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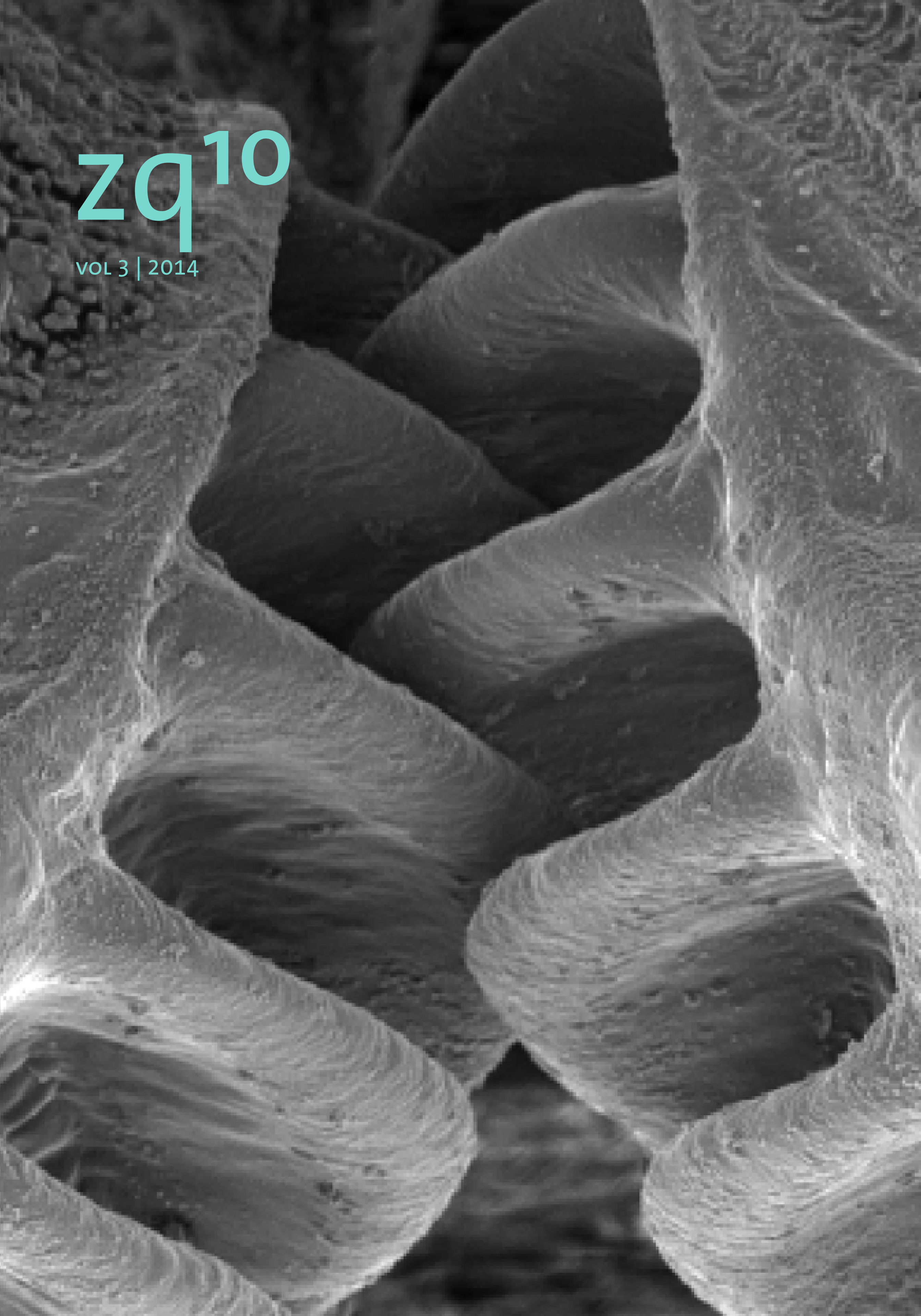

