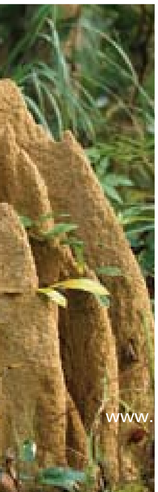
MIMICKING NATURE

BY PHIL FUNG, P.ENG., AND NICOLE AXWORTHY

PROPONENTS OF SUSTAINABLE ENGINEERING DESIGN CONTEND MANY ENGINEERING SOLUTIONS CAN BE FOUND IN NATURE.



We live in a world of challenges and opportunities. Today, as the world population continues to grow and standards of living rise, there are increasing demands on the world's resources. Engineers are tasked with accommodating the needs of increasing numbers of people and improving living conditions, and thus are at the forefront of making decisions that will have long-term implications for the planet.

It comes as no surprise that innovation and sustainability have begun to shape government policies, corporate strategies, developments and investments. Sustainable engineering design is a conceptual and practical challenge for all professional engineering disciplines. The goal is to solve a problem to meet current and foreseeable requirements without degrading the social, economic or physical environment, while also leaving room for adaptability to take advantage of future opportunities and resilience to endure future risks. It is a philosophy of designing physical objects and the built environment to comply with the principles of economic, social and ecological sustainability–otherwise known as the triple bottom line.

While traditional engineers design and develop structures and machines from engines to biomedical products for the modern world, sustainability engineers focus in particular on the effects of their designs on the environment and future generations. Sustainability engineers might research a new way to make waste systems more efficient, design alternative energy machines, or build new, sustainable infrastructure. Sustainable engineering as a field of study has exploded within the last five years, as universities around the world strive to incorporate new theories into their engineering programs, to meet the public's demand to construct smarter, more sustainable cities and communities.

LESSONS FROM NATURE

Nature operates according to the laws of natural selection and survival of the fittest. To survive and reproduce, organisms need to be resilient to unforeseeable changes to the environment. They use local natural resources and energy

The self-cooling system of termite mounds (left) inspired the design of the Eastgate Centre in Harare, Zimbabwe, also known as "the anthill" (right). The mid-rise building has no conventional air conditioning or heating, yet stays regulated year-round with dramatically less energy consumption than like-size buildings using a ventilation system that operates in a similar way to termite mounds.

that are constantly cycled, reused and renewed. They don't produce permanent garbage and they aren't toxic to their living environment. They don't require an energy grid or equipment to operate. Essentially, they've done everything human beings want to do, but without destroying the biosphere or mortgaging our future. The species that surround us have learned how to live in unison with the biosphere, so why can't we?

Biomimicry is the discipline of observing nature and applying nature's lessons to human design and innovation. Nature is the world's largest research and development laboratory, and has been testing and retesting biological designs and strategies for billions of years. Countless examples illustrate the wisdom of nature in the means by which organisms are adapted in such things as body style, physiological processes, water conservation, thermal radiation, and mutualistic relationships to ensure their species continue to survive within their environments and their unique limiting factors. In large measure, all of these adaptations result in the conservation of energy and reduction of waste, and a number of engineering and architectural applications have learned from these natural processes to create products and buildings that are models of resource efficiency. Commercial products have been developed that mimic the design of termites, whales, butterflies and lotus leaves, as well as lobsters, spiders, red algae, kingfishers, owls, blue mussels and sharks.

TERMITE-INSPIRED VENTILATION

How do you keep a mid-rise building in the middle of Zimbabwe cool without air conditioning? Unlike termites and other nest-building insects, humans pay little attention to making buildings fit their environments. Long before air conditioning was created, passive cooling was being used by termites. Keeping the temperature and humidity within termite mounds constant while getting rid of CO_2 demands an efficient process of gas exchange. A typical mound with about two million inhabitants needs to "breathe" about 1000 litres of fresh air each day. Termite mounds include flues that vent through the top and sides, and the mound, itself, is designed to catch the breeze. As the wind blows, hot air from the main chambers below ground is drawn out of the structure, helped by termites opening or blocking tunnels to control air flow.

