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About Zygote Quarterly

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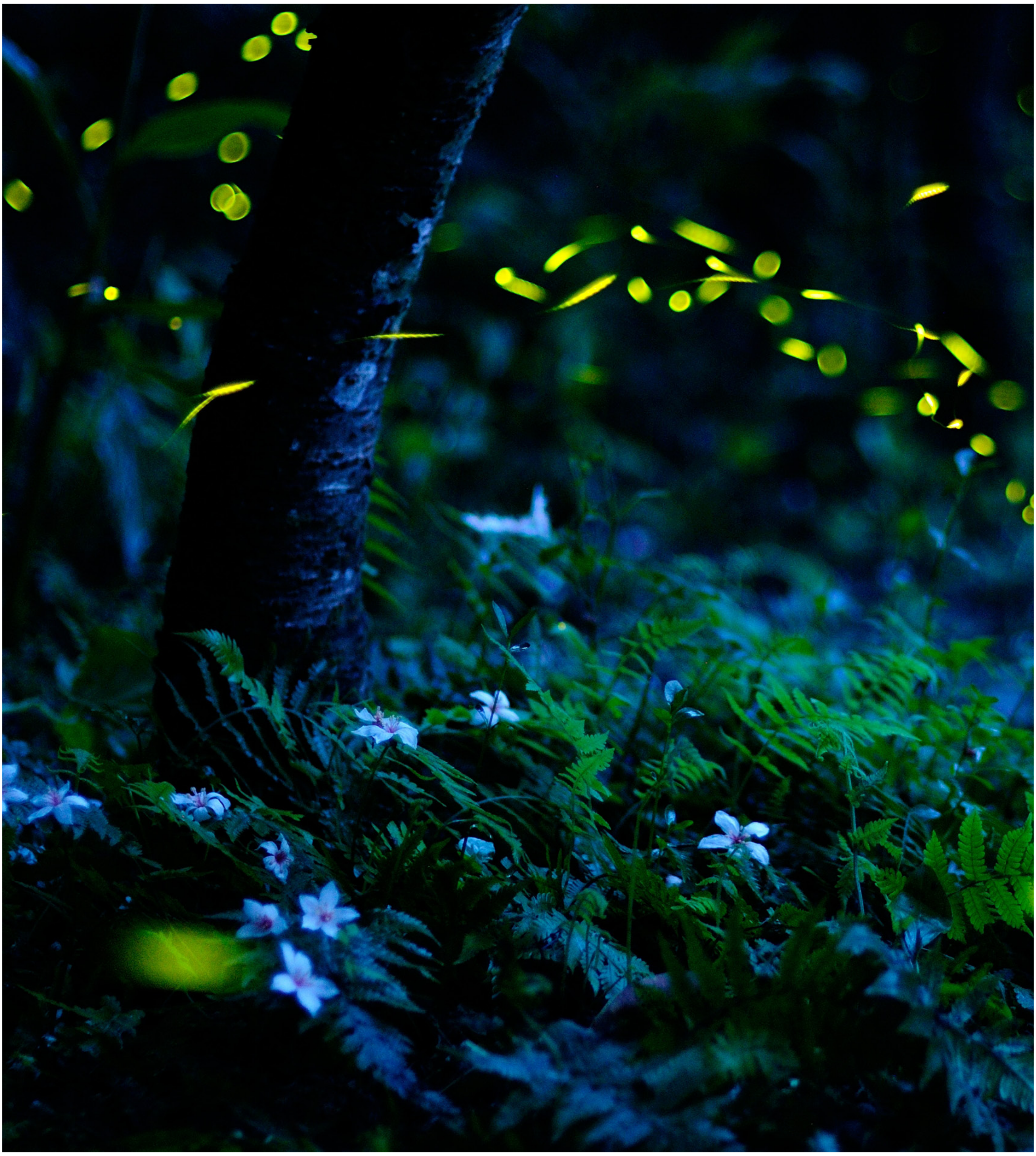


Firefly

Photo: AJ1008, 2012 | Flickr cc

Editorial

On Being a Skeptic

In this issue's case study we suggest that a little skepticism can be healthy for a new discipline where real results are hard to winnow from promotion. When does healthy skepticism turn into critical inquiry? It takes sustained effort to get at the truth once a paradigm no longer makes sense, and to act on that truth. Progress is made when skepticism is imbued with a sense of purpose and put in service to that purpose.

The Lauder lab at Harvard, one of the subjects of our first article, exhibits that pursuit. Our two interviewees, Rolf Mueller and Scott Turner are two scientists who also exemplify this approach in their study of the morphology of bats and the behavior of termites, two animals whose historical record has been rife with misconceptions. True skepticism might also be characterized by independence, rather than contrariness. Independent thinking can mean including the overlooked or the undervalued, as the Dunn Lab at North Carolina State University has done in their study of belly button bacteria in Heidi Fischer's feature.

Skepticism is probably built in to the training of a scientist, but what about the designer? There seems to be a delicate and continually shifting balance between imagining the unthought and crafting the realizable. This is the great adventure of design, and, we are sure, the reason many are drawn to the profession. This balancing is an art itself, and the criteria for judging its success, particularly in the world of the bio-inspired, are not well defined. Indeed, perhaps they can never be neatly catalogued.

Studio Roosegaarde, our portfolio subject this quarter, is part of a growing movement of designers seeking to make our built world more responsive to the people who inhabit it. Creating interactive pieces animated by human movement and behavior is a nascent field and the mechanical look of many of the pieces shown belies the basic inquiry being made. Responsiveness and adaptability are both biological traits. We feel that the relatively simple exploratory constructions being made today will pioneer the more biological solutions of tomorrow.

We also report on an event from one of the most robust design cultures in the United States, the automotive design world. While we thought the biologically-themed design challenge at the LA Auto Show was significant, the results were a bit disappointing. The gap between the blue sky and solid ground was too wide in many of the entries. More to the point: critical scientific inquiry was missing. Nevertheless, the fresh ideas that were proffered at this event can only make one hopeful of the powerful possibilities of more science-based ideas. Scientists and designers have a lot to learn from each other, and their collaboration will be critical to our future. It is our pleasure to watch the progress.

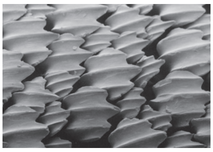
We are also watching the progress on other fronts. Cataloguing and comparing analytical approaches to bio-inspired design is an activity critical to growing the profession and we review Ashok Goel et al's latest compendium.

Spreading the word and forming affinity networks is also important, so we continue our "World" series with a cameo of the Israeli Biomimicry Organization.

Finally we are pleased to announce the first two issues of the Spanish language version of ZQ. Their publication was part of the festivities marking the 70th anniversary of Universidad Iberoamericana in Mexico City on January 20. Many thanks to Spanish edition editors Raúl de Villafranca, Carolyn Aguilar, Azucena Garca and Manuel Quirós.

Thanks for visiting and happy reading! ×

Tom McKeag, Norbert Hoeller, and Marjan Eggermont



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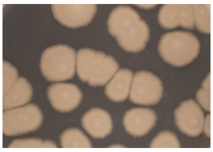

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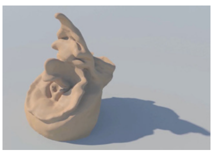

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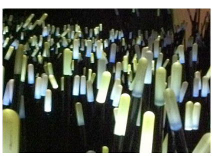

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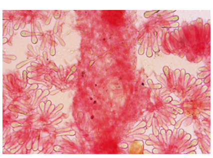

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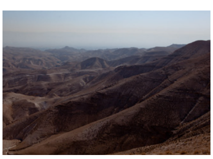

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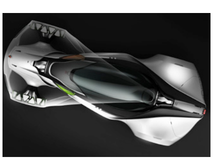

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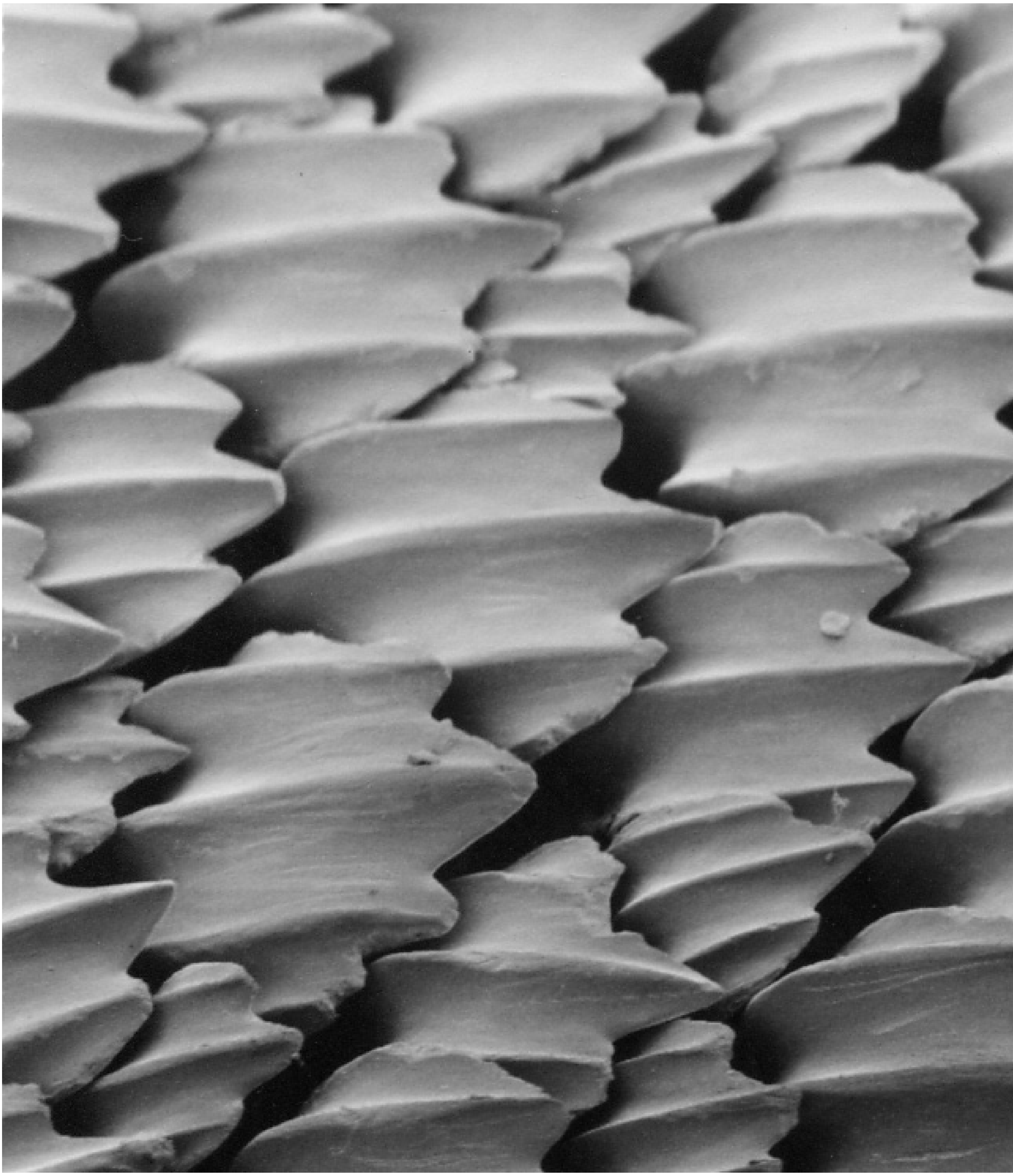
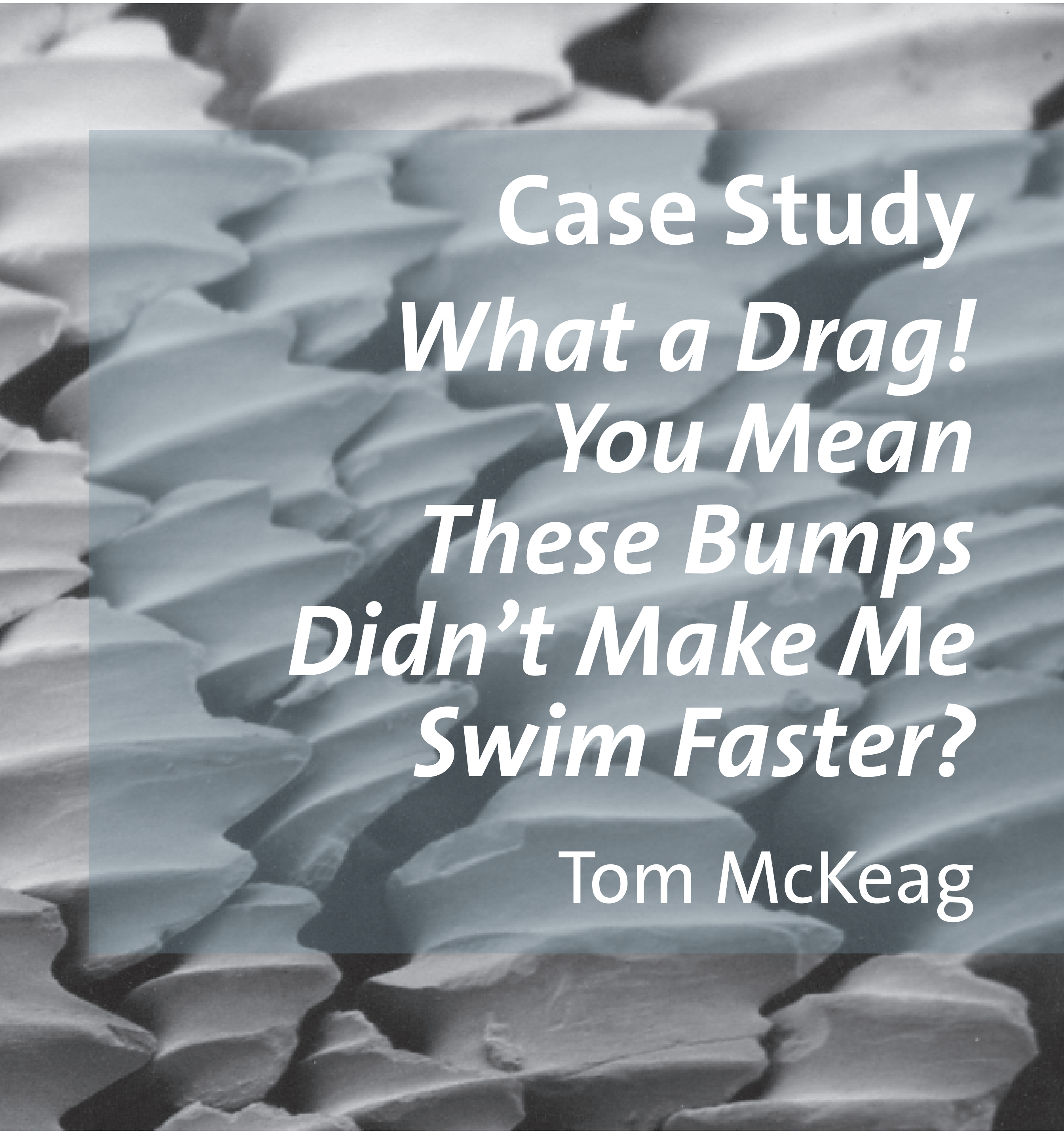


Denticules cutanés du requin citron (*Negaprion brevirostris*)

Photo: Pascal Deynat/Odontobase, 2011 | Wikimedia Commons



Case Study
What a Drag! You Mean These Bumps Didn't Make Me Swim Faster?

Tom McKeag

What a Drag! You Mean Those Bumps Didn't Make Me Swim Faster?

"Don't forget - reality is drag, not its coefficient"

- Steven Vogel

Some Inconvenient News

In 2011, Dr. George Lauder's Lab at Harvard took some Mako sharkskin they had bought at the local fish market and put it in a flow tank to test how much the dermal denticles on the skin reduced the friction drag on their flexible robotic foil. They wanted to know whether all those bumps on the shark really made a difference in speed, so they tested the flow of water over the skin of a rigid foil and of a flexible one; with the denticles and without. It turns out they really do matter, increasing self-propelled swimming speed (SPS) by an average of 12.3% in the flexible foil.

As part of their experiment they also tested a silicone riblet fabric they had made and Speedo's Fastskin FS II material. The riblet design also increased speed by up to 9.5%, but the famous Fastskin swimsuit material showed no significant increase in speed due to the orientation of its surface...none. As a matter of fact, the material was deemed faster in some instances if it was turned inside-out. According to the researchers:

> "The proposed drag-reduction properties of Speedo® Fastskin surface ridges is thus called into question when the locomotion of this material made into flexible foils is compared with that of controls with no surface indentations... Our ESEM images ... of the Speedo® fabric also evoke doubts about whether the swimsuit surface functions as shark-skin-like riblets as the surface indentations bear little resemblance to either shark skin or engineered riblet materials .... Manufactured riblet materials have sharp longitudinal rib structures (Bechert and Bartenwerfer, 1989) that can cause alterations in boundary layer flow .... A cross-cut of the Speedo® material shows dents instead of ribs, with large distances between the dents. If we treat these dents as riblets, the height to spacing (h:s) ratio would be ~0.1. A two-dimensional riblet surface with h:s=0.1 resulted in a maximal passive drag reduction of 0.5% (Bechert et al., 2000), supporting our results of either no drag reduction or drag enhancement with impaired swimming performance resulting from the Speedo® material."

Importantly, the team found that the flexible movements of the shark were key to the extra speed and that it appeared that the denticles induced a slight increase in the vacuum formed forward of them. This seemed to suggest, for the first time, that they served to increase thrust. When low pressure zones or vacuums form on one side of a foil like a wing or a sailboat's sail, they "pull" a moveable object into the lower

Shark silhouette

Photo: haakonhansen, 2003 | Flickr cc

pressure zone, helping the plane go up (lift) or the sailboat go forward (thrust). You may recognize this as related to Bernoulli's principle.

> "What we found is that as the shark skin membrane moves, there is a separation of flow – the denticles create a low-pressure zone, called a leading-edge vortex, as the water moves over the skin," Dr. Lauder told the *Harvard Gazette* in 2012. "You can imagine this low-pressure area as sucking you forward. The denticles enhance this leading-edge vortex, so my hypothesis is that these structures that make up shark skin reduce drag, but I also believe them to be thrust enhancing."

The Lauder team published their findings in the *Journal for Experimental Biology* in November, 2011, just in time for the run-up to the London Olympics the next summer. By then, Speedo had moved on, its R&D section, the Aqualab, touting a new method for extracting seconds of speed out of swimmers, a "system" of integrated cap, goggles, and suit. The Fastskin3 was designed with more traditionally determined streamlining, anatomical customization, a non-absorptive suit and selective body shaping caused by its constrictive fabric.

In its wake Speedo had left nearly a decade's worth of sophisticated, breathless and seemingly mistaken media attention on sharkskin since Fastskin was introduced in the 2000 Sydney Olympics and Fastskin II in 2004. Speedo was not alone: some seven companies had joined the commercial feeding frenzy and produced similar suits before they were banned by the International Swimming Federation (FINA) in July, 2009.

The Fastskin II swimsuit had been made famous by Michael Phelps' performance in the 2004 Athens Olympics, where he won an unprecedented eight medals, all while wearing the suit. Much of the improved performance then, and subsequently, had been attributed to the mimicking of a shark's skin and Speedo continues to make this claim when explaining the product technology on its website.

> "What we have shown conclusively is that the surface properties themselves, which the manufacturer has in the past claimed to be biomimetic, don't do anything for propulsion," said Lauder.

Still, it is hard to argue with success. Fastskin II's scions were the Fastskin FS-Pro, 2007, and the LZR ("laser") Racer. The LZR Racer suit has been credited with enabling the plethora of aquatic speed records at the Beijing Olympics in 2008. Ninety-four percent of all swimming races won, and 98% of all medals won were by swimmers wearing the suit. In total, 23 out of the 25 world records broken were achieved by swimmers in the LZR Racer suit. The LZR suit is made of elastane-nylon and polyurethane with ultrasonically welded seams. It is water repellant, quick drying and compressive, meaning that it squeezes the swimmer's body into a more hydrodynamic shape and position. Speedo did not include the dermal denticle feature in the production of either of these two suits.

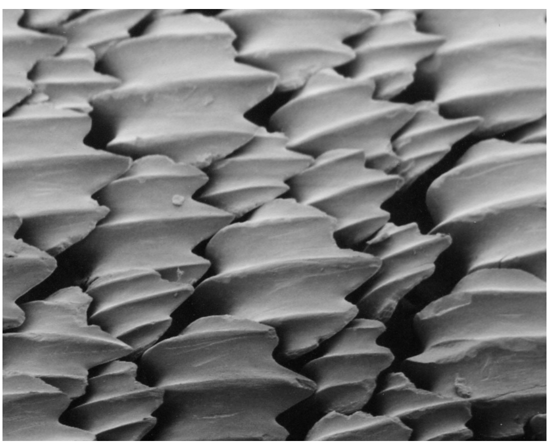
Regarding the success of Fastskin II, Lauder had this to say:

> "There are all sorts of effects at work that aren't due to the surface. Swimmers who wear these suits are squeezed into them extremely tightly, so they are very streamlined.

> They're so tight they could actually change your circulation and increase the venous return to the body, and they are tailored to make it easier to maintain proper posture even when tired. I'm convinced they work, but it's not because of the surface."

The Principle Behind the Effect

While the reason for Fastskin II's success may be in doubt, there is no question that the naturally occurring phenomenon does exist. Water flowing over a shark's body is channeled at the micron level by many tiny placoid scales, called dermal denticles or "skin teeth". Primarily, it keeps the fluid flowing smoothly in a laminar fashion and speeds up the fluid close to the surface of the shark. This reduces the difference in velocity between the near-surface flow and that further away in the water, and in turn allows the fluid to travel along the body of the shark further before splitting off into turbulence. The result is a narrower wake behind the shark, less drag and faster speed for less effort.



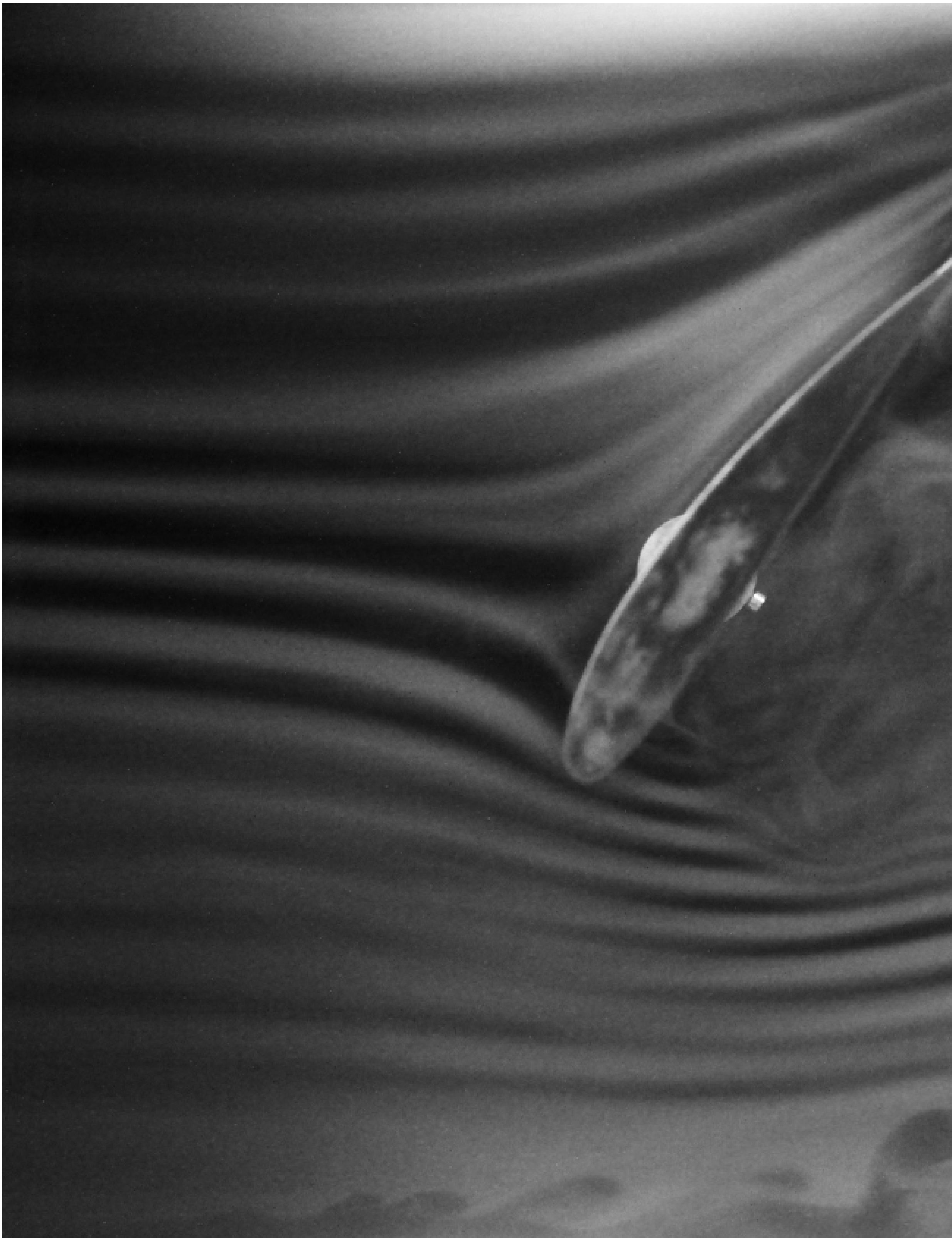
Denticules cutanés du requin citron (*Negaprion brevirostris*)

Photo: Pascal Deynat/Odontobase, 2011 | Wikimedia Commons

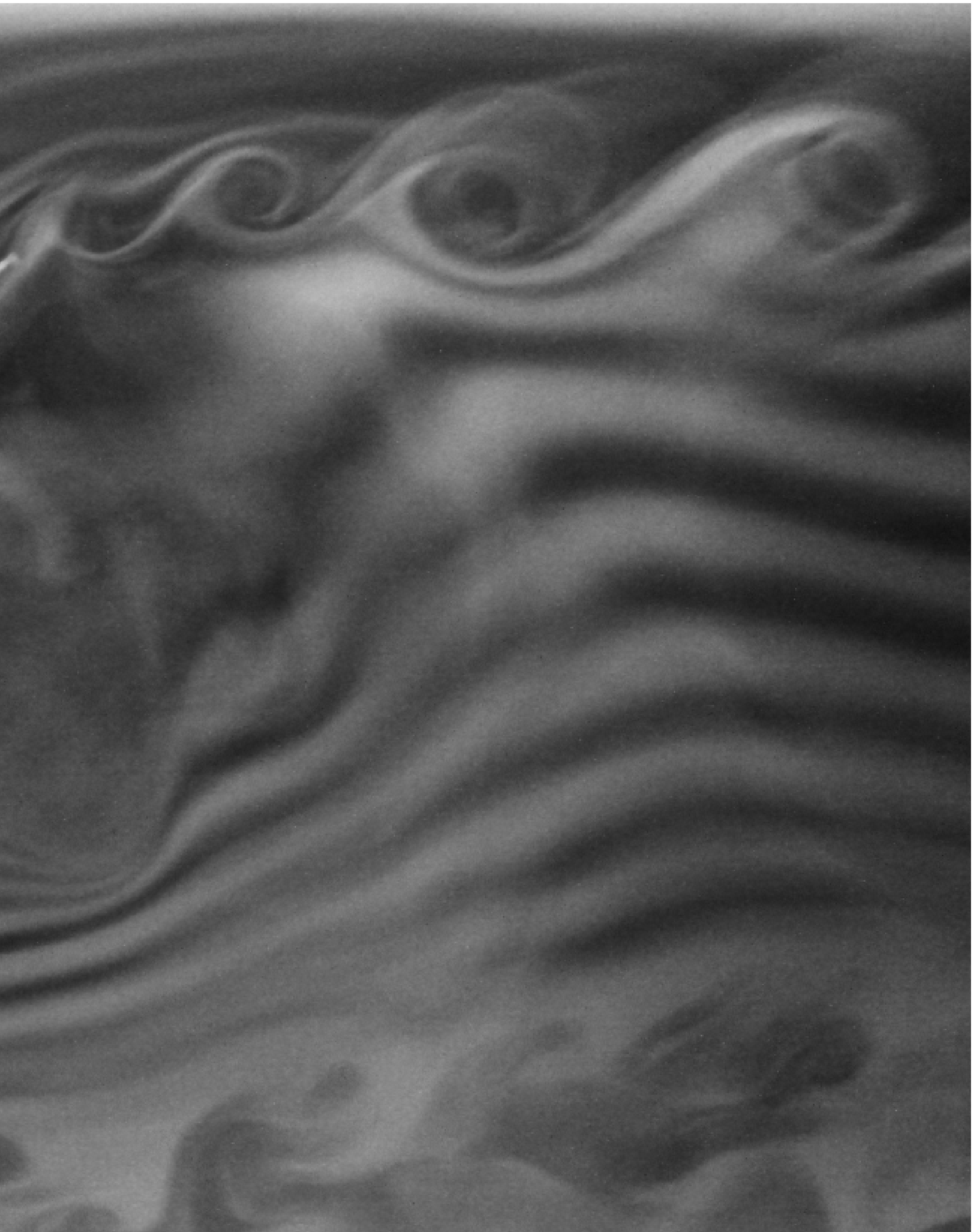
Drag is a critical controlling factor for any organism that lives and works in a fluid and has to abide by its rules. It can be defined broadly as resistance to motion and, for our purposes, comes in two basic forms: pressure drag and friction drag. Pressure or form drag can be envisioned when you think of inserting a blunt cylinder like your leg into a stream of water. The water piles up in front of the cylinder and must make its way around the object. Pressure drag is associated with the energy required to move fluid out from in front of an object in the flow and then back in place behind the object. Hydrodynamic shapes like the shark body solve a significant portion of this problem, but not all of it.