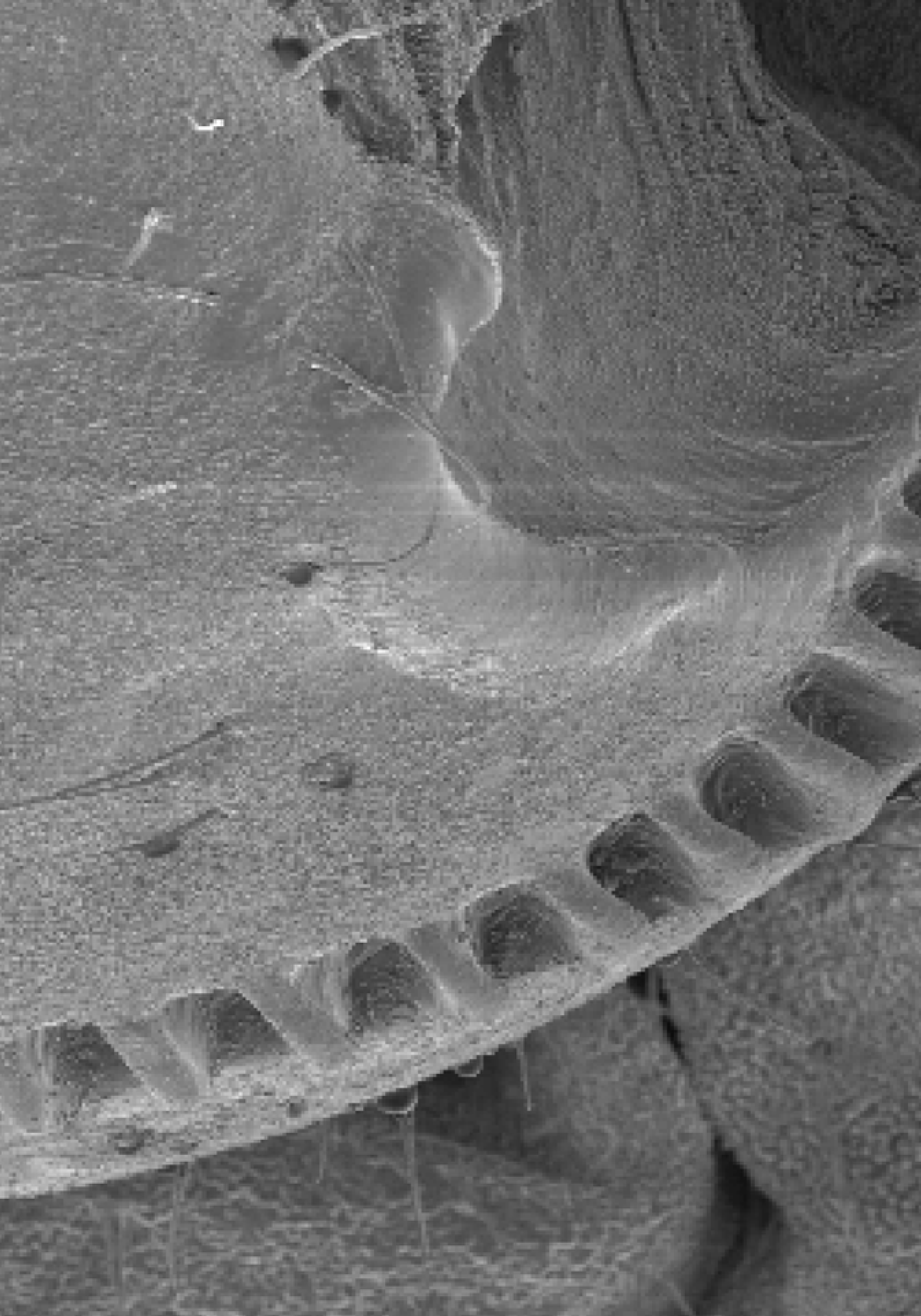

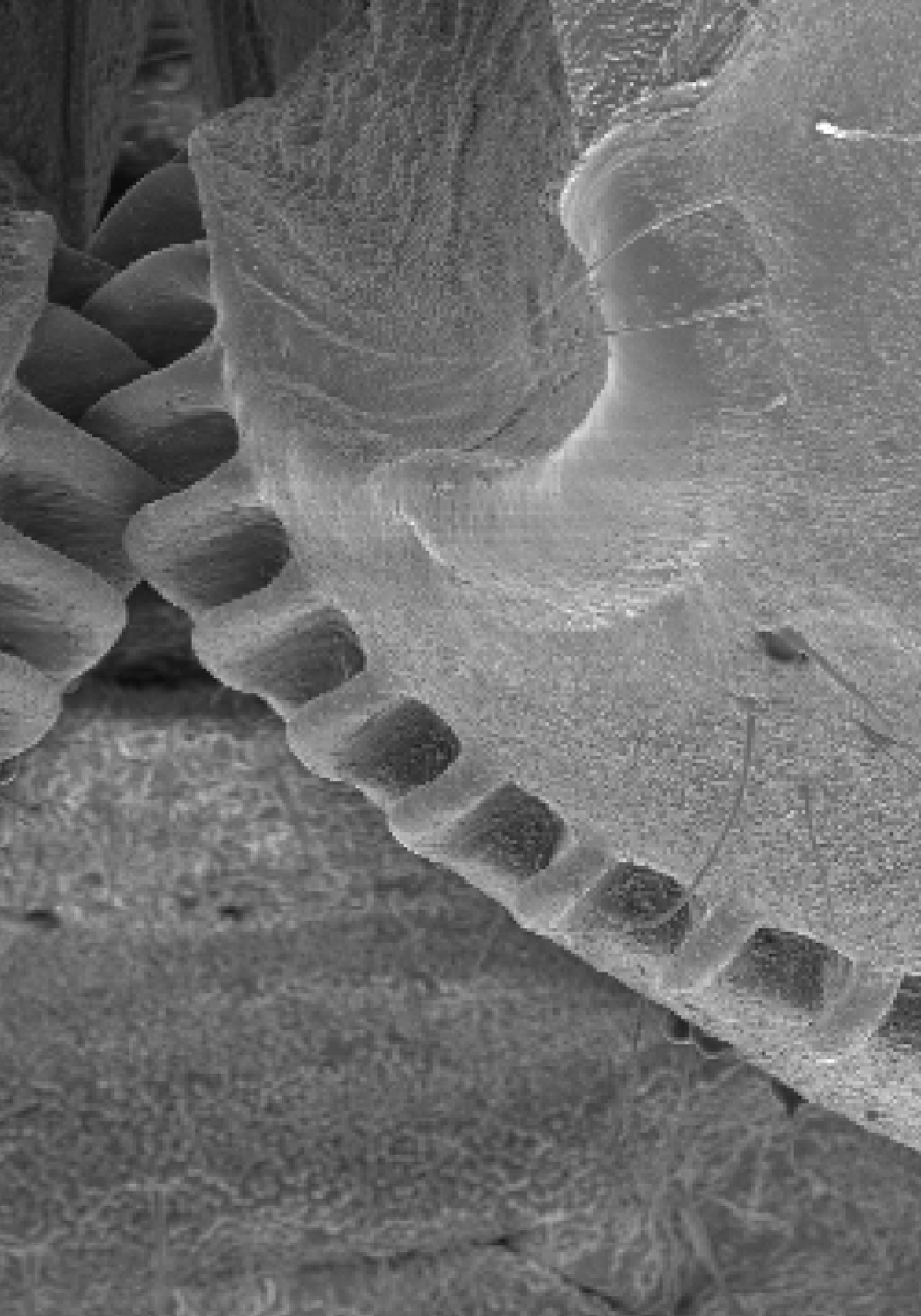

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Planthopper nymph (*Issus coleoptratus*)

Photo: MacRo b, 2010 | Flickr cc

Editorial

We are pleased to report on a significant scientific discovery in this issue, the first demonstration of intermeshing gears seen in an animal. As it turns out the possessor of this device is remarkably unprepossessing, a common backyard insect called the leafhopper. Its feats of performance, performed every day under our noses, are prodigious, and Malcolm Burrows and Gregory Sutton explain its ability and how their successful collaboration came about. In our interview section we hear the views of two Canadian academics, Tomislav Terzin and Megan Strickfaden who are also collaborating, mixing their expertise in biology and industrial design.

The systems approach to problem-solving is highlighted throughout this issue in the practice of our portfolio guest, Exploration Architect's Michael Pawlyn, a review of Fritjof Capra's latest book on the subject, and an interview with architect Ray Lucchesi who describes two of his projects in the desert precincts of Las Vegas.

Heidi Fischer takes us underground with the weird and wonderful star-nosed mole in her "Science of Seeing" column. Taryn Mead and Norbert Hoeller provide an overview of the International Organization for Standardization (ISO) initiative to achieve the "international standardization of biomimetic methods and approaches" along with an update on North America's involvement.

Finally, we launch a new section, "Product Design", with our inaugural feature on the lighting designs of Lindsey Adelman. Our Spanish translations proceed apace and we are happy to report that three of our issues can now be read in Spanish, with the rest soon to follow. We wish you happy reading in whichever language. ×

Tom Norbert Marjan

Tom McKeag, Norbert Hoeller, and Marjan Eggermont

Issus nymph

Image courtesy of Malcolm Burrows

Case Study

Gearing Up (and away): How a little backyard bug might change engineering

Tom McKeag

Gearing Up (and away): How a little back-yard bug might change engineering

"The problem," says Dr. Gregory Sutton of University of Bristol, "Is that we never get to go on safari! Our knowledge is so limited about the insect world right around us that going further afield than Girton Wood, a ten minute bus ride from Cambridge, would be research malfeasance." He laughs and shakes his head in mock despair.

He is making light of one of the most remarkable biomechanical discoveries made in recent times. Dr. Malcolm Burrows of the University of Cambridge and he have discovered that a common backyard insect possesses something that humans, in all our chauvinism, thought exclusive to our own clever engineering: intermeshing gears. Neither cast nor forged, these gears have *evolved* and given the bug an Olympian capacity to jump.

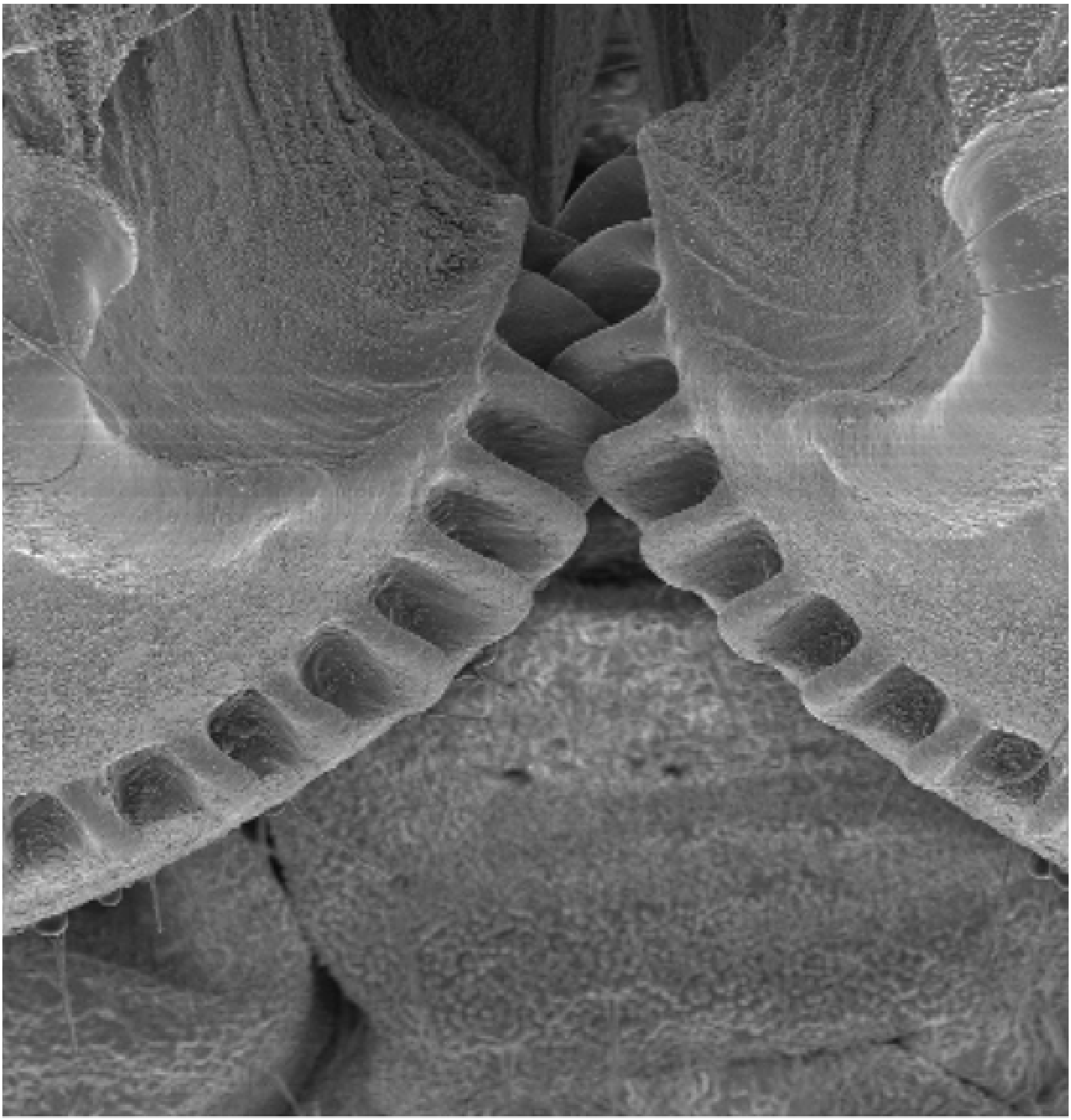
"This is the first demonstration of interactive gears by any animal" says Dr. Burrows, and the implications of this recent discovery might take years to evaluate. The extreme performance capability of this insect makes the newfound knowledge of its mechanism especially important to the field of engineering. Moreover, their tale of scientific collaboration is an interesting view into the challenges of interdisciplinary research and discovery.

