

Bionics in Action: The Nature of Invention

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Life has been performing design experiments for 3.8 billion years and the best ideas on the planet today are those that perform well while economizing on energy and materials. Whatever a company's design challenge, the odds are high that one or more of the world's 30 million living creatures have not only faced the same challenge, but have evolved effective strategies to solve it, thriving. This article explores how bionics and biodesign have been critical to Franco Lodato's trend-setting products. Strategies can range from the mimicry of nature to conceptual abstractions. In one of his projects, a woodpecker provoked a fresh look at the design of an ice axe. In another, the exterior shells of lobsters and other crustaceans suggested a layered polymer design for the coverings of rugged cell phones.

Key words: Biodesign; Biomimicry; Innovation; Product development; Sustainability

INTRODUCTION

Living creatures are superbly adapted to apply the physical and chemical laws of the universe in order to increase their chances for survival. In fact, it can be strongly argued that most of the inventions created by humans appear in the wild in some form. There are a few exceptions. On Earth, nature has never invented the wheel and certainly nuclear energy seems beyond the realm of possibility. Einstein pointed out that "the significant problems we face cannot be solved at the same level of thinking we used when we created them" (9). This suggests that we must develop new ways of looking at familiar situations. We must redescribe or reenvision what it is we think we know about the world and ourselves.

Considering the vast biological diversity on Earth, there is enormous potential for innovation inspired by nature. Research and development is ongoing in a number of engineering fields, including:

Aeronautics: Engineers looked to successful designs found in nature to build faster, safer, and

more efficient flying machines with wings that twist for steering and wing surfaces that "morph" or change in shape in response to variable in-flight conditions.

Robotics: Using insights gained by observing insect flight, engineers are designing a class of miniature unmanned aerial vehicles that can take off from and land in a standing position, fly at very low speeds, and hover like a dragonfly.

Bioengineering: A spider's silk web is light, flexible, and strong. Pound for pound, it is three times stronger than steel. Potential applications for an engineered version include seat belts, bulletproof vests, human ligaments, and construction material.

Design and innovation are no longer just about making things, but about conceptualizing, envisioning, packaging and the conveyance of knowledge. In order to weigh real alternatives, we must examine and embrace the multiplicity of meanings extant in the world.

The designer's new challenge is dematerialization; in other words, finding ways to disburden the environment while servicing business and indus-

try's goal of efficiency for the sake of profit. We must share what we know or our predicament will surely worsen.

Digital technology is enabling us to work with greater efficiency, generating considerably less waste. We are literally building solutions out of thin air, our ideas manifest in bits and bytes. Broadband technologies are making it possible to move vast quantities of information weightlessly and economically. Video conferencing is eliminating the necessity of physical presence. Today we can travel great distances, attend international conferences, visit foreign museums, and go to school abroad, all electronically. All of these activities promote dematerialization. The less burdened the environment, the greater the chance that we will prosper. Knowledge of what it means to prosper is something we will undoubtedly gather along the way, and nature can be the best model to follow.

BIONICS AND BIO-DESIGN

Biological systems are characterized by their miniaturization, their sensitivity, their high degree of flexibility, their ability to adapt to changing environments, and their high degree of reliability. These design features offer a great range of possibilities for research seeking to derive engineering principles from natural systems by adapting these principles for the improvement of manmade systems.

While the term "bionics" dates back to around 1958 (5), the concept of mimicking nature very likely dates to prehistoric times. One can imagine prehistoric man fashioning a weapon resembling the claws of the wild animals he fought, or imitating his natural surrounding for camouflage.

Leonardo da Vinci may be the first true bionics researcher. Many, if not most, of his designs were based on observations in nature, including an "ornithopter," a flapping wing aircraft patterned on his careful anatomical studies of birds (Fig. 1).