Associated with this concept is the point of separation. Typically the fluid flowing around an object will separate from the surface of the object at its widest girth. It will leave behind a vacuum of sorts, a low pressure zone, and water from downstream will actually head upstream, obedient to Bernoulli's principle. This is something every river kayaker knows, as you can catch a ride upstream at the eddy line behind a rock or other obstruction in the stream. This separation initiates turbulence aft of the object and is what starts to form von Karman vortices at sufficient velocities and total chaos at even higher speeds.

Friction drag, by contrast, is associated with the interactions between the fluid and the surface parallel to the flow, and the attraction between molecules of the fluid in the flowing water (streamlines) proceeding out from the solid surface. Theoretically, the fluid at the surface will have no speed whatsoever (the so-called no-slip zone) and each conceptual streamline parallel to that surface will be faster the further away from the surface they get, until they equal the mean



Fog (water particle) wind tunnel visualization of a NACA 4412 airfoil at a low speed flow (Re=20.000) | Photo: Georgepehli, 2010



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velocity of the surrounding undisturbed water (the free stream velocity). It is this measure of the energy needed to transfer momentum, in a velocity gradient, between the surface and the surrounding water that can be defined as friction drag.

Drag is affected by four factors: the viscosity of the fluid (how resistant to flow it is), speed, size of the solid and the density of the fluid. These will determine whether fluid flow is laminar or turbulent. For the free moving shark, the higher the velocity, the higher the drag, an unavoidable tax on speed. Thicker fluids are more resistant to cross momentum and therefore more likely to exhibit smooth, laminar flow. "Pouring oil on troubled waters" is a metaphor based on reality. Sailors knew that the more viscous oil would reduce surface chop in the sea. Guar, for instance, a naturally occurring polymer, has been used on the inside of pipes to reduce turbulence and speed up flow.

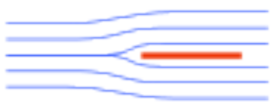
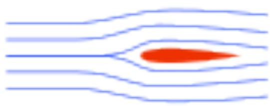
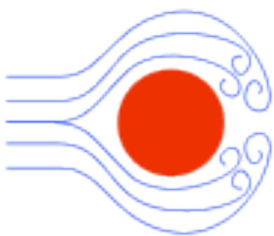
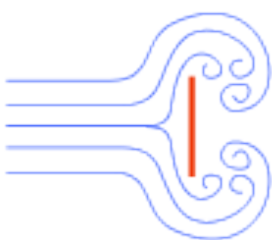
The relationship between these four factors determines the very useful Reynolds number (Re), a dimensionless ratio of inertial forces to viscous forces. For a flat plate placed in a flow tank, for example, the Re would equal the fluid density x velocity x the length of the plate divided by the dynamic viscosity of the fluid.

The Reynolds number is important because it provides a reliable and predictive benchmark for laminar versus turbulent flow. It is an indicator of the steepness of the velocity gradient discussed above. For a flat plate placed in a test tank a Re below 500,000 typically represents laminar flow (viscous forces dominate), and above represents turbulent flow (inertial forces dominate). When the viscous forces dominate, the velocity gradient will be more gradual; when inertial forces dominate, the velocity gradient will be steep and short with turbulence initiated sooner. The dermal denticles are believed to smooth out this gradient thereby delaying the start of this turbulence.

The Animal Behind the Strategy

Fast-swimming sharks are the animals most studied for this phenomenon, a member of the elasmobranch fishes that comprise sharks, rays and skates. All have some version of the rough skin that is covered by placoid scales or dermal denticles. There is a good reason why they are so called; the scale is very similar to mammalian teeth in that its base has a soft pulp of dentine covered by a hard enamel and is rooted by collagen into the skin of the shark. This base is topped by the scales, which form an overlapping, flexible and complete surface. The scales over most of the body of fast-swimming sharks are approximately 0.2–0.5 mm and have very fine and regularly spaced, 30–100 µm, longitudinal ridges that are aligned with the axis of the body. Scale geometry can vary across an individual and species.

The Shortfin Mako (*Isurus oxyrinchus*), has been chosen by many researchers for its high speeds, distinct scales and relatively common occurrence. It is in the family Lamnidae, which also includes the White Shark (*Carcharodon carcharias*), and arrived 55 million years ago, fairly late in the 400 million year evolution of sharks. It is found in temperate and tropical waters worldwide and is one of only four species of endothermic sharks. It feeds on a wide range of prey from turtles to mackerel to marine mammals, cephalopods and

Shape and flow	Form Drag	Skin friction
	0%	100%
	~10%	~80%
	~90%	~10%
	100%	0%

Drag | Shape and flow

Redrawn from http://en.wikipedia.org/wiki/Drag_(physics)

White shark | Pterantula (Terry Goss), 2006 | Wikimedia Commons

even birds. It is, quite obviously, at the top of the food web. It is listed as "vulnerable" by the International Union for the Conservation of Nature (IUCN 3.1), the lowest step of threatened status.

This is a very fast animal and is considered to be the fastest species of shark. It has been recorded at 50 kilometers per hour (31 mph) with bursts up to 74 kilometers per hour (46 mph), but maximum speeds are still open to debate. It is a pelagic or open ocean animal, swimming to recorded depths of 150 meters and will travel over 2,000 kilometers to seek prey or a mate. As a long-distance traveler it has a fusiform shape and thunniform propulsion, meaning it undulates its caudal or tail fin, literally "like a tuna". All of the most powerful large swimmers use this technique: whales, dolphins, tuna and sharks.

The great speed of the Mako leads to a very high Reynolds number and high turbulent flow in the boundary layer between the shark's surface and the free stream flow. While the turbulent flow will stick to the surface longer and not separate into wake, it will also cause a lot more friction drag, five to ten times more than if the flow was laminar. This is where, researchers believe, the riblets come in.

Other Anti-Drag Applications

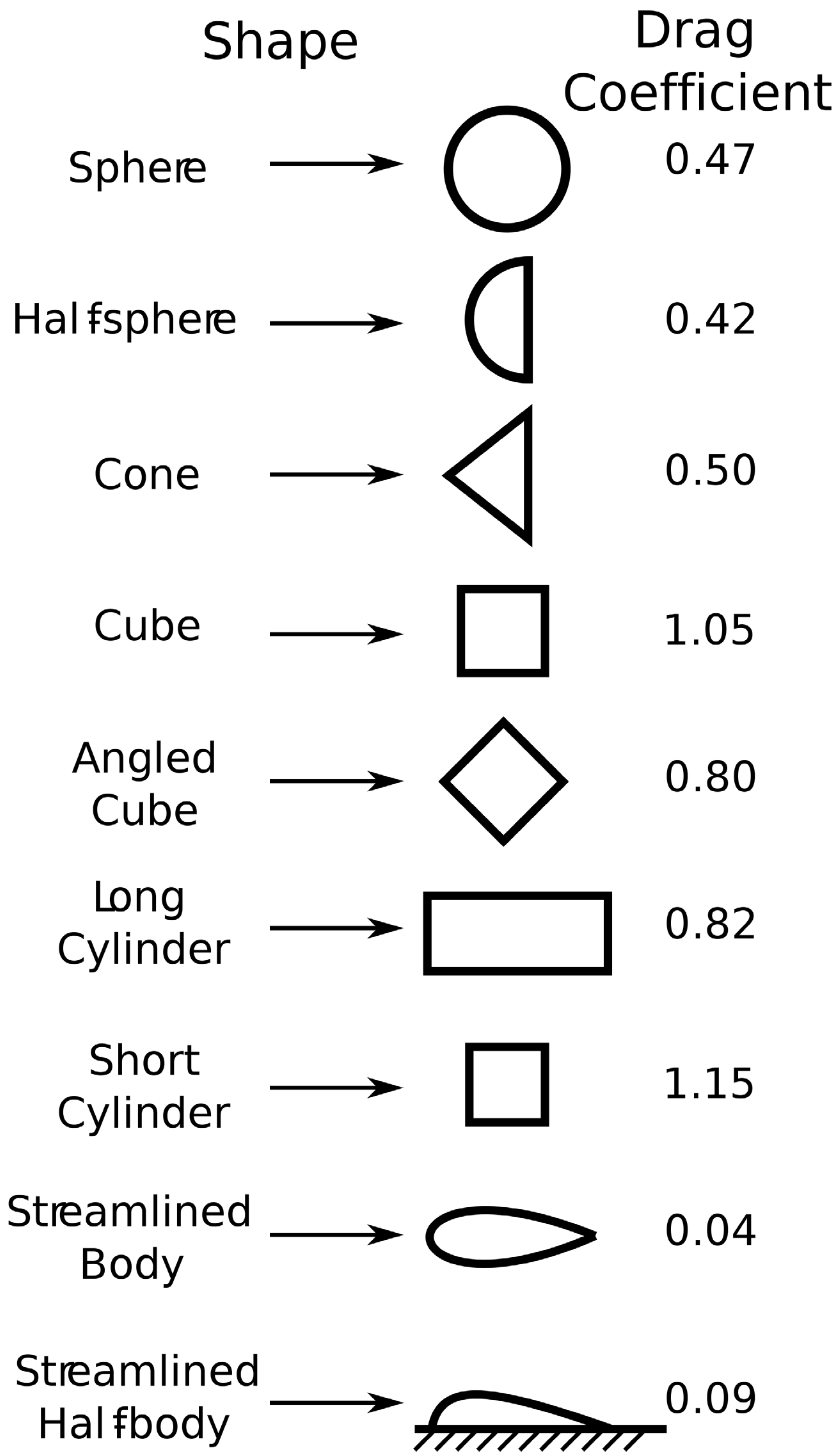
Swimsuit manufacturers are not the only ones interested in reducing drag. Anything that moves through a fluid or has a fluid flow around it or in it produces drag and it is in a manufacturer's interest to lessen it. Pipes, culverts, tubes, planes, boats and cars all are affected by this phenomenon.

Boat makers have known of the advantage of micro-ribbing on hulls for a long time. In 1987, the United States racing yacht, *Stars and Stripes*, won back the America's Cup from Australia with a hull that had micro riblets designed by the Langley Research Center of NASA. As a result of the initial testing the 3M Company developed an extruded vinyl film with the riblets and Langley tested it on a Learjet, recording an eight percent drag reduction capability. The Boeing Company, 3M and the Flight Research Institute of Seattle, Washington collaborated on the development of the first water tests of the riblet film in 1984. Pipes have also been lined with the riblet film, but it was found that grooving the pipe itself with brushes not only cleaned its surface but provided the same drag reduction.

Similarly, 3M's Renewable Energy Division has collaborated with several institutions including the St. Anthony Falls Laboratory at the University of Minnesota and the Department of Aerospace Engineering, University of Illinois at Urbana-Champaign, in testing the film on wind turbine blades.

You should note here that these riblet films are continuous groove and ridge geometries that, while mimicking the height and spacing of the shark denticles, do not reproduce the placoid scale shapes.

A product that does come close to this geometry is Sharklet Technologies' anti-bacterial coating. The product was originally developed for anti-drag performance related to algae growth on the hulls of submarines and ships. In 2002, Dr. Anthony Brennan, a materials science and engineering professor at the University of Florida, began work for The U.S. Office of Naval Research



Drag coefficient | Image: TheOtherJesse, 2008 | Wikimedia Commons

C-17 vortex: The “smoke angel” is caused by wing vortices at the plane’s wingtips

| Photo: Tech. Sergeant Russell E. Cooley IV, 2006 | Wikimedia Commons

to find new antifouling strategies for the fleet. The Navy coated its first ship with derivative coatings in 2009.

Lufthansa Technik AG, in collaboration with Airbus Operations, the Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM), and Mankiewicz coating manufacturer of Hamburg, has been testing a sharkskin-inspired surface on portions of two of its Airbus 340-300 airplanes since 2011. Its engineers would like to know how durable these surfaces are and if their performance can be maintained during all environmental conditions: UV radiation, heat, cold, rain, ice, dust and chemical de-icers. Eight patches of 10 x 10 cm have been placed on the fuselage and leading edge of the wings.

The painting test, called "the multifunctional coating project", measures the performance of a technique originally developed by Fraunhofer Gesellschaft. A clear topcoat of lacquer is sprayed onto a base coat and a silicone film with the negative shape of the shark riblets is applied with pressure into the wet coat, the lacquer is quickly cured with UV light and the film is removed. The topcoat is multifunctional because it both protects the base coat and with its grooves decreases drag along the surface of the plane. Each rib is 50-60 microns wide and 20-30 microns deep.

In the Fraunhofer application technique, a unit operable by robot employs rollers that lay down the printed silicone film, a UV lamp like that used in the printing industry, and a wide nozzle to spray the lacquer. Within a matter of seconds the system sprays the lacquer and embosses it with the silicone mold, curing it with the UV radiation. It can produce a square meter per minute.

Lufthansa hopes the painting technique could save as much as 1% of fuel consumption. The Lufthansa Group flies over 600 aircraft and fuel represented 20% of its operating costs in 2012, at a cost of 7.4 million euros, nearly $10 million USD. Fuel costs continue to go up and were 50% higher in 2012 than in 2010. The system being tested would produce a coating with a shorter lifespan (five years versus the standard eight), but paint drying times would be shorter and the plane made faster.

The testing of the new paint technique was done as part of the European Union's Clean Sky research program. Clean Sky, a Public Private Partnership between the European Commission and the Aeronautical Industry, was established to reduce the environmental impact of commercial aviation. In addition to removing some CO_2 from the skies, such a strategy could also help save Lufthansa from paying fines for excess carbon emissions at EU airports. The requirement is now being applied to airlines this year as part of the European Union Emissions Trading System.

On the inside of pipes, on the wings of aircraft, the blades of turbines or the hulls of ships, drag, you might say, is here to stay. That doesn't mean, however, that we cannot negotiate the terms of co-existence. Whether it is in clothing or vehicles or conveyances, nature has some lessons for making us or the fluids around us flow faster. ×

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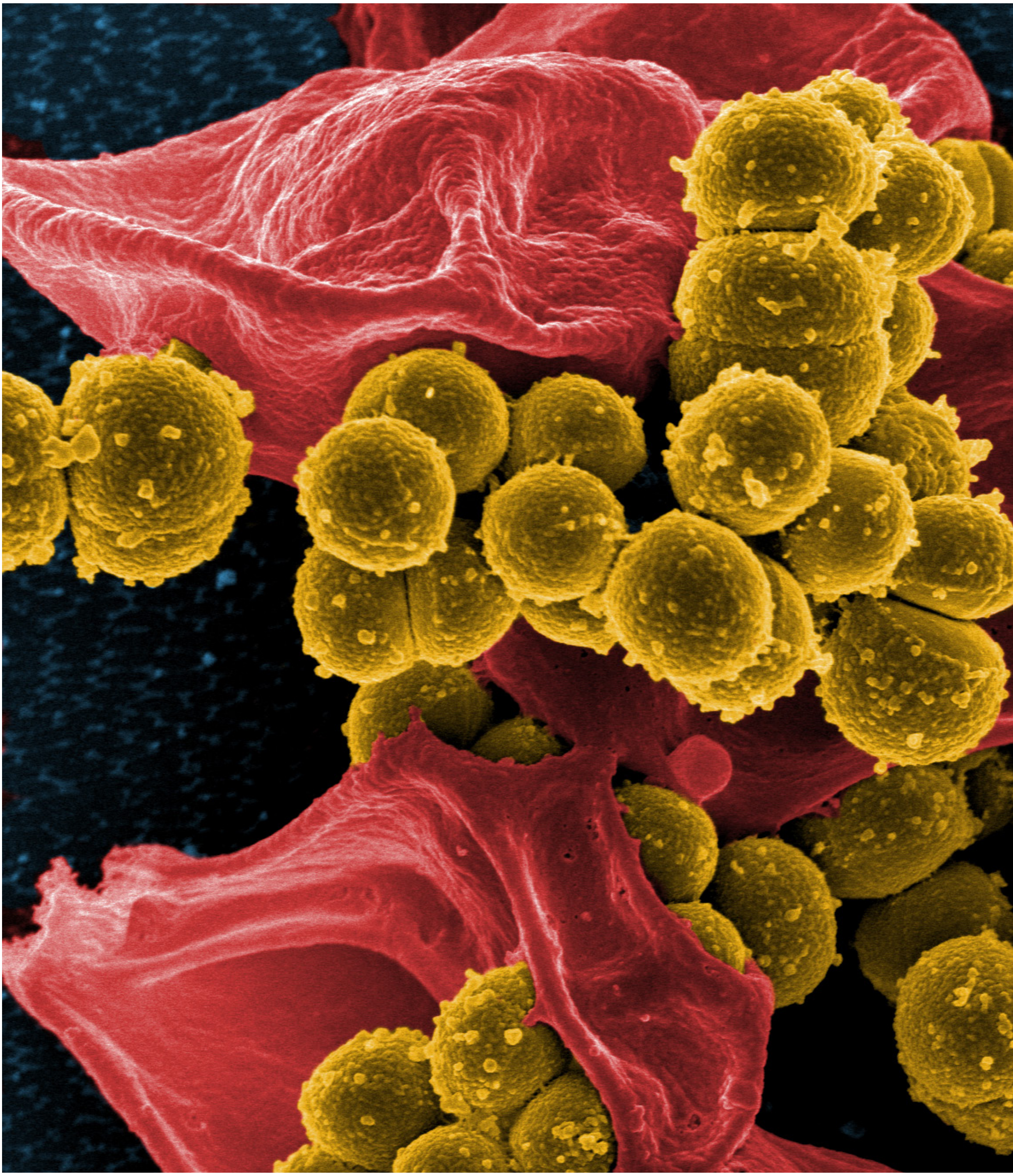
A foetus of a small-spotted catshark

(*Scyliorhinus canicula*)

Photo: Sander van der Wel , 2010 | Wikimedia Commons



Micrograph of Methicillin-Resistant *Staphylococcus aureus* (MRSA)

Photo: NIAID Flickr, 2006 | Wikimedia Commons

The Science of Seeing
Tales from the Belly Button

Adelheid Fischer

Tales from the Belly Button

Careful observation is vital to successful outcomes in biomimicry. It is so essential that future biomimetic enterprises will either succeed or fail depending upon the attention that we bring to them: individually as scientists, educators and practitioners and collectively in our organizations and institutions. As Frederick Franck points out in his book The Zen of Seeing, *there's looking and then there's seeing. It's good to know the difference. "We do a lot of looking: we look through lenses, telescopes, television tubes," he writes. "Our looking is perfected every day—but we see less and less. Never has it been more urgent to speak of seeing."*

Welcome to the fourth in a series of essays entitled "The Science of Seeing."

During her freshman year at North Carolina State University in 2009, Britné Hackett learned of a program that offered aspiring research scientists a spot in a university lab along with professional training and mentorship. The opportunity seemed like a perfect fit. "I had always envisioned myself in a white lab coat doing medical research," Hackett observes.

She applied and landed a post in Professor Rob Dunn's lab. She was assigned to a team studying the social transmission of fungal disease in a colony of North Carolina ants. Little did she know that the course of her life was about to change—and in a way she never could have imagined.

It all started the day the newbie scientist looked up from the lab's ant nest and posed a few questions to postdoctoral researcher Jiri Hulcr. Hackett's queries were at once beguilingly simple and profound. What exactly was a fungus? she wondered. And what was its function, especially if it sickened and sometimes killed its hosts? One thing led to another and the two soon were discussing the fact that, like ants, human bodies were, well, crawling with microscopic organisms—bacteria, mites, molds, yeasts and fungi, to name a few. "It was amazing to me that there are things that walk around with you on your body that you can't see. I wanted to see them," Hackett says.

So Hulcr and Hackett decided to ask their lab mates to swab their own skin so that they could culture the microbes in Petri dishes. Because belly buttons were likely to be overlooked in the scrubbing of a daily shower, Hulcr's wife, Andrea Lucky, suggested that they might be an especially rich reservoir of microbial biodiversity from which to draw samples. Happy to play along with the lark, the lab's students, along with director Dunn, obliged by dropping their waistbands.

A photograph of each Petri dish, labeled with the name of its donor, appeared on the lab's New Year's card. Hulcr's meager sprinkling of microorganisms fell into the category "Too Much Scrub-

Micrococcus (Actinobacteria): Bacteria can be beautiful. Some species of *Micrococcus* (*M. luteus*) produce yellow colonies, others (*M. roseus*) red ones, at least when grown in agar. *Micrococcus* species are aerobes; like us, they need oxygen. They are unlikely to do well too deep inside a belly button, but on the surface as elsewhere on our skin, they thrive. *Micrococcus* can survive extreme drought and long periods of starvation. This toughness predisposes them to a life spent clinging to our desert-dry flesh.

Photo and text courtesy of Neil McCoy and YourWildLife.org

bing." Dunn's culture, even sparser, was filed in the column "Wimpy Sampling." Hackett's thick impasto of microbial growth was classified, along with two others, as "Healthy Ecosystem." The card was sent not only as a New Year's greeting but also as a celebratory salute to the "diversity of both the microbes as well as us, people."

But after the laughter had died down, the scientists began to take a closer look. A really close look. What they discovered led them back into evolutionary history as well as catapulted them into the chronic health woes of contemporary society. At the time, the lab's research had begun to move in a new direction. Dunn decided to chart a course to take their inquiries deeper into the waters of public engagement. "One way to make science public," Dunn explained, "is to work with people to study their own lives." What better way to kick off a new citizen science campaign, they reasoned, than to ask participants to do a little navel gazing? And so in 2011, the Belly Button Biodiversity Project (BBBP) was launched.

To date, the BBBP has collected, genetically sequenced and analyzed samples from the belly buttons of more than 583 volunteers around the country. News updates of the results were reported on National Public Radio and in the *New York Times*, *Scientific American*, *Atlantic Monthly* and *Slate*. From the data also has come a scientific paper that was published in a 2012 issue of the journal *PLOS ONE*.

"Belly buttons are ridiculous," Dunn wrote in a September 2013, blog for *Scientific American*, "and yet the life we study in them is not; it includes both dangerous and life-saving species, though in just what mix and why, well, that is what we'd like to know."

An estimated 100 trillion microbes live on or in the human body. A fine sheath of teeming life, what Dunn calls our "verdant cloak of existence," lives between our toes and in our eyelashes, under our fingernails and on the soft patch of skin behind our ears. "There are more bacterial cells on you right now than there ever were bison on the Great Plains, more microbial cells, in fact, than human cells," writes Dunn in his 2011 book *The Wildlife of Our Bodies: Predators, Parasites, and Partners That Shape Who We Are Today*.

Collectively, these organisms, invisible to the naked eye, occupy a world that is as wild and biodiverse as any terrestrial or aquatic ecosystem on Earth. This newly discovered realm, known as the human microbiome, is generating a lot of buzz in scientific circles these days, even though it's been right under our noses—quite literally—for eons.

In 2008, the National Institutes of Health launched a five-year initiative, known as the Human Microbiome Project, to learn more about the microorganisms that live in close association with people. The preliminary results have been nothing short of astounding. To date, for example, HMP researchers have counted 75-100 species of bacteria that reside in the human mouth. Based on the current rate of discovery, they estimate that the final tally will exceed

Staphylococcus: Like almost any bacteria in the wrong place, *Staphylococcus* species such as *Staphylococcus epidermidis* can become pathogens. Yet when living on your skin, *Staphylococcus* are far more likely to be beneficial, working as our first line of defense against pathogen invasion. *S. epidermidis* can use oxygen for respiration; however, when oxygen is in short supply (as it might be deep in your belly button), it switches to fermenting sugars. In other words, right now you might be making a teeny tiny bit of navel wine.

Photo and text courtesy of Neil McCoy and YourWildLife.org

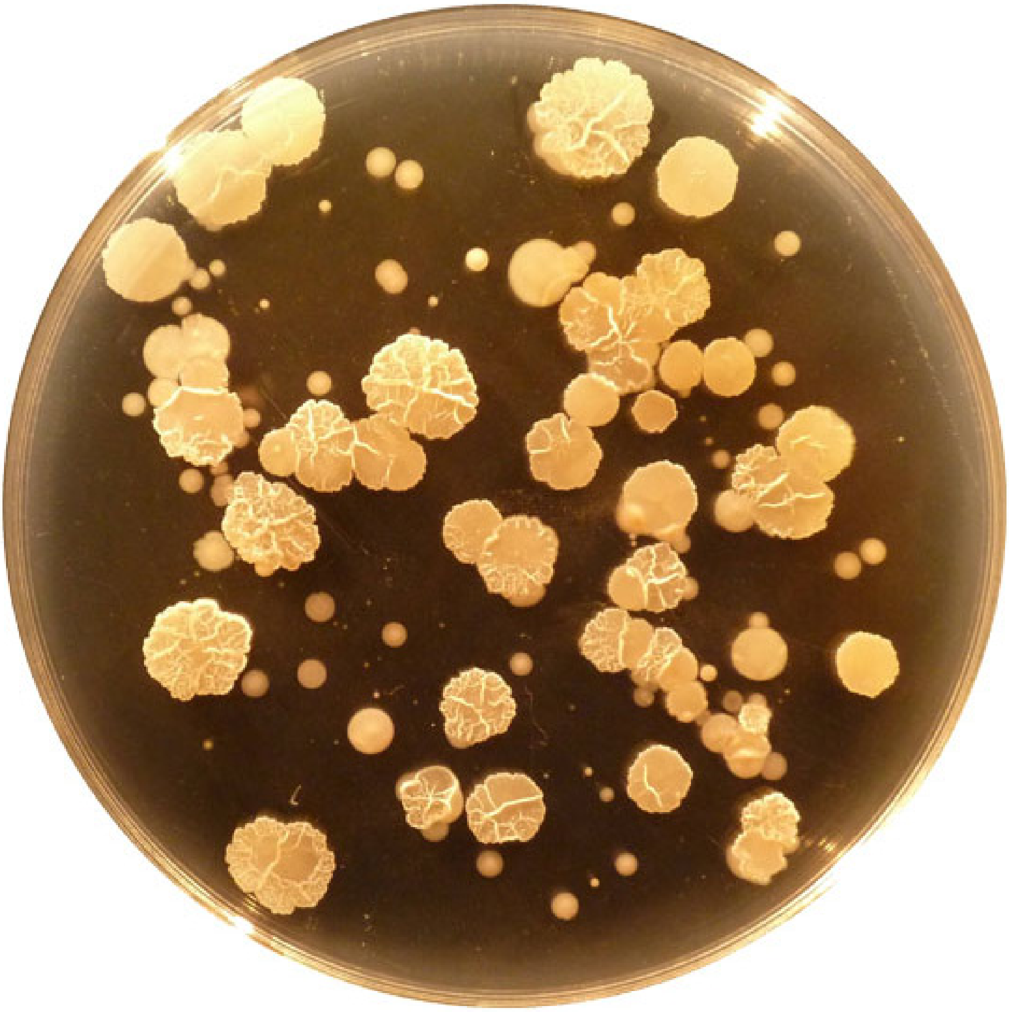
5,000 species. More than 1,000 species of bacteria make their home in the human gut, not to mention scores of fungal species.

The Belly Button Diversity Project only compounds the wonders and mysteries of these NIH findings. The researchers in Dunn's lab turned up 2,300 species in the 500-plus samples they collected. Only a small subset—a mere eight species—appeared frequently (and these were members of families that occur in dry, nutrient-poor conditions, like the "desert that is your body," Dunn quips). Scores of microorganisms were new to science—and not just unidentified species but also whole new genera that remain to be characterized.

Then there were the curious puzzlers. How did a bacterium associated with pesticides, for example, show up in Dunn's sample? And what about the belly button that contained a bacterium whose only other documented location was in a soil sample in Japan? The cause of the riddle? The donor had never set foot in Japan.

For some people, the yuk factor of the microbial cloak is enough to send them screaming into the shower. Increasingly, however, researchers are cautioning against hyper-hygiene practices like the daily rinse. They're discovering that our microbial roomies are essential to human health and well-being. Many of them help ward off pathogens. Human skin cells, for example, exude waxy secretions that feed beneficial bacteria. In exchange, the bacteria emit moisturizing films that soften skin, preventing dry cracks that, like back doors left open, allow ill-intentioned intruders to gain entry into the body. Other bacteria teach skin cells to distinguish allies from mischief makers, enabling the cells to develop their own defensive antibiotics. Six hundred species of bacteria float in human breast milk, inoculating the guts of infants with the microbes they need to absorb vitamins, minerals and calories from the food they eat. Curiously, in this microbial bath scientists also have discovered sugary bribes known as oligosaccharides. The sugars appear to be designed not as nourishment for infants, who are unable to digest them, but as sustenance for a cadre of good gut bacteria that keep bad actors from colonizing a baby's digestive tract.

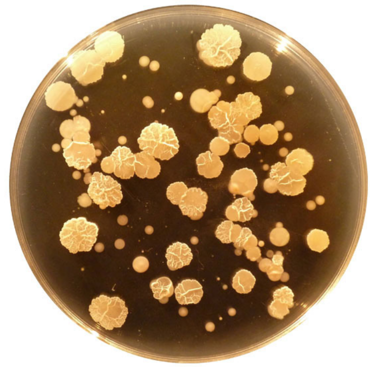
Increasingly, scientists and health experts now implicate our sterile modern environments—their hypercleanliness, wanton use of antibiotics, their simplification of plant and animal diversity—for the growing incidence of autoimmune and chronic inflammatory disorders including asthma, Crohn's disease and multiple sclerosis, even obesity and diabetes. "If the germ theory is the idea that the presence of bad species can make you sick, the growing sense seems to be that the opposite can also be true. We can get sick because of the absence of good species—or even just the absence of the diversity of species" Dunn writes. These insights have given rise to a healing modality known as medical ecology in which doctors assume a new role as "microbial wildlife managers," writes Carl Zimmer in a 2012 article in the *New York Times*.



Bacillus: Right now wars are happening on your body. Bacteria are fighting other bacteria, fungi and even viruses. Among your skin's true warrior clans are species of the genus *Bacilllus* such as *Bacillus subtilis*. *Bacillus subtilis* produces antibiotic compounds that can kill other bacteria and even foot fungi. Right now it may be doing this on your skin. We tend to think of the life on our skin as somehow stable and yet like any wild kingdom the individuals alive at any moment are the result of millions of independent wins and losses.