The Discovery: precision engineering at the micron scale

Issus coleoptratus is a tiny but champion plant-hopper insect common in Europe. Not only can the creature jump a long way relative to its six-millimeter size (sometimes as high as a meter), it also does this very quickly. Within one millisecond of stimulus, it can generate as much as 500-700 g's of acceleration and speeds of up to five meters a second (11 mph).

Dr. Sutton explained this action in the recent article "Insect jumping, an ancient question" for the Human Frontier Science Program, one of the sponsors of his research. "This is far from easy, as these jumps require the insect to navigate three extremely difficult biomechanical challenges: 1) generating the necessary power, 2) directing the power through the legs to generate a controlled jump, and 3) synchronizing the two legs so that differential leg extension does not cause the animal to spin out of control. To solve these problems, evolution has developed biological structures that are strikingly similar to the man-made devices: composite bows, mechanical linkages, and most surprisingly, gears."

As when we pull back a bow, the insect slowly builds up elastic energy in its body and holds it in tension until the quick release allows the springiness of the material itself to amplify the force. With apologies to his Biology colleagues



Gears

Image courtesy of Malcolm Burrows

100 µm

for his anthropomorphic analogy, Dr. Sutton related it to the human body: “Your hamstring muscles generate force for your leg jumping, but let’s suppose that one of your hamstrings was connected to your knee and the other was connected to your shoulder. To jump you would lock your leg joints, and your entire ribcage would bend in on itself like a bow. Unlock one of your legs and your bent ribcage would be released in recoil... and off you would go.” You certainly would: a little back of the envelope figuring pencils out a leap about as high as a ten-story building.

The springiness of the insect body that stores this elastic energy is due to a regular strategy of nature, the use of composites to solve a contradictory challenge: How to make a material flexible enough to bend, but stiff enough to spring back and not break, Dr. Burrows explained.

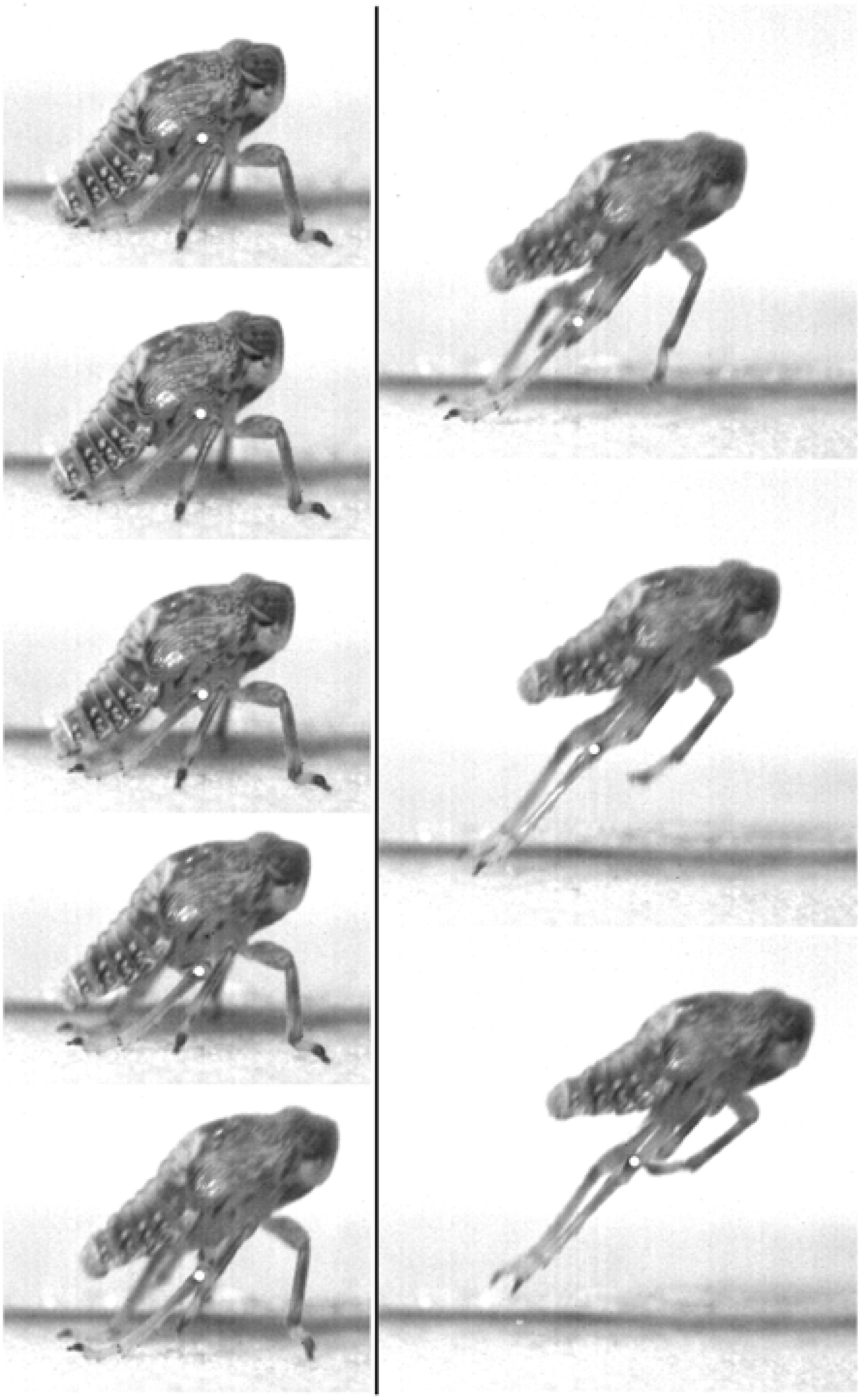
> “The exoskeleton (cuticle) of insects is hard in some places (for example the hard backs of many beetles) or it can be soft and pliable (the articulations of many joints). At one extreme the cuticle is tanned and is very hard but has a tendency to crack under strain; at the other cuticle is soft and rubbery and made of a protein called resilin. To jump rapidly and powerfully, most insects need to use a catapult mechanism and this requires energy to be stored in deformations of the skeleton. Bending hard cuticle through a small distance will store much energy but at the risk of the skeleton fracturing. On the other hand, soft resilin will need to be bent a greater distance to store much energy. Put the two materials together, however, and you get to a structure like an archery bow; the resilin will prevent the structure cracking and will always ensure that it returns to its original shape after each use permitting a further accurate jump. With the gears the mixture of the composite can be varied to allow rigidity in some place and more flexibility in others.”

This force, as powerful as it is, has to be translated to a form that will do work, and this is where the mechanical linkages come in to play. Planthoppers use a small muscle in the femur/tibia joint of their leg to redirect the force of the unbending body. One leg powers the move and the other determines direction. The bug still has one challenge left, however, and that is synchronizing the two legs.

The researchers found that in its nymphal phase *Issus* uses the equivalent of a spur gear to aid its record-breaking leaps. Burrows and Sutton had initially surmised that there must be some mechanical structure to do this, since the time was too fast to be triggered by nerve impulses, which typically would happen in the range of 5-6 milliseconds.

