers from the Swiss Federal Institute of Technology (EPFL) have been incorporating biomimetic characteristics to structural engineering problems in an adaptive deployable tensegrity bridge (tensional integrity based on a synergy between balanced tension and compression components). The bridge can carry out self-diagnosis and self-repair utilizing a machine learning algorithm.

**RELEVANT CODES AND STANDARDS**

While many codes, standards, and regulations serve as a starting point for establishing sustainability goals and targets, it is possible that by first seeking the sources of inspiration and examples from nature, the design community may improve upon these standards and create models that go beyond any of those outlined below.

- ASHRAE Standards
Buildings

- Executive Orders
  - Executive Order 13514
- Federal Codes
  - Federal Energy Code—Commercial Buildings
- Legislation
  - Clean Air Act—US Code Title 42 Chapter 85

ADDITONAL RESOURCES

WBDG

**Building Types / Space Types**
Applicable to all Building Types and Space Types

**Design Objectives**
- Aesthetics
- Cost-Effective
- Functional / Operational
- Productive
- Sustainable

**Products and Systems**
Building Envelope Design Guide:
- Below Grade Systems
- Foundation Walls
- Floor Slabs
- Wall Systems
- Fenestration Systems
- Roofing Systems

Federal Green Construction Guide for Specifiers:
- 07 33 63 (02930) Vegetated Roof Covering
- 07 55 63 (07530) Vegetated Protected Membrane Roofing
- 31 25 73 (02635) Stormwater Management by Compost
- 32 10 00 (02700) Bases, Ballasts, Paving
- 32 12 43 (02795) Porous Paving
- 32 71 00 (02670) Constructed Wetlands
- 32 90 00 (02900) Planting
- 33 16 20 (11201) Rainwater Harvesting

**Organizations**
- Biomimetic-Architecture
- The Biomimicry Guild
- Biomimicry Institute
- Center for Biometrics
- Rocky Mountain Institute

**Publications**
- Nature's 100 Best: Top Biomimicry Solutions to Environmental Crises—A compilation of the top hundred different innovations of animals, plants, and other organisms that have been researched and studied by the Biomimicry Institute.
Architecture
- **Design and Nature II** by Ed M. W. Collins et. Al. 2004. Contains proceedings of 2nd international conference on design and nature. Brings together researchers around the world on a variety of studies involving nature's significance for modern scientific thought and design.
- **Wonders of Animal Architecture** by Sigmund A. Lavine. 1964. Examines how creatures like arthropods, vertebrates, birds, and rodents build their homes.

Biography
- **Buckminster Fuller's Universe** by Lloyd Sieden. 1989. Explores Fuller's examination of significant underlying principles in nature.

Biology
- **Biomimicry: Innovation Inspired by Nature** by Janine Benyus. 1997. Demonstrates how nature's solutions to survival needs have been the creative jumping-off points for individuals seeking solutions to human challenges, developing, or simply revitalizing processes or products.
- **Life Itself: Exploring the Realm of the Living Cell** by Boyce Rensberger. 1998. A digest of everything currently known about the mechanisms by which living cells perform their myriad of tasks.
- **Natural Earth, Living Earth** by Miranda Smith and Steve Parker. 1996. Full-color photography shows how living things interact with the functions and conditions of the earth.
- **The Way Nature Works** by Editor Jill Bailey. 1992. Drawing on a series of questions that children might ask, a team of scientists proposes answers in this manual for adult readers. They address large issues such as atmospheric phenomena, ecosystem relationships, and animal communication with brief essays, each well illustrated with charts, diagrams, and photographs.
- **The Work of Nature: How the Diversity of Life Sustains Us** by Yvonne Baskin, et al. 1997. Baskin examines the threats posed to humans by the loss of biodiversity. Biodiversity is much more than number of species—it includes the complexity, richness, and abundance of nature at all levels.

Chemistry
- **Biomineralization** by Stephen Mann. 2002. Describes a new type of chemistry that brings together soft and hard material for the design of functionalized inorganic-organic materials.

Design
- **Biologic: Environmental Protection** by Design by David Wann. 1990. Guide to designing our way out of the environmental conundrum we are in by taking a system's view of technology—asking, "how does it fit in?"
- **Deep Design: Pathways to a Livable Future** by David Wann. 1996. A new way of thinking about design by asking: "What is our ultimate goal?" The idea is to produce designs that are sensitive to living systems.
- **Design for the Real World, Human Ecology and Social Change** by Victor Papanek. 1984. One of the world's most widely read books on design. Author provides a blueprint for sensible, responsible design.

- **Design with Nature** by Ian L. McHarg. 1969. A blend of philosophy and science, author shows how humans can copy nature's examples to design and build better structures.