In 1996, architect Mick Pearce collaborated with engineers at Arup Associates to build a mid-rise shopping centre and office block in central Harare, Zimbabwe, that has no air conditioning, yet stays cool, thanks to a termite-inspired ventilation system. The Eastgate Centre, also known as "the anthill," is modeled on the self-cooling mounds of *Macrotermes michaelseni* termites. These termites maintain the temperature inside their nest to within one degree of 31 C, day and night. The mounds accomplish this even when the external temperature varies between 3 C and 42 C. Eastgate uses only 10 per cent of the energy of a conventional building its size, saved $3.5 million in air conditioning costs in the first five years, and rents space for 20 per cent lower than a newer building next door.

This is very different to the way ventilation works in our modern buildings. Here, fresh air is blown in through vents to flush out stale air. Scott Turner, a termite expert at the State University of New York in Syracuse, thinks there is something to be gleaned from the termites' approach. "We could turn the whole idea of the wall on its head," he said in a *New Scientist* article. "We should not think of walls as barriers to stop the outside getting in, but rather design them as adaptive, porous interfaces that regulate the exchange of heat and air between the inside and outside. Instead of opening a window to let fresh air in, it would be the wall that does it, but carefully filtered and managed the way termite mounds do it."

WhalePower has designed wind turbine blades inspired by the shape of a whale flipper, called tubercle technology. At left is a Wenvor test turbine blade retrofitted with tubercles on the leading edge. The unique design enables a steeper operating angle of the blade and a 40 per cent increase in performance. Left photo: WhalePower

BUILT LIKE A WHALE FLIPPER

Sea creatures have evolved over millions of years to maximize efficiency of movement through water; humans have been trying to perfect streamlined designs for barely a century. The shape of whale flippers with one bumpy edge has inspired the creation of a completely novel design for wind turbine blades. This design has been shown to be more efficient and quieter, but it also defies traditional engineering theories.

Wind tunnel tests of model humpback flippers with and without leading-edge tubercles (bumps) have demonstrated the fluid dynamic improvements that tubercles make–a staggering 32 per cent reduction in drag, 8 per cent improvement in lift, and 40 per cent increase in angle of attack over smooth flippers before stalling.

Inspired by the flippers of humpback whales, WhalePower has developed something truly remarkable–tubercle technology that takes its name from the bumps on whale flippers. The edge allows efficient operation at slower speeds without stalling or lowering the pitch of the blade. Tubercle technology is more than just another blade design: it's a fundamental advance in fluid dynamics that will transform a host of machines built on that challenging science. Turbines, compressors, pumps and fans will never be the same again.

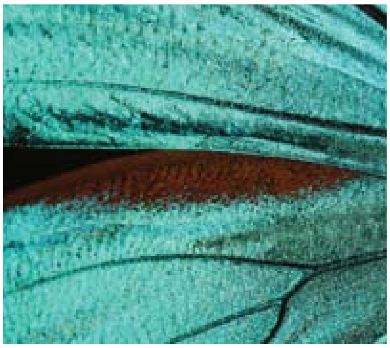
"Engineers have previously tried to ensure steady flow patterns on rigid and simple lifting surfaces, such as wings. The lesson from biomimicry is that unsteady flow and complex shapes can increase lift, reduce drag and delay 'stall,' a dramatic and abrupt loss of lift, beyond what existing engineered systems can accomplish," says Frank Fish, PhD, one of WhalePower's founders, and professor of biology, West Chester University. "In the case of the humpback whale, vortices formed from tubercles on the front edge of flippers help to generate more lift without the occurrence of stall, as well as enhancing manoeuverability and agility," he explains.

