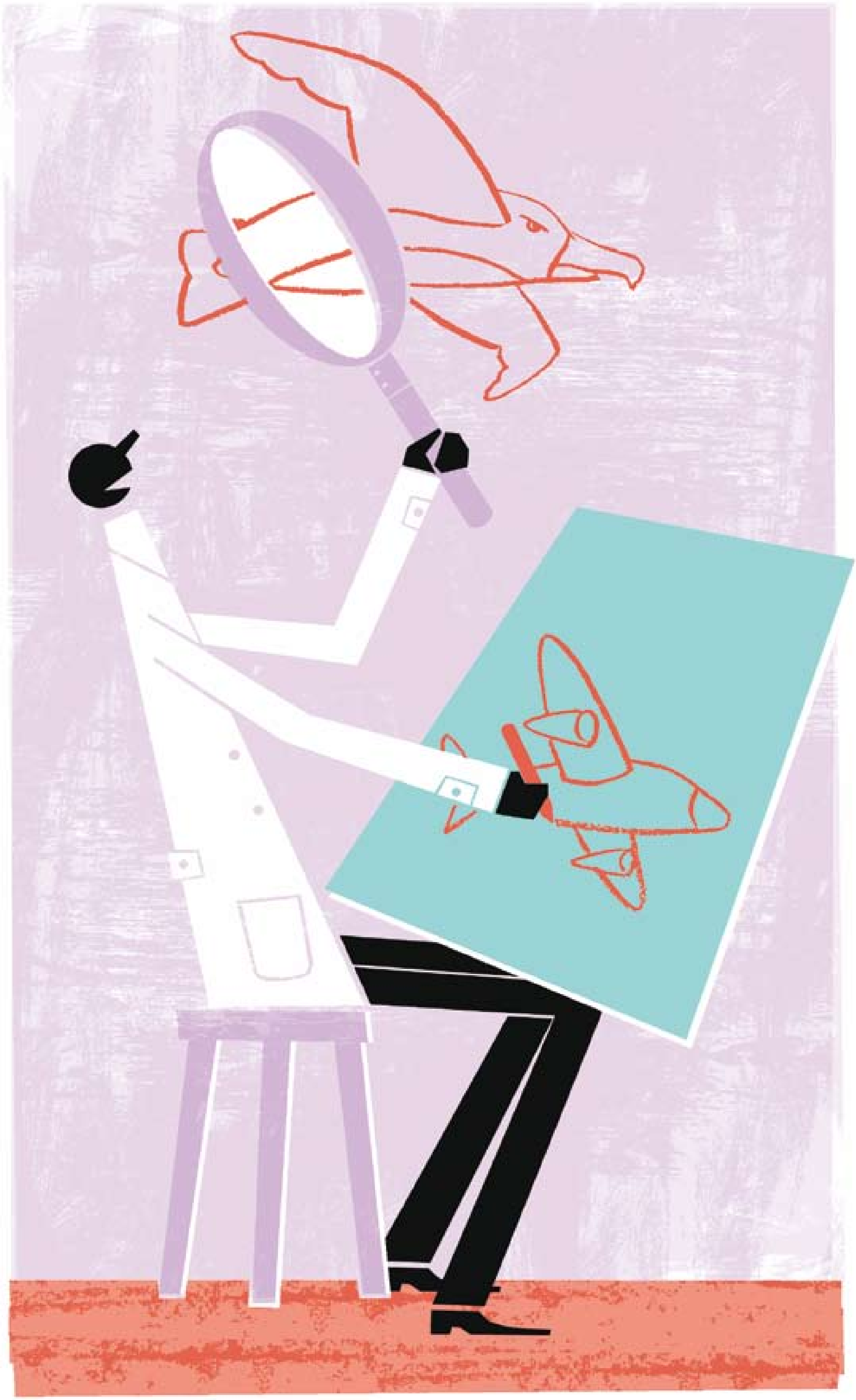

Biomimicry: from curiosity to commercial reality

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"Nature imitates art", argued Oscar Wilde, but today's scientists imitate nature. This article examines the remarkable field of biomimicry, in which nature's ingenious solutions to problems that have long baffled engineers are imitated and adopted. The authors highlight leading examples and show how companies can get best prepare themselves to make the most of nature.