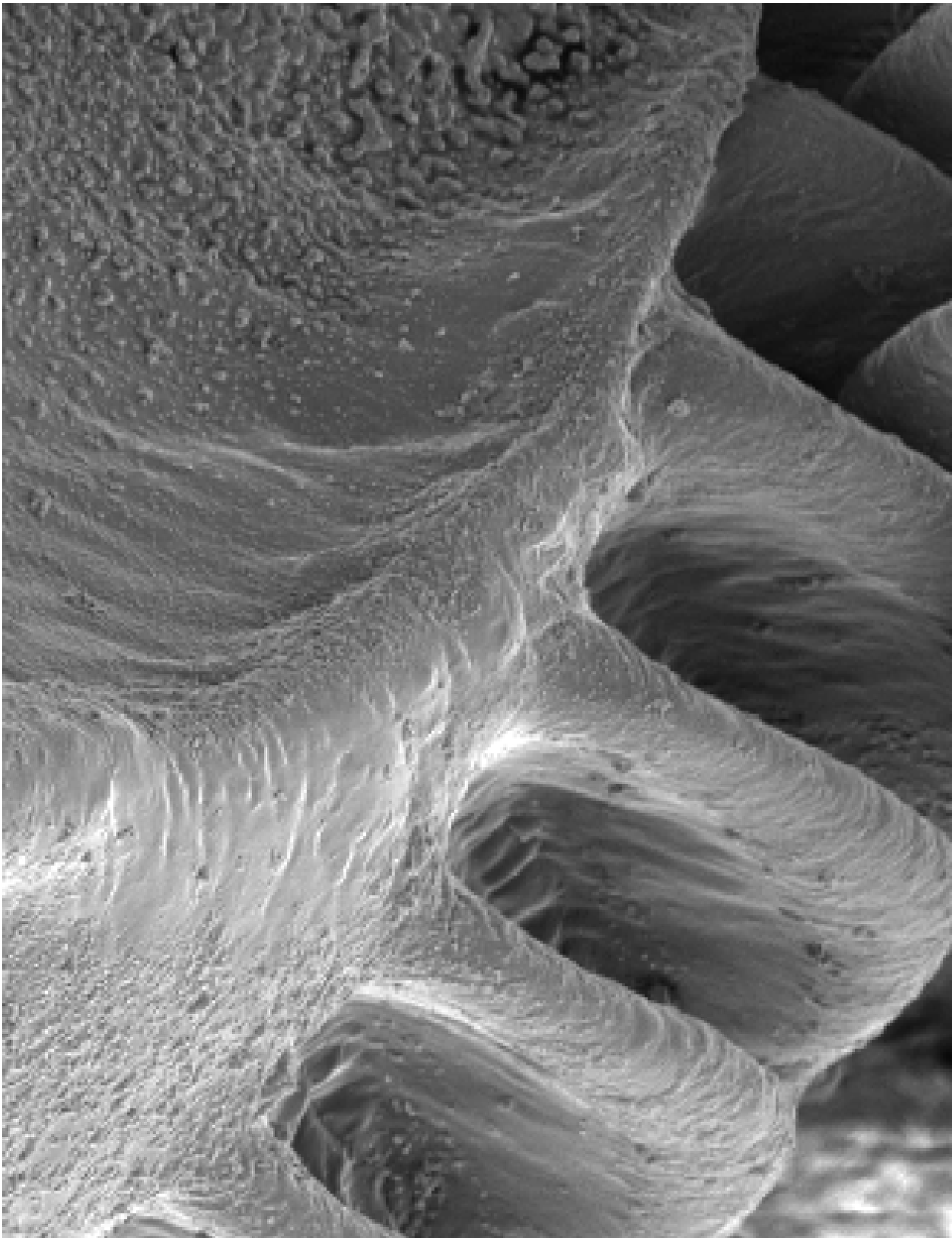
There was. *Issus* tucks its rear legs underneath its body and on the second joint away from the body (trochanter) of each leg is a geared strip that meshes with its mate when the animal ratchets its legs to cock its body for the spring. This meshing prevents the animal from spinning to one side as the animal would do if the legs did not fire at precisely the same time. As it turns out, this is very precise indeed: the legs spring within 1/300,000 of a second of each other. This yaw control is an important advantage to a creature that needs to land on target to reach food or escape predators.

The strips have 10 to 12 gear teeth, asymmetric in their form, looking like shark fins on just

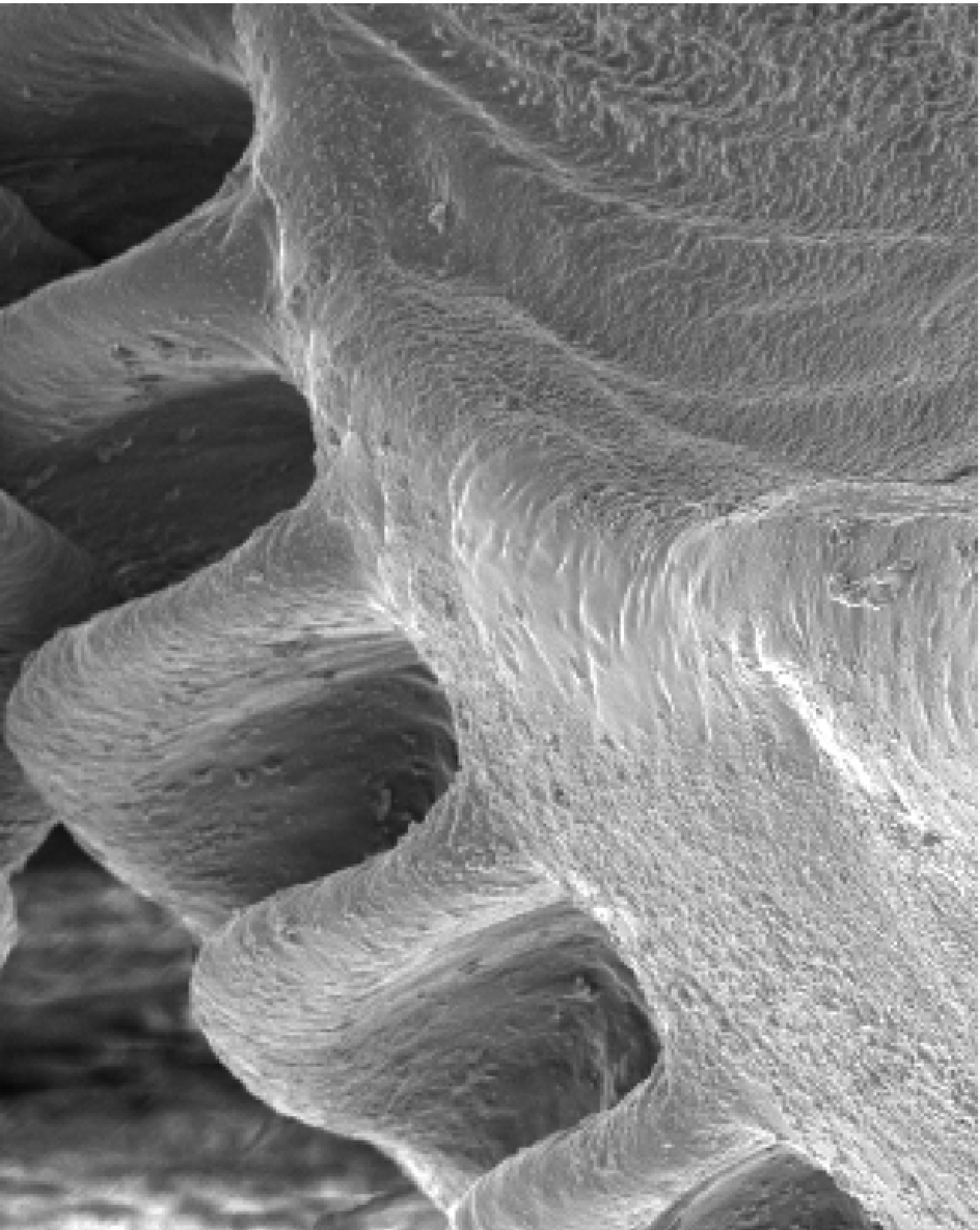


Issus jump sequence

Photo courtesy of Malcolm Burrows



Issus gears | Photo courtesy of Malcolm Burrows



Issus coleoptratus nymph

Photo: bramblejungle, 2012 | Flickr cc

a portion of a circle. Each tooth is about 50 microns in width and 15 to 30 microns in length and about 30 microns apart from its neighbors. Like so many parts in nature these too are made from a composite for both hardness and durability: in this case, chitin, that sugar-based polymer of choice in the insect world, and sclerotin, a protein.

High stress areas are reinforced with chitin and it was fascinating to Sutton to see the two materials show up so dramatically in different colors under UV light: chitin showing black, resilin blue.

The researchers suppose that, like most jumping insects, *Issus* may have started out with coordinating its jumping legs using friction alone; having rough areas on its legs that gradually were naturally selected as a patterned roughness that turned into the more precise cogs. The more precise mechanism enabled a more accurate landing, which might have been a huge advantage to *Issus* but not to the majority of other jumpers, who, obviously, did not wander down that evolutionary path.

Issus jettisons this advantage in its final molt, and the adult employs the more common friction pad to time its spring action. The researchers posit that this might be because of the irrevocable loss of function from a broken tooth should the now-no-longer-growing animal have an accident. They further speculate that the unusual asymmetry might be an advantage in managing wear and tear in repetitive motion that has limited degrees of freedom.

Essential to the discovery and demonstration of the gear mechanism was the use of high speed video cameras. The gear structures had been observed in the 1950's, but no one had demonstrated their functionality; the action was simply too fast to be seen. The cameras used by Burrows and Sutton shot film at as much as 35,000 frames per second. At that shutter speed, getting enough light on the subject became the critical factor.