**Economics/Business**
- **Natural Capitalism: Creating the Next Industrial Revolution** by Paul Hawken, Amory Lovins, L. Hunter Lovins. 2000. Three top strategists show how leading-edge companies are practicing "a new type of industrialism" that is more efficient and profitable while saving the environment and creating jobs.

- **Nature of Economies** by Jane Jacobs. 2000. Dissects relationships between economics and ecology through a multilayered discourse around the fundamental premise that "human beings exist wholly within nature as part of a natural order."

**Engineering**

- **Design Homology** by David Offner. 1995. A mechanical engineering textbook that contrasts human designs with nature's designs.


**Evolution**
- **On Growth and Form: The Complete Revised Edition** by D'Arcy Wentworth Thompson. 1992. Classic work of biology and modern science sets forth seminal "theory of transformation"—that one species evolves into another not by successive minor changes in individual body parts but by large-scale transformations involving the body as a whole.

**General Science**


**Innovation**
- **Invention by Design** by Henry Petroski. 1996. Philosophical and cultural study of the process of invention including case studies.

- **Nature: Mother of Invention** by Felix Paturi. 1976. The book provides an overview of bioinspiration, noting that scientists can learn from natural structures of all sizes and put their knowledge to use in a number of ways, often by studying nature at the nanolevel, where the distinction between nature and human technology is often blurred.

- **The Gecko's Foot: Bio-Inspiration, Engineering New Materials and Devices from Nature** by Peter Forbes. 2005. Presents technologists' pure research into nano-anatomy, followed by their applied and, as many entrepreneurs hope, commercial mimicry of nature's ingenuity.

**Material Science**
- **Biomimetic Materials Chemistry** by Stephen Mann (Editor). 1995. Provides a unified, up-to-date approach to
the applications of biological concepts, products and processes in material research.

- **Biomimicry** by Stephen Mann. 2002. Describes a new type of chemistry that brings together soft and hard material for the design of functionalized inorganic-organic materials.
- **Biomolecular Materials** by Editor Christopher Viney et al. Materials Research Society. Volume 292. 1992. Design of material synthesis, assembly, processing and physical optimization strategies based on examples from nature
- **Structural Biomaterials:** *(Revised Edition)* by Julian F.V. Vincent. 1990. The book presents a biologist's analysis of the structural materials of organisms, using molecular biology as a starting point. It is an excellent introduction to the field which attempts to stimulate interest in biomaterials.

**Mechanics**

- **Life's Devices: The Physical World of Animals and Plants** by Steven Vogel, Rosemary Calvert. 1988. This is an entertaining and informative book that describes how living things bump up against non-biological reality.
- **Life in Moving Fluids** by Steven Vogel. 1996. This book is for biologists who want to come to the beginning of a quantitative understanding of a wide variety of adaptations, and for general readers who want to see how fluid mechanics work in a varied and often surprising context.
- **Structure, Form, Movement** by Heinrich Hertel. 1963. Explores various means in which nature manifests structure, form, and movement.
- **The Biomechanics of Insect Flight** by Robert Dudley. 2002. Explores insect physiology, functional morphology, paleontology, aerodynamics, behavior, and ecology. The book excels as a synthesis of all these fields, and as a unique source of information on the subject of insect flight as a whole.

**Patterns**

- **The Power of Limits: Proportional Harmonies in Nature, Art and Architecture** by Gyorgy Doczi. 1981. *The Power of Limits* was inspired by the continuity of natural patterns. The book explores how certain proportions occur over and over and are also repeated in how things grow and are made.
- **The Self-Made Tapestry: Pattern Formation in Nature** by Philip Ball. 2001. This deep, beautiful exploration of the recurring patterns that we find both in the living and inanimate worlds will change how one thinks about everything from evolution to earthquakes.
- **The Shape of Life** by Nancy Burnett. 2002. Based on the National Geographic -Sea Studios Foundation series seen on PBS. Every animal that ever lived fits into one of only eight basic body plans. Those basic forms have given rise billions of species of animals and continue to define the shape of life on Earth.

**General**


**Design and Analysis Tools**


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The effectiveness of Building Information Modeling (BIM) tools and processes has been recognized by the industry and owners are beginning to adopt Triple Bottom Line accounting practices, to enhance economic performance and environmental and social performance. However, the widespread and practical application of Green BIM remains largely unrealized. A result of millions of years of successive improvement through natural selection, nature seems to have a solution for everything – find out how we’re using them to solve modern, human problems.

Leonardo da Vinci design for an Ornithopter. Perhaps one of the most famous examples of biomimicry is evident in the history of human flight. Leonardo da Vinci is largely recognised as a key instigator in its development, as he made the first real studies on birds and human flight in the 1480s. His original design, called the Ornithopter, was never created, but was a principal in showing how man could potentially fly.