Photo and text courtesy of Neil McCoy and YourWildLife.org

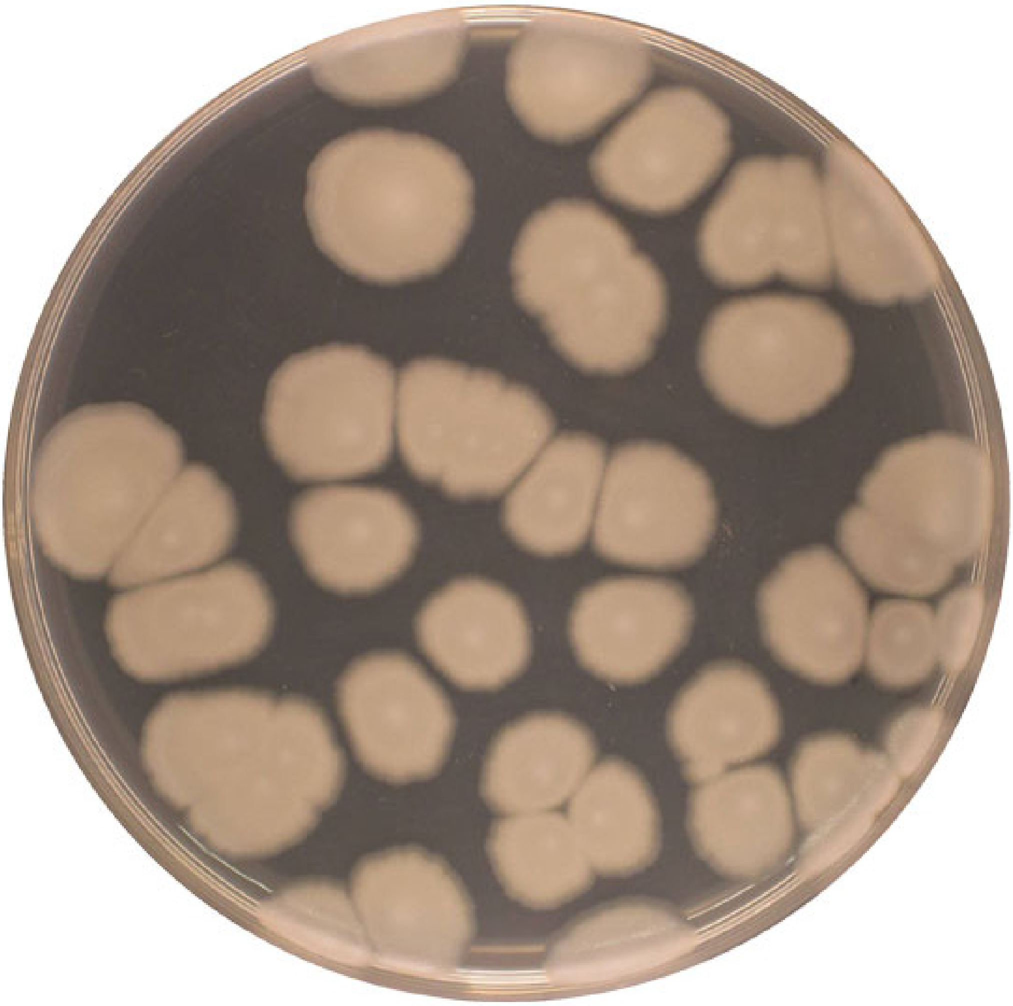
When it comes to the human microbiome, the surprises, the mysteries and the possibilities seem endless. “The closer you look, the more you find,” says Susan M. Huse, a scientific contributor to the microbiome project.



Looking closer at the invisible world around us has become a mantra for Britné Hackett as well. Back when the first belly-button cultures began to grow, she recalls, “I was thinking that all the plates were going to come back with lots of similar-looking white clumps. When I saw all the differences, I thought wow! It opened up this new realm of more and more questions. I started to learn just what research really is all about after that.”

These days the hunt for the invisible fuels Hackett’s inquiries as a budding young scientist, both in and outside the lab. She credits her early ant work for helping her to become comfortable around insects, allowing her to work on another project in the Dunn lab: the Arthropods of Our Homes. These days her job is to catalogue bugs collected from residences in the Raleigh-Durham area for an exhibition at the North Carolina Museum of Natural Sciences. “We live around these things,” Hackett points out. “We’re in constant interaction with them, but we just don’t pay attention. How many different kinds of ants live in your backyard? You might have one from Japan. You may have an Ethiopian fly just chilling on your windowsill.”

“Every day to me is miraculous,” she says. “I have this new understanding and appreciation. I want other people to have the same thing.” ×



Clostridiales: The Clostridiales include bacteria like *Anaerococcus* and *Clostridia*. Some *Clostridia* species are bad news (think botulism), but most are harmless or even beneficial. The *Clostridiales* are anaerobes; they don't use oxygen to make their way in the world. Individual microbes of this group are spindle-shaped and motile. They may be urging themselves across your skin right now, heading from inhospitable ground in a direction their simple senses tells them might be better, some place like your belly button, or maybe your ear, though who can say. Like the stories of individual humans, the trajectories and fates of each individual bacterial cell on your body will be unique.
Photo and text courtesy of Neil McCoy and YourWildLife.org

Hoverflies (*Simosyrphus grandicornis*) mating in midair
Photo: Fir0002/Flagstaffotos, 2006 | Wikimedia Commons

People
Interviews with
Rolf Mueller and Scott Turner

Greater dog-like bat (*Peropteryx kappleri*) with mites on the back of the ear

Photo courtesy of Brock Fenton


Interview
Rolf Mueller

winter 2013 **People:** Interview **Author:** Rolf Mueller

Rolf Mueller has studied various aspects of bat biosonar from the perspectives of biophysics and bioinspired engineering for almost 15 years and has (co)authored about 50 peer-reviewed, full-length publications on the topic. In particular, he has worked on statistical signal processing of sonar signals in complex natural environments, biosonar beamforming, and biomimetic sonar systems. The focus areas of his current research are the extraction of adaptive design rule analysis from biodiversity as well as time-variant sensing principles. In his current position as Associate Professor in the Mechanical Engineering Department at Virginia Tech, he is also working with the university's Institute for Critical Technology and Applied Science (ICTAS) on organizing Virginia Tech's bioinspired science and engineering (BIST) research community. An important partner for this effort is the Smithsonian's National Museum of Natural History, where he also holds an associate position. He also serves as the director of the Shandong University – Virginia Tech International Laboratory in China that seeks to understand the biophysics of dynamic processes in bat biosonar.

What are your impressions of the current state of biomimicry/bio-inspired design?

Over the last few years, biomimicry/bio-inspiration has progressed nicely on making a case why looking towards biological systems for inspiration can be a good idea. There are numerous and varied case studies that illustrate the utility of biological model systems in engineering and design. Along with this growing body of evidence has come a wider recognition of the field as well as a greater interest in pursuing research in the area. The latter has been reflected in a steady increase in the number of related publications and patent filings. I believe that the expansion of biomimicry/bio-inspiration is not a random fluctuation, but has been facilitated by long-term fundamental changes that have taken place in the life sciences as well as in engineering: Over the course of the 20th century, the life sciences have been thoroughly transformed from being qualitative and descriptive to being quantitative and analytic. During the same period, engineering has progressed from being limited to analyzing simple problems, to dealing with levels of complexity that in quite a few cases are a match for the complexity of living systems already. As a result of these fundamental changes, I see the possibility that the current growth in biomimicry/bio-inspiration can be sustained for a significant time into the future.

What do you see as the biggest challenges?

Bioinspiration is not yet a scientific discipline in its own right. It lacks a theoretical foundation that would be applicable to all problems of mimicking biology and is at the same time specific to the field. Mature fields of science and engineering have such theoretical underpinnings that have been turned into objective sets of methods for solving problems in the field. A good indication for whether a problem-solving method can be regarded as objective is when the methods can be realized in a physical device or in a computer algorithm. At present, there are no automated devices or computer algorithms that could extract inspiration from biological systems into engineering or design. Hence, the process of transitioning insight from biology into engineering or design still resembles an art more than a science.

Batcave in China | Photo courtesy of Rolf Mueller

Digitized bat specimen (Little big-eared bat, *Micronycteris megalotis*) rendered to show skin sufaces, skeleton, and brain | rendered by Dane Webster, Virginia Tech

Image courtesy of Rolf Mueller

What areas should we be focusing on to advance the field of biomimicry?

Predicting the areas of future breakthroughs has been notoriously difficult and has failed numerous times. As a consequence, a broad approach that emphasizes intellectual curiosity and the quest for fundamentally new knowledge over expected societal needs and how they should be addressed is probably the best for bioinspiration as it is for any other area of the sciences. However, there are some general ways in which biological and man-made systems tend to differ that are potentially significant for improving the capabilities of engineering solutions:

(i) embedding: biological systems tend to be very well embedded into their physical worlds, i.e., they have implicit/built-in knowledge regarding the relationships in the world that allow them to realize their functions with a minimal effort

(ii) integration: the components of biological systems are integrated in ways that make the system much more capable than its individual parts

(iii) biodiversity: biological solutions are highly diverse and often demonstrate how a single principle can be adapted to multiple uses

(iv) dynamics: biological solutions tend to be much more dynamic than engineering solutions which often rely on static or stationary approximations.

While bio-inspiration could have a transformative impact on engineering in all four areas, it seems to me that including the biodiversity aspect is particularly worthwhile. So far, research in the area has been largely concerned with discovering new functional principles from individual case studies. However, biological evolution has been particularly good at adapting a single functional principle to a large number of uses. An understanding of how evolution has achieved this feat can only be gained when considering the biodiversity level. At the same time, it could mean a major breakthrough in our ability to customize technology.

How have you developed your interest in biomimicry/bio-inspired design?

I have been fascinated with the capabilities of biological systems for a long time. Originally, I used biomimetic systems primarily as a way to better understand biological function through a synthetic approach. Lately, I have become more interested in developing technology based on insights in biological function, but gaining a better understanding of biology in the first place is still important to me.

What is your best definition of what we do?

My research is best defined as an iterative two-step process, where Step 1 is aimed at understanding biological function from an engineering perspective and Step 2 is to synthesize biomimetic/bio-inspired devices that embody the insights from Step 1.

Catching bats in a Hindu temple in Tamil Nadu, India | Photo courtesy of Rolf Mueller

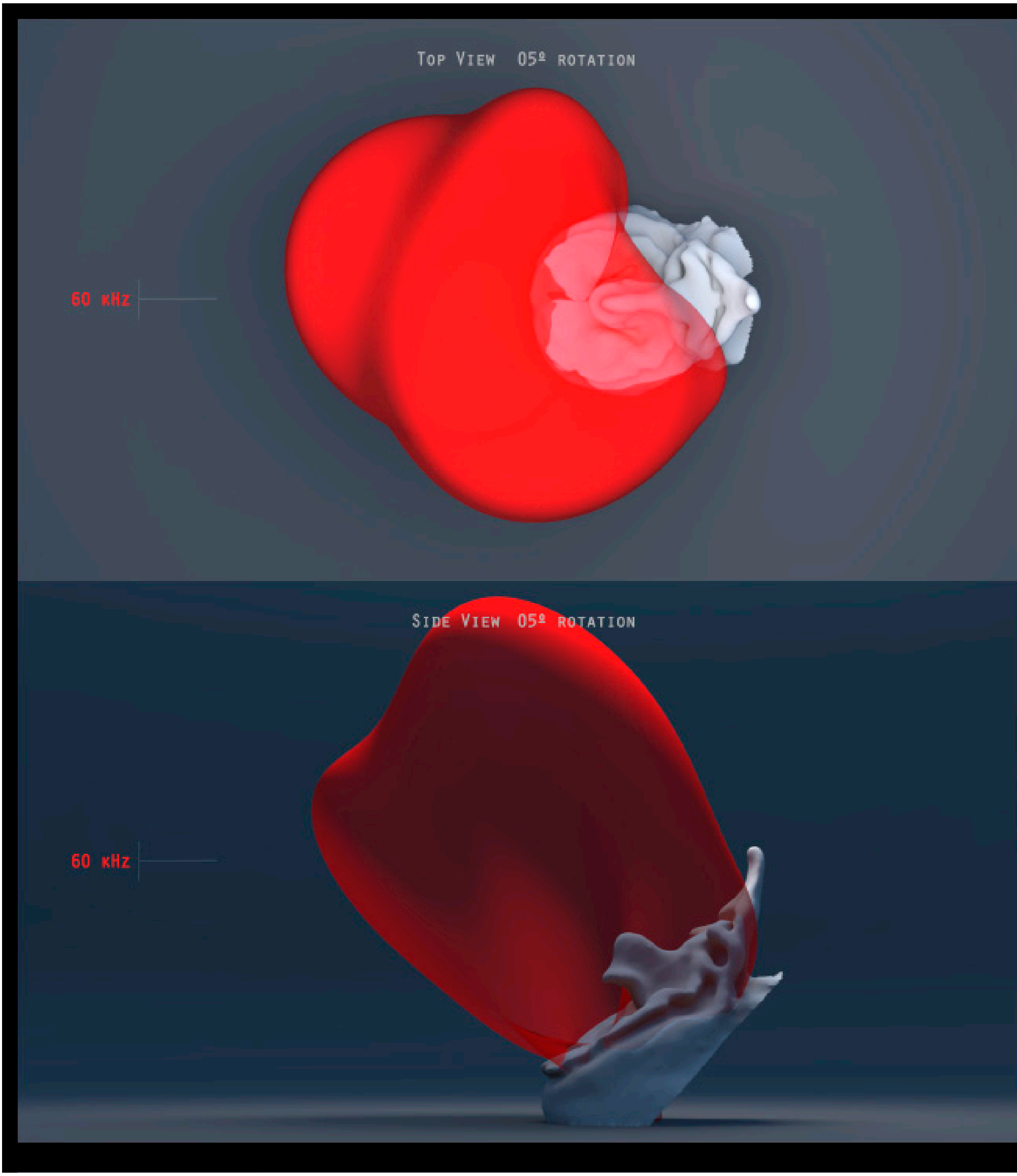
Antillean ghost-faced bat (*Mormoops blainvillei*) - the conspicuous lip protrusions could play a role in shaping the animal's ultrasonic emissions | Photo courtesy of Brock Fenton

By what criteria should we judge the work?

From where the field stands, I believe the most important criteria would be scientific validity and depth, contribution to fundamental progress, and originality. While positive societal impacts are an important final goal, they are hard to predict and should not be used to stifle creativity and the expansion of knowledge.

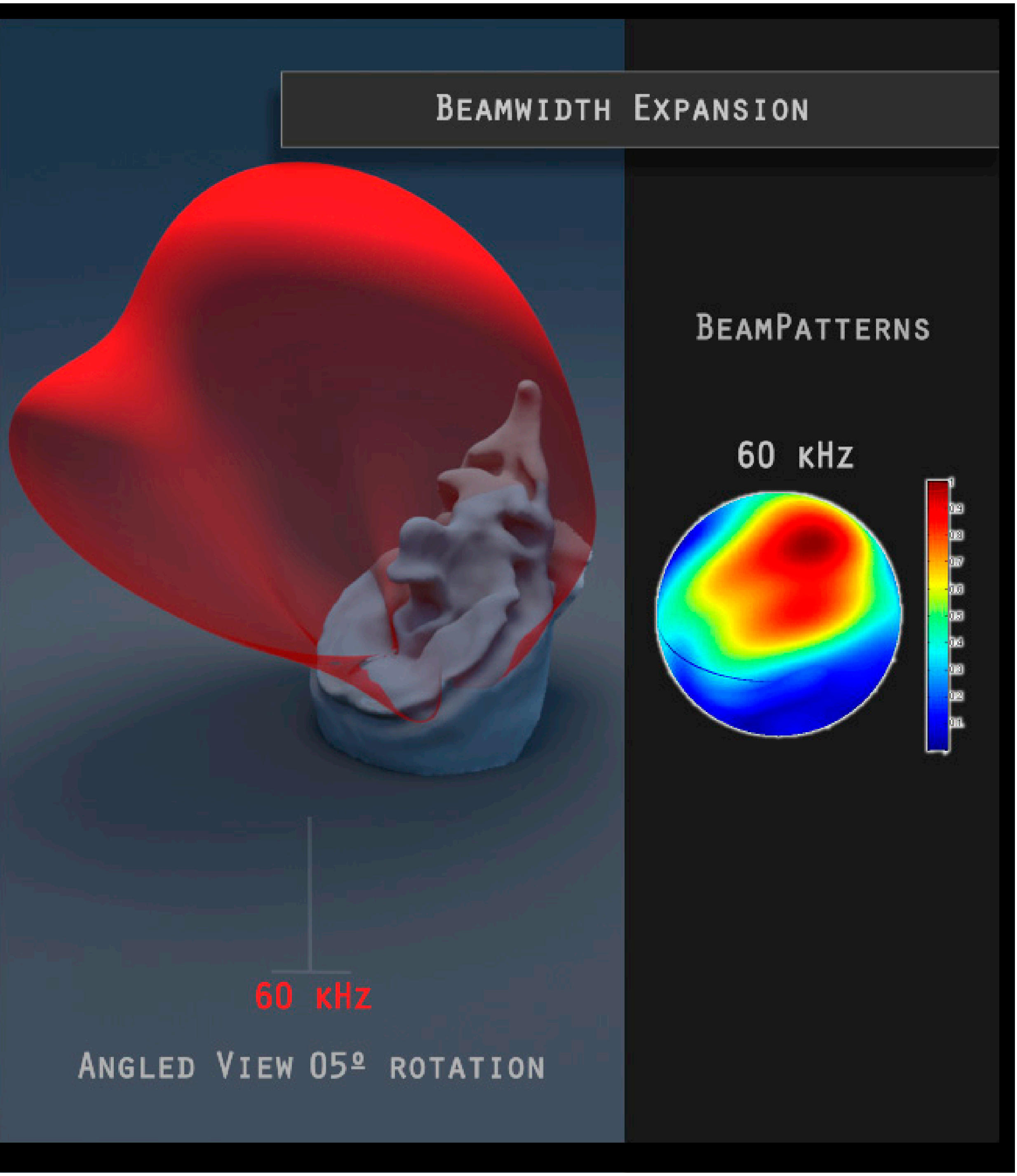
What are you working on right now?

I am looking at the biosonar system of bats as a model for smarter sensors and sensing systems. Bats have an incredible ability to extract information from difficult environments such as dense thickets using the echoes to just a few ultrasonic pulses received at two ears. At the same time, their brains mass is often only a fraction of a gram. It is hence my working hypothesis that bats must have found ways to encode and extract important information that go way beyond our current engineering capabilities. Being able to reproduce the function of bat biosonar could lead to shrinking the size of sonar and radar arrays by two orders of magnitudes, e.g., from several meters into the range of a few centimeters. It could also lead to miniature ubiquitous sensors that could operate reliably even in unstructured environments. My present work includes the study of actual animal behavior using techniques such as high-speed video recordings with multiple cameras, ultrasonic recordings, and laser Doppler velocimetry, simulations using supercomputers, and small biomimetic devices.



Computer predictions of the ultrasonic emission beam at 60 kHz (red) produced by the noseleaf (gray) of a greater horse-shoe bat (*Rhinolophus ferrumequinum*) | rendered by Dane Webster, Virginia Tech

Image courtesy of Rolf Mueller


Beamwidth Expansion
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60 kHz
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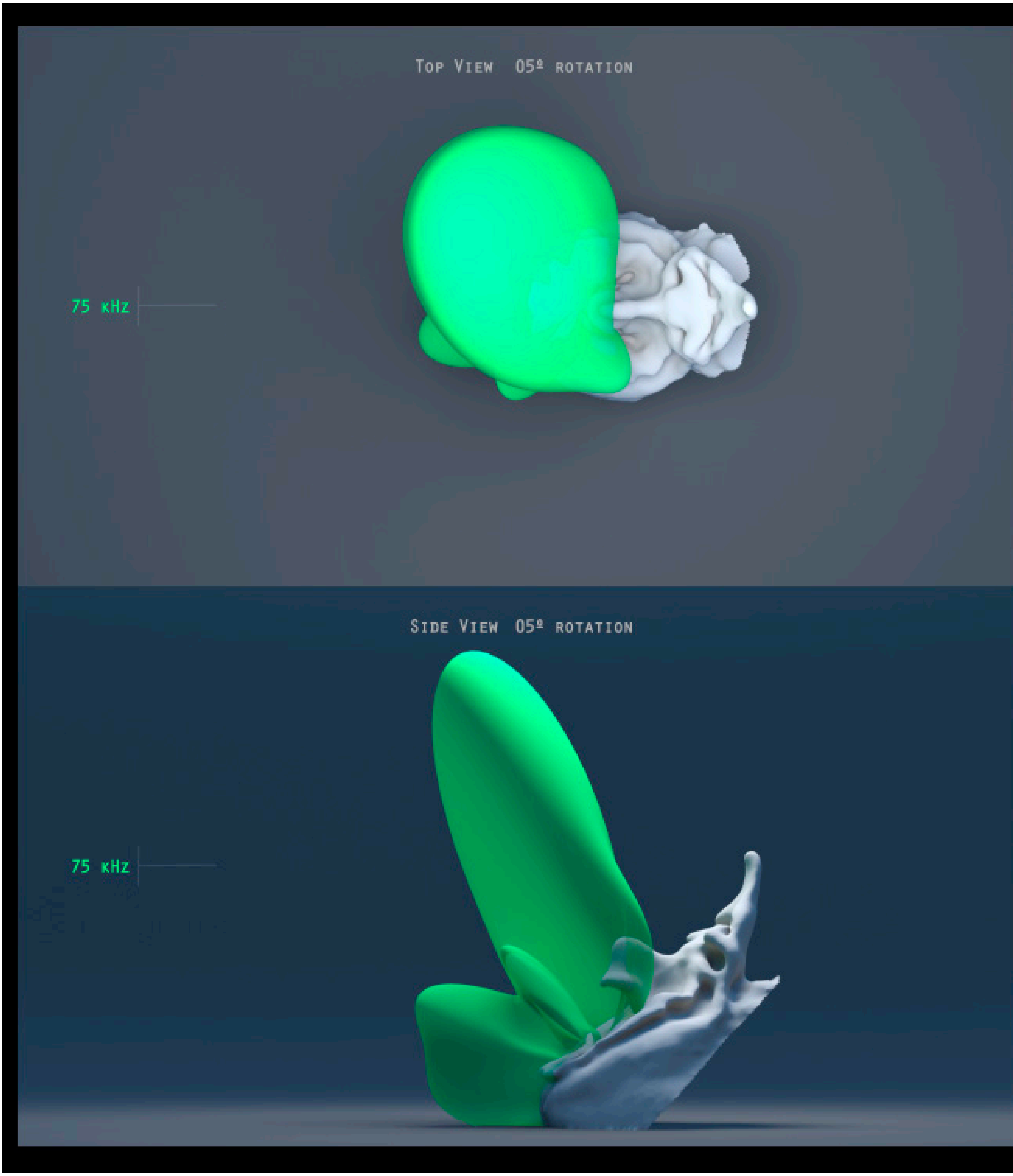
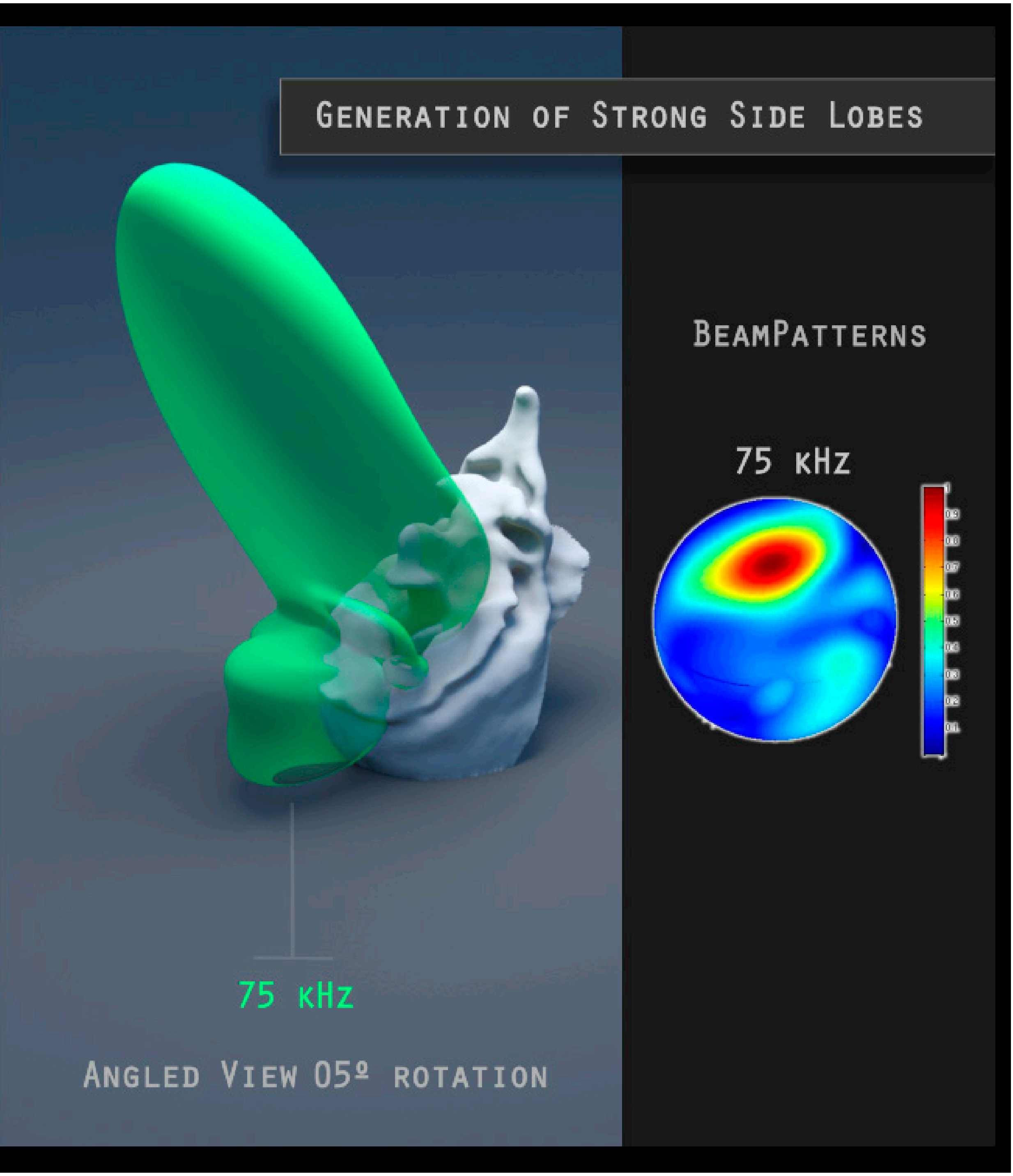