The *Collaboration*

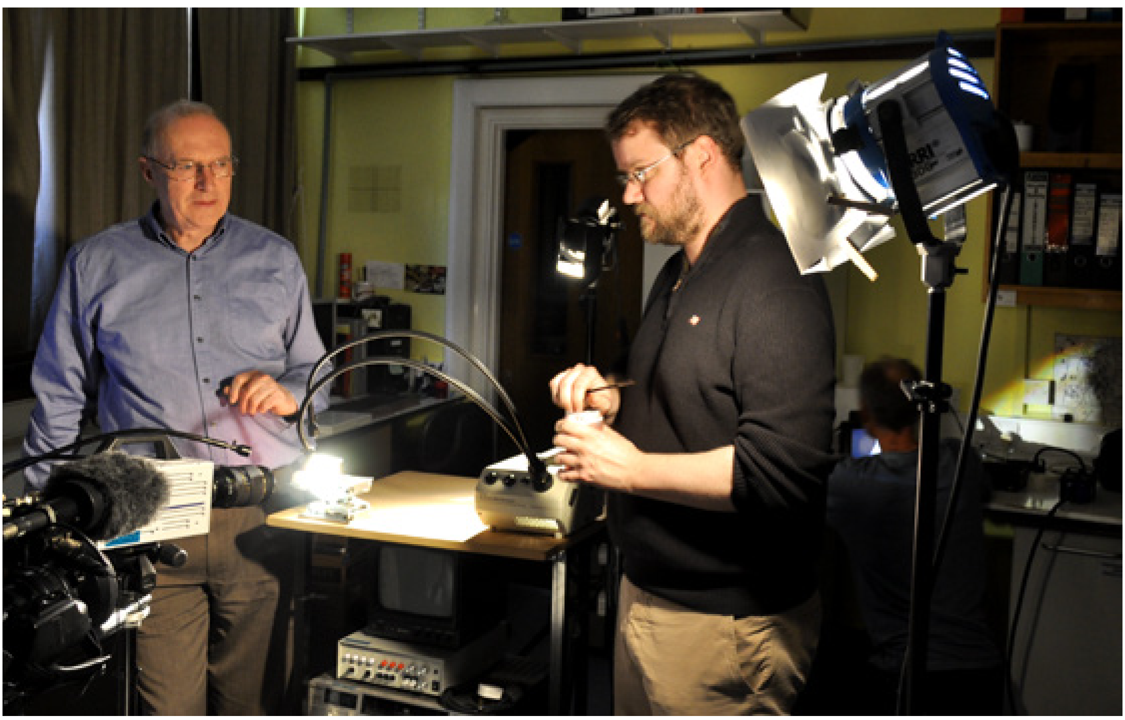
Dr. Burrows, a Fellow of the Royal Society and Emeritus Professor at the University of Cambridge, is a neurobiologist by training with many years of research in the field of intracellular processes. He had gotten interested in insect physiology and their stimulus/response mechanisms; in particular he had spent the better part of his career looking at how interneurons control movements like walking, flying and jumping. Especially jumping: locusts, froghoppers, leaping cockroaches, leafhoppers and the pigmy mole cricket all have come under his attentive gaze. According to Sutton, he is the consummate careful and diligent investigator and was an expert in "putting electrodes in impossible places." Burrows was in quest of a new neural mechanism that might explain the synchronicity and speed of the insect leg movement. If he could find a neurological explanation for this, it would likely mean the discovery of a new type of neural pathway, the stuff of Nobel prizes.

> "I first noticed these gears in about 2008, (some of their structure had been described in 1957 by Sander) and then made some high speed movies of the gears in action while the animal performed movements that resembled natural jumps."

Burrows had concluded, however, that the cause of the speedy leg action was not this new neural pathway, but must be mechanical. He wrote a paper about his findings and circulated it about for feedback from the scientific community and from this a collaboration was born.

> "I submitted a paper on jumping mechanisms in froghoppers (a small plant sucking bug- that turns out to be one of fastest jumper of all insects studied so far) and it was clear that one of the anonymous reviewers understood far more about the biomechanics than I did. I asked the journal if the reviewer would be interested in engaging in a discussion about the biomechanics of jumping. A while later I had an email from a Greg Sutton about visiting for the summer and working on jumping insects. He duly arrived and we spent a great summer filming insects and Greg started producing models based on the real behaviour. Greg then secured two fellowships which he was able to hold in series enabling him to be in Cambridge for a number of years. Only gradually did it emerge that he was the anonymous reviewer."

The collaboration that first summer was not easy, says Sutton. "Dr. Burrows was a biologist with a basic understanding of mechanics, and I was a engineer with a basic understanding of biology. At first, it was very hard to follow each



Malcolm Burrows and Greg Sutton

Image courtesy of Malcolm Burrows

other's expert reasoning and form a common understanding, but eventually we were able to work more smoothly together."

There was no magic formula or template for this collaborative success. "The best intentions, hard work and mutual respect without understanding (all of the other's knowledge)" were the key, says Sutton.

The collaboration has produced a remarkable discovery that might not have been possible without it, according to Dr. Burrows.

> "Both to me as a biologist and to Greg as an engineer, functional gears were not something an insect should have. But the structures look like gears and we showed that they work like gears.
>
> For me the collaboration has been a delight and the essential part of my research for many years. The combination of engineering insights (Greg) and biological (mostly neurobiological from me) have contributed far more than one discipline alone could have achieved. The success of the collaboration is the result of learning to speak the same language – and I don't just mean American and English – and taking advantage of the different insights that are generated."

As for other disciplines, Dr. Sutton is quick to point out that they are indeed called in for many projects that he works on although not this one. Julian Vincent, biomimetics pioneer at Universities of Reading and Bath and now at Oxford, on biomaterials and Steve Rogers of the University of Sydney, Australia, on the ecological context of the organism, are two experts that Sutton has conferred with often. Despite the ability to call in experts from other fields, the demand on the principal investigators for interdisciplinary knowledge is intense. Sutton, with a doctorate in biomechanical engineering already, says wistfully, "I wish I had a PhD in gearing."

Possible applications

For co-discoverer Gregory Sutton, this adaptation bespeaks a selective specialization that holds lessons for human technologists. "The gears," he says, are built for "high precision and speed in one direction. It's a prototype for a new type of gear." Asymmetric spur gears can also be an advantage if more load capacity is wanted for less weight and size.

Perfect synchronicity, however, is the strong suit here. There are three issues that come to the fore when determining what the optimum tech app is for this: "backlash" is the slippage occurring when the gears are not perfectly aligned, which to some degree is unavoidable. Friction becomes an issue when you get to smaller scales and typical involute gears are optimum at 6-12 inch diameter. Wear and tear or durability becomes an important issue over time and designing a geometry and material mix that avoids this is critical.

In the world of human technology, gears are typically radial and symmetric, the so-called involute gear invented by the famous Swiss mathematician Leonhard Euler. They can be configured in any number of geometrical arrays so that they mesh together. The universal transaxle gears on your car are good examples. Euler had an added constraint that nature does not, and that is he needed a precise and neat mathematical formula that could be drawn and then made from metal using tools that cut in a circle with a simple radius.

"Nature, however, does not care about the formula for this" says Sutton, when discussing the complicated factors comprising a successful combination of shape and matter, and "... is not cutting anything, but adding material as it needs it according to stress." Logarithmic curves and teeth that are all slightly different in shape and size along those curves, as exhibited by the Issus, are not a problem in this type of biological process. Understanding this process is another matter: it is complex and many questions remain unanswered, such as the functional development of the hook-shaped teeth.

Asymmetrical spur (or cogged) wheels similar to the insect variety are comparatively uncommon, but do exist in, for example, the world of mechanical clocks. Here, the angular velocity of the mechanical gear is an order of magnitude greater than that of its natural counterpart.

Today's manufacturing capabilities have Sutton excited by the possibilities of a higher performing gear: additive manufacturing is closer to the process that nature uses and advances in materials, including functional grading of composites, and our ability to manufacture things more precisely at a smaller scale may combine to make this gear a more common sight.

One of the keys, of course, would be the amount of energy able to be stored by the device's material and the amplification produced relative to the force needed. In that regard, nature seems to have us beat, at least in regard to common materials. Collagen, that natural protein in your tendons and bones, according the data reviewed by Dr. Steven Vogel, professor emeritus of Duke University, can hold approximately 16 times the energy relative to its weight than spring steel.

It is also possible that we may learn other things from *Issus*. Researchers Burrows and Sutton point out that the teeth on the cam-like strips have curved fillets at their base that reduce the likelihood of their shearing off, very similar to machined parts. They also suggest that the composite material in the teeth is functionally graded with a greater amount of protein in the mix where durability is needed over hardness. This is a common strategy in nature and it is evident in your own bone.

Given our widespread ignorance of the insect world, and the increased use of tools like high speed recording devices, Sutton is convinced that we will see many more examples like the gears on Issus; "as many as 150 more in our lifetime." In nature and technology we have long seen a use of elastic stored energy to do work, particularly when speed and powerful force were required. Using the inner structure of the material and time to first store and then amplify force, like the leafhopper does, could mean saving energy in achieving extreme performance.

The scientific collaboration across the Atlantic between Drs. Burrows and Sutton continues as they investigate the wonders in our own backyard.

> "We are currently collaborating on how insects like praying mantids make very accurate jumps to a target – something it is hard to make a robot do. Our current thinking is that mantids rotate their front legs (the ones they use to grab prey), the hind legs and the long abdomen as elements of a gyroscopic

control mechanism, rapidly exchanging angular momentum between them," says Dr. Burrows. "Now that Greg has been weaned off Twinkies (largely because of their scarcity in the UK) and has discovered the delights of Cornish Pasties our collaboration seems set to continue for a long while. I hope it will be as enjoyable and successful as it has so far proved to be." ×

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Malcolm Burrows

Image courtesy of Malcolm Burrows

Branching Burst by Lindsey Adelman

Photo: Lauren Coleman

Product design
Lighting
Lindsey Adelman

Lindsey Adelman designs and produces lighting in Manhattan. Inspired by structural forms found in nature, as well as the visual tension that results from mixing hand-blown glass with machine-made metal parts, her signature chandeliers have made her one of the most in-demand lighting designers in America.