If you have ever visited the African city of Harare, you may have been struck by the rather odd architecture of the Eastgate Centre. With its massive brick and concrete outer walls, it hardly fits the picture of a modern mixed-use office-and-retailing high-rise. Appearances can be deceptive, however. The building is a genuine engineering feat modelled on the nests of Africa's indigenous termites. The self-cooling mounds of the nest ensure that the temperature inside remains within a very small, comfortable range, despite huge variations in the outside temperature. The Eastgate Centre's architects have mimicked the termites' mound design, succeeding in doing away with the need for an expensive air-conditioning system.

This example is but one of many human inventions that have found inspiration in nature. The science that takes nature as a "model, measure and mentor" is called biomimicry, often also referred to as bionics. In this article we will first describe the meaning of biomimicry, then we will demonstrate biomimicry's evolution from scientific curiosity to business reality across a variety of industries. Finally we will indicate what it takes to capture this business opportunity successfully.

Biomimicry defined

Biomimicry is a discipline that turns to the natural world for ideas and solutions. It originates from the observation that nature has already solved many problems similar to the ones researchers and engineers are still struggling with today. After four billion years of trial and error, evolution has yielded highly efficient systems and processes. Rather than trying to "reinvent the wheel", we might as well have a look at what nature can teach us.

And it turns out that nature can teach us quite a lot. Biomimicry provides valuable insights and opportunities for new or improved materials, shapes, functions or even systems and algorithms. Speedo, for instance, took advantage

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of the microstructure of shark skin to develop its record-selling FSII Fastskin swimming gear. The distinctive nose design of the 500-series Shinkansen Japanese bullet train mimics the kingfisher's beak, while its pantograph (the device that conducts the electric current from the overhead lines to the train) creates vortices to reduce air resistance noise just as owl plumage does. Scientists from the University of Newcastle are examining the possibilities of automatic collision avoidance in cars based on how locusts detect imminent collisions within the locust swarm and trigger escape behaviour. And the ant colony optimisation algorithm used by the datamining programme AntMiner+ mimics ant behaviour in their search for food in order to solve computational problems.

As for business success, Velcro is probably the most frequently cited example. George de Mestral invented, developed and patented the two-sided fastener in the 1950s after he and his dog came back from a walk, covered in burrs. The plant seeds bear hooks to attach themselves to the fur or clothing of passing animals or people, and thus hitch a ride to new and hopefully fertile soils. The hooks clinging to the tiny loops in the fabric of his trousers were all the inspiration de Mestral needed to come up with the design that would soon conquer the world. The two major global players in the "hook-and-loop fastener" industry, Velcro Industries (based in the Netherlands Antilles) and Aplix (based in France), realised sales of US$ 285 million and US$ 170 million respectively in 2006.

During past decades, biomimicry inventions like the ones described above popped up occasionally. In recent years, however, bionic research and applications have become omnipresent. They have now become genuine "hot stuff", both in academia and industry. In her book "Biomimicry – Innovation Inspired by Nature", Janine Benyus sets out nine basic laws for drawing inspiration from nature (see box). These are guiding principles for any business looking to benefit from biomimicry opportunities.

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Nine basic laws in "natural design"

1.	nature runs on sunlight
2.	nature uses only the energy it needs
3.	nature fits form to function
4.	nature recycles everything
5.	nature rewards cooperation
6.	nature banks on diversity
7.	nature demands local expertise
8.	nature curbs excesses from within
9.	nature taps the power of limits

From "Biomimicry – Innovation Inspired by Nature" (Perennial, 1998) by Janine M. Benyus

The business case for biomimicry

From our research and work with clients, we find that companies are pursuing biomimicry opportunities for three reasons. First, biomimicry can open a pathway to radical innovation and new business. Second, it can lead to more effective and efficient products. Third, a biomimicry initiative sits well with the current search for "green" credentials. Let's look at these three reasons in more detail.

a. A pathway to radical innovation

Biomimicry opens pathways to new product categories or even industries. It can radically change the way engineers and designers look at existing problems. Close study of nature's example provides inspiration for breakthrough ideas and disruptive new technologies. Biomimicry thus has the ability to create entirely new growth areas and boost revenues.

For example, Degussa pioneered R&D on the lotus effect, which opened the way for self-cleaning surfaces. The leaves of the lotus flower have a surface that is rough if you look at it at nano-scale, and significantly reduces the contact area with water droplets. As a result, the surface is water-repellent, and water droplets rolling off take with them any dirt or dust accumulated on the lotus leaf.