Another example of early contributions from the mimicking of nature extends beyond the field of architecture. The South American water lily, *Victoria regia*, inspired 19th century architect Sir Joseph Paxton to design the Crystal Palace in Hyde Park (Fig. 2). This plant has delicate floating leaves up to 2 m in diameter, yet is able to support a weight

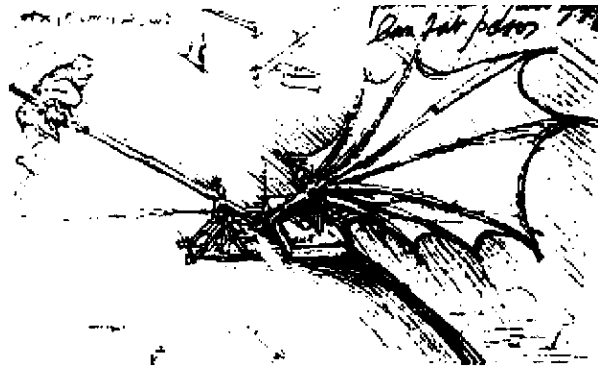


Figure 1. Leonardo da Vinci's ornithopter wing.

of 90 kg. The underside of the leaf carries a system of hollow ribs that give both strength and buoyancy. Concerning his building, Paxton wrote, "nature was the engineer, nature has provided the leaf with horizontal and traverse girders and supports that I, borrowing from it, have adopted in this building" (2).

DEFINITION

Major Jack Steele, U.S. Air Force, coined the term "bionics" in 1958 to describe what was then an emerging research approach at the interface between natural and synthetic systems. He defined bionics as "the analysis of the ways in which living systems actually work and having discovered nature's tricks, embodying them in hardware" (4).

The Columbia Encyclopedia defines bionics as follows: bionics (bî-ôn' îks) study of living systems with the intention of applying their principles to the design of engineering systems (3).

Many others definitions can be found in the literature; for the purposes of this report I have chosen the following as my working definition: Bionics is the derivation of engineering principles employed in natural systems, and the application of these principles to the design or improvement of materials and technological systems (Fig. 3).

Bionics may be classified in five main categories:

Total mimicry: an object, material or chemical structure that is indistinguishable from the natural product (e.g., early attempts to construct flying machines).

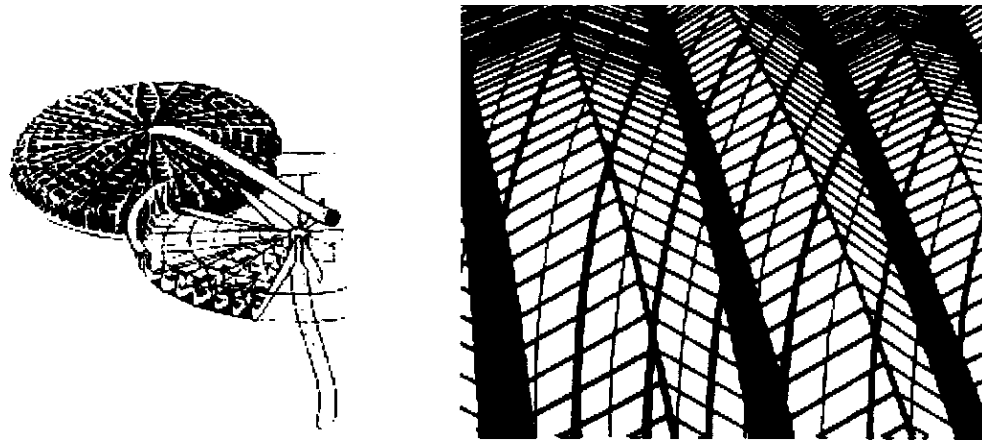


Figure 2. South American water lily, *Victoria regia*, and the line drawing of the ribbed structure of the Crystal Palace.

Partial mimicry: a modified version of the natural product (e.g., artificial wood).

Nonbiological analogy: functional mimicry (e.g., modern planes and use of airfoils).

Abstraction: the use of an isolated mechanism (e.g., fiber reinforcement of composites).

Inspiration: trigger for creativity (e.g., design for Crystal Palace via the South American Water Lily).

BIODESIGN: THE NATURAL STATE

Biodesign considers the internal and external architecture of living machines to be extremely efficient design solutions developed to perform multiple roles and functions in their corresponding environments.