Could you tell us about how you are inspired by nature? Are you inspired by form, pattern, function, process, or systems in nature?

I am inspired by form in the way Nature maximizes power and energy and minimizes material and effort used. I am also inspired by the fact that Nature is in constant motion. Everything is getting older, or being born, or shifting into its next incarnation – with no drama. In designing a light fixture, or a company, these things are good to keep in mind. I look to the broken symmetry found in many natural objects as well as patterns found in cracks in clay, vines, connecting walls of bubbles, repetition of sound – especially ocean waves – and tree branches. I am also fascinated by what grows to cover the surface of other natural or man-made objects like moss, lichen, shelf fungus, and barnacles.

What kind of techniques do you use for your work?

I incorporate metal processes such as milling, casting, extruding, drilling, bending, forming, deep-draw, spinning, and plating. Our custom hardware is combined with hand-blown glass, hammered bronze, 3-D printed plastic, turned walnut, and hand-built porcelain.

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

I get many images in my mind and then have to see them become real. Have to see if it will work the way I think it will work. It becomes such a driver that I set up everything else in my life to let this happen. When I have an urge for something to happen – whether it is a success or a failure – I never question just trying it. And there are a lot of failures and surprises. I suppose Nature is the real teacher here again with the 'no drama' lesson. You don't see a mushroom having a fit when a bug is nibbling on it. In designing I try to pay attention to what is happening in reality – and design with it, for it. It is easier to be part of the audience sometimes after the "experiment"has been set up. Does that make sense?

I love making forms that are larger than I am – but still retain a quality of offering illumination with an unassuming form. I try to create work that combines visual tension with some sense of serenity. Bringing out the best of any raw material gets you half way there already.

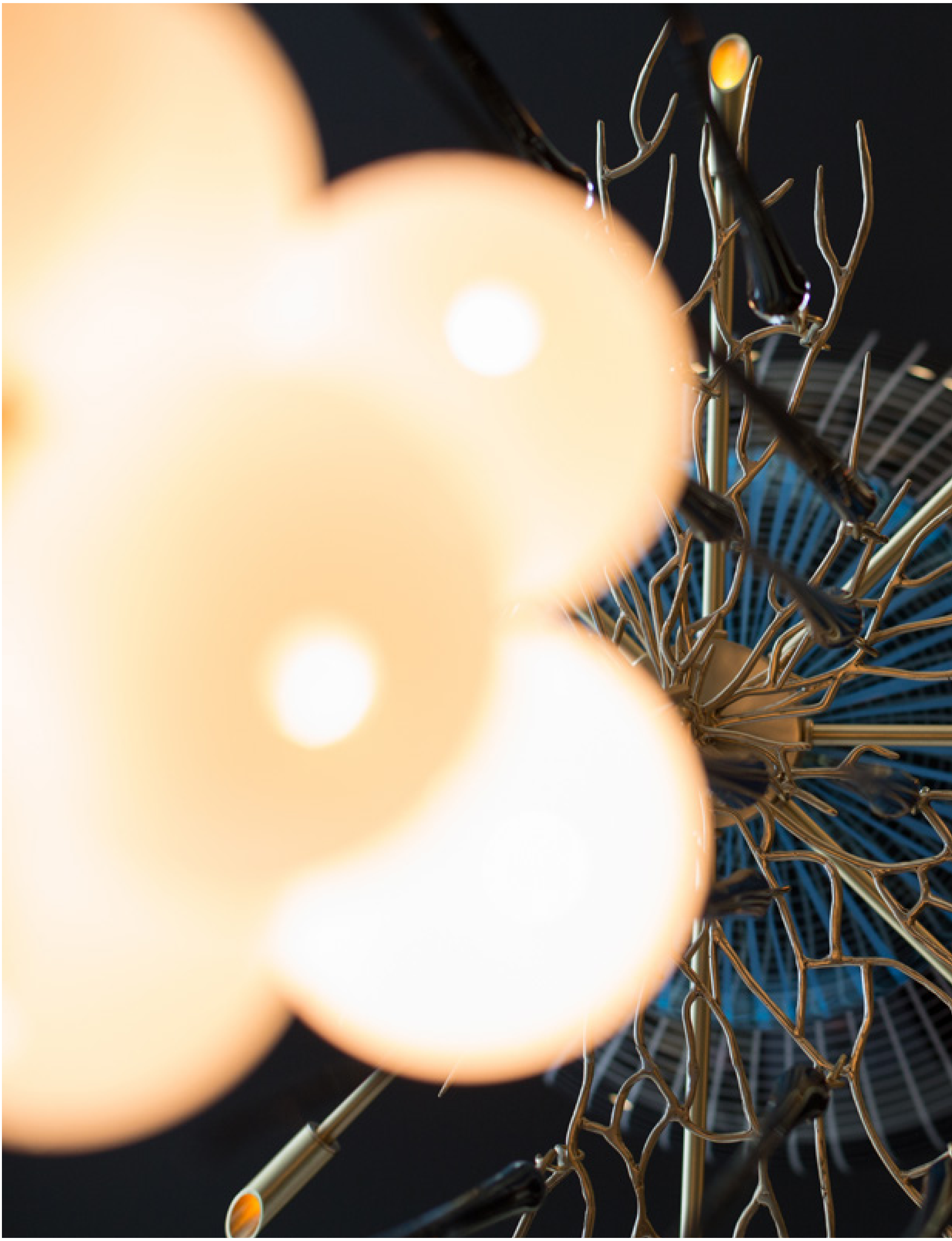
What are you working on right now? Any exciting projects you want to tell us about?

I am working on a music video. It is really fun. We are 25 people at studio now. We made the track, and the costumes, the jewelry, the wallpaper, furniture, and of course lights – and we are dancing too! Success or failure? The future will tell us! ×

Lindsey is part of *NYC Makers*, The MAD Biennial from July 1, 2014 to October 12, 2014 at the Museum of Arts and Design in New York City.

Catch floor light CF.02.04 with opal glass by Lindsey Adelman | Photo: Lauren Coleman

Branching disc fixture with porcelain disc shades, and brushed brass hardware by Lindsey Adelman | Photo: Lauren Coleman



Totem 2 by Lindsey Adelman | Photo: Lauren Coleman

Cherrybomb with cobalt blue and gold mini-globes by Lindsey Adelman | Photo: Lauren Coleman

Custom 40-bulb *Agnes Cascade* in brushed brass by Lindsey Adelman | Photo: Lauren Coleman

Baby star-nosed moles

Photo: Hillbraith, 2009 | Flickr cc

The Science of Seeing

It's the Mix Not the Match That Makes the Magnificent Mole

Adelheid Fischer

It's the Mix Not the Match That Makes the Magnificent Mole

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

When I was a kid, my friends and I spent many hours tinkering with a toy called Mr. Potato Head. A shapeless, plastic spud, Mr. Potato Head could be accessorized with an assortment of goofy features: bug eyes and jug ears, mustachioed schnozzes, gangly legs attached to clodhopper shoes. No technical skill was required; just the willingness to suspend one's sense of propriety and proportion. Indeed, courting outrageousness was key to the enjoyment of the game.

Judging by the kinds of photographs that appear on our wall calendars, screensavers and Flickr accounts, you might assume that nature never took this bric-à-brac approach to design. We are drawn to images that showcase nature's symmetry, elegance and restraint like the delicate radials of a spider web or the Fibonacci whorls of neatly packed seedheads or the patterned panes of color on a butterfly's wing. It's as if nature were always decked out for opening night at the opera and never for a masquerade ball. Yet nature courts outrageousness more often than we think, takes tongue to cheek, jabs thumb to eye and wreaks more than a little Mr. Potato Head havoc with its designs. Witness the male fiddler crab which grows one claw far larger than the rest. Sidling along marsh flats, he holds this exaggerated appendage slightly aloft and crooked like a man with a bandaged arm about to elbow his way into a crowded bar. Behold too the moose whose rectangular bulk, like a massive sideboard, perches on improbably tall legs. Recall its long-faced homeliness and the furred bell slung under its chin, features that give the animal an uncanny resemblance to Abe Lincoln.

When it comes to winning the grand prize for ungainly proportions and strange add-ons, however, (what science writer Natalie Angier calls the "all-star uglies") few animals can best the star-nosed mole. This palm-sized mammal inhabits wetlands from southeastern Canada into the eastern U.S. Although it sports a lustrous coat of dark, mink-like fur, the haute couture ends there. In true Mr. Potato Head fashion, star-nosed moles are endowed with squints of bead-black eyes and outsized front paws that are as scaly as chicken feet. Shaped like catcher's mitts, each paw ends in a set of curved, pearly-pink nails that are as long as they are tough. Then there's the matter of the animal's tail. Highly irregular in its thickness, it constricts at the base, swells along the midsection and tapers at the end like a snake that's gorged on a nest of day-old mice.