Self-repairing "smart" materials are another example. Many network partnerships between specialist companies, universities and research institutes are currently working on mechanisms that allow materials to compensate for small cracks and structural distortions, based on the self-repairing abilities of plants.

b. More effective and efficient products

In addition to radical innovations, biomimicry can lead to "more with less" kind of improvements of existing products. Energy efficiency is one example of an area where biomimicry solutions surpass applications and production processes using conventional designs. The Eastgate Centre in Harare is a good example (see box for more details). Another example comes from PAX Scientific, a US industrial design firm. It has designed fans, propellers, impellers and aerators based on the three-dimensional logarithmic spiral shape found in the shells of molluscs. The firm's designers have found that this shape reduces energy requirements in fans and other rotors by 10 to 85 per cent, depending upon the application. Fan blade noise reduction of up to 75 per cent serves as a nice extra to the technology's already impressive performance.

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Transport is another sector where bionic applications could lead to higher energy efficiency. In the second half of the 1990s, a research lab at the Technical University of Berlin tested a shark skin-inspired foil to improve the aerodynamic characteristics of aircraft surfaces. The research proved that optimal application of the foil would enable an Airbus A340 to take 15 extra passengers aboard without increasing fuel consumption.

More economical material usage is another potential benefit of biomimicry solutions. Bionic designs use shape instead of extra material to improve the functionality of a product, thus often eliminating the need for expensive, high-tech materials. Dye sensitised solar cells (DSSC), for example, mimic plant photosynthesis. While they cannot compete with silicon wafer-based solar cells in terms of efficiency, they rely on advanced yet low-cost materials and easy manufacturing processes to cut the price to about one tenth of "classic" solar cells. This price/performance

Energy efficiency in the Eastgate Centre in Harare

The Eastgate Centre relies on its thermal mass and changing environmental conditions for cooling. In the daytime, temperatures in Harare typically rise to 40°C, yet at night they can fall to a mere 10°C. The building's material absorbs the warmth building up during the day, limiting the rise in the temperature inside to about 2°C. As outside temperatures drop at night, the accumulated warmth is released and pulled out through 48 brick funnels on the roof. High-volume fans assist the natural stack mechanism, giving 10 nocturnal air changes per hour, compared to only two air changes per hour by day. This ensures pleasant indoor conditions all year round, except for some rare occasions when hot, humid days and cloudy nights negatively affect thermal performance.

The passive mechanism of climate control eliminates the need for the high-tech air-conditioning plant that is typical for comparable buildings. On a total construction cost of $ 36 million, this created a cost reduction of US $ 3.5 million. In total, the project cost 20 per cent less than a comparable neighbouring air-conditioned building constructed simultaneously. Moreover, the building's operating expenses are significantly cut: at 108 kWh per square metre per year, the Eastgate Centre's energy consumption is 20 to 50 per cent below five other office buildings examined in Harare. Greenhouse gas emissions are reduced to 68 kg of CO2 per square metre per year, adding ecological benefits to the economic ones.

ratio may even enable them to become competitive with fossil fuel electricity generation in Europe.

A third type of "more with less" kind of product improvement relates to the use of waste, both in production processes and product utilisation. All around us, nature demonstrates how to close loops and use waste as food for other flows and processes. Application of this principle leads to a redefinition and elimination of the concept of waste, leading, for example, to the creation of new profit centres that commercialise superfluous product streams. What one party considers waste may be sheer gold to another

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c. Providing naturally green credentials

Finally, many companies find that biomimicry is a priceless opportunity to develop or strengthen their public image. At a time when fashionably green and socially responsible companies are flooding the advertising scene, the bionic argument can set your company apart and label it as progressive, innovative and proactive about the environment. For example, PAX Scientific, the design firm whose corporate tagline is "Capturing the Force of Nature", states on its vision webpage: "To ensure that our actions reflect our values, we endeavor to ask ourselves: does it benefit people, promote prosperity, and tread lightly on the planet?"

Engaging successfully in biomimicry

These examples demonstrate that biomimicry is a fascinating field of innovation holding significant commercial opportunity. Capturing this opportunity successfully requires a thoughtful approach. There are four key factors for success: a prepared mind, networking, perseverance and a sense of perspective.

a. A prepared mind

Imagine you have decided to give biomimicry a prominent place in your innovation strategy. Should you then instruct your R&D managers to escape collectively from the confinement of their corporate labs and venture out into the wild, in the hope of stumbling on some natural phenomenon that wonderfully solves their technological problem? Or should you put several of them tightly together in a newly created, well advertised "biomimicry department", so that anyone with a brilliant observation from nature knows where to find them? In other words, should you expect biomimicry innovation to come about by technology-pull or nature-push?