MIMICKING A BUTTERFLY

Moving beyond e-ink, tomorrow's e-book readers will feature colour displays and the ability to show video. To meet the needs of the most demanding users, e-book readers will also need to feature long battery life and displays that are bright enough to read even in direct sunlight. Qualcomm's mirasol displays address these needs using technology that mimics the colouration of a butterfly's wings.

Qualcomm looked to the unique properties of butterfly wings to improve display technology. These highly developed structures reflect light so that specific wavelengths interfere with each other to create bright colours. This same principle was applied to display technology to make brighter, more readable, lower-power displays in mobile devices. The screen does not require light from behind (backlight) to strengthen it like most LCDs. This makes them more efficient–even more efficient than e-ink technology.

Qualcomm's mirasol display is based on a reflective technology called IMOD (Interferometric MODulation), with micro-electro-mechanical systems (MEMS) structures at its core. This MEMS-based innovation is both bistable, meaning it is both extremely low power, and highly reflective, so the display can be seen even in direct sunlight. IMOD pixels require little power except when their state is being changed. This makes IMODs more energy efficient



Qualcomm's new mirasol technology is the first full-colour, video-capable display on a prototype e-book reader (right). Built on the concept of the iridescence of a butterfly's wing (left), the technology reflects light rather than transmitting it the way LCD screens do.
Right photo: Qualcomm

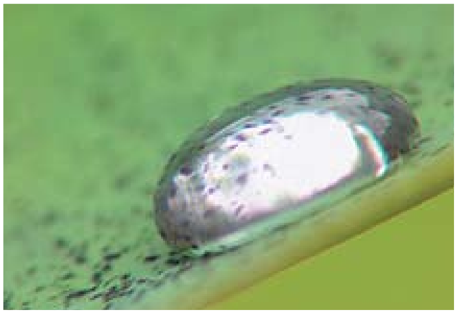
than LCD-type displays. Because IMODs are reflective displays, they actually become brighter when there is more ambient light, making them easier to see in direct sunlight or other bright conditions. The technology also has a faster refresh rate than e-ink. According to Qualcomm, not only do static images appear more quickly, but the displays can also show video.

LOTUS-EFFECT SURFACE FINISHES

Why does water roll off a duck's back? Or a butterfly's wings? Or a lotus leaf? Because a duck, a butterfly and a lotus leaf have surface textures that interact with water molecules differently than animals, insects and plants that absorb water. Some plant leaves seem to be dirtier after a rain than before–water seems to move all the dirt in one or two directions that leaves a track of dirt. The lotus leaf, on the other hand, gets clean when it rains. The surface topography of the lotus leaf interacts with water molecules so the water rolls off the leaf and takes the dirt with it.

Surface finishes inspired by the self-cleaning mechanism of lotus plants and other organisms, such as many large-winged insects, have now been applied to paints, glass, textiles and more, reducing the need for chemical detergents and costly labour. For example, the German company Sto Corp. has used new research to create a self-cleaning exterior paint called Lotusan that repels water and dirt after drying. The paint mimics lotus leaves, whose micro-roughened surfaces create a super-hydrophobic effect. Dirt particles adhere to water droplets that roll down the lotus leaves. Similarly, water runs off a Lotusan-sealed building taking the dirt with it. By mimicking this effect, a wall painted with Lotusan can be cleaned easily with no toxins, using only water. Lotusan also reduces the build-up of micro-organisms that flourish in damp and dirty conditions. It resists the growth of mold, mildew, bacteria and algae because water does not stay on its surface.

As these examples show, we must find a way to equitably share and conserve the Earth's limited natural resources. Sustainable engineering design should work within the context of the environment, not outside of it. The nature and outcomes of engineering design should be harmonized with nature to secure the supply of food, energy and water for today and tomorrow. Σ



Lotusan exterior coating, developed by Sto Corp., possesses a highly water-repellent surface similar to that of a lotus leaf, where water droplets roll off and take dirt with them (top). The photo above shows a building with Lotusan coating, where water and dirt flow off immediately and the facade remains dry and attractive.
Photos: Sto AG