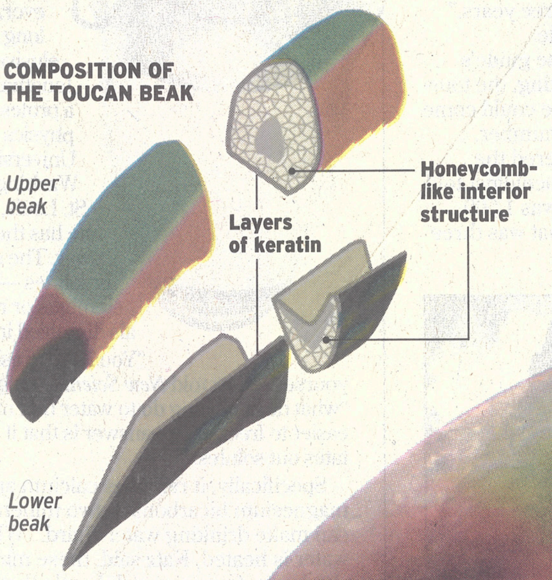
quest
science • arts • tv

LLOYD GROVE
Publisher Judith Regan is the target of the latest tell-all fiction by an ex-employee, the columnist says / F7

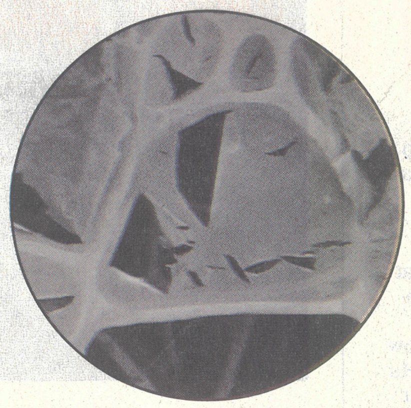
WEDNESDAY
June 7, 2006
F
THE SAN DIEGO UNION-TRIBUNE

Nature's laboratory

Scientists and engineers look to nature to learn "new" ways of manufacturing materials and building structures. At UCSD, scientists have examined the beak of the tropical toucan bird to learn why it is so strong yet so light.



SURFACE STRENGTH
The surface of the toucan's beak is made of layers of keratin, the same protein in fingernails, arranged in thin tiles affixed with an organic adhesive. The staggered tile structure resists cracks, giving the beak its strength.



INTERIOR RIGIDITY
Added integrity is provided by a honeycomb of stiff bone fibers connected by membranes in the interior of the beak.
UCSD images

Charlie Neuman / Union-Tribune

Biomimetics – *noun*, the science of studying and copying nature to solve mechanical problems

Imitation of life

For new ideas in materials and engineering solutions, nature fills the bill

By Bruce Lieberman
STAFF WRITER

Marc Meyers was a boy in Brazil when he first recognized the ingenuity of nature. Hiking with his father at the edge of a vast rain forest, he found the skeletal remains of a toucan and picked up its large beak.

He was amazed at how light it was — and how strong.

Today, the materials scientist at UCSD is studying what makes that beak, the product of millions of years of evolution, so exquisitely perfect for the tropical bird. The answers may someday lead to revolutionary designs for human innovation.

Meyers is one of many scientists and engineers who study biomimetics — a rapidly changing field that looks to nature for engineering innovations. Mimicking nature is not new. After all, the grace of a bird in flight inspired Leonardo da Vinci and the Wright brothers.

But today, scientists' ever increasing knowledge of genetics, modern computing and advances in materials science is providing new opportunities to learn from biology and copy it.

Humans are great innovators, but the natural world has been evolving for hundreds of millions of years. Why reinvent the wheel?

"We need to learn how the creatures in nature are doing what they're doing," said Yoseph Bar-Cohen, a senior scientist at NASA's Jet Propulsion Laboratory in Pasadena who has written extensively on biomimetics.

"You're talking about the biggest lab that ever existed and ever will."

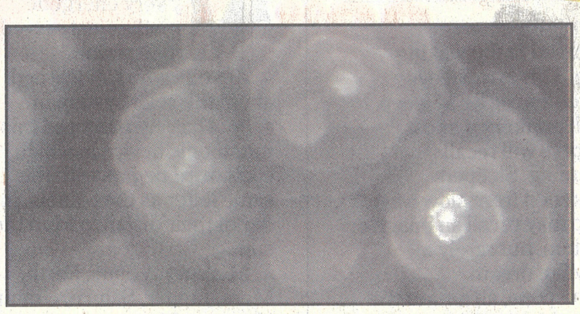
Or, as Janine Benyus, author of "Biomimicry," puts it: "Animals, plants and microbes are the real engineers … After 3.8 billion years of research and development, failures are fossils and what surrounds us is the secret to survival."