Biodesign is probably the earliest type of design methodology used by man, and examples of its ap-

Integrating biodesign

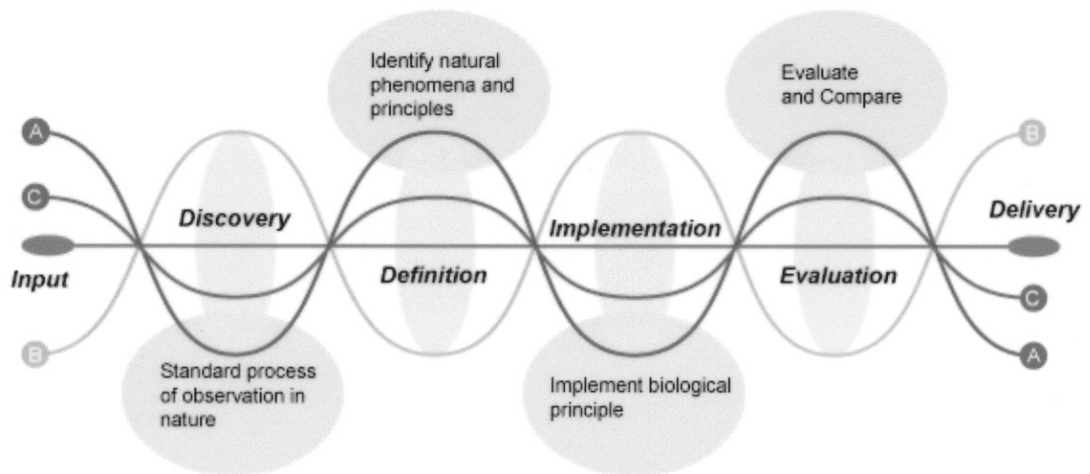


Figure 3. Biodesign process by Franco Lodato.

plication are abundant throughout our history. Probably the greatest beneficiary of this design methodology is the area of transportation design. Early conquest of the air and oceans by man was made possible by using biodesign as the baseline of the objects traveling through these mediums. The use of a fish form for a boat hull or a submarine and the form of a flying bird for the basic configuration of an airplane are not coincidental design solutions. Interestingly enough, these design adaptations were made with very little, if any, scientific knowledge of fluid dynamics, but with only the convictions of the pioneer designers that the shapes of these living machines were the best suited forms to perform in the respective environments.

Nature's highly advanced designs have a common objective: the harmonization of form and function, achieved through the balance of internal and external forces acting on the natural system and the integration of several functions into the form.

An example of design integration is clearly observed in the analysis of the shape of a powerful swimmer such as the shark (Fig. 4). This creature has devices like the mouth, gills, eyes, and sensors integrated into its form in a way that the interference with flow is minimal, yet the function of these organs are unimpeded (7). Its skin has many functions: it is a heat exchanger, an environmental sens-

ing device, and a self-sealing tank, just to mention a few (8).

The fact that biodesigners refer to the forms or structures of the living world as design models is based on the abundant evidence that shows these forms or structures to be accurate mathematical representations of the balance between environmental and functional forces exerted on the creature, and not the result of random or spontaneous events.

The processes involved in the biodesign approach can be divided into four stages:

1. Select features of living organism which exceed present technological capabilities.
2. Discover and derive principles and processes responsible for their superiority.
3. Develop models and methods to describe biological systems in terms useful to designers.
4. Demonstrate the feasibility of translating this knowledge into dependable and efficient hardware.

BIOMECHANICS

Biomechanics uses the laws of physics and engineering concepts to describe motions undergone by the various body segments, and the forces acting