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Practice shows examples of both approaches. Speedo researchers explicitly went to look for natural examples of efficient aquatic propulsion when developing the Fastskin FSII swimming suit, which was launched at the 2000 Sydney Olympics. Mercedes-Benz actively went on a hunt for animals that have remarkable aerodynamic characteristics when it tried to develop a new, extremely aerodynamic car, ultimately leading to the boxfish-imitating bionic concept car in 2005. And the search for new high-performance adhesive solutions has inspired numerous researchers to turn to the gecko, trying to unravel the mystery of its ability to walk on walls and ceilings.

But George de Mestral was not looking for new fasteners at all when he came up with his idea for Velcro. Mick

Pearce, the Eastgate Centre architect, had his idea for applying the air-conditioning tricks used by termites after watching one of David Attenborough's wildlife films. And the self-regenerating capacities of living plant and animal tissue have sparked research into self-repair mechanisms and consequently self-repairing materials and surfaces.

While the nature-push approach so far appears to have been somewhat stronger than the technology-pull approach, we expect the latter to gain in importance. Biomimicry first attracted serious academic interest in the 1980s and early 1990s. The seeds sown at that time are now bearing fruit, with many bionic technologies coming of age. The growing number of success stories and associated buzz trigger a self-reinforcing dynamic. While the biomimicry landscape is still dominated by small companies – often spin-offs from universities and scientific research institutes – large companies are now also finding their way in. They are likely to follow a structured technology-pull approach.

What counts ultimately is the ability to combine nature-push with technology-pull. To that effect, it is important to stimulate awareness, curiosity and openness about biomimicry among your R&D people. As successful innovation managers know, serendipity favours the prepared mind.

b. Networking

While the biomimicry landscape is still dominated by small companies – often spin-offs from universities and scientific research institutes – large companies are now also finding their way in.

Biomimicry is a diffuse domain without clear boundaries, and one where "open innovation" applies par excellence. Participating in networks with industrial and academic partners is of high importance, for several reasons.

The first reason is economic efficiency. Few companies could afford to attract and employ experts from all fields of natural sciences to scour nature for solutions to their technological challenges. It is rather inefficient to employ an army of biologists in the hope of solving one or two problems. Even then it is unlikely that these experts would be able to keep track of all the new discoveries being made in their field of research. Furthermore, a biologist's discovery of a new principle of Mother Nature's engineering genius doesn't necessarily lead to a brilliant idea for a technological breakthrough. It is much more efficient to participate in competence networks where scientists and engineers from a wide variety of disciplines meet.

Effectiveness is the second reason for participating in networks, which abound in the biomimicry domain (see Table 1). Especially in Germany, industry and academia join forces in biomimicry competence networks such as BIOKON and Competence Network Biomimetics. At the more international level, BIONIS (UK) and the Biomimicry Institute (USA) deliver excellent networking results. By participating in cross-disciplinary forums, industry and academia seek several advantages, such as:

- Easy access to information about breakthrough research, know-how and intellectual property. Many of these networks have extensive databases through which researchers can share new discoveries about biological mechanisms and industry can launch its call for help.

- Identification of collaboration opportunities. The exchange of information and ideas through the network can lead to match-making and partnerships, in which academia is stimulated and funded by industry for both research and development. As many of these networks are international, they expand the participants' realm of partnership opportunities.

- Scouting for winners. Many biomimicry innovations originate from small companies that do not have the financial muscle to bring their product to market by themselves. Large companies can use these networks to spot promising start-ups and gain early (exclusive) access to a novel technology. Stomatex, for example, is a British company that produces a highly breathable elastic fabric. It pumps out excessive humidity by mimicking the way plants regulate the movement of water vapour and other gases between the interior of the plant and its environment. Stomatex is marketing its increasingly popular product through manufacturers of sportswear and outdoor gear such as Nike, Iill-Sport and Nexus.

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Table 1: Biomimicry networks and activity domains

	BIONIS	BIOKON	Competence Network Bionics	Biomimicry Institute
Energy & resource efficiency	●	●		●
Elimination & control of (hazardous) substances	●			●
Use of renewable & biodegradable materials	●			●
Added functionality in materials & structures	●	●	●	●
Biomedical & pharmaceutical applications	●	●		
Architecture & design, intelligent buildings	●	●		●
Biologically inspired decision-making, optimisation strategies	●			●
Materials & lightweight structures	●	●	●	●
Robotics, fluid dynamics, flying, swimming, drag	●	●	●	●
Sensors, information processing, communications	●	●		●
Packaging	●			●
Surfaces	●	●	●	●
Colour creation				●

Source: Arthur D. Little analysis

c. Perseverance

It would be imprudent to conclude from the myriad of fascinating examples that biomimicry is the perfect route to instant success. Not every biomimicry idea survives the long and difficult path to realisation. While gecko-based adhesive tape, for instance, is currently a hot topic in various research programs, it was in fact developed at the University of Manchester in 2003. The sticky tape was believed to be as effective as the real gecko's feet, and Spiderman wannabes volunteered to be hung from the lab window.