Nothing, however, can top the animal's nose. Sprouting from its snout is a circlet of 22 fleshy appendages that are so nimble and mobile that they seem to have a life of their own. This pink, anemone-like organ elicits unequivocal disgust. "Like fresh bits of sirloin being extruded through a meat grinder," cried Angier in a 2010 *New York Times* article entitled "Masterpiece of Nature? Yuck!" "Petals on a nightmarish flower," wrote Carl Zimmer in *Discover* magazine. "A Medusa-like rosette," exclaimed mole experts Martyn Gorman and R. David Stone.

All joking aside, the judgments we make about star-nosed moles and other organisms, what we consider yucky or pleasing, funny or scary, soothing or appalling, carry serious implications. They often seal the fate of many of the creatures around us. Witness the 2007 report from a trio of wildlife biologists who placed lifelike rubber replicas of turtles and snakes in the middle of a roadway along the Canadian shore of Lake Erie and stood back to record what happened. Of the 2,000 drivers studied, 2.7 percent went out of their way to intentionally squash the decoys. Reptiles aren't the only animals to be persecut-

Star-nosed mole (*Condylura cristata*)

Photo: Amada44, 2005 | Wikimedia Commons

Range of *Condylura cristata* (Star-nosed Mole) across North America

Photo: Supportstorm, 2010 | Wikimedia Commons ed. In some parts of the country, drivers routinely swerve to flatten armadillos, opossums, slugs or such road-kill feeders as ravens and vultures.

Aesthetic judgments even appear to bias scientists, the very people who might help to rehabilitate the reputations of so-called ugly organisms by bringing to light the elegant ways in which they execute complex tasks or the beneficial roles they play in keeping ecosystems whole and healthy. Alas, it turns out that scientists can get suckered in by a pretty face as much as the rest of us. In a 2010 study in *Conservation Biology*, biologists Morgan J. Trimble and Rudi J. Van Aarde of the University of Pretoria in South Africa reviewed the scientific literature for about 2,000 animal species in South Africa. Their conclusion: a few species hogged the lion's share of scientific resources and attention whereas information for many other species was "virtually nonexistent." The average number of scientific publications for threatened species of large mammals, for example, was more than 500 times that of threatened amphibians. "In the eyes of science," the authors observe, "all species are not created equal."

Why the disparity? Scientists, it turns out, likely harbor many of the same biases as the general public. Commonly studied species, Trimble and Van Aarde write, also tend to be the most charismatic. "Most scientists are in it for the love of what they do," Trimble reported to Angier in the *New York Times*, "and a lot of them are interested in big, furry cute things."

This explains why I've been such a diehard fan of the work of Dr. Ken Catania ever since reading about his research on star-nosed moles in the 1990s. As the story goes, Catania was "starstruck" as a young graduate student in neurobiology at the University of California, San Diego. In a 2008 article in *SEED* magazine, neuroscientist Glenn Northcutt, Catania's graduate advisor, recalls that his student was adamant about studying the obscure mammal, even going so far as to declare to Northcutt, "I want to work with star-nosed moles, and if you don't let me, I'm going to go to another lab."

Catania didn't focus on star-nosed moles because they were the easiest, most direct route to a Ph.D. True, the animals only grow up to seven inches long and weigh in at an average of two ounces; yet studying them in the wild is fraught with challenges. Although the animals are wide-ranging, they spend most of their lives underground, using their massive front paws like powerful shovels to excavate tunnels through mucky wetland soils, working at remarkable speed. Scientists observed one mole, for example, that tunneled 235 feet in a single night. Many burrows open up into streams and ponds where the moles' broad, flat paws become amphibious-assault gear, propelling them through the water to intercept aquatic staples such as crayfish, insects and even frogs and fish.

Carrying out research on moles in captivity isn't easy either. As laboratory subjects go, moles are fairly high-maintenance animals. They require large containers of soil and have voracious appetites, consuming their weight in worms daily.

Catania is an example of what can happen when a scientist plies his trade of patient observation and is fearless about beating the bush in pursuit of his curiosity, wherever it might lead him. In the process, he has slowly nudged the needle of public opinion from repugnance to respect when it comes to his odd little subjects, including their chopped-sirloin noses, which Catania's research has shown is not related to their sense of smell. So why then do they go to such great lengths where their sniffers are concerned?

Microscopic analysis of the nose surface has revealed a honeycomb pattern of tightly packed pimple-like structures, known as papillae. Named Eimer's organs in honor of the German scientist Theodor Eimer, who in 1871 discovered similar features on the plain noses of European moles, each papilla contains a core of epidermal cells that function as sensory receptors. Although it measures only about 0.6 inches from tip to tip at its widest point, the nasal structure of star-nosed moles contains more than 25,000 Eimer's organs.

Some scientists initially suggested that the animal's nasal frill is used to detect the electrical fields created by the sweat and mucous of its prey. Catania, on the other hand, demonstrated that the Eimer's organs do something altogether different. An examination of the mole's brain showed that a larger-than-average portion of the cortex was devoted to somatosensory processing; that is, making sense of the blitz of stimuli relayed by the sense of touch. Some of that information was coming from the mole's tail. When held erect, it trails along the ceiling of the mole's underground tunnels, much the way human hands might feel their way down a dark corridor. The tail performs a double duty. During winter, it also stores fat like a portable pantry. When prey becomes scarce, the mole simply draws on these reserves to tide it over to better times.

The majority of the somatosensory information, however, is gathered by the mole's nasal appendage. From there, it travels to the animal's brain on a neural highway made up of more than one hundred thousand nerve fibers. This is nearly six times the number of neural connections between the human brain and hand. According to a paper published by Catania and fellow neuroscientist Jon Kaas, the mole's nose "is clearly a major source of information about the mole's external environment and may be one of the most sensitive and highly developed touch organs among mammals."

This combination of somatosensory hardware and software allows the animal to receive an extremely refined tactile impression of everything it encounters. When searching out prey, for example, the tentacles are extended in a forward position, "fingering" the surrounding world. When the mole lifts its nose, the tentacles retract. So swift is this back-and-forth motion, that at every second the tentacles touch a different area—not once but ten times or more. With response times measured in nano increments, the moles are able to distinguish a worm from a tree root and snap it up faster than a hungry youngster can slurp a spaghetti noodle.

By analyzing cross-sections of brain tissue, Catania made one of the most astounding discoveries of all: the star pattern of the nasal tentacles is mirrored in the actual structural pattern of the brain.

These are just some of Catania's amazing neuroscience discoveries. Along the way, however, he

Baby star-nosed moles

Photo: Hillbraith, 2009 | Flickr cc

Mole hand

Photo: Didier Descouens, 2012 | Flickr cc has pursued some quirky sidelines, spinning the straw of ordinary observation into the gold of scientific discovery. Catania is the first scientist to capture pregnant moles from the wild and to observe the birth and development of their young. In newborn moles, the star-shaped appendages appear as embedded ridges on the face, giving the animals a kind of wrinkled muzzle. In week-old moles, the epidermal tissue that encases the stars sloughs off, revealing the more defined contours of the tentacles. Shortly thereafter, the appendages detach from the face and assume the free radial form of the adult mole. It turns out that this is a unique pathway for appendage development in animals which, typically, be they fingers on a monkey, antennae on a moth or wings on a bird, are all outgrowths of a body wall. Not so the mole's nasal frill.

That's not all. Catania noticed that when the animals swim underwater, they blew bubbles—lots of them. In 2006, he published research in the journal *Nature* showing that star-nosed moles and a species of water shrew (*Sorex palustris*) can smell their prey while submerged. They do so by rapidly exhaling and inhaling bubbles, between five and ten times per second. The exhaled bubbles pick up odor molecules. When inhaled, these molecules alert the animals to the presence of prey. The moles and water shrew became the first mammals discovered to use underwater olfaction, an ability that earned them a place in the zoological history books.

As if this research were not quirky enough, Catania also investigated the field methods of the commercial earthworm pickers in Appalachia who supply his lab moles with food. Using a time-honored tradition known as worm grunting, the harvesters create underground vibrations by drawing a metal rod against a wooden stake in the ground. The action routs earthworms out onto the forest floor by the thousands. Explanations of this phenomenon abound, including one by Charles Darwin in his famous 1881 treatise on earthworms. He suggested that beating the ground created vibrations that were similar to those made by burrowing moles. Earthworms fled to the surface, he conjectured, where their mole predators would not follow them. In a 2008 article in *PLoS One*, Catania affirmed Darwin's hypothesis, demonstrating that worm grunters mimicked the sounds of approaching moles.

From time to time, I check in with Catania's lab to see what surprising new insights he and his grad students are generating. I find this work to be a source of hope and good cheer. Maybe it has something to do with the MacArthur Fellowship, the so-called genius grant, that Catania won in 2006. In a roundabout way, it affirms for me that there is still something a little right about a world that would confer one of its most prestigious awards on someone doing this kind of work.