Computer predictions of the ultrasonic emission beam at 75 kHz (green) produced by the noseleaf (gray) of a greater horseshoe bat (*Rhinolophus ferrumequinum*) | rendered by Dane Webster, Virginia Tech
Image courtesy of Rolf Mueller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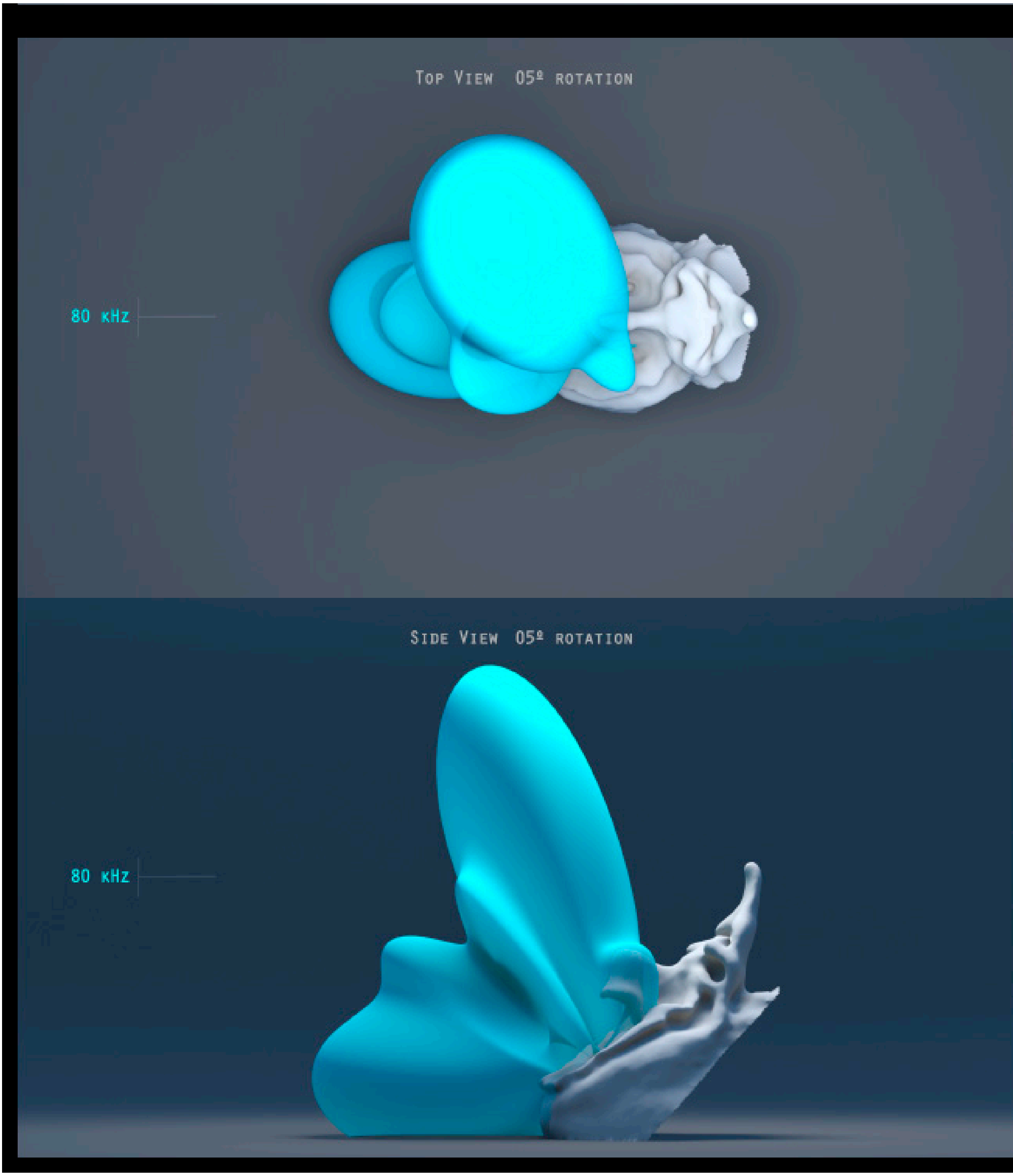
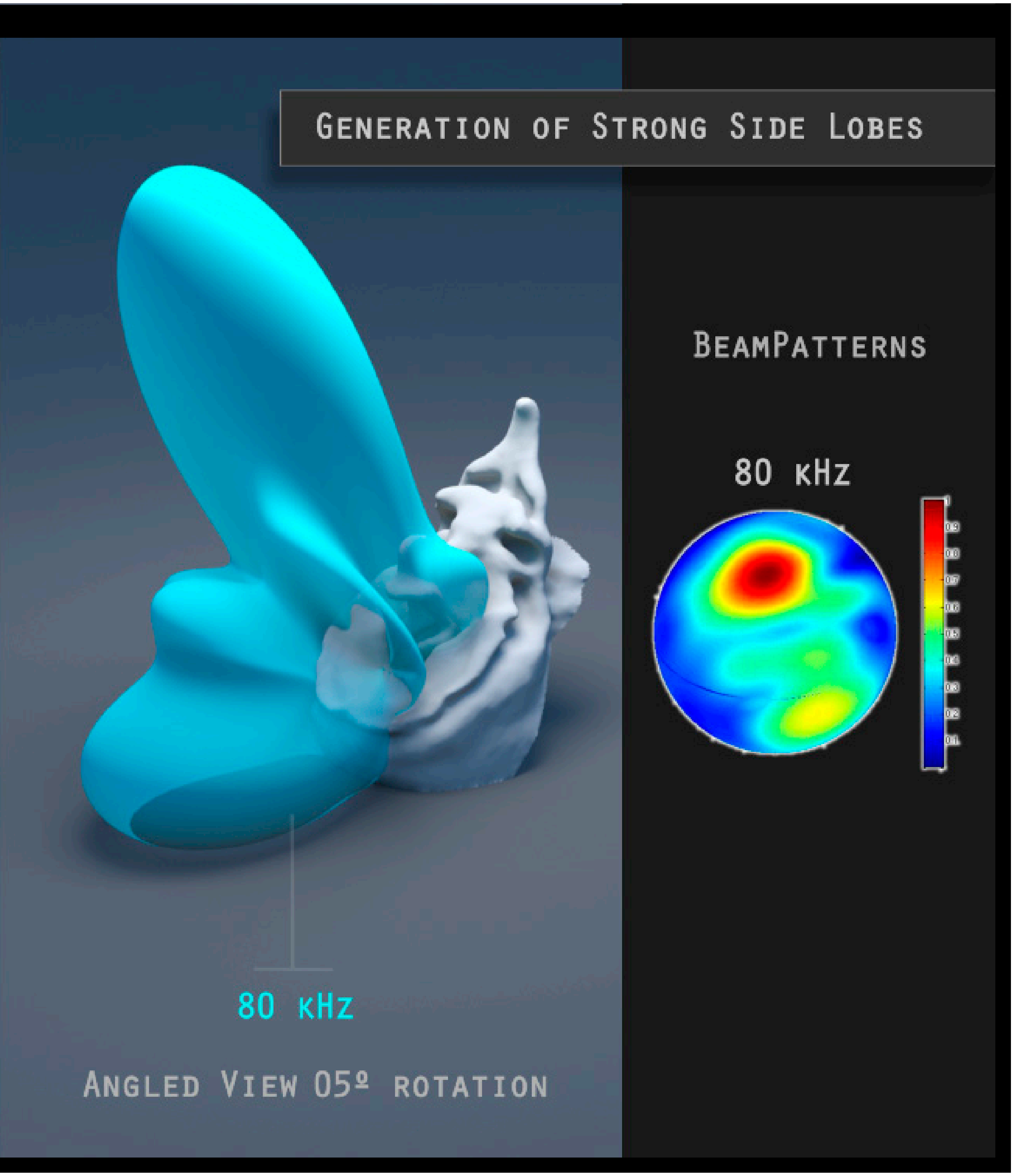


Computer predictions of the ultrasonic emission beam at 80 kHz (blue) produced by the noseleaf (gray) of a greater horseshoe bat (*Rhinolophus ferrumequinum*) | rendered by Dane Webster, Virginia Tech

Image courtesy of Rolf Mueller


GENERATION OF STRONG SIDE LOBES
BEAMPATTERNS
80 kHz
80 kHz
ANGLED VIEW 05º ROTATION

How did you get started in biomimicry/bio-inspired design?

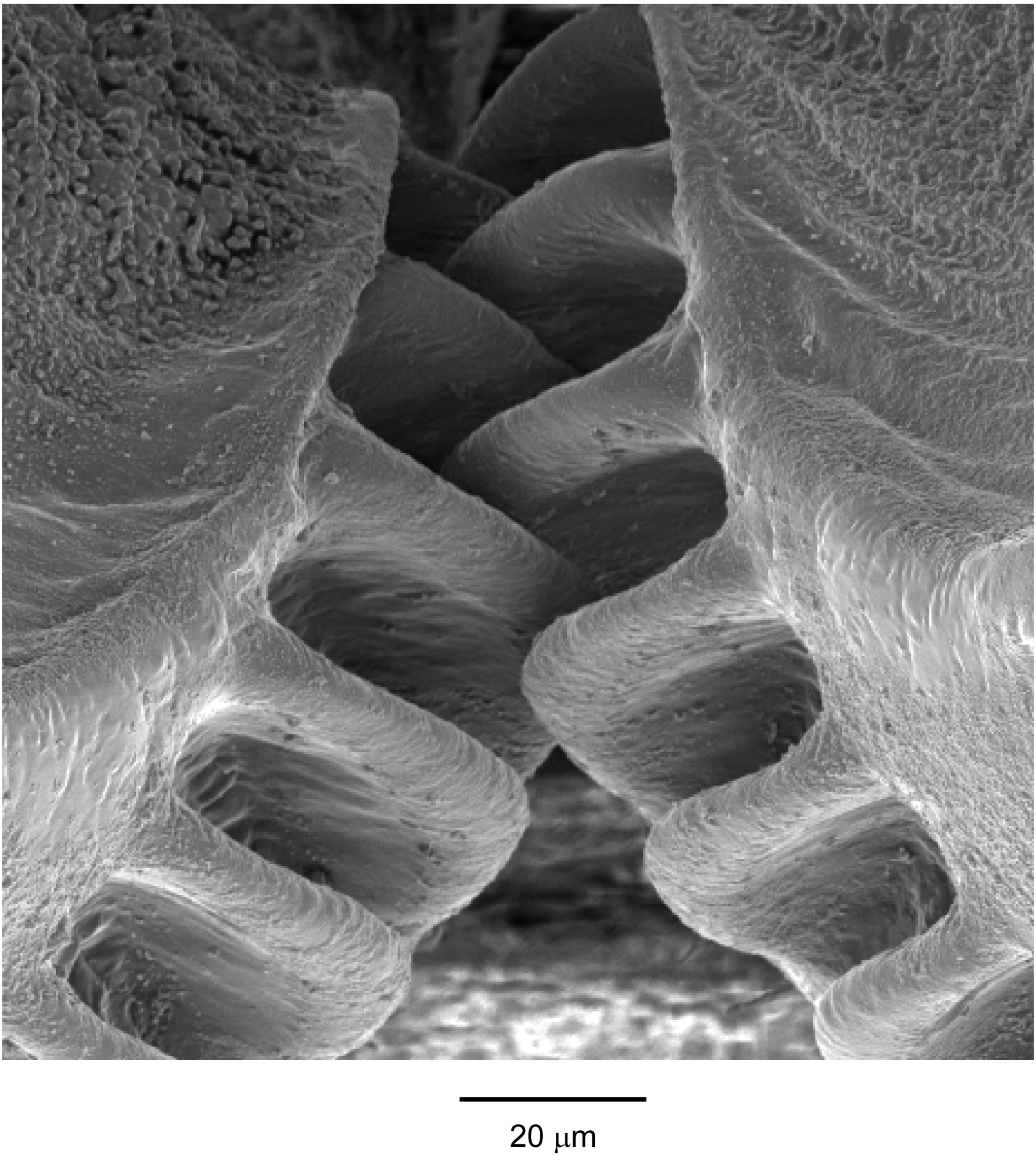
I was looking for a way to understand the function of bat biosonar. Experiments with animals appeared to be very tedious, so I figured that working with biomimetic systems would allow much better experimentation.

Which work/image have you seen recently that really excited you?

The research/images on the gears in the planthopper insect (*Issus coleoptratus*) have been an amazing discovery. I would have never guessed that something so close to gears could be found in a biological system. To me, this underlines that biological evolution and engineering are driven by the same constraints and the layout of the same solution space of the common physical world that they share. This does not prove that bioinspiration is always the best approach for finding a solution to an engineering problem and I see no reason to believe that this is the case. However, the gears in planthoppers are a great example of how biological evolution and engineering can converge on the same solution. To me, this possibility makes bioinspiration worthwhile exploring.

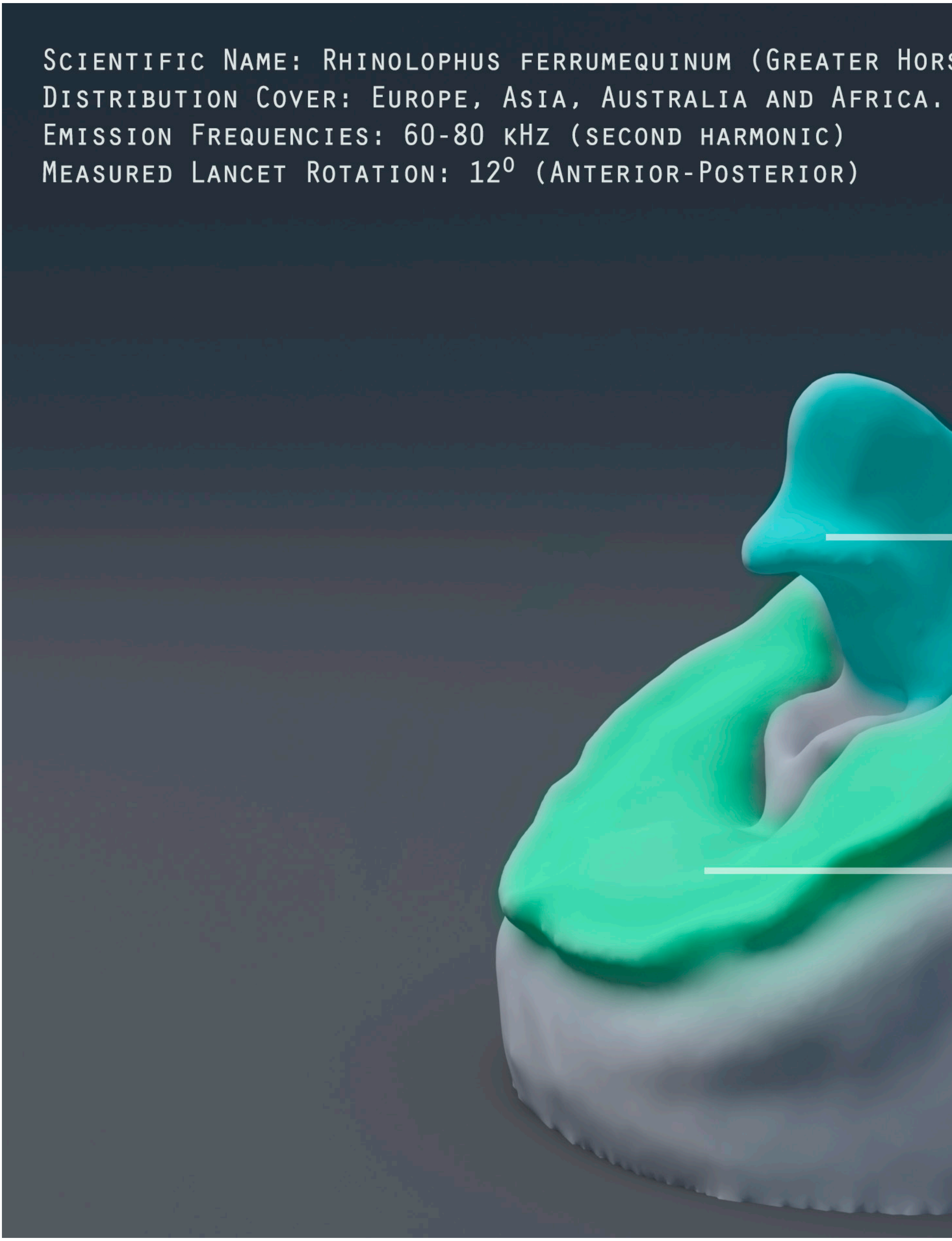
Issus **nymph**

Image courtesy of Malcolm Burrows

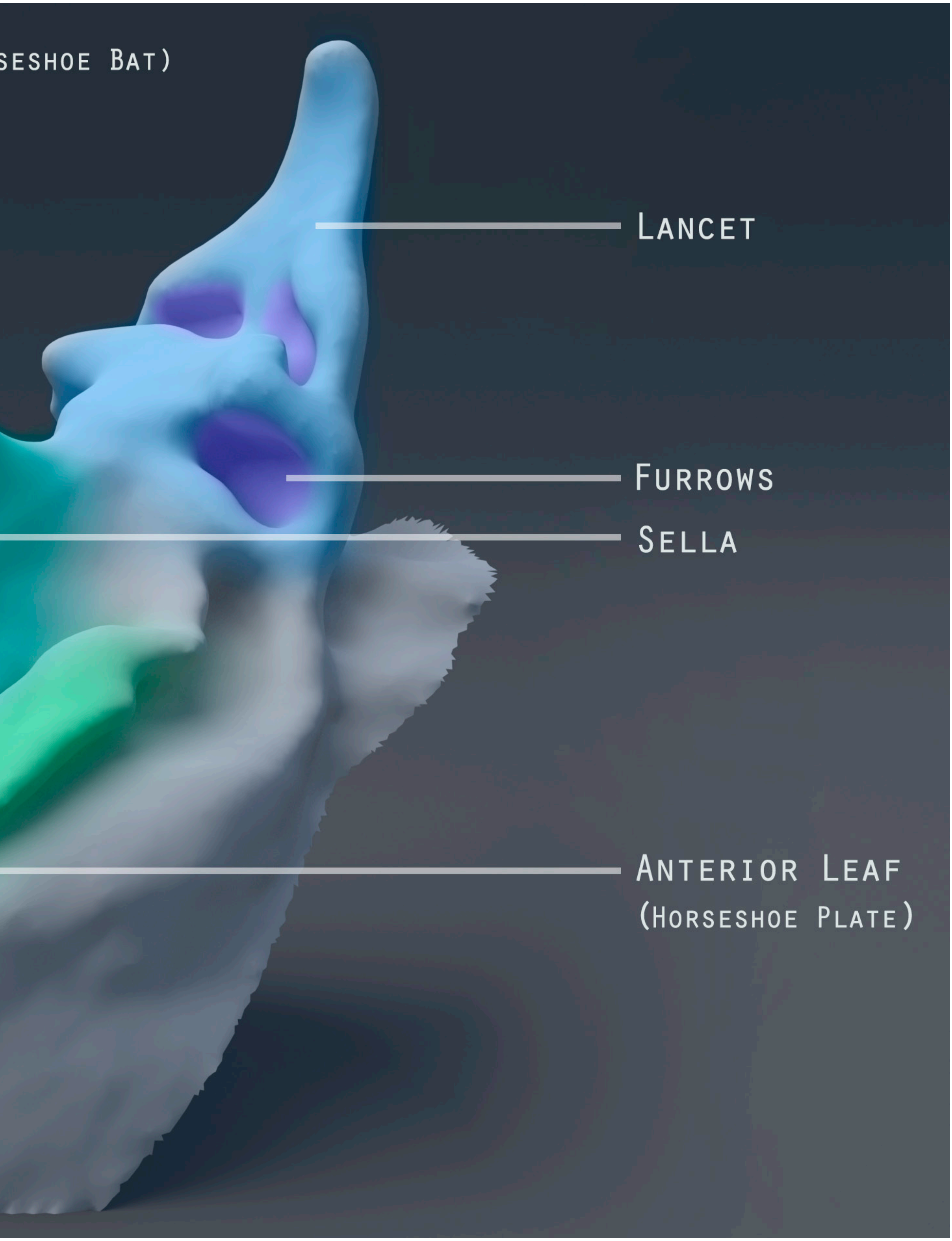


Insect gears

Image courtesy of Malcolm Burrows



The noseleaf of the greater horseshoe bat acts like an intricate megaphone baffle | rendered by Dane Webster, Virginia Tech



| Image courtesy of Rolf Mueller

What is your favorite biomimetic work of all time?

Since bio-inspiration/biomimetics are not mature disciplines yet, it is probably too early to pick an all-time favorite. I am holding out for a discovery that is clearly the result of a systematic search with objective methods rather than a gift of serendipity. I believe that once we see this happening, we will know that bio-inspiration has been taken to the next level.

What is the last book you enjoyed?

Midnight in Peking by Paul French - not so much for the writing but certainly for the story. I am pretty familiar with most of the key places featured in the book and learning about this story has added a new dimension to that.

Who do you admire? Why...

Admiring people always bears the danger of developing into a personality cult, so I try not to do that.

What's your favorite motto or quotation?

"Behold the turtle. He makes progress only when he sticks his neck out." by James Bryant Conant.

What is your idea of perfect happiness?

Being able to focus on a science problem and being able to forget about everything else. Understanding something new in the progress.

If not a scientist/designer/educator, who/what would you be?

Sorry, but I cannot imagine anything else. ×

Boat ride on a field trip in Vietnam | Image courtesy of Rolf Mueller

Termites in a mound, Perinet, Madagascar

Photo: Gavinevans, 2011 | Wikimedia Commons

Interview
Scott Turner

Scott Turner is Professor of Biology at the State University of New York College of Environmental Science and Forestry (SUNY-ESF) in Syracuse, New York. His principal research focus is the emergence of superorganismal structure and function in the mound building termites of southern Africa. This is motivated by a larger interest in the interface between physiology, evolution and design. He is the author of two acclaimed books: *The Extended Organism. The Physiology of Animal-Built Structures* (2000) and *The Tinkerer's Accomplice. How Design Emerges from Life Itself* (2007), both published by Harvard University Press. Through the generosity of the Templeton Foundation, he has been a visiting scholar at Cambridge University, where he has begun to work on his third book, with the working title *Purpose and Desire. Evolution's Second Law*.

What are your impressions of the current state of biomimicry/bio-inspired design?

I see biomimicry/bio-inspired design as being in a bit of a transitional phase right now. After the original flush of excitement, arising largely from publication of Janine Benyus' book, *Biomimicry*, there is a kind of sobering up going on, so to speak, as engineers and biologists really are starting to talk with one another, and realizing just how different they are, how different the questions and intellectual traditions each come from are, and the challenges in melding them constructively.

What do you see as the biggest challenges?

Well, I'm coming into this from the perspective of a biologist / physiologist / evolutionist, but I'd say that the biggest challenge is going to be answering the deceptively simple question: what, precisely, about living nature should inspire us? In biomimicry's early days, there seemed to be this overarching presumption of the perfecting power of natural selection. Biomimicry's initial enthusiasm and optimism streamed from the assumption, I think, that there were solutions lying around everywhere in living nature, just waiting to be picked up, that would give us more effective, efficient and environmentally friendly uses of energy and materials. Yet, I can point to any number of living systems where that's not true, indeed, I can point to living systems where wanton use and waste of resources is an evolutionarily viable strategy. So, from my point of view, I think biomimetics could stand to take some of the stars out of its eyes, and start looking critically at what it is we think living nature can tell us.

Before feathers get too ruffled, let me hasten to add that there are challenges for my own "side" as well. In general, we biologists are culturally very averse to any discussion that invokes principles of design, principles that architects and engineers have long been comfortable with. It brings up bad memories of the supposedly dark, pre-Darwinian days. That's also an unfortunate cultural bias, because it means that despite being literally immersed in good living designs everywhere, we biologists don't have a good understanding of just where, and how, the well-functioning organism arises. So, we biologists have a lot to learn ourselves.

Plaster cast of the internal structure of a termite mound. In collaboration with Dr. Rupert Soar

Photo courtesy of Dr. J. Scott Turner

Scott Turner in front of a plaster cast of the tunnel network of a Macrotermes mound | Image courtesy of Scott Turner

What areas should we be focusing on to advance the field of biomimicry?

I think the most fertile area of inquiry will be in understanding precisely how good design in living nature actually comes about. I'm likely to be stepping on some toes here, but there are aspects of biomimicry that ooze an almost cult-like devotion to a kind of "bio-formalism", the notion that nature necessarily provides models of "things" that, if we imitate their form, will inspire objects that function well. Living nature is not like that! Another aspect of that is what my colleague Rupert Soar has called "bio-bling", the notion that decorating our built structures with the many beautiful forms to be found in nature will produce buildings that are more in tune with nature, whatever that means.

So, I think we would do well to understand how good design in living nature comes about in the first place. My own thinking is that the roots of a sound theory of biomimicry are likely to be found in physiologically inspired thinking, "physiomimetics" if I can use the word. In living nature, good design more often than not seems to come, not from some genetic specifier (the biological side of the formalism cult), but from managing the dynamic disequilibrium that is inherent in the widely misunderstood concept of homeostasis. If we could build homeostasis into the bio-inspired designs we make, we would have something like a "true" biomimicry.

How have you developed your interest in biomimicry/bio-inspired design?

Well, as most people who've read this far will have already concluded, I'm not really a biomimeticist, I'm a physiologist. And of social insects to boot! But the origin of good function is one of the fundamental questions in physiology, and pursuing that question wherever it leads has been the central theme in developing my own thoughts about life, what it is and how it works. Specifically, look at the termite mounds that are the current focus of my study. These things are more than a pile of dirt, heaved up from the soil by the termites that build them. The mound is, in fact, a remarkably sophisticated organ of physiology, just like the heart and lungs are in more conventionally defined organisms like ourselves. Yet, they emerge at a scale unlike any other organ of physiology on the planet. How does that happen?

The connection to biomimicry/bio-inspired design is an obvious one, since the biomimetics that I'm tangentially involved with seeks to do the same things with our buildings and artefacts. In making the connection, though, it's vital that we first understand the workings of the source of our inspiration.

What is your best definition of what we do?

Hmm, I'm hardly qualified to say, but I would venture this definition anyway:

"Biomimicry / bio-inspired design seeks inspiration in living nature for structures and processes that are ecological in nature."

By what criteria should we judge the work?

Now that's an interesting question. On one level, I suppose it has to be what works for the clients that are paying us. Whether the "client" is a

TermitePlanet

Photo: Rantz, 2010 | Flickr cc

private company or investor, or the tax-paying public, biomimicry is ultimately an aesthetic claim on that investor's attention. In that sense, biomimicry is not a scientific principle, but an aesthetic one. On another level, biomimicry makes a specific scientific claim: that looking to nature will give us objects and processes that are more efficient, more beautiful, and more in tune with nature, which includes the human user of our designs. The last criterion is an especially interesting one, because good bio-inspired designs needn't be scientifically sound. Some of the early "termite-inspired" buildings, for example, were using a functional model for how the mound works that was probably completely erroneous. Yet, the designs worked beautifully, although not for the reasons that inspired them.

What are you working on right now?

Mostly, I'm working on a large multidisciplinary project, involving colleagues from England, the United States, India and Namibia, with expertise ranging from advanced fluid mechanics to swarm intelligence to natural history. The aim of this project is to work out the fundamental principles of how termite mounds work and how they come to be. We already have the broad outlines of this, but being able to apply it to things like climate management of buildings will mean getting to the bottom of some tricky basic principles. That work is being funded by the Human Frontiers Science Program, based in Strasbourg.

The other big focus of my work is a third book, with a working title *Purpose and Desire: Biology's Second Law*, which I hope to have ready to go sometime early in 2014. The book explores some of the cultural origins of modern evolutionary thought, specifically around the implied intentionality of design. The title is meant to be a contrast with Jacques Monod's famous book *Chance and Necessity*.

How did you get started in biomimicry/bio-inspired design?

I stumbled into it, actually. As I've said, I'm a physiologist by training and disposition. Even though termite mounds opened up my eyes to the whole issue of biomimicry and bio-inspired design, the work on termite mounds came about more-or-less by accident. When I was teaching at the (then) University of Bophuthatswana (now the University of Northwest in Mafikeng), in the now defunct South African homeland of Bophuthatswana, I was tasked with developing a laboratory presentation. There were lots of termite mounds around the campus, and the story of air flows within them was so well-established that I thought that demonstrating the air flows would be a simple way to discharge my task. Imagine my surprise (and embarrassment) when the air flows turned out to be nothing like what the accepted story said they had to be! It's fair to say I've spent the last twenty years trying to recover from that embarrassment.

Which work/image have you seen recently that really excited you?

I quite admire what Julian Vincent is doing to try and build a rational basis for bio-inspired design.

What is your favorite biomimetic work of all time?

Has to be the lotus leaf!

What is the last book you enjoyed?

Quartered Safe Out Here, by George MacDonald Fraser. Fraser is better known as the author of the Flashman series of books, which I discovered while living in South Africa. The Flashman books are brilliant examples of what I call "ribald history", wonderful examples of history as literature, but packaged in a racy, and decidedly politically incorrect wrapper. I could describe them, but better that I recommend you read them. *Quartered Safe Out Here* is Fraser's war memoir of the Burma campaign that sought to sweep the Japanese Empire out of Southeast Asia. What I liked about it was the same qualities he brings to the Flashman books: a wonderful ability to develop characters and their stories, from a perspective that is true, but rarely polite or politically correct.

Who do you admire? Why...

I admire a lot of people, but after giving this question a lot of thought, I think I'd have to say that Lynn Margulis, who died just two years ago last November, sits at the top of that list. On a scientific level, I think I've never met a more courageous thinker. All through her career, from her work on the evolution of the eukaryotic cell, to some of her more recent controversial ideas on topics ranging from Gaia to the failings of Neodarwinism to HIV and AIDS, she was always someone who would champion the outlier and intellectual outcast, sometimes seemingly just so that idea would have a defender. That diminished her, in some eyes, but I have to disagree—even if she was espousing an idea that I couldn't agree with substantively, she always posed the disagreement in a provocative and intellectually honest way. Science needs

Endocasting in practice

Source: http://www.esf.edu/efb/turner/termitePages/termiteEndocasting.html

that: once science pretends to consensus, it ceases to be science, in my opinion. On a personal level, I came to know Lynn when I was writing my first book—my publisher had contacted her for help with reviewing the book manuscript and for a publication blurb, and her generosity and open-mindedness toward me was truly mind-blowing. As I got to know her a little better as a person, and saw the joy she took in students, and saw her as she often was, in the midst of the tumultuous swirl of students and fellow scholars that always seemed to be drawn into her orbit, I saw in her something of the beau ideal of the intellectual life.

What's your favorite motto or quotation?

Progress every day.

What is your idea of perfect happiness?

I pretty much have it now. I have a loving family and kids that have grown enough for me to start enjoying them as people. And I can't think of a better career than scholar/scientist/professor. What obligations I do have, namely teaching (which is really having conversations with students about science), are pretty enjoyable, even if they leave me spent sometimes. And having the freedom to pursue what interests me, and get paid for it, is a treasure beyond measure.

If not a scientist/designer/educator, who/what would you be?

I probably would have been a historian. After a misspent youthful interlude as a college drop-out, when I returned to college to pursue a degree, I was torn for a while between studying history and studying biology. What finally decided it for me in the end was that biology seemed to have more field trips and girls. It was that shallow. ×

The mushroom *Termitomyces reticulatus* photographed in Namibia

Photo: Candice, 2009 | Wikimedia Commons

Intimacy White, detail 2 | Materials: Smart foils, wireless technologies, electronics, LEDs, copper and other media. Daan Roosegaarde with the team of Studio Roosegaarde and invited designers V2_, Maartje Dijkstra, and Anouk Wipprecht.

Portfolio
Daan Roosegaarde

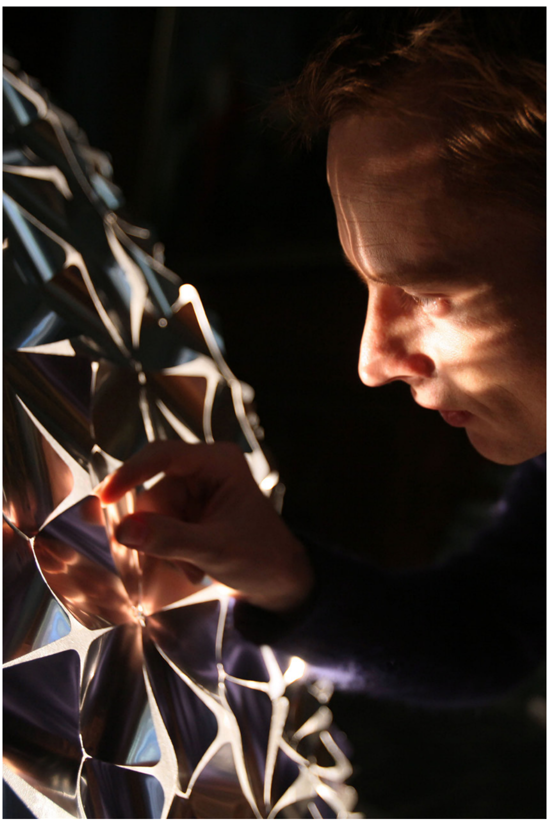
Author:
Daan Roosegaarde

Artist and innovator Daan Roosegaarde explores the dawn of a new nature that is evolving from technological innovations. With projects ranging from fashion to architecture, he creates smart and social designs that instinctively interact with people and landscape.