Unfortunately the production process proved to be too lengthy and expensive to ensure commercial success.

Manufacturers of incumbent technologies tend to benefit from established economies of scale, tight customer relationships, a well running global manufacturing and supply infrastructure and certified products that are designed into their customers' requirements.

Even when the technological viability of a biomimicry solution has been proven, it may take dogged determination to introduce it into others' products and convert it into commercial success. Take, for example, the use of Velcro fasteners in disposable nappies. The first granted US patent mentioning the potential use of Velcro as a fastener was filed in June 1961, only three years after de Mestral filed his original Velcro patent in the US. Yet a diaper patent filed in 1987, 26 years later, and referring to the use of Velcro fasteners, still states "its manufacturing costs are too great to be considered as a viable substitute." Despite their obvious consumer benefit, Velcro fasteners didn't become widespread in nappies until 1997 when Kimberly-Clark introduced them in its Huggies line. This long journey was due to the requirement for the Velcro fastener to displace an incumbent technology, namely refastenable tape introduced by Procter & Gamble in the early 1980s. Manufacturers of incumbent technologies tend to benefit from established economies of scale, tight customer relationships, a well running global manufacturing and supply infrastructure and certified products that are designed into their customers' requirements. Furthermore, the substitution threat encourages the incumbent manufacturers to accelerate innovation and reduce costs in turn.

Perseverance doesn't stop when – finally – the product is launched commercially. The biomimicry discovery will need continual development, long after the original product has found its way to the market. For example, research is currently underway to make so-called nano-Velcro that would allow bonds about 30 times stronger than conventional epoxy adhesives. While individual carbon nano-hooks were first created nearly 15 years ago, no one has yet found a way to grow them en masse routinely. As Walter Elliot said: "Perseverance is not a long race; it is many short races one after the other."

d. Sense of perspective

We must realise that following nature's example will not always work for the artificial world of technology we have created. But that shouldn't stop us from being inspired.

With so many benefits, it would be easy to think that biomimicry holds the magic key to solving all technology's problems. Unfortunately, anyone venturing into bionics needs to understand that it is no miraculous cure-for-all. Over millions of years of evolution, nature has solved its problems through a combination of radical solutions and changing the problem's boundary conditions. Very often this is not an option in applying these tricks of nature into modern-day technology. In many cases certain aspects need to be maintained due to technological and/or practical aspects. Take, for instance, the boxfish, which still outperforms Mercedes-Benz's bionic car on the aerodynamic level. This is mainly because designers couldn't get around aspects like passenger space, road safety and items such as mirrors and wheels, significantly disturbing the car's aerodynamic performance.

Moreover, we often apply stricter and harsher design criteria and boundaries than nature does. Extremely high or low temperatures, high or low pressures, resistance or predefined reactions to complex synthetic chemicals - these are just a few of the challenges that sometimes limit biomimicry's applicability in modern-life technology. We must realise that following nature's example will not always work for the artificial world of technology we have created. But that shouldn't stop us from being inspired.

Insights for the executive

Biomimicry is in for a bright future. Numerous examples from all around us clearly demonstrate that biomimicry isn't just the latest trend, but is here to stay. It has morphed from scientific curiosity into business reality. Tapping into the biomimicry promise requires an open and prepared mind, the willingness to participate in worldwide networks of academia and industry, and technological and commercial perseverance (see Table 2).

Table 2 **The benefits and success factors of biomimicry business initiatives**

Benefits	Key success factors
A pathway to radical Innovation	A prepared mind
More effective and efficient products	Networking
Providing naturally green credentials	Perseverance
	A sense of perspective

Source: Arthur D. Little Analysis

Almost any sector of industry can benefit from the insights acquired by studying biological phenomena. From looking at current research and development projects, it is clear that biomimicry will continue to have an impressive impact on areas such as materials science and thus on the downstream industries that make use of these materials. Spider silk – which is five times stronger than DuPont's Kevlar® aramide fibre – and the built-in protein crack arresters of abalone shells are but two examples of how limited human understanding of materials still is, and how much still remains to be learned and discovered.

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