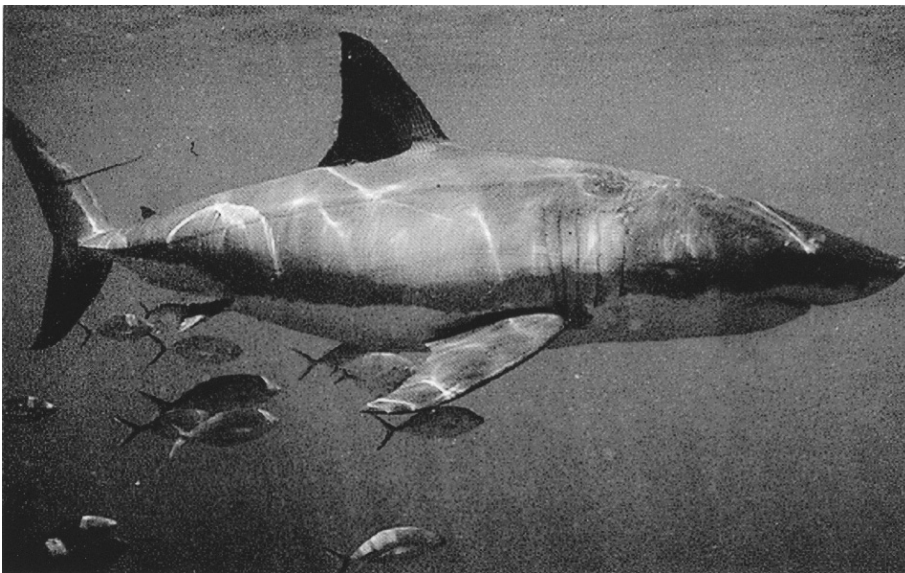


Figure 4. The hydrodynamic shape of a white shark.



Figure 5. Pierre Tardivel descending a mountain using the Woodpecker from the documentary *Steep* by Mark Obenhaus. Picture by Chris Noble (courtesy of Sony Pictures Classic). *New York Times*, B7; December 21, 2007.

on these parts, during normal daily activities. The interrelation between force and motion is important, and must be understood and applied in the conceptualization and design of products.

By using biomechanics, and understanding and applying some of the information related to the human body relative to its dimensions and movement limits, we are able to define important design criteria to implement in our product design concept that demonstrate the increase in performance.

ANTHROPOMETRY AND ERGONOMICS

Anthropometry is the study of human body measurement for use in human related classification and comparison, and is part of Ergonomics, which is the science of designing the environment to fit the wishes and abilities of the people who have to operate within it.

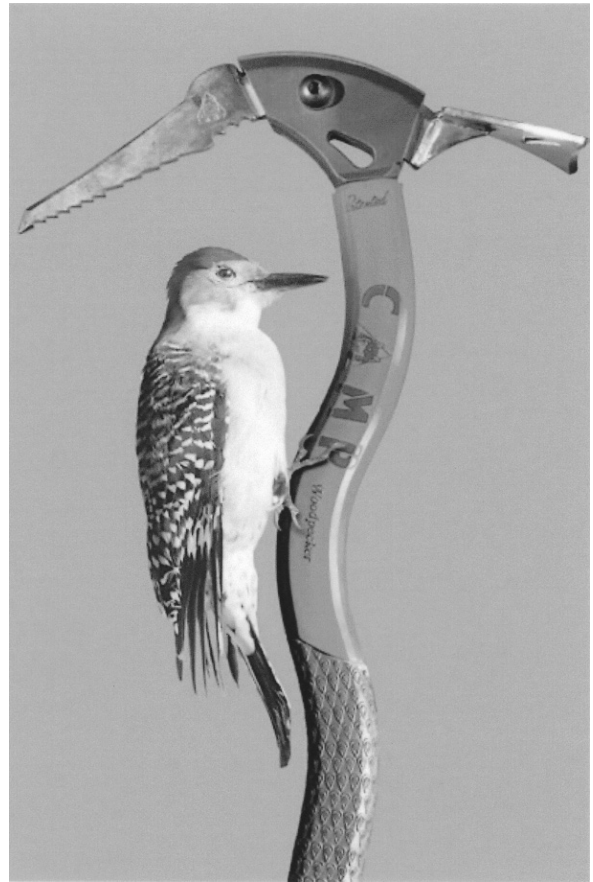


Figure 6. CAM woodpecker axe. Photograph courtesy of Jonathan Kantor. K. Rockwood, *Biomimicry: nature-inspired designs*. Fast Company; October 1, 2008 (<http://www.fastcompany.com/magazine/129/truly-intelligent-design.html>).

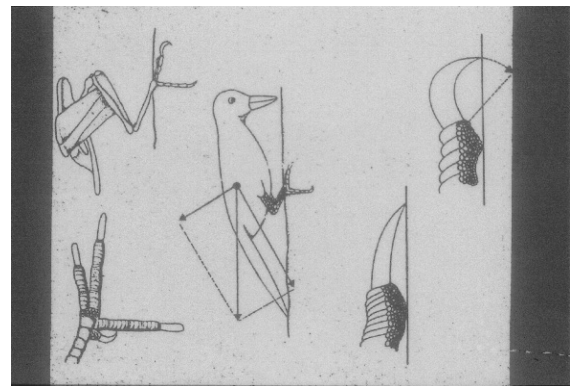


Figure 7. Schematic of the weight distribution of the woodpecker describing the spring effect of the tail and the tenso-structured nail effect in their fingers nails (drawing by Franco Lodato).