With studios in Rotterdam and Shanghai, Roosegaarde and his team of engineers and designers create interactive designs such as Dune, Intimacy and Smart Highway. This connection, established between ideology and technology, results in what Roosegaarde calls 'techno-poetry'.

Roosegaarde has won the INDEX Award, People's Choice Award CCN, TIM Award Most Innovative Leader, Charlotte Köhler Award, two Dutch Design Awards, the Media Architecture Award and China's Most Successful Design Award. He has been the focus of exhibitions at the Tate Modern, the National Museum in Tokyo, the Victoria and Albert Museum in London, and various public spaces in Europe and Asia.

Daan Roosegaarde is also a frequent invited lecturer at international design conferences such as TED and Design Indaba, and TV guest at De Wereld Draait Door and Zomergasten.



Portrait Daan Roosegaarde with his Lotus Dome

Studio Roosegaarde

What kind of approaches do you use for your work?

I aim to create smart and social designs that instinctively interact with sound and movement with projects ranging from fashion to architecture. My works function as exploration of the dynamic relation between architecture, people, and technology.

How have your ideas changed since you first started?

My ideas haven't changed, the world around us has.

How does design influence the way you see the world? Do you feel that you see things around you differently?

By creating interactive designs that instinctively respond to sound and movement, our studio explores the dawn of a new nature that is evolving from technological innovations. My designs,

INTIMACY is a fashion project about the relation between intimacy and technology. Its high-tech garments 'Intimacy White' and 'Intimacy Black' are made out of opaque smart foils which become increasingly transparent based on close and personal encounters with people. Social interactions determine the garments' level of transparency, creating a sensual play of disclosure. | Daan Roosegaarde such as *Dune*, *Intimacy* and *Smart Highway*, are tactile high-tech environments in which viewer and space become one. This connection, established between ideology and technology, results in what I call 'techno-poetry'.

Who/what inspires you creatively? What do you 'feed' on the most?

The key to inspiration lies in looking around. What is needed, what is the problem? There are tons of opportunities, it is our job to look for them and change them into answers.

What are you working on right now? Any exciting projects you want to tell us about?

At the moment there are a few new and exciting projects starting to get some grip. First of all *Smart Highway*, in which we will release the first kilometer in a few weeks, here in the Netherlands. The goal is to make roads which are more sustainable and interactive by using light, energy and road signs that automatically adapt to the traffic situation. Then our newest success, our *Smog* project, has two goals; first to clean air locally in public parks and secondly to create an unique art experience in the middle of the city of Beijing where people can meet and share ideas.

What is the last book you enjoyed?

My latest book was the one by Kevin Kelly: *What Technology Wants*.

What's your favorite motto or quotation?

Don't copy-paste, but copy-morph. ×

Intimacy Black detail

Daan Roosegaarde

Dune 4.2 panorama 1 | Daan Roosegaarde

Dune 4.2 detail 1 | Daan Roosegaarde

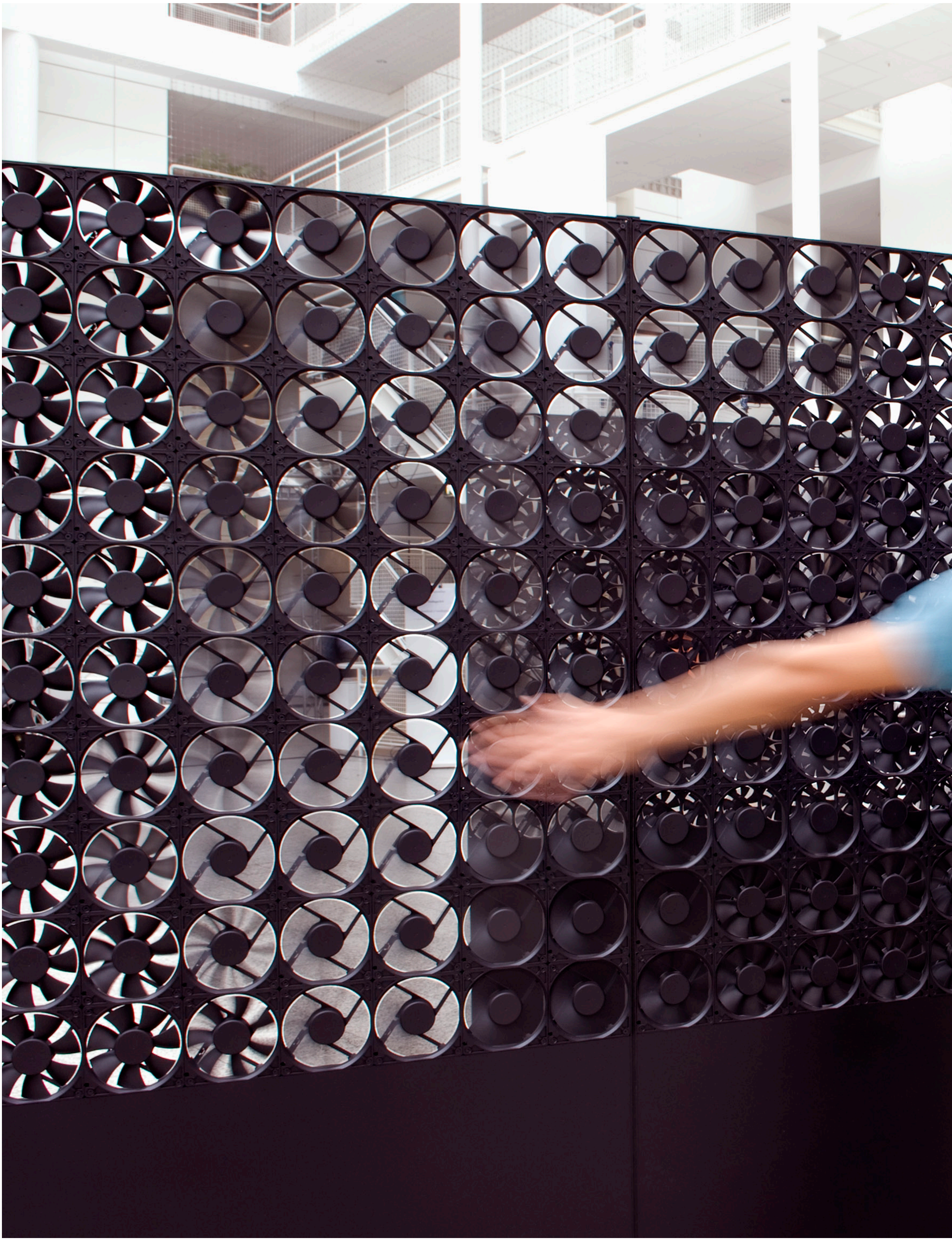
Materials: Hundreds of fibers, steel, sensors, speakers, software and other media. | Daan Roosegaarde

DUNE 4.2 is a new, permanent interactive landscape residing alongside the Maas River in Rotterdam, NL. This public artwork of 60 meters utilizes less than 60 Watts while intuitively interacting with its visitors; rendering the installation sustainable as well as cutting-edge in construction. Within this setting, Rotterdam citizens are able to enjoy a daily 'walk of light'.

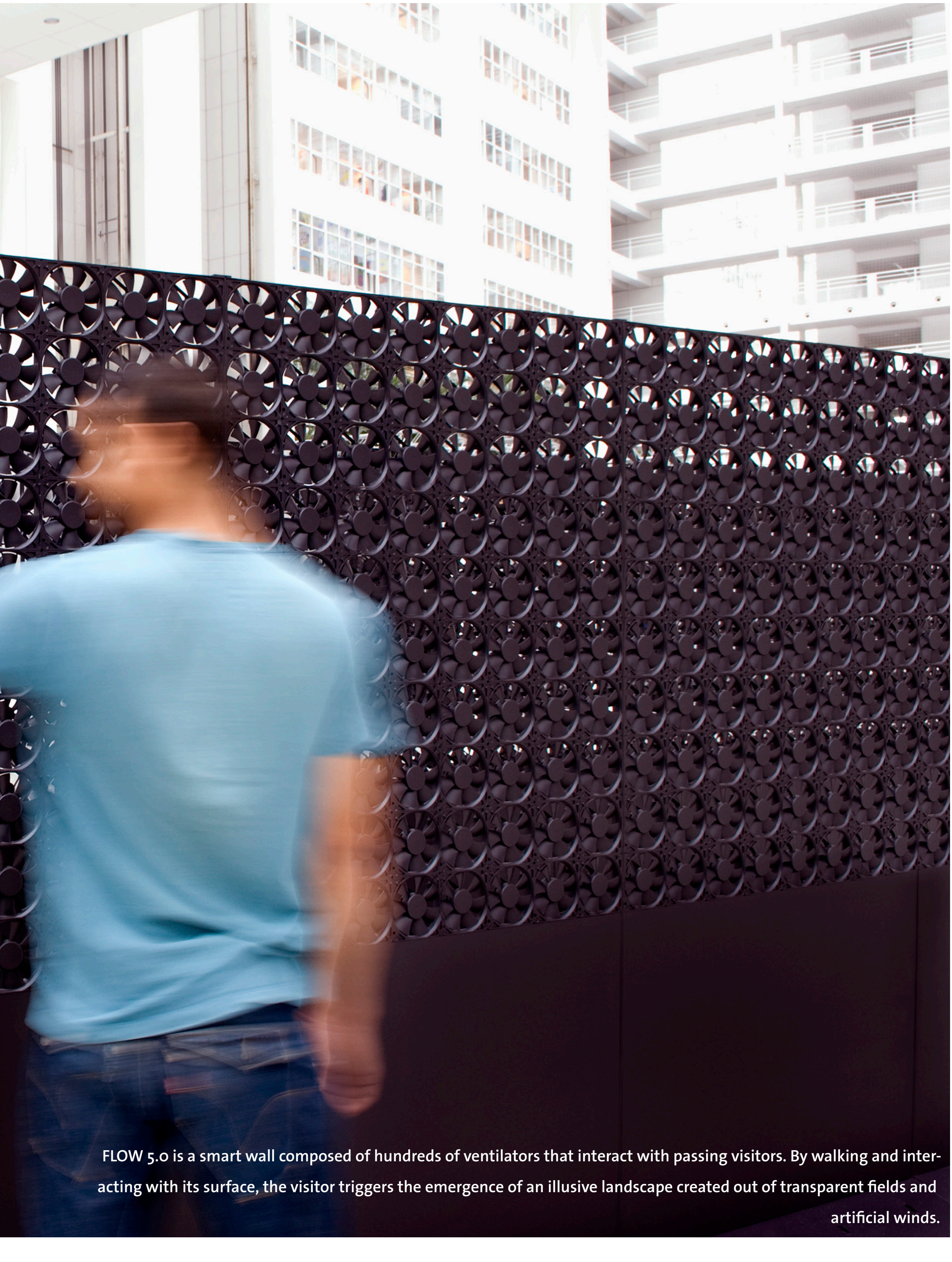
Dune detail | Daan Roosegaarde

Dune Stedelijk 2 | Daan Roosegaarde

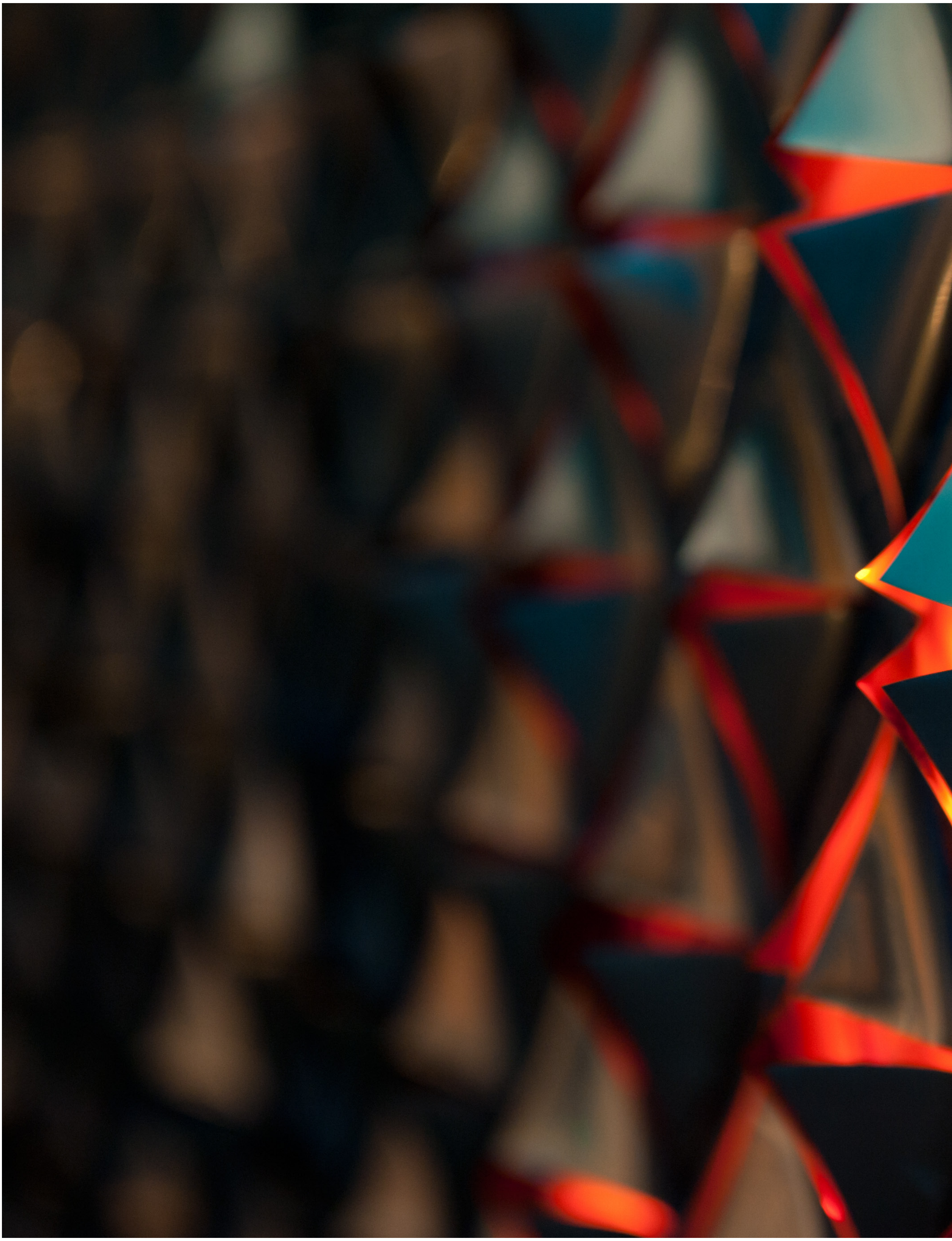
Flow 5.0 detail | Daan Roosegaarde



Materials: Hundreds of ventilators, aluminum, sensors, microphones, electronics, software and other media | Daan Roosegaarde

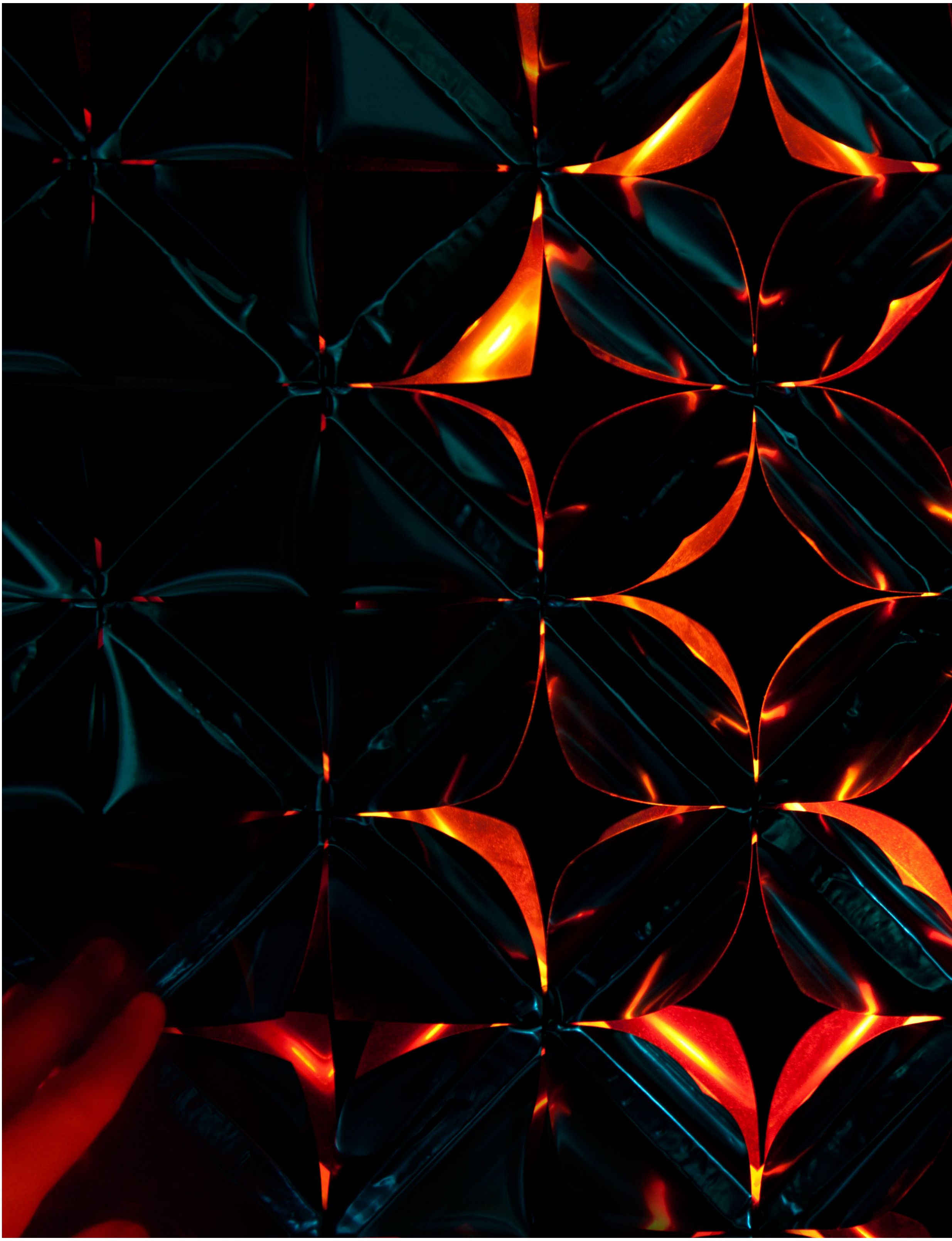


FLOW 5.0 is a smart wall composed of hundreds of ventilators that interact with passing visitors. By walking and interacting with its surface, the visitor triggers the emergence of an illusive landscape created out of transparent fields and artificial winds.

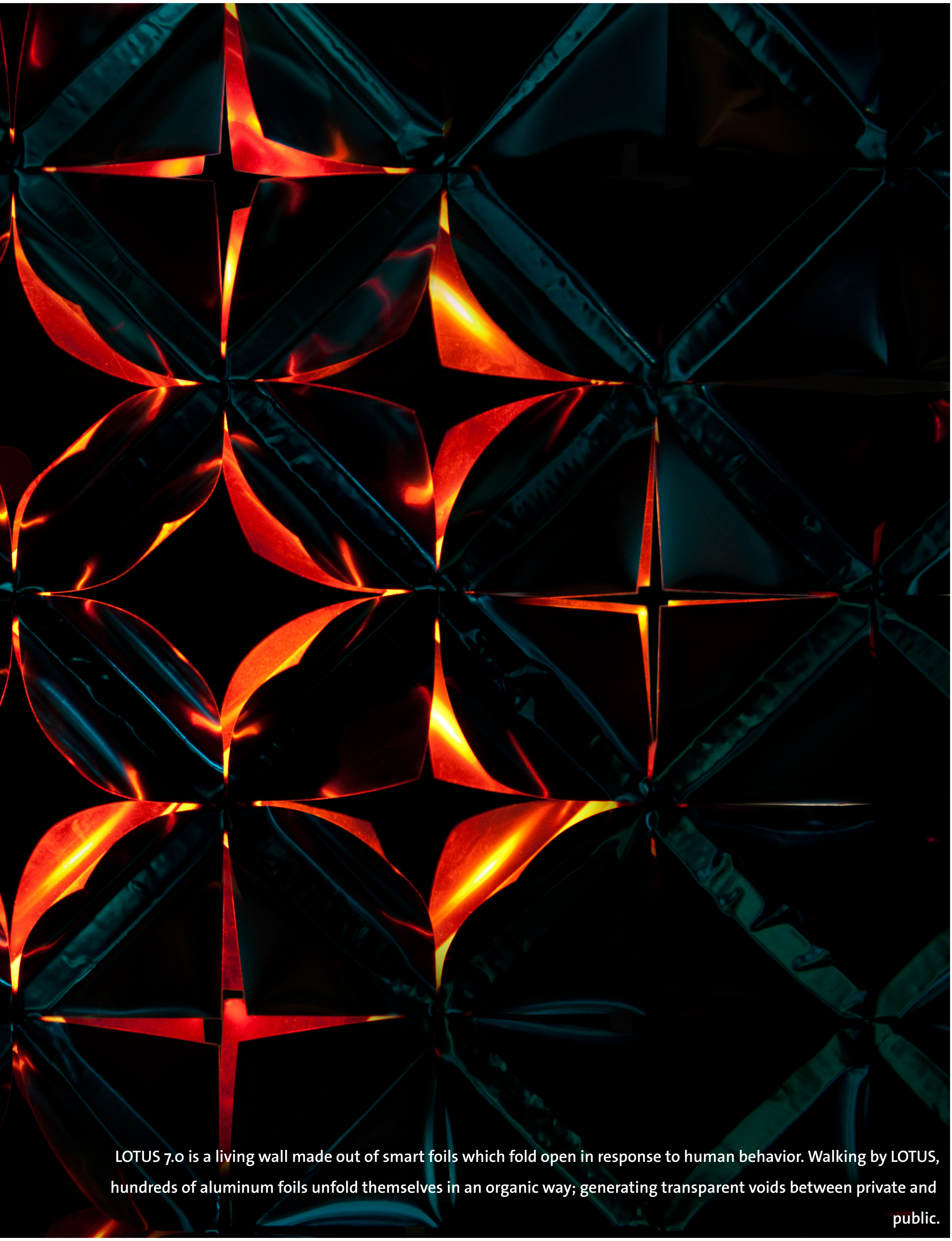


Lotus 7.0 detail | Daan Roosegaarde

Lotus 7.0 visitor | Daan Roosegaarde



Lotus 7.0 morph | Materials: Smart foils, lamps, sensors, software and other media | Daan Roosegaarde

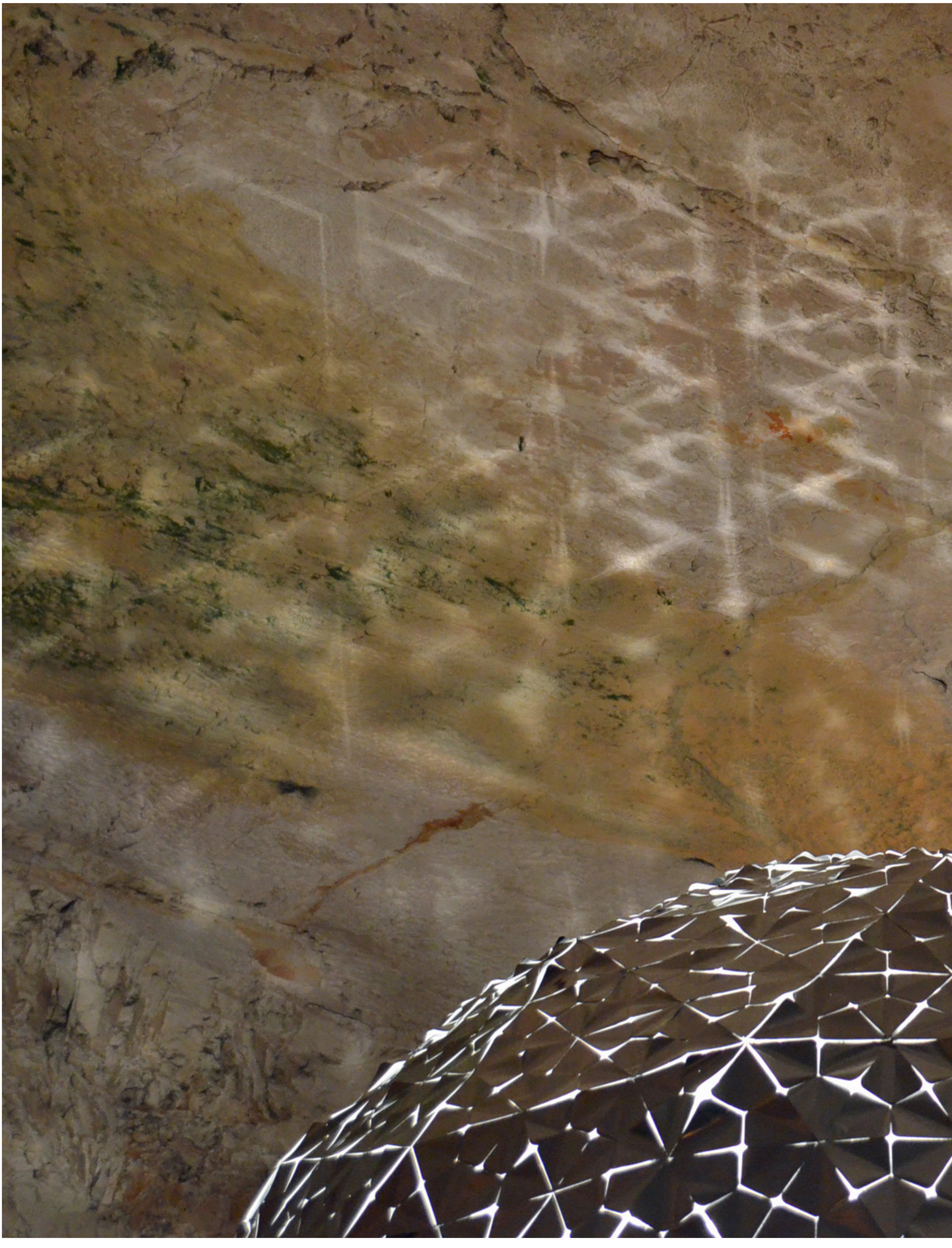


LOTUS 7.0 is a living wall made out of smart foils which fold open in response to human behavior. Walking by LOTUS, hundreds of aluminum foils unfold themselves in an organic way; generating transparent voids between private and public.

Lotus Dome | Daan Roosegaarde

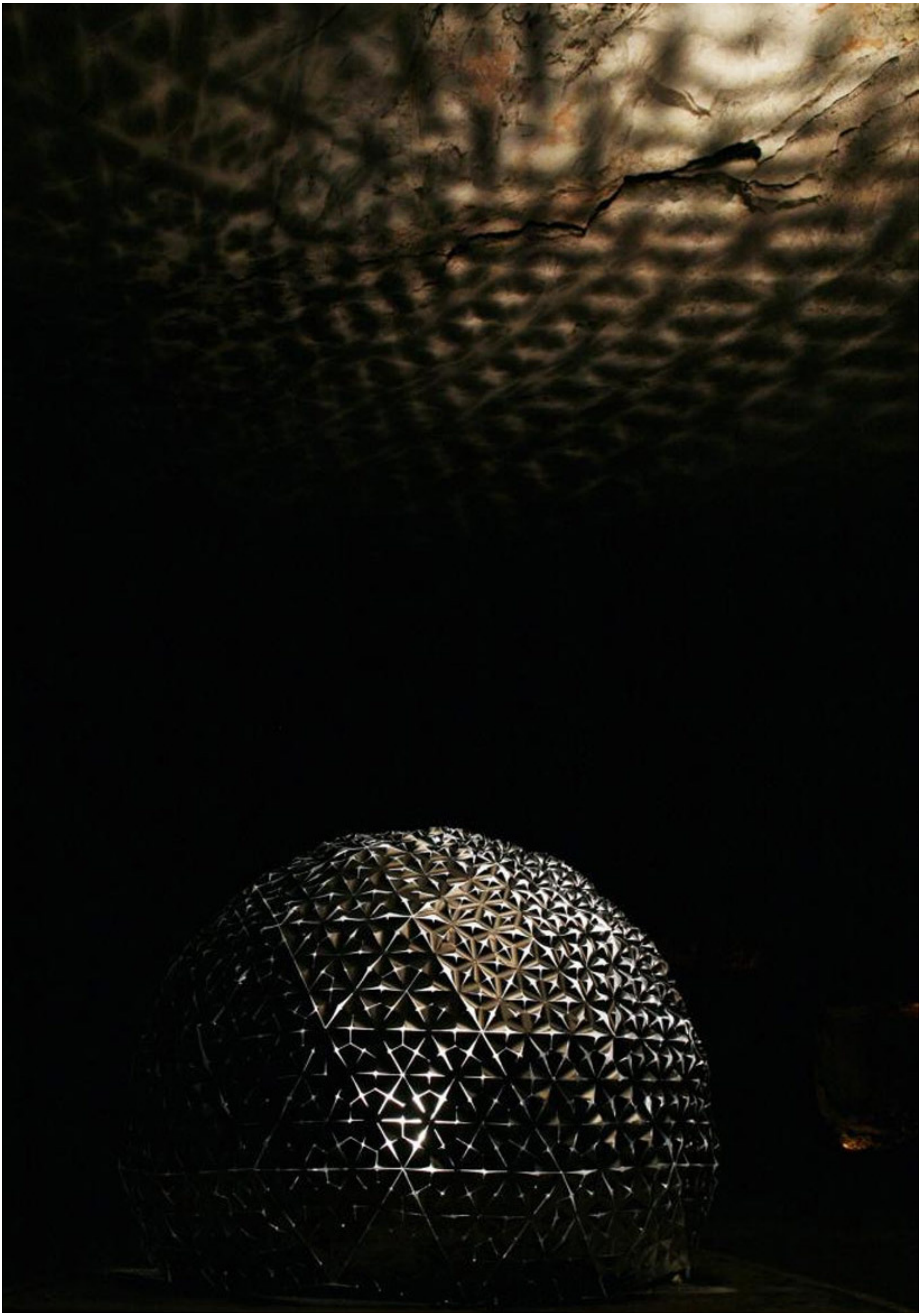
Materials: Dome of 3 x 3 x 2 meters with smart foils, lamps, electronics, sound and other media | Daan Roosegaarde

LOTUS DOME is a living dome made out of hundreds of smart flowers which fold open in response to human behavior. Placed in Sainte Marie Madeleine Church in Lille LOTUS DOME creates an interactive play of light and shadow. As a futuristic vision on the Renaissance LOTUS DOME merges elements of architecture and nature into an interactive environment.