Inspired by human and animal muscles, Bar-Cohen is developing artificial ones by experimenting with electroactive polymers — plastics that change their shape in response to electricity. He foresees a day when humanlike robots will be more than characters in science fiction novels.

SEE Nature, F4

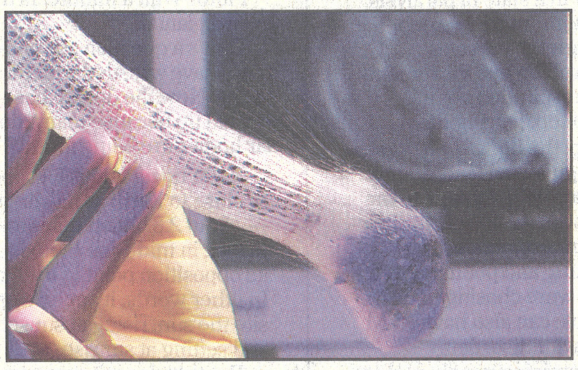
Unlocking marine mysteries

Understanding sea creatures as diverse as abalones and sea sponges could lead to the development of novel ceramics, a replacement for Kevlar or more powerful fiber optic cables.



UCSD image

SHELL STRUCTURE
On the abalone shell surface, hexagonal tiles of calcium carbonate are stacked. The tiles can slide to absorb the energy of a blow.



Bell Labs image

SILICA FROM SEAWATER
The deep-sea sponge Euplectella, or Venus flower basket, builds an ornate lattice cage by absorbing hydrated silica from seawater. Glass fibers at one end of the cage have remarkable fiber optic properties – rivaling those of commercial telecommunication fibers.

SOURCES: UCSD; Bell Labs

MATT PERRY / Union-Tribune

Tensegrity – *noun*, an engineering concept in which tension and compression are combined to keep a structure in stable equilibrium.

▶ **NATURE**

CONTINUED FROM F1

Architecture of plants, animals inspires scientist

"Strong and robust artificial muscles," Bar-Cohen wrote in a journal article this spring, "may enable us in coming years to produce biomimetic legged robots that can run as fast as a cheetah, carry mass like a horse, climb steep cliffs like a gecko, reconfigure their body like an octopus, fly like a bird and dig tunnels like a gopher."

• • •

Forty years after that hike in the rain forest, Meyers finally laid his hands on a toucan beak and cut into it. What he found was an outside shell of lightweight keratin —— the same protein that makes hair, fingernails and horse hoofs. A closer look under an electron microscope revealed overlapping tiles of keratin in multilayered sheets. These staggered tiles prevent cracks from propagating in the shell. An organic glue fuses the keratin tiles and helps absorb the energy of a blow.

That alone, however, doesn't account for the beak's strength. In the interior, a matrix of stiff bone fibers are connected by drumlike membranes — a structure akin to a honeycomb with each cell sealed tight.

The highly organized structure gives the beak its rigidity and structural integrity.

With this perfect, lightweight tool, a toucan can reach berries at the tips of branches, without strain or being thrown off balance.

"It's as if the toucan knew mechanics and knew materials," Meyers joked.

Meyers can envision the day when the beak will inspire revolutionary structures for aircraft, cars and other vehicles where strength and weight are crucial.

The toucan's staggered tile structure is not unique. In a lab at Scripps Institution of Oceanography, Meyers and his students also study live abalone to understand how they grow their super tough shells.

The shells are composed almost entirely of a type of calcium carbonate called aragonite in a complex arrangement of micron-scale tiles.

"These tiles are very well-layered, like brick and mortar," said Albert Lin, one of Meyers' graduate students. "It makes something that is literally orders of magnitude stronger than its very weak base materials."

If scientists could replicate abalone shell material, they might be able to manufacture novel ceramics, or replacements for Kevlar (the tough, light, synthetic fiber used in bulletproof vests) and other impact-resistant materials.

For Meyers, the toucan and abalone are prime examples of how nature incorporates building materials into the design of a structure.

"We have materials engineers who develop materials and design engineers who design. They are separate communities," he said. "In nature, these things go hand in hand. The material is part of the design process all the way from the beginning."