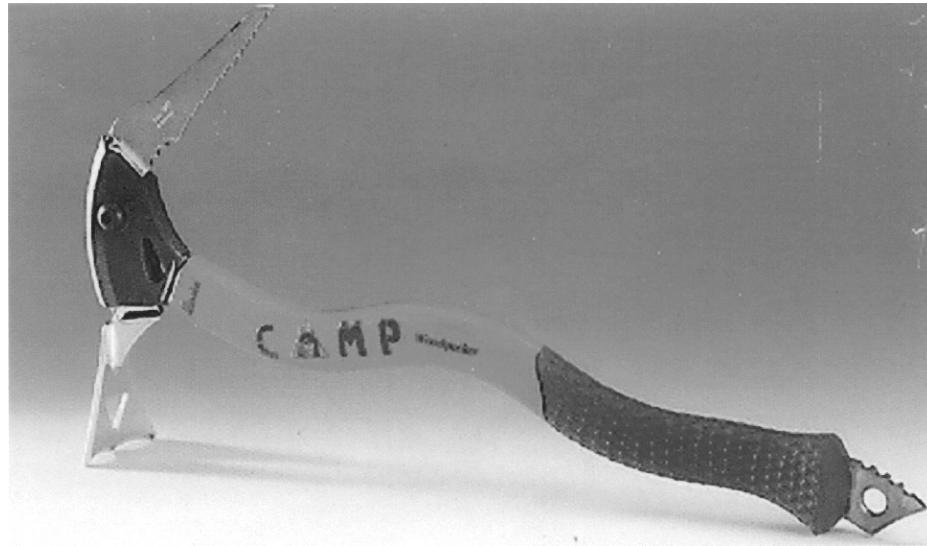


Figure 10. Picture of the first production prototype December 1990 (courtesy of CAMP Italy).

Designing for people means accommodating people, for comfort, contentment, freedom, and maximum productivity. Accommodating everyone is an ideal goal that may not be achievable. Ideally a design may have to accept the largest and the

smallest male or female adult. It may have to be acceptable for use by children and, in many cases, the handicapped.

It is in these types of cases that Anthropometric science intervenes. During the course of my career, I have been implementing these approaches in the development of innovative products as sporting tools, cooking systems, furniture, automobile interiors, motorcycles, oral care systems, shaving systems, writing instruments, and, most recently, at Motorola, wearable communication devices.

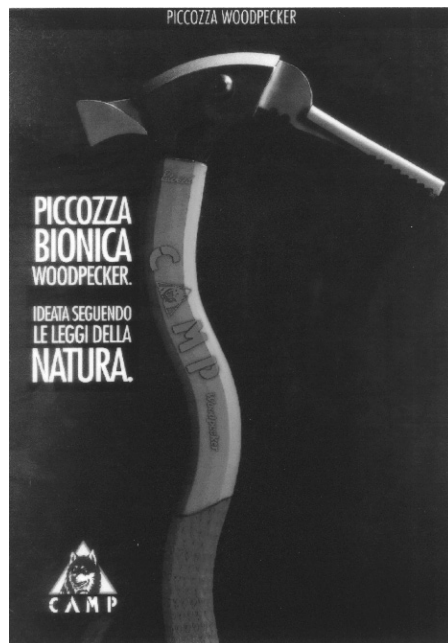


Figure 11. CAMP uses the biodesign inspiration to develop a full marketing campaign for the whole line of climbing products (courtesy of CAMP Italy).

DEEP DESIGN: MIMICKING NATURE FOR LIVING

A bird in flight motivates our dreams and inspires our imagination. Leonardo da Vinci's intricate designs for flying machines were inspired by his studies of bird and bat wings. The Wright brothers created stabilizers for their airplanes by analyzing how a turkey vulture uses its body to reduce turbulence (11). Natural forms are repeatedly used as an abstract source of inspiration. Bionic researchers have gone a step further, referencing biology as the foundation of design.