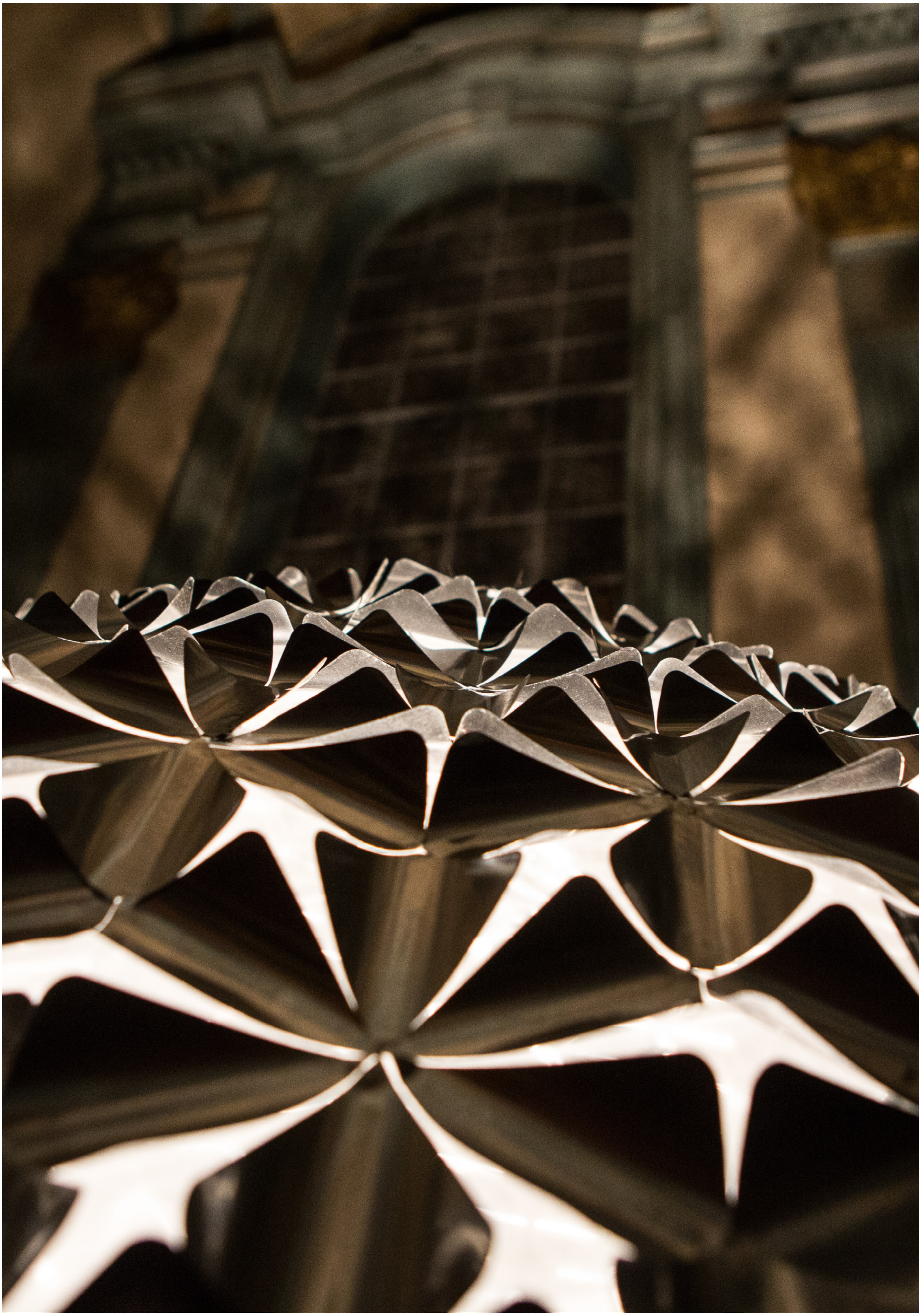


Lotus Dome Jerusalem Cave detail | Daan Roosegaarde

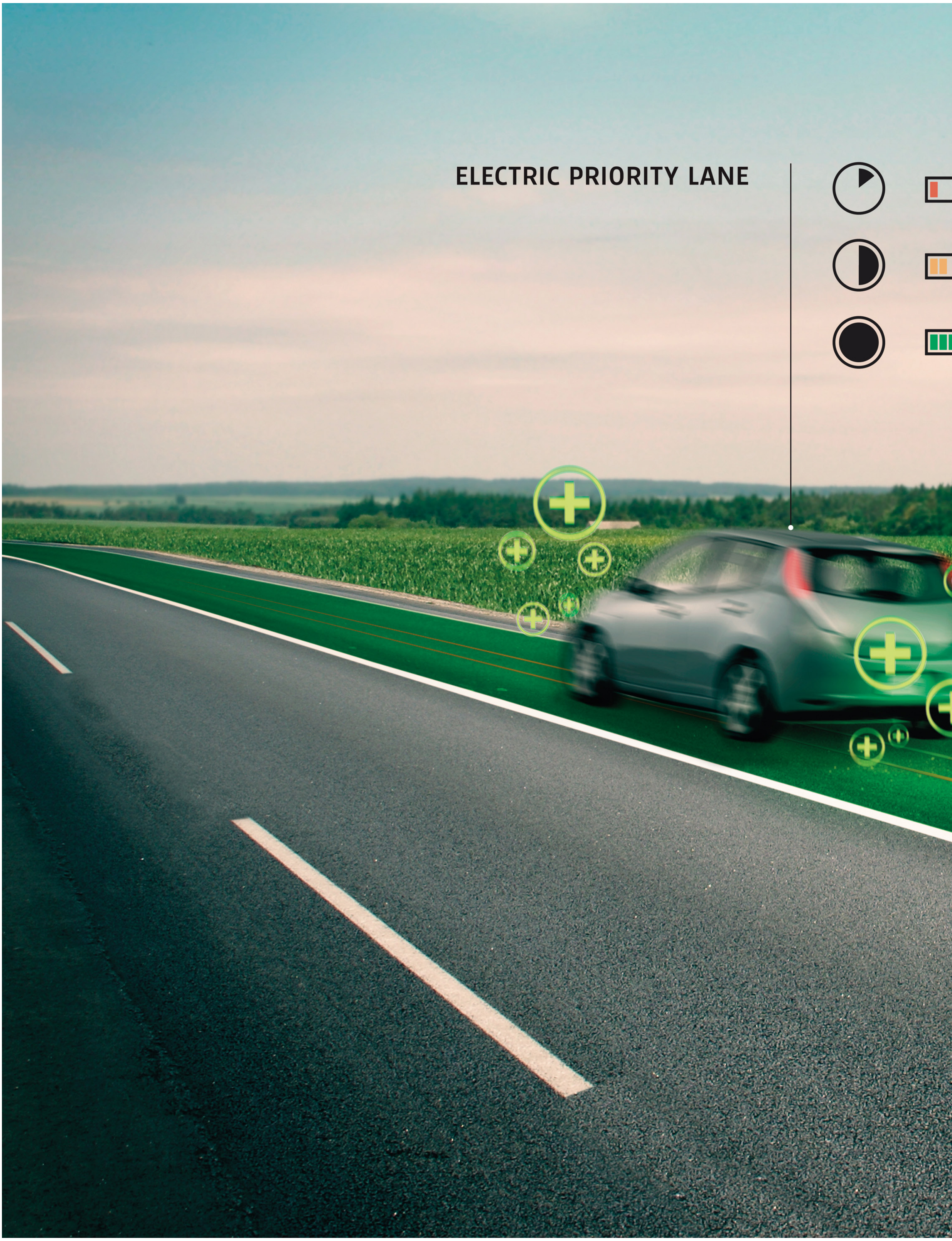
Lotus Dome Jerusalem Cave | Daan Roosegaarde



Lotus Dome Jerusalem Cave | Daan Roosegaarde



Lotus Dome | Daan Roosegaarde

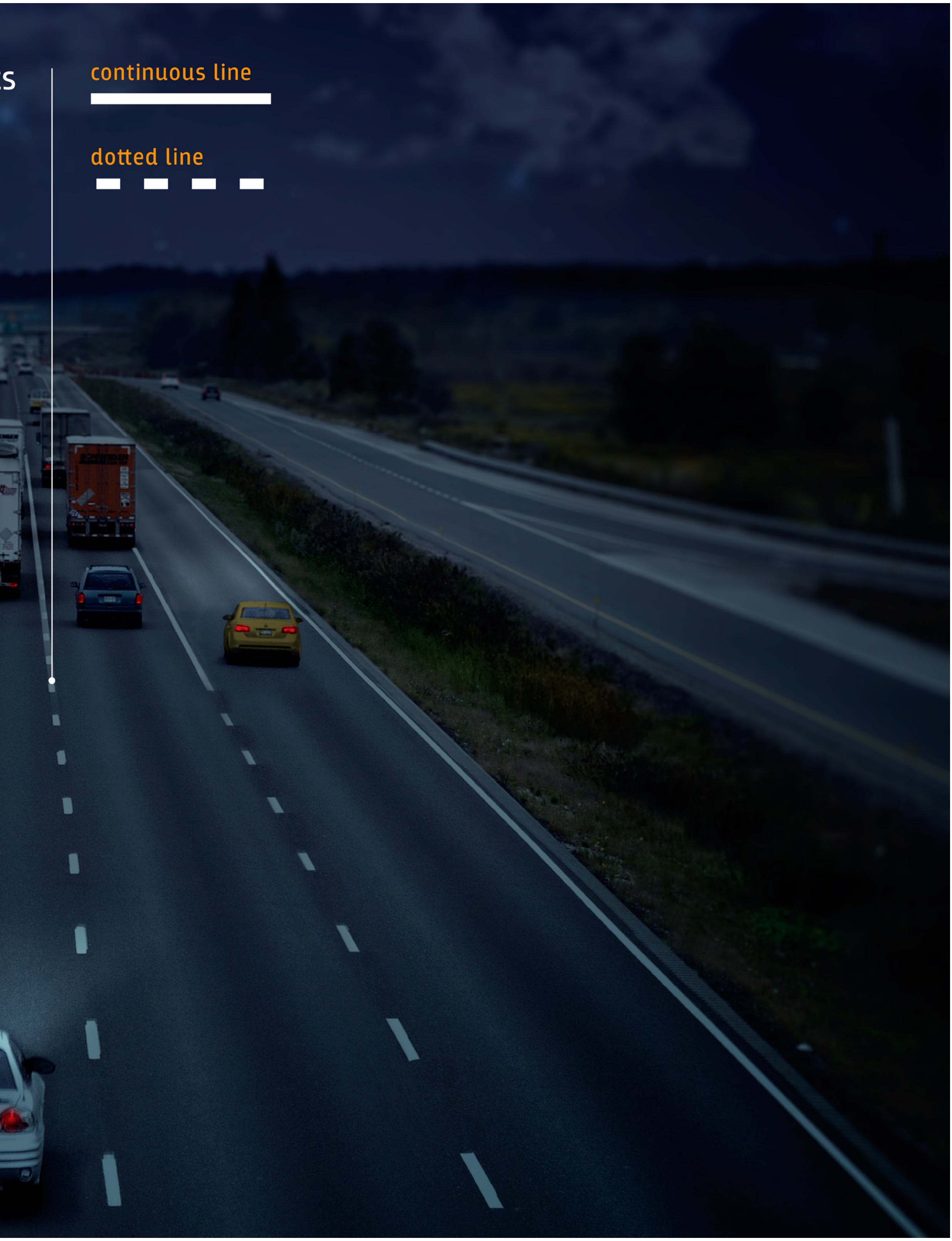


Smart Highway | Electric Priority Lane | Studio Roosegaarde

Smart Highway | Interactive Light | Studio Roosegaarde

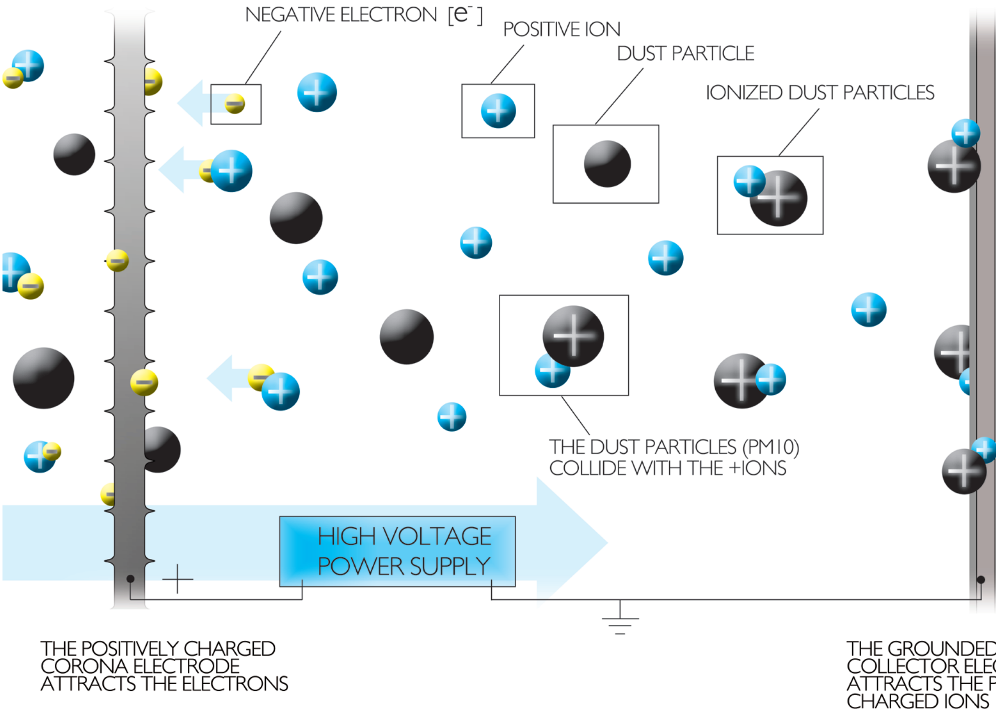

RACTIVE LIGHT

Smart Highway | Dynamic Lines | Studio Roosegaarde


continuous line
dotted line

Smart Highway | Dynamic Paint | Studio Roosegaarde

Smart Highway are interactive and sustainable roads of today. Designer Daan Roosegaarde and Heijmans Infrastructure develop new designs and technologies for this 'Route 66 of the future'. New designs include the 'Glow-in-the-Dark Road', 'Dynamic Paint', 'Interactive Light', 'Induction Priority Lane' and 'Wind Light'. The goal is to make roads that are more sustainable and interactive by using light, energy and road signs that automatically adapt to the traffic situation. Awarded with 'Best Future Concept' by the Dutch Design Awards 2012 the first meters 'Smart Highway' will be realized in 2013 in the Netherlands.

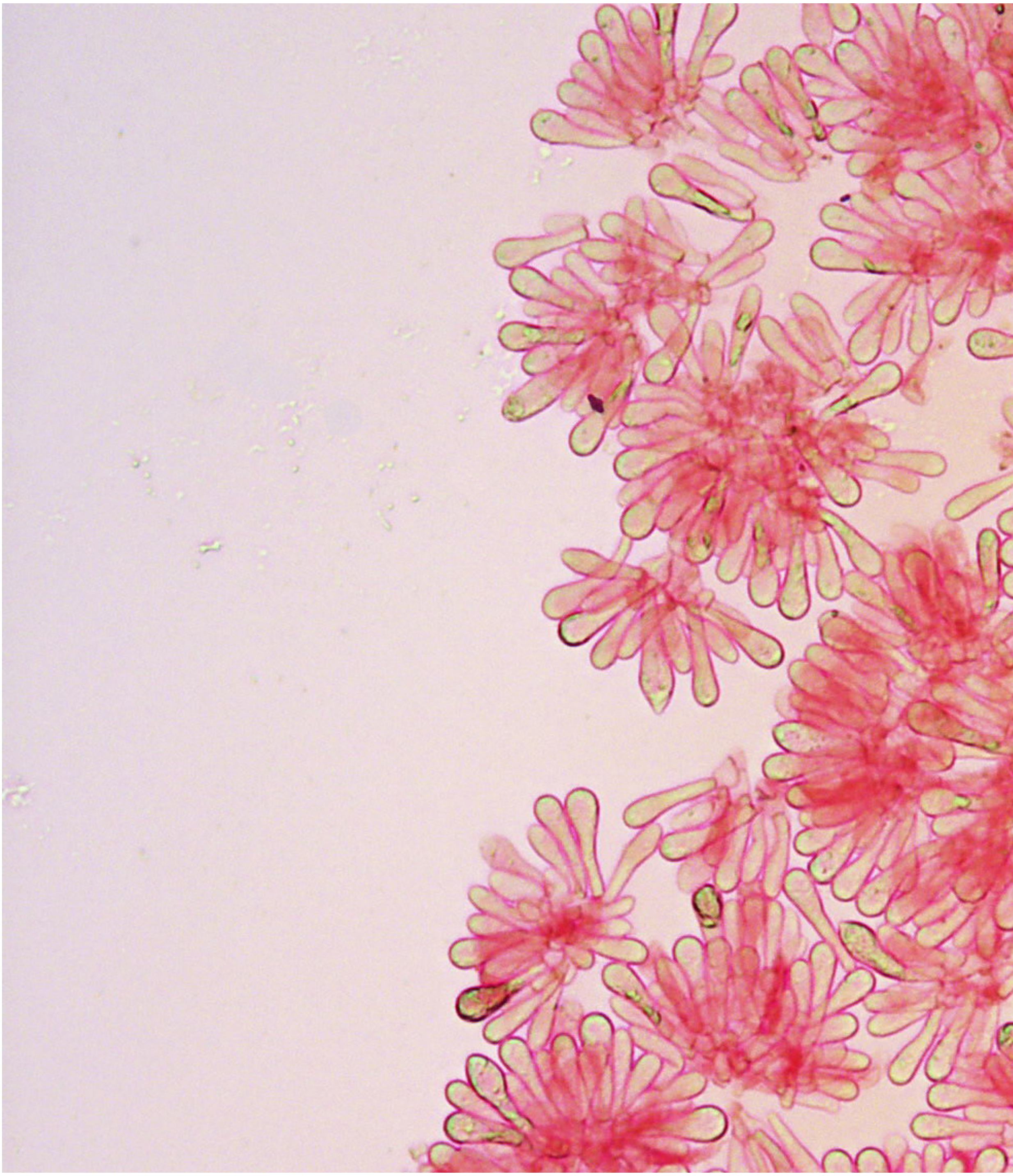


Lidi and Daan testing smog | Studio Roosegaarde

Smog Roosegaarde | Studio Roosegaarde

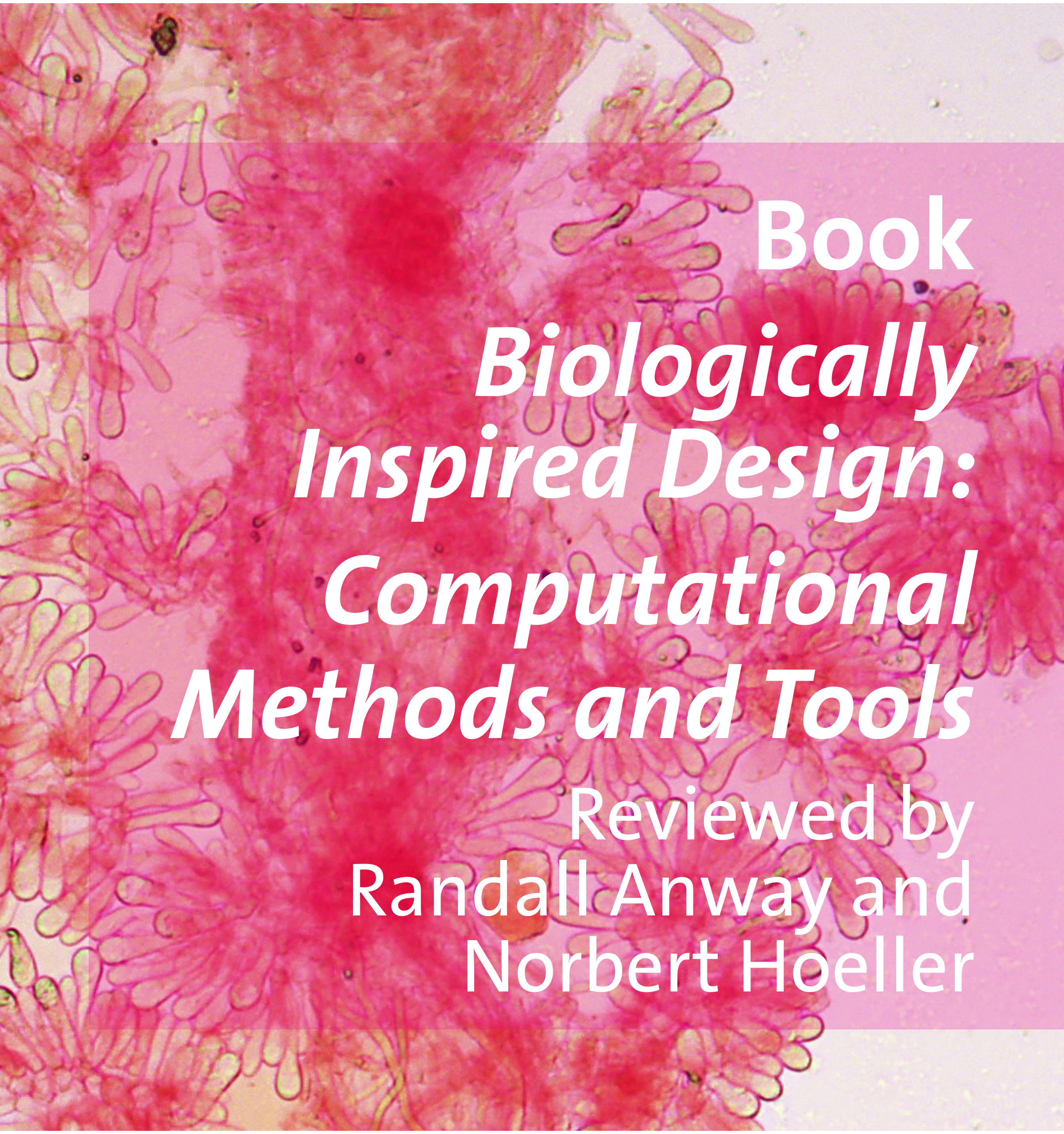
Smog Beijing CCTV Tower | Studio Roosegaarde

Daan Roosegaarde with his team of ENS Europe and expert Bob Ursem (TU Delft) are creating nano technology to clean the air of Asian cities. By making a weak ion electromagnetic field (similar like static electricity that attracts your hair) the smog components in the air are pulled down to the ground where they can be easily cleaned. This creates gigantic holes of clean air in the sky. Here people can breath, and see the sun again. The projects has two goals; first to clean air locally in public parks and secondly to create an unique art experience in the middle of the city of Beijing where people can meet and share ideas.



Amanita phalloides basidia

Photo: ressaure, 2011 | Flickr cc



Book

Biologically Inspired Design: Computational Methods and Tools

Reviewed by Randall Anway and Norbert Hoeller

winter 2013

Book
Biologically Inspired Design

Reviewed by:
Randall Anway and Norbert Hoeller

Biologically Inspired Design: Computational Methods and Tools by Ashok K. Goel, Daniel A. McAdams and Robert B. Stone (eds.)

Prepared by Randall Anway and Norbert Hoeller

Ashok K. Goel is a Professor of Computer and Cognitive Science in the School of Interactive Computing at Georgia Institute of Technology in Atlanta, USA. He is the Director of the School's Design & Intelligence Laboratory (http://dilab.cc.gatech.edu) and a Co-Director of the Institute's Center for Biologically Inspired Design (http://cbid.gatech.edu/). Ashok conducts research into artificial intelligence, cognitive science and human-centered computing, with a focus on computational design, modeling and creativity. His research explores analogical thinking, systems thinking, visual thinking, and meta-thinking as fundamental processes of design and creativity.

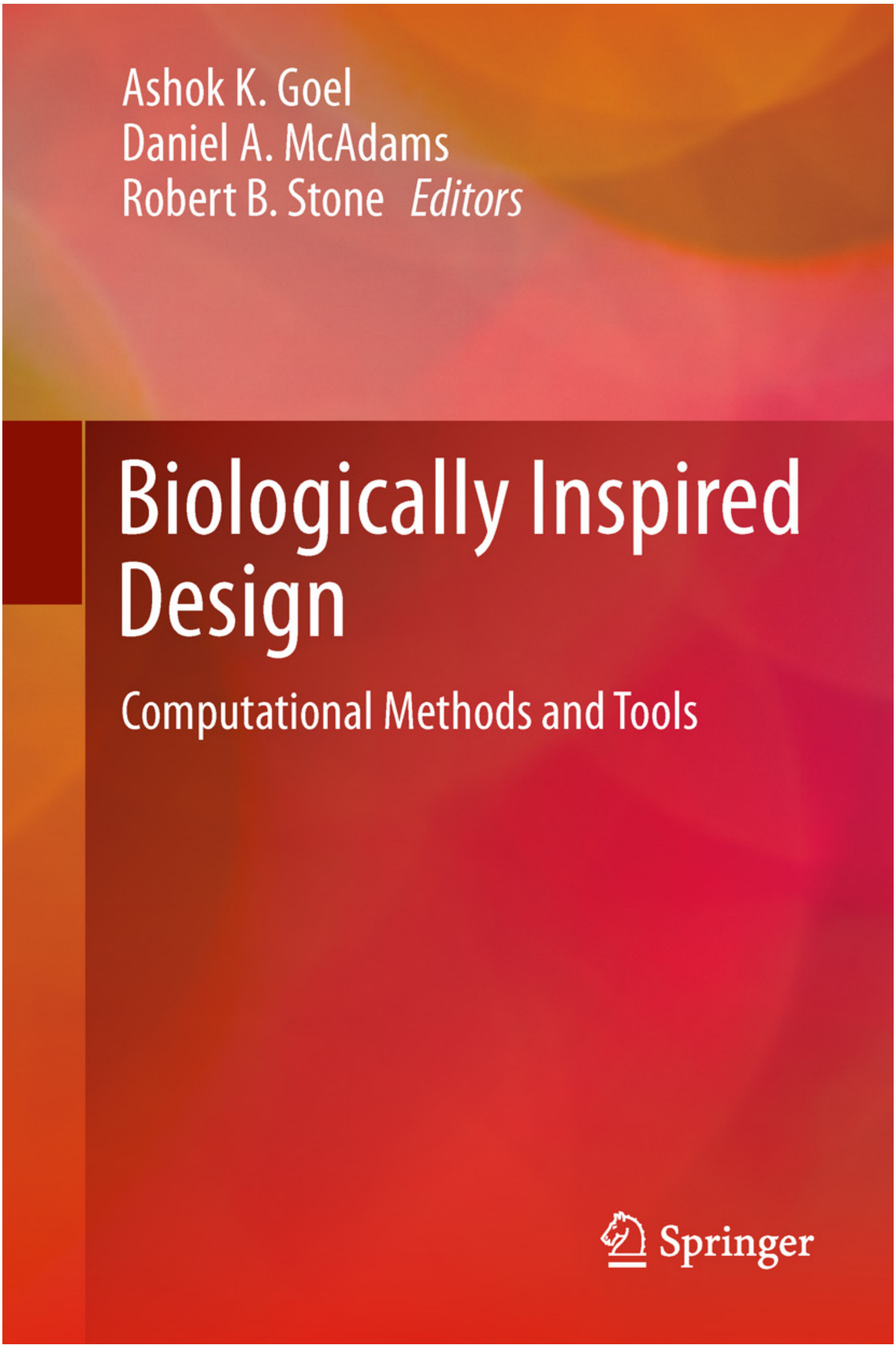
Dr. Daniel A. McAdams is currently an associate professor in the Department of Mechanical Engineering at Texas A&M University. His research interests are in the area of design theory and methodology with specific focus on functional modeling, innovation in concept synthesis, biologically inspired design methods, inclusive design, and technology evolution as applied to product design. Dr. McAdams leads the Product Synthesis Engineering Lab (http://www.prosedesign.org/).

Dr. Robert B. Stone is a Professor and the Interim Head of the School of Mechanical, Industrial and Manufacturing Engineering at Oregon State University. Dr. Stone's research interests include design theories and methodologies, specifically automated conceptual design techniques and concept generation techniques such as biologically inspired design. He leads the Design Engineering Lab (http://designengineeringlab.org).