Tendons are another example. They are built from collagen formed into multiple structures — microfibrils, subfibrils, fibrils and fasciles — that together make a strong, stretchable tissue that allows animals to use their muscles and move.

Weak materials, ingenious design, Meyers said.

Man-made products, on the other hand, are based on developing complex materials in factories that often produce toxic byproducts, said Robert Skelton, a UCSD engineer.

"We produce things like Mylar and Kevlar and titanium and super-strong materials . . . yet nature uses really simple materials, like amino acids, but clever geometry."

The way humans approach materials and design is going to change, Meyers predicts, partly because the materials humans now use — ceramics, plastics, aluminum and steel — are reaching their limits in terms of the stresses we place on them.

The search is on for new materials, but engineers also are exploring new ways to use what they already have.

"We have to use these materials in a much more ingenious, intelligent way, in more creative ways," Meyers said.

• • •

In 1992, Skelton saw an astounding structure in the Netherlands that had been created by an artist, Kenneth Snelson.

The sculpture, an 80-foot tower, consisted of an arrangement of metal rods connected by cable. It sounds simple enough, but by balancing tension in the cables with compression in the rods — which don't touch one another — the structure itself appears to defy gravity. From a distance, the cables dissolve from view and the metal rods appear to be floating in air.

Skelton looked at it and experienced a kind of eureka moment.

"As an engineer and a scientist, I stood and looked at this thing and I thought, 'My god, this guy, this artist, has a better idea about structures than any engineer I ever met.' "

Snelson was using tensegrity — a term coined by Buckminster Fuller, creator of the geodesic dome, from a contraction of the words tensile and integrity. Tensegrity is an engineering concept that combines tension and compression to keep a structure in stable equilibrium.

Skelton and others have since viewed tensegrity as an idea that could lead to new architecture for bridges, buildings, airplanes and spacecraft. Such structures could be engineered light, strong, flexible and even adjustable, he said.

Skelton and his colleagues are working on developing aircraft wings that can change their shape in flight — eliminating the need for ailerons, rudders and flaps..

In his lab at UCSD, Skelton and his students have built small models of towers made from sticks and string. At the base of the structure, tension in the strings can be electronically adjusted to cancel out the shaking of a simulated earthquake.

Tensegrity is a concept used by nature, Skelton has found. For instance, the strength of spider silk is based on principles of tensegrity. Weight-for-weight, spider silk — called nature's strongest fiber — is about six times stronger than steel.

On close examination, scientists have found that spider silk is made from amino acids organized into strands connected to pleated sheets of material that can compress like an accordion. The strands provide the silk with the ability to stretch, or endure tension, while the sheets give it the ability to compress.

Spider webs need to hold together while buffeted by a breeze and weighed down with morning dew — both of which can exert tension and compression on the web's strands. They also need to stop a fast-moving insect in its tracks — stretching but not breaking on impact.

Red blood cells use the same properties of tensegrity, Skelton and UCSD bioengineer Amy Sung have found.

The cells carry oxygen through blood vessels and capillaries to every part of the body. They must be able to fold and bend, squeeze and twist through very tight spaces.

Skelton and Sung found that a tensegrity architecture on and near the surface of the cells promotes flexibility by combining tension and compression.

Knowledge of the tensegrity mechanics of red blood cells, said Skelton, should give medicine increased knowledge about what goes wrong in certain blood diseases such as hemolytic anemia, in which red blood cells are prone to rupturing.

By exploring the beauty of both art and the intricacies of biology, engineers could be on the verge of creating an entirely new way of building things.

"I'm personally convinced that these tensegrity architectures, this way of putting material together, will revolutionize the way we build structures of all kinds," Skelton said.

For Meyers, who spent years exploring the properties of metals and other inorganic materials, studying the natural world is far more interesting.

"You see an animal, you see a crab, you see an abalone, and it has life," he said. "Looking at a bird is better than looking at a piece of silicon carbide."

There's no mystery, no majesty, to how a piece of steel is made, Meyers said. But a living creature is something entirely different.

"You start to think about evolution and complexity, that this is an end point of millions of years."

MORE INFORMATION

- Yoseph Bar-Cohen ndeaa.jpl.nasa.gov/nasa-nde/biomimetics/bm-hub.htm
- Marc Meyers, UCSD www.jacobsschool.ucsd.edu/FacBios/findprofile.pl?department=MAE&last_name=Meyers
- Robert Skelton, UCSD maeweb.ucsd.edu/~skelton/