Bionics deals with the technical transformation and application of structures, procedures, and developmental principles of biological systems. It is



Figure 12. Series of Motorola iDEN rugged phones (i305, i530, and i325 series) developed implementing biodesign approach (design by Franco Lodato, courtesy of Motorola).

an interdisciplinary research field that combines biology with engineering, architecture, and mathematics. Over the last decade, with our increased focus on nature, the field of bionics has exploded. Today, features derived from nature are commonly used for design improvement and even for marketing strategies.

In the Bible, Ecclesiastes 1:10, it is written, “Is there anything of which one might say, See, this is new? Already it has existed for ages which were before us.” This is a well-known truth to bionic designers. Through evolution, nature has refined its forms, processes, and systems over a multitude of incremental steps. The complex interplay of evolutionary forces assures the quality of the resulting system.

This lengthy process has resulted in highly adapted systems. According to the principle of evolutionary convergence, diverse living creatures may have specific structures in common. The processes of adaptation to and selection for the respective environments have determined, generation after generation, the development of analogous characteristics. For example, the shark, ichthyosaurs, and dolphin (a fish, reptile, and mammal, respectively) share similar characteristics. Over centuries, evolution has determined that the characteristics suitable for an aquatic environment are a streamlined shape, fins in place of limbs, and a caudal fin for stability.

Learning from nature, we should reference these structures as ideals to emulate in our designs.

In his text, *Chance and Necessity*, Jacques Monod made a distinction between the two moments of the evolutionary process (6). First, the appearance of certain structures is a chance phenomenon. Then, adaptation or refinement is necessary for the success of the structure in successive generations. One might suggest that this is also the standard process of technological design. Bionics, however, works to reinvent the design process; to start with the necessity and to look back at nature to find the answer. Therefore, we can skip the chance phase and assume that nature has tested the principles and mechanisms for us.

Other examples include the works of Ignazio and Igo Etrich, who built the first tailless glider by copying the seeds of anemophilous dispersion plants whose seeds, transported by the wind, are able to cover considerable distance; Max O. Kramer’s antiturbulence linings for submarine devices, which imitate the dolphin’s skin structure; and Georges de Maestral’s Velcro, which was inspired by burdock seeds (*Arctium lappa*) that stick to the skin of animals. Furthermore, bionics has enjoyed conspicuous financing by NASA and by some US military agencies (10). Their aims are to investigate the flight of nocturnal predators that attack prey while flying in utmost silence and the neuromuscu-

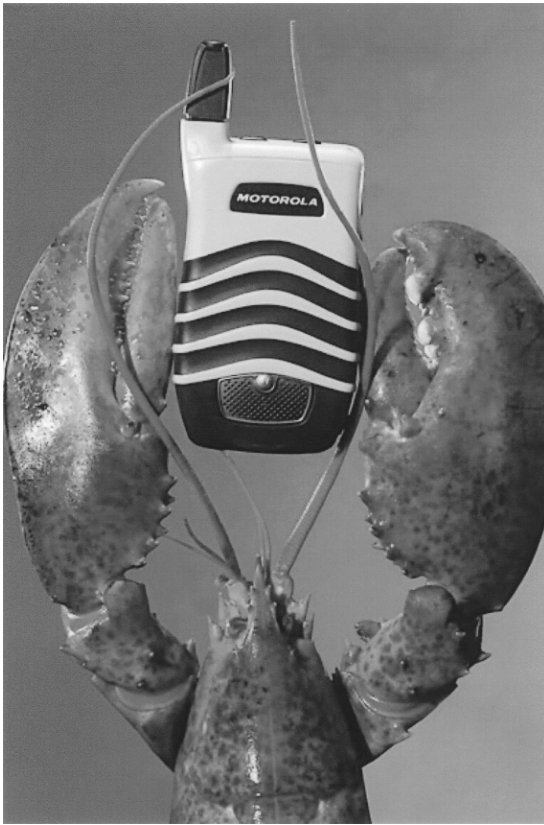


Figure 13. Motorola i560. The i560 meets military standards for withstanding shock, dust, vibration, and temperature variation. Photograph courtesy of Jonathan Kantor. K. Rockwood, *Biomimicry: nature-inspired designs*. Fast Company; October 1, 2008 (<http://www.fastcompany.com/magazine/129/truly-intelligent-design.html>).

lar coordination of certain coleopteran capable of memorizing the morphology of the terrain they have covered.