Keywords: Biomimicry, Biologically inspired design, Computer-aided design, Engineering design, Design computing

The authors' intentions for the book are made clear in the preface: *"The scientific challenge now is to transform [biologically inspired design] into a repeatable and scalable methodology. This requires addressing several big challenges*

- *to use the paradigm to address increasing numbers of real problems*


Ashok K. Goel
Daniel A. McAdams
Robert B. Stone Editors
Biologically Inspired Design
Computational Methods and Tools
Springer

- *to document the best practices of successful applications of the paradigm and develop a theory of biologically inspired design*
- *to develop computational methods and tools that can make biologically inspired design repeatable and scalable*
- *to educate new generations of would-be-designers in the paradigm of biologically inspired design."*

Although the book is largely written by academics and targets educators/researchers interested in bio-inspired design, the foreword, preface and particularly the publisher's overview sets expectations that the book "enable[s] the design practitioner to apply such methods to their design problems." Beyond describing a series of research initiatives, this raises questions as to whether the chapters in this book:

- show an awareness of the practice of design in general and bio-inspired design in particular
- provide evidence for the efficacy of the tools and methods
- communicate in ways that are accessible to practitioners
- provide insights that advance the emerging field of bio-inspired design

Structure

The book starts with a foreword by Janine Benyus. The twelve chapters explore various aspects of the four challenges described in the preface with a focus on computational methods and tools, starting with an overview of two NSF workshops that led to this book and ending with an analysis of how evolution and design by analogy influence the practice of biologically inspired design.

Foreword (Benyus)

In the foreword, Benyus suggests that bioinspired design as a discipline sits at a crossroads. On one hand, she highlights the need for leaps in engineering innovation and her closely held belief in the promise of insights from biology. On the other, she recognizes that "most inventors... want a set of transferable ideas" and "there are still miles to go before [design insights from biology] are translated into a product or process".

She asserts that what is required at this point is to chart a course for giving inventors "access to nature's ideas" driven by information tools designed to enhance innovation. To fail in this endeavor is for biomimicry to remain an isolated domain of a few innovators.

The challenges are not trivial, she explains, yet work is already well underway. By bringing together and building on successful research in a variety of domains she calls attention to the possibility that desirable results may be brought to bear in the near-term.

Connecting various research threads grounded in function provides a common basis for building a new bridging discipline for design. Benyus' underlying assumption is that new capacities in information tools, training and refined theory will bring a wider adoption of bio-inspired design methods. This, in turn, will help in bring solutions for 'the worthy conundrums of our era' closer to reality.

A vision of this magnitude demands coherent strategy and high-level execution. The stage is thus set for outlining a systemic and strategic approach to bioinspired design. The work ahead is complex and deeply involved, but as readers, we enter a story already in progress; research is underway in a variety of loosely connected areas, which are fairly robust by themselves. Further work is needed but useful and demonstrable results can be seen in: computation, interface design, design theory, modeling and simulation, manufacturing, managing innovation, educational effectiveness, and more.

Preface (Goel, McAdams, Stone)

The editors lay out the scientific challenge of transforming bioinspired design into a 'repeatable and scalable' methodology and outline several sub-challenges they regard as important. Providing a brief background for each chapter, they reveal what the compilation brings together and their editorial emphasis, which is primarily on computational tools.

Affirming Benyus' convictions regarding the promise of bioinspired design and the need for timely empirical research, the editors share her aspiration for broader engagement, through further scholarly and practical collaborative pursuit of the work discussed in the chapters.

Chapter 1: Charting a Course for Computer-Aided Bio-Inspired Design (Stone, Goel, McAdams)

A 2011 workshop series sponsored by the US National Science Foundation brought together many of the researchers contributing to this volume. There, attendees shared findings relating to work in the emerging field and collectively drew conclusions for potential next steps. The workshop explored applications currently in the research phase and catalyzed a synthesis of various disciplinary perspectives.

Chapter One relates the work presented in the book in relation to the workshop and within a functional perspective specifically useful for bioinspired design research. Drawing distinctions between variants of bioinspired design and their respective goals, it provides deeper context and motivations for the process of bridging engineering and biology for practical purposes.

Insights from biological systems may aid innovators who are dealing with complex challenges that strain the capabilities of current human-made systems or demand entirely new approaches. Chapter 1 closes with a call for an NSF program specific to bioinspired design that could create new research opportunities and sources of funding.

Chapter 2: The AskNature Database: Enabling Solution in Biomimetic Design (Deldin, Schuknecht)

The AskNature Database (http://www.asknature.org) was developed with the intention of enabling solutions in biomimetic design based on a common understanding and language around 'functions'. This chapter describes the design and status of the database at the time of publication including the biomimicry taxonomy, biological strategy pages, biomimetic products, an integrated search engine and social networking capabilities. It further describes how the tool has been used over a period of several years.

Since it was launched in 2008, the AskNature database has grown in content (1,300 pages) and visits (nearly 1.8M page views by 0.5M unique visitors in 2012). AskNature could benefit from in-depth analysis including validation of the taxonomy, how users interact with the database and what the outcomes have been.

Chapter 3: A Natural Language Approach to Biomimetic Design (Shu, Cheong)

Building on a body of prior work in Natural Language processing, Shu and Cheong place the effort to support bioinspired design within a larger context of work whose general aim is to integrate vast amounts of natural language text into computationally tractable applications.

More particularly, the authors inquire how particular design activities - problem definition and search for relevant analogies - are or could be supported more effectively through what they term a 'natural language' approach.

They provide somewhat detailed accounts from an academic setting of design problem definition and analogy search using a keyword approach combined with qualitative reasoning and analysis to interpret the relevance or applicability of candidate solutions.

One of the longest chapters in the book, the authors offer a pitch for coupling their approach with others: what could make it useful, practical, and scalable. Two of the more interesting conclusions drawn are suggestive towards further work:

- Formal frameworks for indexing and reasoning with biological information may be beneficially coupled with computational linguistic techniques to advance the field of bio-inspired design.
- Information extraction from text may be beneficially coupled with pattern finding techniques to advance bio-inspired design, engineering, and biology.

Chapter 4: A Thesaurus for Bioinspired Engineering Design (Nagel)

Nagel presents a versatile tool that can be used at multiple points in bioinspired design, shown particularly to be applicable to the conceptual stage of engineering design.

Briefly, the tool correlates distilled sets of biological and engineering terms and as such continues to be a work-in-progress. At this point, terms and concepts have been incorporated that support bioinspired engineering design. The innovative development of a structured framework that intermediates the two domains makes a fundamental contribution to facilitating more productive interactions between engineering, biology, and bioinspired design communities.

Analogy, metaphor and the use of tools are common and even expected in engineering. It can be expected, then, that linking engineering

Mold on ground coffee

Photo: ressaure, 2011 | Flickr cc

and biological terminology around functional themes could yield a measure of value in collaborative interactions.

A variety of bio-inspired design tools, techniques and methods are briefly surveyed and it is emphasized that what they all share is an abstraction step to reveal a functional principle. This can be viewed in the context of a broader base of formal design language research efforts, specifically in relation to the Functional Basis (an effort supported by National Institute of Standards and Technology and others) and generally in relation to ongoing efforts to develop software representations modeling specific aspects of natural and artificial systems.

Development of the thesaurus is described at some length, in terms of resources and procedures used for populating, refining, and validating its content and structure. The thesaurus has also been integrated into a tool for organized search, which aids fine-grained search control to yield more relevant and focused results.

The author describes integration of the thesaurus with another tool called the Design Repository (http://design.engr.oregonstate.edu/repo) which stores models of biological systems and over 130 consumer products indexed by engineering function. Designers can also work with a repository-associated concept generator, the morphological evaluation machine and interactive conceptualizer tool (MEMIC), to develop conceptual designs. Utilizing an established computational method for concept generation, this approach expands the range of potential biological solutions presented for engineering consideration. While it assists in identifying biological solutions, analogies and components for engineering, the designer needs to identify elements within the engineering domain to support the suggestions that MEMIC offers.

Developed to help bridge a ‘knowledge gap’ between engineering and biology, the engineering-to-biology thesaurus addresses specific challenges for collaboration between these disciplines. While the authors assert that such collaborations are still uncommon, some discernable patterns can presently be handled with such linguistically-based tools and thus has the potential to facilitate greater inter-domain productivity, increase interaction between its users and the knowledge resource, and “increase a designer’s efficiency when working across the engineering and biology domains.”

Chapter 5: Function-based Biologically Inspired Design (Nagel, McAdams, Stone)

The authors propose a systematic but flexible bio-inspired methodology that integrates with existing functional design methods and design tools. The framework applies to both problem-based (challenge-to-biology) and solution-based (biology-to-design) pathways. The key elements are:

- the engineering-to-biology thesaurus (described in Chapter 4), to assist with searching biological literature and model biological systems
- biological functional modeling method
- organized search tools
- concept generation approaches

The authors validated their methodology using two methods. The first started with descriptions of six existing biomimetic technologies, converted them to function/flow pairs using the Functional Basis and queried the biological knowledge database with the help of the engineering-to-biology thesaurus. In all cases, biological analogs were found that showed a connection to the concept underlying the product. The second started with three design case studies and used the above methodology to identify bio-inspired concepts and then search for preexisting engineering solutions implementing the required functions. Again, the validation was successful for all three cases.

The methodology appears to be sensitive to the needs of designers, although the target audience seems to be engineers familiar with the Functional Basis approach. The methodology does not appear to address the unique challenges of bio-inspired design, with the exception of the engineering-to-biology thesaurus. The underlying assumption that "much of nature exhibits functionality and behavior in a comparable context to engineering" does not address the inherent complexities described in Chapter 12 nor the differences in culture between biologists and engineers.

The attempts to validate the methodology are admirable but the relevance of the two methods needs to be established. The first reverse-engineers a biomimetic product to identify biological analogs, testing in only one direction the task of building useful analogies. Even if a biological analog is found, it can be difficult to turn that knowledge into a viable engineering concept. The second method demonstrates that this methodology is at best as good as 'business as usual' engineering. Although one case study mentions an external research group that had run out of ideas, it implies that bio-inspiration caused them to re-evaluate a concept that they had earlier discounted. Further investigation revealed that this concept had already been explored by another research group.

Although promising a systematic and flexible way of helping designers make connections between the biological and engineering domains, it is not clear what effort would be required to extend applicability outside of the engineering, whether the methodology can deal with the complexity of biological systems and the lack of engineering-grade descriptions, and whether it can deliver solutions that are truly innovative.

Chapter 6: Information-Processing Theories of Biologically Inspired Design (Goel, Vattam, Wiltgen, Helms)

The authors remark that while the practice of bioinspired design seems to be gaining acceptance, notable success has been ad hoc rather than systematic and by implication effectively neither reproducible nor scalable in an engineering sense. To ground the practice in principled, transferable methods requires more rigorous study than has been accomplished to date.

Characterizing the current work as a step in a 'long term agenda' of developing methodology, pedagogy and technology, the chapter focuses on observations and analysis in the context of a university level course in bioinspired design. Task-oriented observations were made around the generation and use of cross-domain analogies in teams of biologists and engineers working in the conceptual phase of a bioinspired engineering design project.

By analyzing information processing involved in the team task and its subtasks, a descriptive and explanatory model is developed. The authors compare this model with prior models in the field that are prescriptive and normative, and offer insights on what fundamentally differentiates biologically inspired design from other kinds.

Based on this analysis, the authors argue that bioinspired design can be seen as a unique and powerful elaboration of generic analogical design and develop detailed task models showing an internally distinctive logic that leverages interactions between solution-based and problem-based design tasks. The authors suggest further work needs to be done to understand the implications of this significant methodological difference.

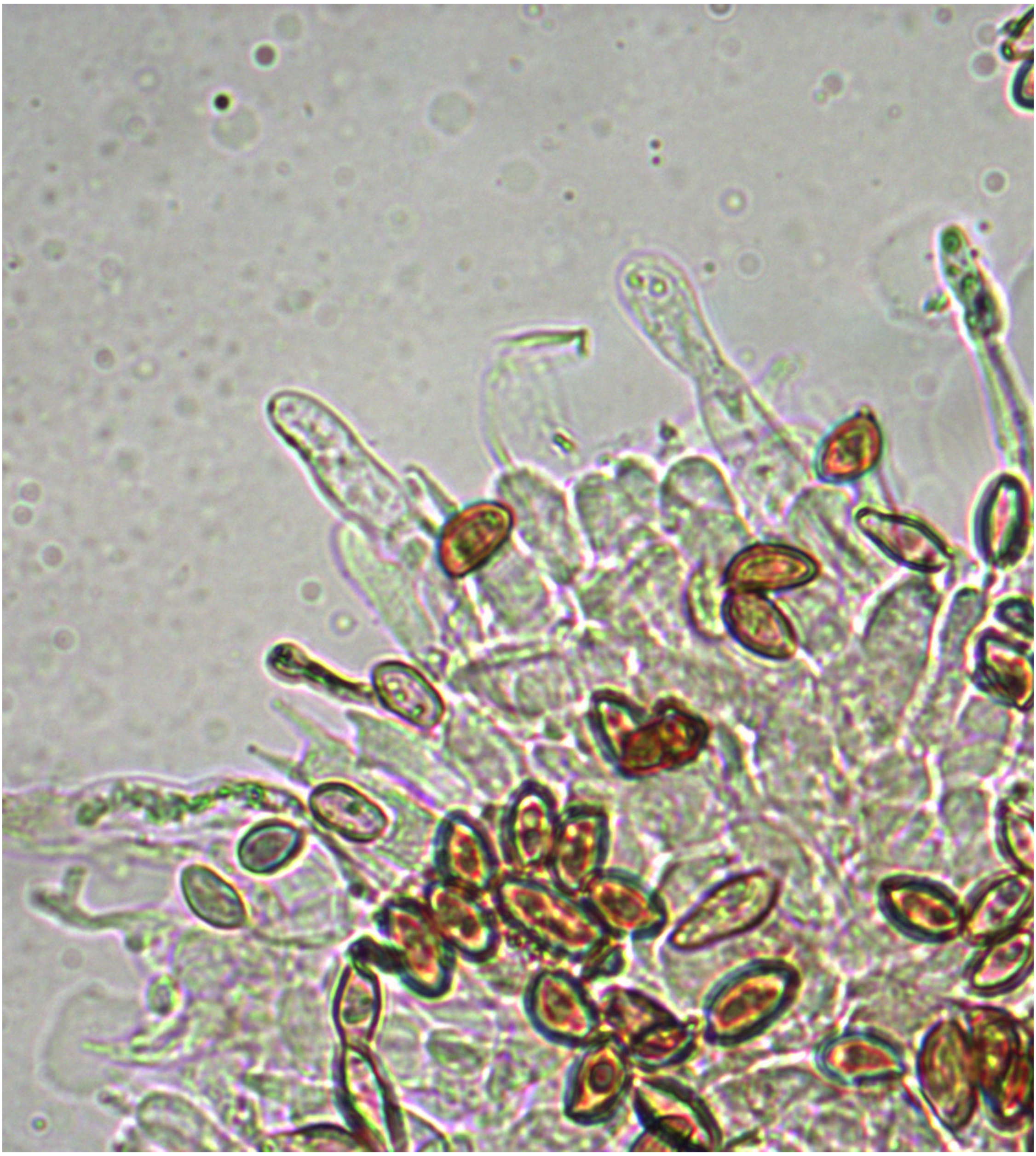
Chapter 7: Adaptive Evolution of Teaching Practices in Biologically Inspired Design (Yen, Helms, Goel, Tovey, Weissburg)

This chapter describes observations and insights obtained through eight years of teaching bioinspired design (BID) to interdisciplinary undergraduate teams at Georgia Tech's Center for Biologically Inspired Design (CBID). The course attracts a broad range of students with established majors and is taught by faculty from biology and engineering. Each team includes at least one biologist and one mechanical engineer, along with students drawn from systems engineering, materials science and design.

The CBID course is based on established research in cognition and learning. Studies have shown that creativity is enhanced through finding and developing analogies between disparate domains such as biology and engineering. Key learning goals of the course include novel design techniques, interdisciplinary communication, science/engineering knowledge outside core domain, interdisciplinary collaboration and application of existing knowledge to a new field.

The chapter describes nine challenges to effective BID and five core development areas. Each development area is expanded into multiple examples. The authors of this chapter demonstrate an in-depth understanding of the challenges of bio-inspired design based on years of observing interdisciplinary student design teams. Although the chapter does not present a large body of evidence, the tools and methods are clearly based on close observation of students. The material is of direct value to educators teaching BID who can 'pick and chose' material based on their particular educational requirements.

CBID appears to spend considerable time teaching students techniques and tools for working in teams, doing innovative designs and evaluating their work. The extent to which these skills are common amongst practitioners in different design disciplines needs to be assessed to determine the immediate value to designers. The chapter does not provide details as to which of the tools and methods have had the largest impact nor the circumstances in which they are most useful. Lastly, although students are not necessarily representative of the larger design community, observations of students may reveal insights into the types of problems where

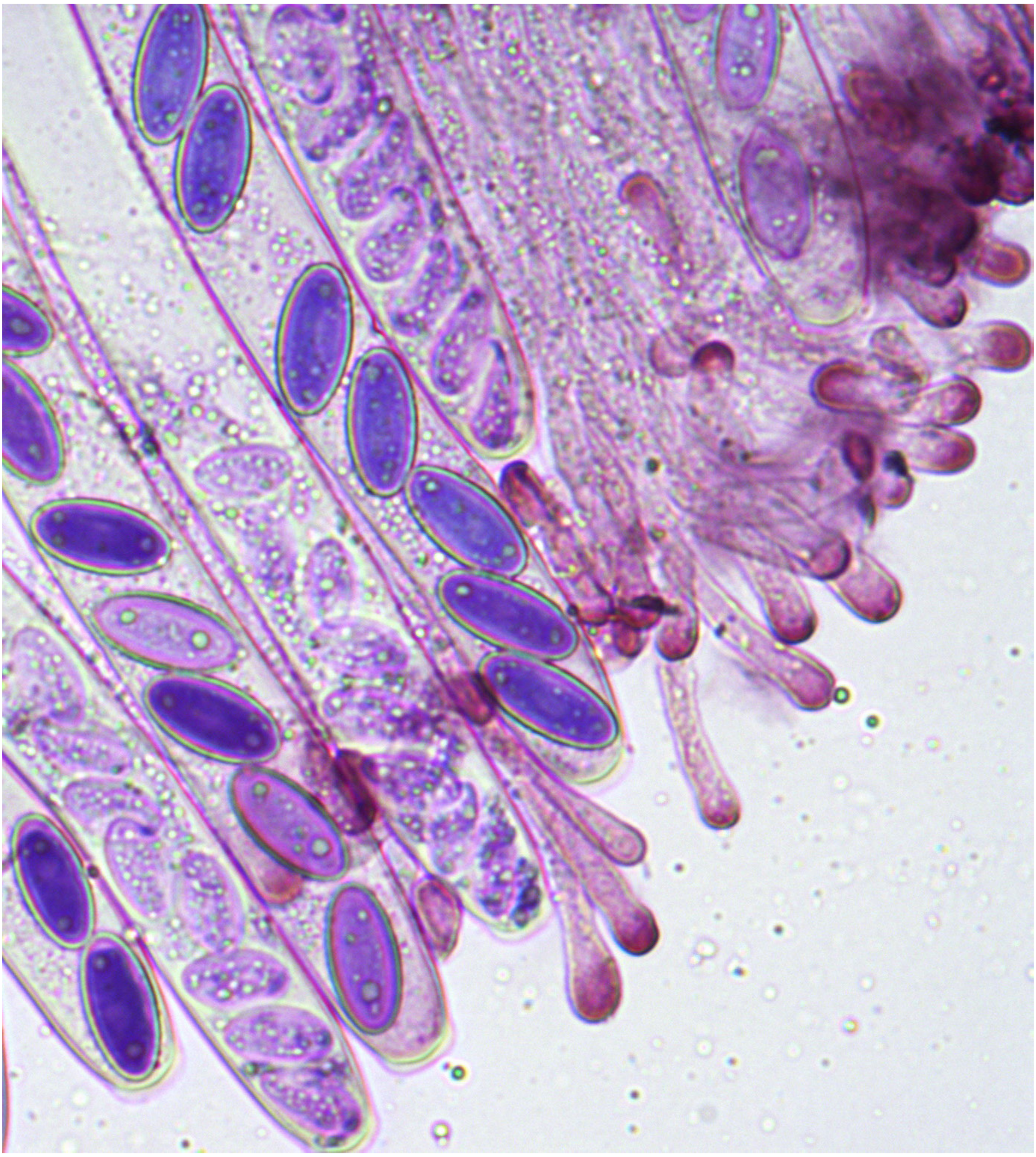


Agrocybe erebia | *cystidia*

Photo: ressaure, 2010 | Flickr cc

Book
Biologically Inspired Design

Reviewed by:
Randall Anway and Norbert Hoeller



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BID is particularly well suited, in terms of delivering innovative solutions to problems that cannot be easily solved using current technological methods.

Chapter 8: Supporting Analogical Transfer in Biologically Inspired Design (Chakrabarti)

Chakrabarti reflects high-level research on supporting the process of analogical transfer in design work and develops a framework for comparing results of specified support processes. What motivates this effort is a desire to more deeply understand connections between support for analogical transfer and trends in high-level design deliverables, such as the number and novelty of designs, the incidence of cross-domain inspiration, and the satisfaction of important criteria.

Noting that descriptive studies of support for analogical transfer are few while prescriptive studies are comparatively plentiful, the authors discuss criticisms and challenges surrounding prior approaches to the latter.

Analogical transfer in the context of bioinspired engineering design involves complex information processing inputs and outputs by human beings at multiple levels of abstraction. This study briefly describes and applies an established research framework called the Design Research Model to help assess the effectiveness of design support, improve understanding of design processes, and develop guidance for designers and researchers.

The research focuses on three main areas for support of analogical transfer: stimuli ('relevant' biological analogs), bioinspired design framework (systematic cross-domain analyses), and guidance (prompting analogical transfer to a model or prototype).

The chapter provides background information on tools used in the study, which was constrained to conceptual design of technical artifacts plausibly meeting requirements typical of engineering work as determined by engineers themselves.

While results are preliminary, the authors demonstrate their understanding of the connection between support and analogical transfer, and clearly suggest positive trends for high-level design deliverables within a systematic framework for bioinspired design.

Chapter 9: Overcoming Cognitive Challenges in Bioinspired Design and Analogy (Linsey, Viswanathan)

The authors suggest that bioinspiration and design by analogy are powerful tools for design yet designers using or attempting to use them face cognitive biases and challenges that unnecessarily impede desirable results.

Arguing that '... tools ... must be designed to effectively overcome these cognitive biases and challenges', they further discuss potential supports to be incorporated into such tools. A contributing factor to the perceived slow progress in bioinspired design and design by analogy, the authors claim, is designers' susceptibility to a common phenomenon they label 'design fixation'. Further, the negative cost of the phenomenon is that designers expend effort suboptimally exploring a narrow solution space, though no attempt is made to quantify it.

Work to date in characterizing operative biases and challenges in design is surveyed, and the authors acknowledge that much remains to be studied. More importantly, study results suggest that design fixation is in some ways predictable and manageable. Various cognitive principles and derivative heuristics are proposed (some task-based and others tool-based) to guide tool designers in understanding and mitigating the situation. These are summarized in a condensed reference table.

Chapter 10: An Engineering Approach to Utilizing Bio-Inspiration in Robotics Applications (Gupta, Bejgerowiski, Gerdes, Hopkins, Lee, Narayanan, Mendel, Krovi)

Gupta and colleagues explored bio-inspired design from the perspective of robotics, a field where requirements often exceed the capabilities of current engineering. Although there are numerous challenges to emulating biology at the detailed level, novel solutions can be developed through careful selection of useful functions from biological analogs and simplifying them to allow successful implementation. The team applied engineering methods to understand biology and then used the knowledge gained to inform engineering designs. Key steps include:

- analyzing functional requirements to assess feasibility of biological inspiration
- identifying biological features that deliver significant performance improvements
- prototyping bio-inspired designs (the chapter mentions Virtual Prototyping and Hardware-in-the-Loop platforms)
- optimizing the design to address engineering constraints

Three case studies were described in terms of functional requirements, inspiration from nature, manufacturing challenges, performance evaluation and lessons learned. The emphasis was on the engineering aspects rather than the process of bio-inspiration. The bird-inspired micro-air vehicle (MAV) example may have been more compelling if it had focused on the "elastically deforming flapping wings" rather than the drive mechanism which seemed to be inspired more by the concept of energy recovery than the avian implementation. The chapter would have benefitted from more detail on finding an appropriate biological analog, analyzing it using engineering tools and methods, and extracting the key features essential to the engineering solution. Lack of expertise in these steps often results in conceptual solutions where implementation is not currently feasible or fixation on aspects of biology that can inhibit progress towards a novel and useful design.

Chapter 11: An Ontology of Biomimetics (Vincent)

Julian Vincent explores the challenges of organizing and collecting biological information for easy access by designers. Databases such as Ask-Nature have proven useful in helping designers learn about organisms and strategies in nature as well as some product applications. However, the structure of databases makes them hard to modify or expand, unsuited to uncovering novel relationship and generally providing limited support for the process of transferring biological concepts into engineering design. Natural language semantic analysis has proven useful in enabling natural language search algorithms but typically do not reveal general biomimetic design rules.

Vincent has been developing an ontology structured around the TRIZ model of resolving problems by making changes that resolve a contradiction. Ontologies provide a rigorous but extendable framework for documenting the relationship between classes and members, allowing novel and valid inferences to be derived (see also http://issuu.com/eggermont/docs/zq_issue_05/102). Vincent has been using his ontology to estimate the novelty of biological solutions across a broad range of scales and identify TRIZ Inventive Principles that are indicative of a biomimetic solution.

The research is still in the early stages. Since TRIZ was originally built on an analysis of patents, it does not adequately reflect the prevalence of information in nature. The ontology does not reflect the pervasiveness of composites and hierarchy in nature because they are part of the background rather than change agents. Lastly, nature presents us with a wealth of solutions but it may be difficult to presciently specify the problem(s) potentially solved due to the complex interaction of contexts, problems and solutions over long periods of time. This is indeed a paradoxical issue for indexing phenomena as 'solutions to problems': we don't know what a problem is until we have it and we don't have a solution until its intrinsic logic is recognized as such. We permanently stare in the face of such matters and don't see their form, so to speak, until we're ready.

Chapter 12: Evolution and Bio-Inspired Design: Natural Limitations (Fish, Beneski)

The final chapter in the book strikes a cautionary tone. The promise of bio-inspired design is based on the assumption that evolution has delivered optimal solutions that can be successfully transferred to engineered systems. The authors provide a primer on evolution and natural selection. Although natural selection works at the level of the individual, evolution relates to changes within populations, specifically the frequency of genes that are collectively expressed as a phenotype. Fitness is determined by the reproductive success of a phenotype relative to other phenotypes within a specific context or niche. It is risky to equate evolutionary success to a single measure of efficiency or performance.

Successfully abstracting structural and functional elements observed in an organism requires a deep understanding of how these elements are integrated in a complex phenotype, the influence of the context and the constraints on evolutionary change. Many organisms are clearly not optimal (from an engineering perspective) due to their ancestral lineage, developmental factors and the compromises forced by interaction of the structural and functional elements comprising the organism.

Significant research may be required, taking into account evolutionary constraints and the importance of context in order to adequately specify functional logic for engineering use in computational tools. While this may appear to benefit biological research, timelines and resource use may at times be driven by task demands and opportunities rather than scientific protocol, raising the potential for interdisciplinary tension. Furthermore, linguistic hurdles can seriously complicate communication, heightening perceived and material risks.

Lastly, biology often works differently from engineering, potentially inspiring novel solutions but also complicating the challenges of successfully transferring those solutions. Successful transfer of natural solutions may often require abandoning key elements of the natural analog, suggesting the need to carefully consider important and potentially complex trade-offs in the normal course of design.

The authors recommended that designers start with "What needs to be improved?" and then identify biological analogs that outperform existing engineering solutions or follow novel solution pathways. Direct or indirect communication between designers and biologists with a deep knowledge of the biological systems is essential. Accurately abstracting and applying the underlying principles typically requires extensive inter-disciplinary collaboration.

Commentary

Overall, this is a book aimed at innovative design by analogy. The prevailing 'paradigm' ('formalism' might be a preferable term) in design is one that values 'industrial strength' approaches to solving human problems. For serious innovation to succeed in that context, it could be argued that innovative design by analogy needs to move out of the protective setting of academic labs and onto factory floors and job sites through field or action research. One of the strengths of this compendium of work by different research groups is that it seeks to transform ad hoc practices of design by analogy and bio-inspired design into a scalable and repeatable methodology by guiding the development of computational tools.

The strength of the book could also be said to be a weakness. If the basic hypothesis is that computational tools are a necessary and sufficient condition for repeating and scaling commercial success in bioinspired and analogical design, it begs discussion of what might be driving complex engineered system design demands in the marketplace. In that vein, a chapter or two seem to be missing in explicitly testing such a hypothesis against legitimate commercial engineering requirements, such as cost considerations. Be that as it may, the book clearly represents a concerted effort and a clutch of qualified successes at a high level of engineering research and scholarship.

The writing is dense and connections between chapters are at times obscure. Editorial quality is uneven and chapters don't appear to have been arranged in an order that reflects the level of organization required to carry out the ambitious program alluded to in the foreword. These aren't major criticisms, rather a suggestion that the diligent and interested reader would be rewarded by choosing an area of interest and digging in.

The closing chapter takes a sober look at the challenges faced by bio-inspired designers. It also suggests opportunities for bio-inspired design, such as engineering challenges that share common characteristics with biological systems and where traditional solutions have reached their limits.

Engineering is increasingly asked to address systemic challenges where simple solutions are either inadequate or have unforeseen consequences. It is worth noting that in some cases, the field of engineering bears a level of responsibility for some of the challenges created even by its most meritorious productions. This is not to place blame but to make observation of an important fact of contemporary life.