To illustrate the power of bionics, I will explain two designs from my work within the field: the ice axe and the handle. The first project came from a sports equipment manufacturer. They requested a design for a multifunctional ice axe able to be used in variable positions, light in weight, of very high structural strength, and with a powerful grip structure. The tool would be used under difficult conditions for both the mountain climber and the materials. In fact, it was to be used at the extremes of 5000 m altitude and in temperatures on the order of -20°C . The ice axe needed to be strong enough to penetrate ice, yet light enough in weight to alleviate the mountain climber's fatigue (Fig. 5).

The natural model selected was the movement of the woodpecker, a bird that chisels into wood to get at the wood-eating insect larvae on which it feeds. The woodpecker (or woodpeckers, given that in Europe there are about 10 species) has an extraordinary aptitude for chiseling. It can do 25 hits per second with a force of impact of 25 km/mm (1) (Fig. 6).

The woodpecker's body is designed specifically for this movement. Bracing itself with its tail, which functions as a spring, woodpeckers can take advantage of both their center of gravity and the configuration of their skull bones to absorb considerable stress. Thanks to this set of characteristics, a woodpecker can utilize its entire bodily structure to increase the efficacy of the percussion. They do not hammer on the wood by simply moving their necks. In addition, their total weight is around only 500 g (Fig. 7).

The handle was designed imitating the woodpecker (Fig. 8). It consists of an inner core of titanium into which is inserted an adjustable aluminum point. These two parts are attached by a hinge inspired by the two valves of a mollusk. Special attention was dedicated to the shape of the handle. Instead of being straight, the handle contains a slight curvature, like the body of the woodpecker. This improves the efficiency of the blow.

The handle is lined with a knurled layer of polybutylene terephthalate (PBT) rigid polyester and covered with an elastic layer of Rynite® to provide the grip. The inspiration for this was the epidermis of sharks, rigid elements overlying a soft base. The overall result is a structure that withstands heat stress, water, dampness, and UV radiation (Fig. 9).

This design strategy led the customer, CAMP (Como, Italy), to change its image, line of products, and marketing strategy. Emphasizing the environmental aspect grabbed the customers' attention and impacted the whole industry sector (Figs. 10 and 11).

Having developed numerous consumer products, more recently I have studied the tough, protective exoskeleton of lobsters and other crustaceans as I designed a new line of rugged, shock-resistant, weather-resistant phones (Fig. 12).

Crustaceans have an outer shell made with hard and soft layers of chitin combined with calcium carbonate. The layering provides a covering that

protects internal organs extremely well. To achieve the same effect and protect the phone's inner workings, my design group used hard and soft layers of polymers (chemical compounds with long repeating chains of atoms) to cover the entire exterior of the phone. The layers are made with substances such as polycarbonate and Santoprene, a rubberlike plastic material (Fig. 13).

My normal approach is to study what is happening in nature first. Observing how nature has resolved challenges and created simple solutions is fascinating. Natural shapes and organisms represent millions of years of evolution—and the final product is all properly done. As humans, our thinking tends to become clouded by our egos. Frequently we assume we can design systems that allow us to overcome nature. As designers we must reassess this assumption, for it is from the processes, shapes, mechanisms, and textures found in nature that we will gain the tools to realize our future.

ABOUT THE AUTHOR



Franco Lodato, M.Sc., IDSA/AIGA, Designer and Innovator, is a Charter Member of the National Academy of Inventors and a member of the Executive Committee of the USF Chapter. He is former Designer in Residence for the College of The Arts at the University of South Florida and holds a master's degree in biodesign from the European Institute of Design in

Milan. Nature inspired design—biomimicry or bionics—is not something you would normally associate with Product Design. But it is what has inspired Franco Lodato during his career. Experienced in the world of wireless communications, wearable technologies, and consumer markets for more than 20 years, he spent much of that time implementing bionic design in these arenas. “Bionics draws from the simplicity, efficiency, functionality, and beauty of design in nature and applies these principles to the design of everyday things,” says Lodato. He has expanded upon this exploration in companies like DuPont, Gillette, Motorola, Herman Miller, and Pininfarina, among others. Lodato's visionary approach implementing design innovations based on nature's paradigms and the holistic consideration of the user's experience is well-published in leading design and technology periodicals. He is a regular speaker at design and innovation conferences worldwide, and holds 56 US design and implementation patents.

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