Although our mechanistic and reductionist worldview has served humankind well, we are entering an age of complexity where drawing inspiration from biology may be useful in both reconciling engineering (a discipline often immersed in the present) with its legacies, while aligning it towards our terrestrial and cosmological future. ×

Publication Details

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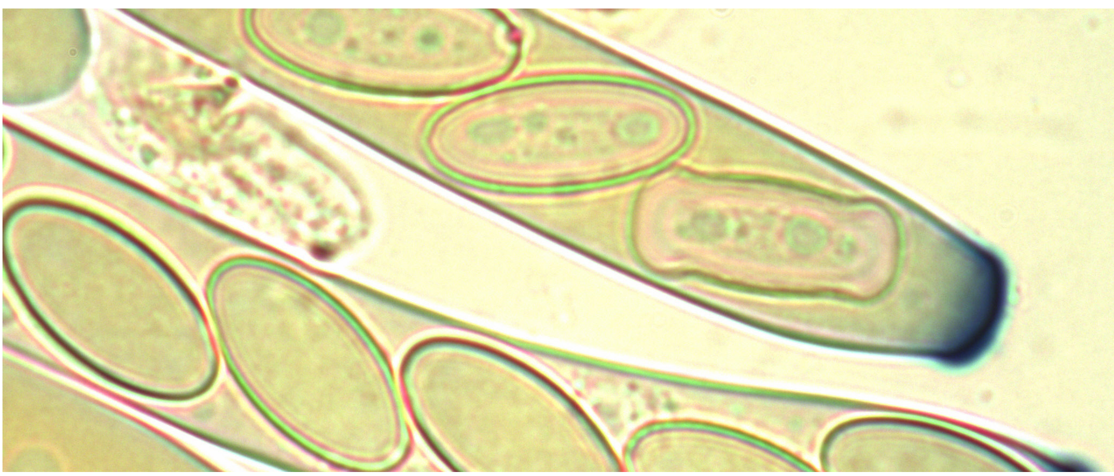

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Hoopoe with Caterpillar

Photo: Janie Easterman,2011 | Flickr cc

World *Interview*
Israeli Biomimicry Organization

winter 2013

World:
Interview

Authors:
Yael Helfman Cohen and Dr. Daphne Haim Langford

Yael Helfman Cohen is a co-founder and general manager of the Israeli Biomimicry Organization, a registered non-profit organization that promotes inventive learning and imitation from nature for sustainable technological designs and applications. Yael holds a M.Sc. degree in Management Science from the Recanati School of Business Administration, Tel Aviv University and a B.Sc. in Industrial Engineering & Management from the Technion - Israel Institute of Technology. Yael is currently a Ph.D candidate in her final stages in the field of Biomimetic Design (Tel Aviv University). She developed a biomimetic design method that incorporates structural patterns in nature and TRIZ based tools.

Dr. Daphne Haim Langford is a co-founder and chairperson of the Israeli Biomimicry Organization and VP Business Development at Xenia Venture Capital leading the life science practice. Daphne has over 15 years of managerial experience. Daphne has been involved in medical device entrepreneurship and specializes in fundraising, strategic planning, marketing, distribution, reimbursement, and product management in the medical device industry. Prior to joining Xenia, Daphne was VP Business Development & Marketing at Medingo. Prior to that, she was General Manager with PerAssist and Product Manager for Carmel Biosensor. Daphne holds a Ph.D degree in Biotechnology from the Technion - Israel Institute of Technology.

How did you get started?

Biomimicry Israel (http://www.biomimicry.org.il/) was established in 2008 after we identified the lack of knowledge about biomimicry in Israel and the big potential this field can provide in terms of innovation and sustainability. Also, we strongly believe that Israel, as the "startup nation", is the best habitat for biomimetic innovation. The combination of high engineering skills, biological research and entrepreneurship spirit can lead to promising biomimetic innovations. In 2008, there was no biomimetic knowledge in Hebrew and our first goal was to change this.

What is your mission statement?

We aim to foster sustainable innovation within the Israeli academic, industrial and education systems. We would like to see a biomimetic industry in Israel that is based on our nation's strengths: engineering and entrepreneurship together with vast biological knowledge (50% of the PhD graduates are from the life sciences).

Who is part of the group? How many members do you have? Are there different types of membership? Are you structured via a specific organizational model?

We are a group of 10 people. Most of us are volunteers. We come from variety of field including engineering, biology, chemistry and business.

What other organizations are you linked to?

We are trying to establish a fruitful relationship with other biomimicry organizations around the globe by exchanging knowledge and ideas. We are considered an environmental organization and are members of the "Life & Environment" (http://www.sviva.net/) umbrella body of environmental organizations in Israel. We are collaborating with several educational organizations in Israel including the "Safari" Zoological Center (http://www.safari.co.il/index.php?tlng=eng) in Tel Aviv.

Waves

Photo: VictorBezrukov, 2012 | Flickr cc

We are participating in the ISO Technical Committee on Biomimetics (http://www.iso.org/iso/home/store/catalogue_tc/catalogue_tc_browse.htm?commid=652577) as representatives of the Standards Institution of Israel (http://www.sii.org.il/896-en/SII_EN.aspx). This committee was established in 2012 and aims to develop an international standard for industry. The challenge is to create a clear framework for biomimetic applications. Four working groups have been created:

1. Terminology and methodology
2. Structures and materials
3. Biomimetic structural optimization
4. Knowledge infrastructure of biomimetics.

We are participating in working group 1, 3 & 4.

What initiatives are you working on? Can you highlight exciting regional research groups working in the area of bio-inspired design?

We can mention a few initiatives:

1. The Israeli biomimicry elementary school initiative exposes students in grades 4-5 to a yearly structured educational program. At the end of the year the students come to Ramat Hanadiv (http://www.ramat-hanadiv.org.il/en) for a day where they present their bio-inspired projects through posters and prototypes to judges who will select the best three.

2. The Israeli biomimicry trail was developed together with Oranim College (http://friends.oranim.ac.il/) in Israel and located in its beautiful botanic garden. The trail includes 10 stops near biomimetic attractions such as the pine cone, the lotus leaf, ant colonies and more. The Trail serves as an attraction point for the general public and a field lab to the college students. A video of the opening of the trail is available at http://www.ntd.tv/en/news/science-technology/20120711/73154-the-biomimetic-trail--watching-the-technology-of-nature.html.

3. The May 27/2013 Israeli biomimicry conference (http://goo.gl/6LTRqq in Hebrew, http://goo.gl/8P6Y1q in English via Google Translate) developed in collaboration with the Holon Institute of Technology (http://www.hit.ac.il/en/) was our first step to consolidate the biomimetic community in Israel.

There are several bio-inspired research groups in Israel, including one at Technion - Israel Institute of Technology (http://www.technion.ac.il/en) that developed the robot snake (http://www.youtube.com/watch?v=vG3JB47Ln9k) for rescue purposes.

What are your plans for the future?

We aim to establish an academic biomimetic center in Israel. For this purpose we are searching for academic partners and governmental support.

Following the success of the Israeli biomimetic conference we hope to widen our scope and host an international conference. Israel has several leading design schools that could provide an interesting design focus to such an event.

Bronchi Bronchioles

Photo: Leandroid, 2008 | Flickr cc

winter 2013

World:
Interview

Authors:
Yael Helfman Cohen and Dr. Daphne Haim Langford

Biomimicry Trail at Oranim College botanic garden

Photo by Dr. Michal Gross

Biomimicry Trail at Oranim College botanic garden

Photo by Dr. Michal Gross

What inhibitors to success have you experienced?

In terms of our target to establish a biomimetic research center or a real biomimetic infrastructure for industry, it is clear that the main inhibitor is access to financial resources.

How are you sustained financially?

So far we sustain ourselves with the services we provide. We give one-time lectures and full courses for professional audiences (engineers, designers, architects, biologists and environmentalists).

What is you geographical "reach" within your region, and where are your members, meeting places, project locations?

We are active all over the country. Our courses are given in Tel-Aviv.

What is the best thing that you've done within the last year? Ever?

We are very proud of our biomimicry newsletter, "News from nature" (http://biomimicrynews.blogspot.co.il/). In Hebrew the word news and innovation are almost the same! We started 4 years ago and today we have more than 3,000 followers. We think it is a good means to convey messages and knowledge to our audience. ×

Olive tree detail

Photo: Jill Granberg, 2006 | Flickr cc

Mazda “AUTO ADAPT”

Design Team: Jacques Flynn, Tim Brown, Seung Joong Kim

Courtesy of the L.A. Auto Show

Article

Taking it to the Street: the LA Auto Show's 'Biomimicry & Mobility 2025' Challenge

Tom McKeag

Taking it to the Street: the LA Auto Show's 'Biomimicry & Mobility 2025' Challenge

While carmakers have had a long love affair with animal shapes and spirits, it has been rare that they have gleaned any functionality from nature. It is noteworthy, therefore, that the 2013 Auto Show in Los Angeles, that capital of freewheeling, should choose bio-inspired design as its 10th Design Challenge topic. Nine contestants vied for first prize in the "Biomimicry & Mobility 2025 – Nature's Answer to Human Mobility Challenges" competition and a winner was selected on November 21.

The entrants were charged with designing a "mobility solution" that would help solve the problem of congestion and pollution, and incorporate features addressing issues like safety, sustainability and flexibility. They would be judged by several criteria including "creative adaptation of nature's laws," and "application of human intelligence to biomimicry in unique ways to improve the efficiency of future vehicles." In the contest, the judges specifically included in the design brief the sustaining of the infrastructure needed to manufacture, sell and maintain the vehicle.

Teams came from Japan, China, Germany and the US, representing some of the main car manufacturers of the world including Subaru, Mazda, BMW, and Toyota. The entries appeared to be divided between those designing an object, a vehicle, and those who were designing a system, usually comprising a vehicle, the infrastructure it would run on and a manufacturing technique. The single vehicle folks could be further divided into the 'go anywhere' crowd and the 'strictly road' types.

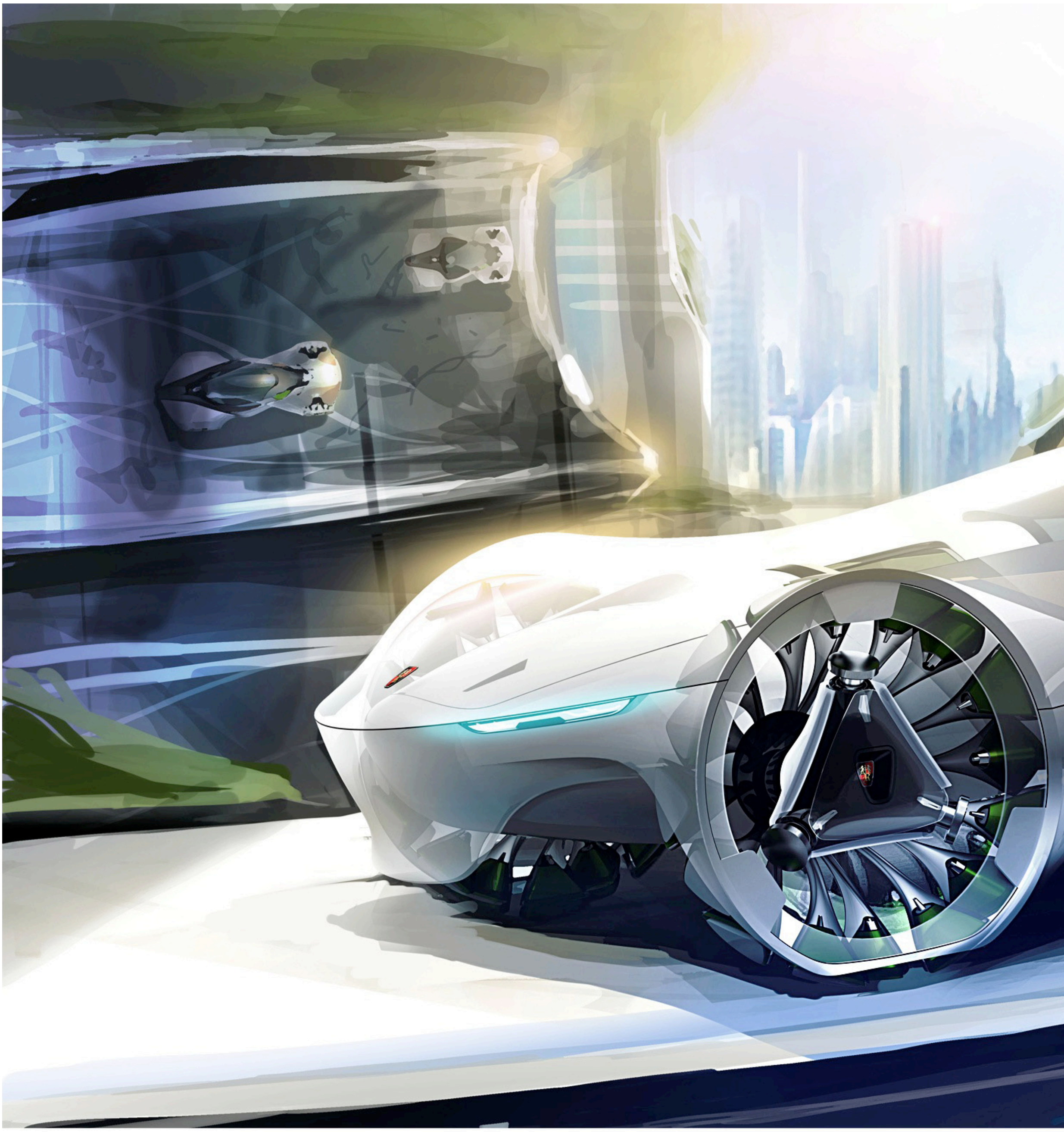
Several common innovation strategies ran through the entries: the automation and regulation of traffic flow; the running of vehicles where they currently do not go (vertical, upside down, on water and in the air); the gathering of material or energy using the mobile vehicle; the recycling of the same. There were also some recurring ecological themes. A car that could change shape to allow for either manual or autonomous operation was described as "a study in symbiotic adaptation," for example. "Urban mutualism" summarized the scheme of cars bringing self-made fertilizer back to the buildings where they park.

The jury for the competition comprised a group of five experienced car designers, a publisher and one scientist, Dr. Gabriel Miller of the Centre for Bioinspiration at the San Diego Zoo. When asked what he thought the best translation of a science idea to design had been, he had this to say:

SAIC Motor Mobilliant

Design Team: Xu Dengtao, Ling Yuzhou, Ji Zhiheng, Niu Wenbo, Zhang Mingxi, Qian Junlin

Courtesy of the L.A. Auto Show



Mobiliant network serves as a public transit system just like taxi »»

SAIC Motor Mobilliant

Design Team: Xu Dengtao, Ling Yuzhou, Ji Zhiheng, Niu Wenbo, Zhang Mingxi, Qian Junlin

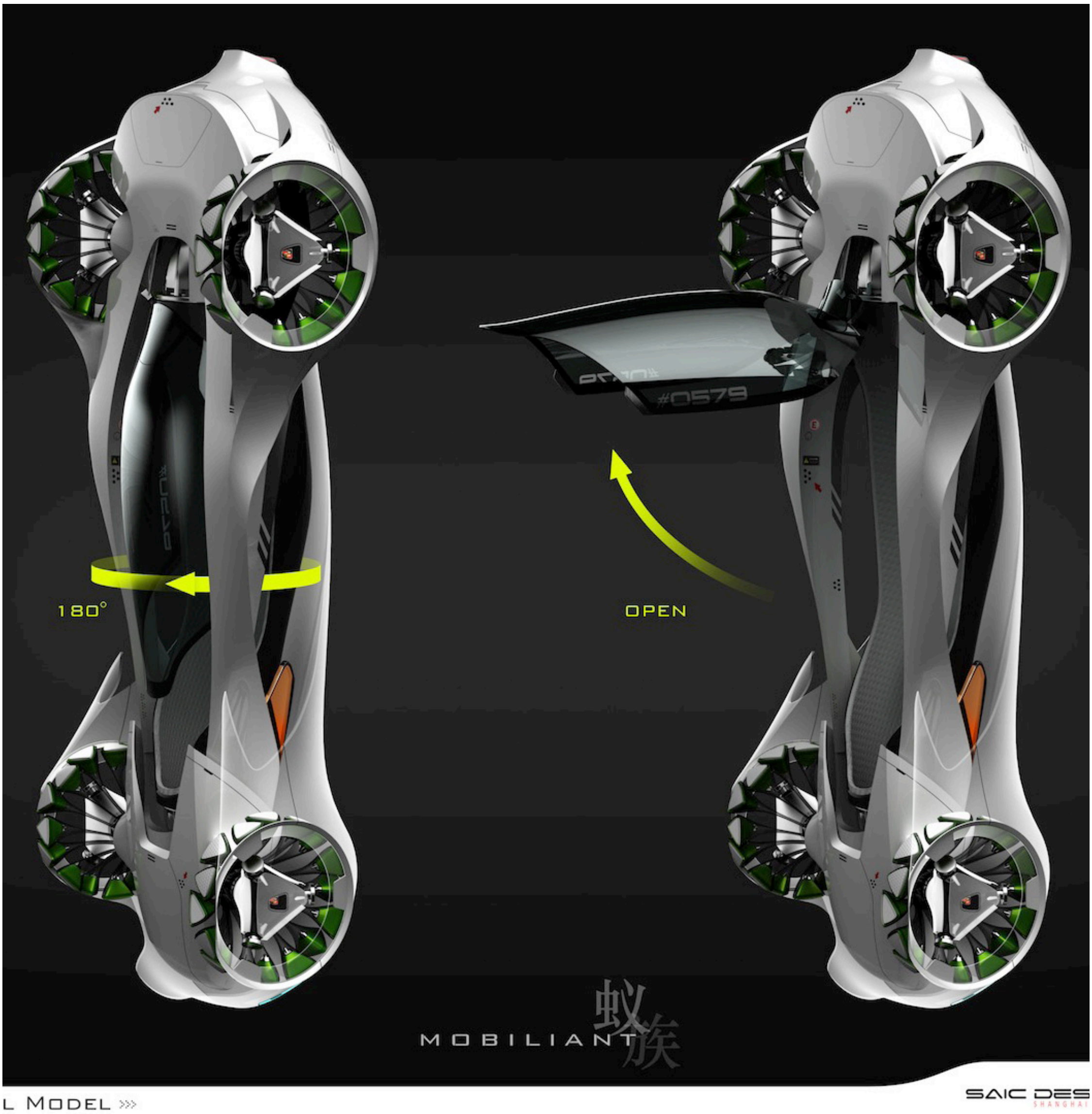
Courtesy of the L.A. Auto Show

> "We saw wonderful creative thinking in these submissions. Natural shapes and forms engendered beautiful designs. Most exciting were ways that nature also inspired improved efficiency. How can we build added functionality while using less energy and mitigating resource depletion? ...SAIC Studio's winning design used efficient principles from mutualisms to envision cars with negative emissions. The concept of a car that gives back to its environment, like an ant that gives back to its host tree, is powerful. We also liked the efficiencies inherent in BMW's fishlike schooling concept, and the way Qoros Automotive's vehicles were efficiently absorbed after use for 'rebirth'."

The winning design submitted by SAIC Motor as the "Mobilant" represented the system solution approach. The form of an ant inspired the one-seater vehicle, and the concept of mutualism, as exhibited by the ant and the trumpet tree, inspired the topology of the system. The vehicles would produce fertilizer as they drove about and return to tall towers where they would disgorge both passengers and the manufactured fertilizer. The passengers would go to their jobs and the fertilizer would go into the production of the biofuel that runs the cars. The vehicles would be equipped with super traction wheels with internal KERS (Kinetic Energy Recovery System) motors allowing them to climb up the sides of the towers and to run in any orientation, including upside down. This ability was critical to innovation in the third part of the system, the roadway infrastructure. Here, all surfaces of interchanges, top, bottom and sides, were cleverly designed to permit free flow of traffic without any crossing of vehicles, and therefore eliminated stopping or yielding.

The ability of the independent vehicles to travel on steep cross slopes, vertically and upside down was essential to the design concept. The miracle traction device in the wheels was described as "nano-layered cilia," but it was not clear from the presentation what that meant. Cilia are typically used for locomotion, as in bacteria, or transport and filtering, as in the human windpipe, but it appeared that the designers were interested in gripping on a surface. It is possible they were referring to the setae on the pads of geckos, the masters of such acrobatics, but that mechanism is a "place and release" movement (albeit a lightning fast one) that does not translate easily to the spinning of a wheel. Dr. Ron Fearing's lab, the Biomimetic Millisystems Lab, EECS, University of California, Berkeley has been able to create a high-friction wheel for a model car (1/18 scale) based on the Gecko, but it can run on only smooth surfaces to steep angles less than vertical.

There are other ways to make these cars stick to non-horizontal surfaces, regardless, including super magnets, and even something as antediluvian as road cables and grips. More challenging would be to allow the driver to arrive without feeling like a pina colada just put in the blender. In addition to driving upside-down to make that left turn at the intersection, the car and driver are spun 180 degrees on the vertical axis in order to exit through the building portal. Despite the stabilizer provided in the car, the changing orientations would likely make one's head spin.



SAIC Motor Mobilliant

Design Team: Xu Dengtao, Ling Yuzhou, Ji Zhiheng, Niu Wenbo, Zhang Mingxi, Qian Junlin

Courtesy of the L.A. Auto Show

Another key concept within the design was using the vehicle to both reduce air pollution and to replenish its own fuel. Modeled after the spiracles of exoskeletons, the car roof would filter pollutants and an "enzyme driven transformer" would employ nitrogen-fixing bacteria to convert them to fertilizer. This fertilizer would be carried up the building tower to be deposited into an urban garden system that produced crops, which in turn are converted to biofuels to run the cars.

Whatever the relative feasibility of this type of enzymatic conversion, a generic accounting also gives one pause. Typically such CO_2 scrubbers are located at high concentration point sources like smokestacks. The surface area needed for collection, mobile storage and crop production seems well beyond the capacity of cars and tower roofs, and it is questionable whether growing bulk crops for fuel on precious real estate would be a practical solution. This is perhaps an unfair criticism of a conceptual competition entry, but the designers purport to be creating an effective system and, in systems, accounting does matter.

What this design did demonstrate was a principle seen in nature, mutualism, reduced to components simple enough to be replicated in our technological world. Along the way the designers came up with some clever ideas to make the components of a system work in a completely new way. Mobilant was deservedly the winner of the competition.

Regarding what lessons scientists and designers could share from this type of exercise of combining science and design, Dr. Miller said this:

SAIC Motor Mobilliant

Design Team: Xu Dengtao, Ling Yuzhou, Ji Zhiheng, Niu Wenbo, Zhang Mingxi, Qian Junlin | Courtesy of the L.A. Auto Show

> "Open-minded dreaming - intrinsic to futuristic challenges - is fuel for both scientists and designers. I'm reminded of Albert Einstein's quot[ation] that 'Imagination is more important than knowledge.' An elegant aspect of the challenge was that imagination launched from knowledge: scientific understanding derived from ants, fish, or silkworms, for example, unexpectedly inspired futuristic vehicles. I feel that scientists could take heart from this application of their work, and designers (and society in general) could perhaps extend more curiosity toward discoveries in diverse fields. I think we'll continue to see great ideas sprout from systematic observation of nature's nooks and crannies."

A second notable example was from Changfeng Motor Corporation, called the "La Brea-Los Angeles Bio Research Project," and was of the single vehicle, 'strictly road' type. This design was novel in its approach: like nature, the designers tried to accomplish two very different functions using the same material. Moreover, that material was organic in form, rather than a collection of the standard mechanical parts.

The designers described a "closed loop and semi-rigid torsion reed network to distribute and manage maneuvering capabilities." This was a bundle of cross-laid tubes that created both the body of the car and the steering mechanism and, assumedly, delivered fluid to what would have to be hydraulic motors at the wheels. Its flexible nature would allow the car to change shape as well, although, unlike another of the entries, this shape change did not make the car significantly shorter for parking. Many practical considerations were unclear: how would the car open up for passengers without interrupting the hydraulics; how would the hydraulic power be transferred to the wheels; how would the propulsion be created and maintained?

The design did, however, represent a true jump in defining the working systems of a vehicle. In that sense it was perhaps the most biologically inspired entry since its functionality was based on an organic mechanism which demanded a whole assemblage of completely new parts and connections.

While many practical considerations seemed to remain unanswered in the Changfeng entry, its long look forward was, perhaps, in the best spirit of this type of competition. Dr. Miller is hopeful about the use of biomimetic paradigms for urban transportation, and believes the study of network theory and complex systems will be increasingly relevant.

> "As we continue to discover more about neuroscience and the functionality of massive parallel networks, the ways we view transportation will shift. ... Advancements in physics and computational neuroscience, gotten from careful observation of nature, could allow people to transport very differently from our present mode of climbing into boxes on wheels...I think futuristic transportation will concern energy more so than matter."

If we consider the movement of energy rather than matter, nature offers us an inspirational buffet. Using increasingly powerful tools to observe energy flow in ecosystems, and learning from the many analogies to energy flow in individual organisms, is a fascinating space to watch."

The LA Auto Show's 2013 design challenge was a mainstream event that considered the biomimetic theme within the wider search for sustainable answers to our mobility challenges. Nearly a million people were expected to attend this year's event. For a nascent bio-inspired design profession, that itself was significant. The entries overall, while sophisticated in their production and steeped in the technical skill of car design, varied in the success of their translations of biological concepts. Even given wide tolerance for "blue sky" thinking, few designs showed much depth of understanding of the inspiring phenomena. Several entries, for example, tried to translate inspiring biological forms to completely different functional applications and, while reasonable to propose, were unconvincing. A multi-functional tail that served as launch spring, airfoil and undulating caudal fin was an example. The level of detail of this device was just not sufficient to suspend one's disbelief.

Similarly, some performance claims simply could not be supported. A vehicle design claiming to be able to walk on water was one of the more egregious examples. It seemed to use less surface area and displacement to weight than tinkerers have needed to support the weight of one man. Scale, in this case, matters. The water boatman insect used as an inspiration takes advantage of the surface tension of water to keep itself up, something unavailable at the helicopter scale, while such flotation is already handled quite nicely in our world by pontoons.

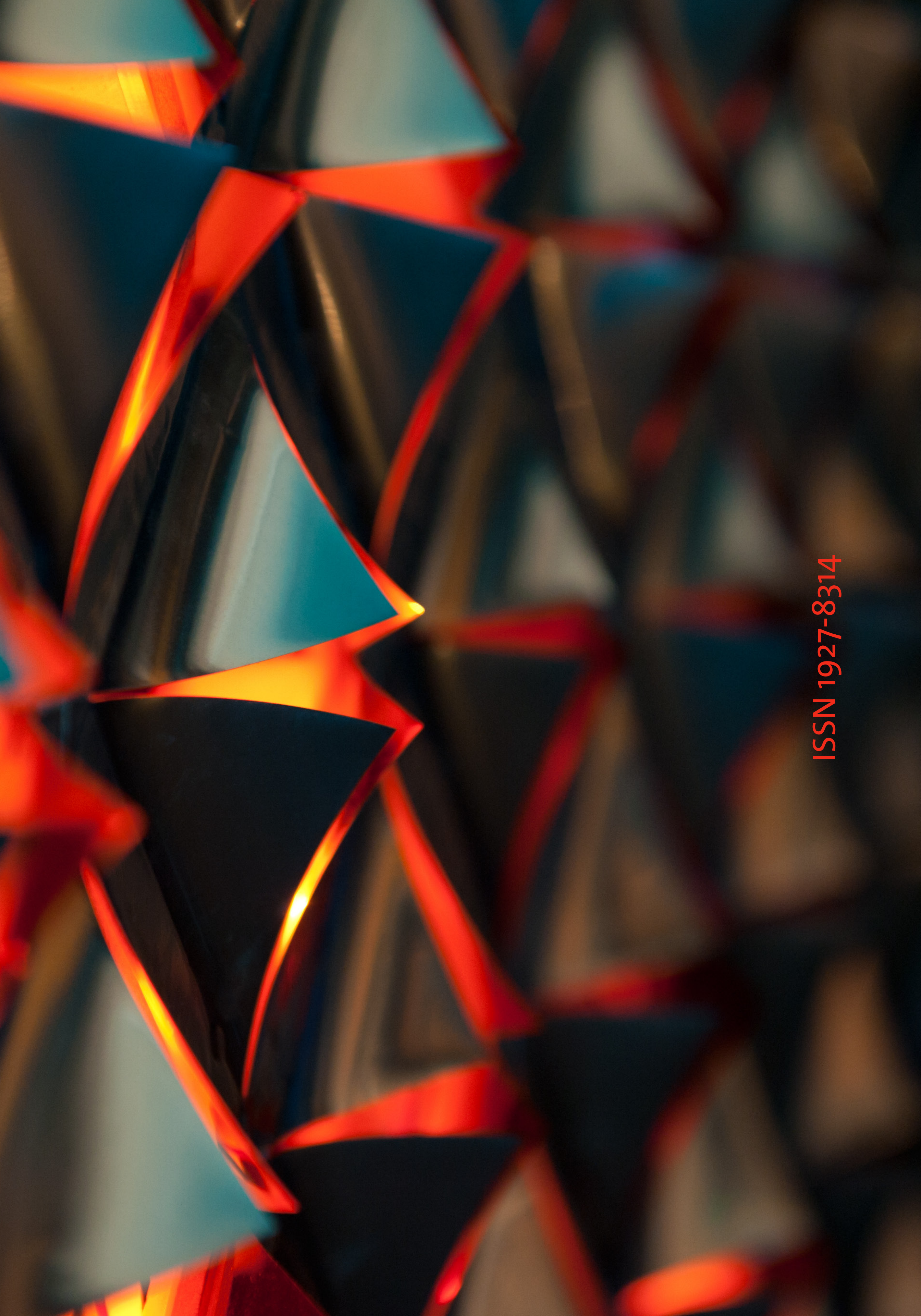
Still, there were some important design innovations to be found within the show as mentioned above. These were cases where a biological principle was first translated and then carried through to its working parts to create an entirely new and innovative technological concept. The question, however, of whether the more rigorous designs outweighed the less does seem to nag. While the message of bio-inspired design was delivered to a wide audience at this event, one has to wonder if it was the right message. ×

Dr. Gabriel A. Miller (Gabe) is the Director of Research & Development at the Centre for Bioinspiration, San Diego Zoo Global.

http://laautoshow.com/design-challenge/

SAIC Motor Mobilliant

Design Team: Xu Dengtao, Ling Yuzhou, Ji Zhiheng, Niu Wenbo, Zhang Mingxi, Qian Junlin | Courtesy of the L.A. Auto Show



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