Asked in 2006 what he planned to do with his MacArthur money—$500,000 of no-strings-attached funding—Catania replied, "I'll continue to examine the most interesting species not in the mainstream—the sort of animals that tell us a lot about brains and how they work," including how our human brains work. Therein lies perhaps the most important finding of all: that ugliness, like beauty, is only skin deep and that if we're willing to dig, even just a little, we'll find enough mystery and amazement in the world around us to occupy us for a lifetime. ×


VBLOCK

Portfolio

Exploration Architecture

Exploration Architecture has been described as pioneers of biomimicry. Current members of Exploration are Niamh Anderson, Oliver Bulleid, Alizee Cugney, Kamil Dalkir, Sonya Falkovskaia, Kelly Hill, Michael Pawlyn, Yaniv Peer, Natalie Savva, and Daniel Winter.

It was established by Michael Pawlyn in 2007 to focus exclusively on this emerging discipline. In 2008 the company was short-listed for the Young Architect of the Year Award and the internationally renowned Buckminster Fuller Challenge. Pawlyn jointly initiated the Sahara Forest Project and is a Founding Partner of Sahara Forest Project AS – a company established to deliver concrete initiatives for restorative growth

Prior to setting up Exploration Michael Pawlyn worked with Grimshaw for ten years and was central to the team that radically re-invented horticultural architecture for the Eden Project. He was responsible for leading the design of the Warm Temperate and Humid Tropics Biomes and the subsequent phases that included proposals for a third Biome for plants from dry tropical regions.

He has lectured widely on the subject of sustainable design in the UK and abroad and in May 2005 delivered a talk at the Royal Society of Arts with Ray Anderson, CEO of Interface. In 2007 Michael Pawlyn delivered a talk at Google's annual 'Zeitgeist' conference and, in 2011, became one of only a small handful of architects to have a talk posted on TED.com. His TED talk has since had over a million viewings. In the same year, his book Biomimicry in Architecture was published by the Royal Institute of British Architects. Exploration is currently working on a range of biomimicry-based architectural projects and a book commissioned by TED.

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

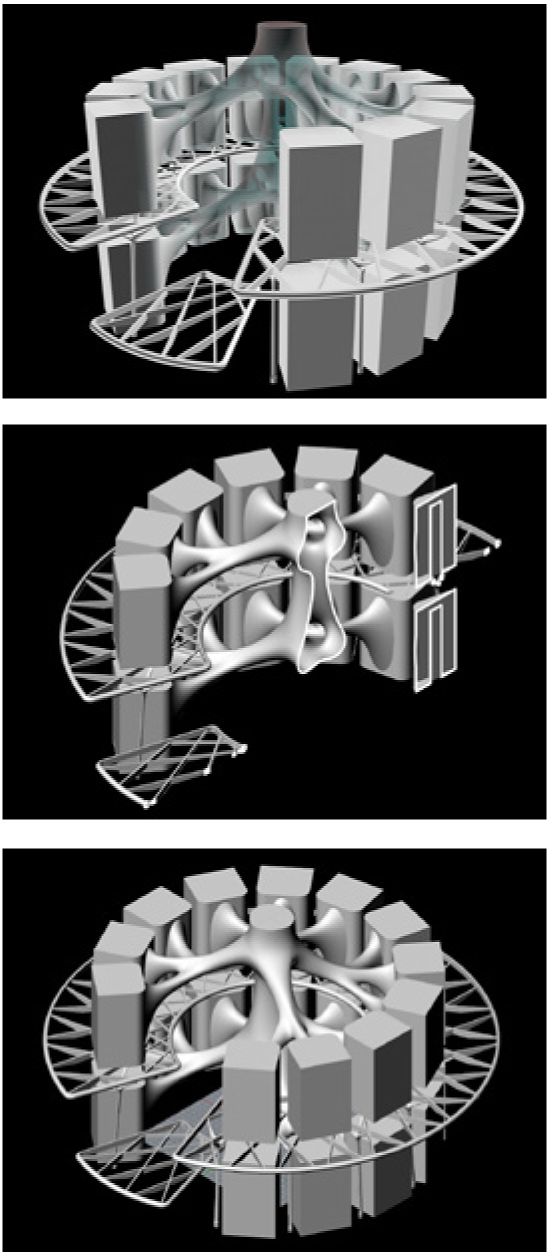
There is definitely a steadily growing interest from designers in improving resources available, although the extent to which designers engage with biomimicry varies widely. I have always found biomorphic design less interesting than truly biomimetic design. This requires an understanding of how functions are delivered in biology and then translating that understanding into innovations.

What do you see as the biggest challenges?

Some of the challenges are fairly practical ones, by this I mean that certain solutions that work extremely well in biology are difficult to translate into solutions that suit human needs. So, for instance, biological structures tolerate a much higher degree of movement than would be acceptable in buildings (both psychologically and in terms of regulations). There is also a huge gulf between the growing, sensing and responding characteristics found in biology and the generally inert and unresponsive nature of conventional building materials. However, there is now an increasing range of self-repairing materials and building systems that are much more responsive. Some of the challenges have more to do with conventional economics, which works to very short time horizons and externalizes anything that is inconvenient or hard to calculate. It is very often the case that biomimetic solutions offer multiple benefits (such as increased resource-efficiency, ecosystem restoration, sequestering carbon, etc.) but conventional economics does not recognize the long-term value of these approaches.

Previous page: One of four projects exhibited at the Architectural Foundation's Central London Project Space, March 7-April 11, 2014, the Mountain Data Centre concept locates an energy-demanding data storage centre within the cool abandoned tunnels of a Norwegian mine. The other projects shown were the Biomimetic Office Building, the BioRock Pavilion, and the Sahara Forest Project. | Image courtesy of Exploration

The BioRock project, shown at the Architectural Foundation exhibition, employs natural biomineralization to grow a structure through electro-deposition of minerals in seawater using BioRock technology as pioneered by Wolf Hilbertz and Tom Goreau. | Photo courtesy of sebtoja



Mountain Data Centre concept drawings (x-ray, section, axonometric) of data banks and air circulation ducts based on Murray's Law, an energy optimization formula that relates the radii of daughter branches to parent branches by balancing volume and pressure. |Images courtesy of Exploration

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

I think we need to develop better design tools to help optimize systems that try to mimic the efficiencies of ecosystems. One of the challenges of this approach is that ecosystems are extremely complex, cyclical and interconnected so mimicking them is far more demanding for a designer than it is to pursue the more conventional approach of simple, linear and disconnected systems. However, with the computing power now available and the potential of biologically-derived algorithms it should get easier and easier. The benefit will be that we can move towards highly optimized, zero waste systems that enhance human and natural capital rather than just financial capital. This is very much what we are aspiring to on The Sahara Forest Project.

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

Since setting up Exploration I continue to read widely and have had the pleasure of working with some inspiring biologists and biomimetics experts. Writing my book *Biomimicry in Architecture* was a great opportunity, not just to read widely about the subject but also to engage with some of the greatest proponents around the world – it was a bit like forcing myself to write a detailed manifesto for everything that I wanted my company Exploration to focus on over the next ten years.

What is your best definition of what we do?

I like to define the discipline as 'mimicking the functional basis of biological forms, processes and systems to produce sustainable solutions'.

By what criteria should we judge the work?

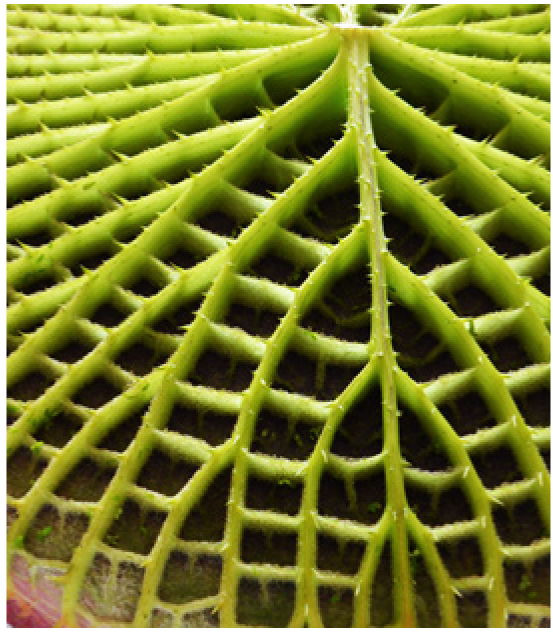
I have always believed that designers have the ability to improve people's quality of life and shape a better future so I think it is also important to assess whether a particular design is based on sound motivation rather than just the pursuit of stylistic novelty. When it comes to judging biomimetic design more specifically, it needs to be judged on the applicability of the source and the thoroughness with which that has been carried through to its realization.

What are you working on right now?

We are working on a number of ambitious schemes including the next phases of The Sahara Forest Project and what could be the first building in the world to be grown from minerals (the BioRock Pavilion). We are also in the early stages of a house based on the structure of abalone and a zero waste textiles factory.

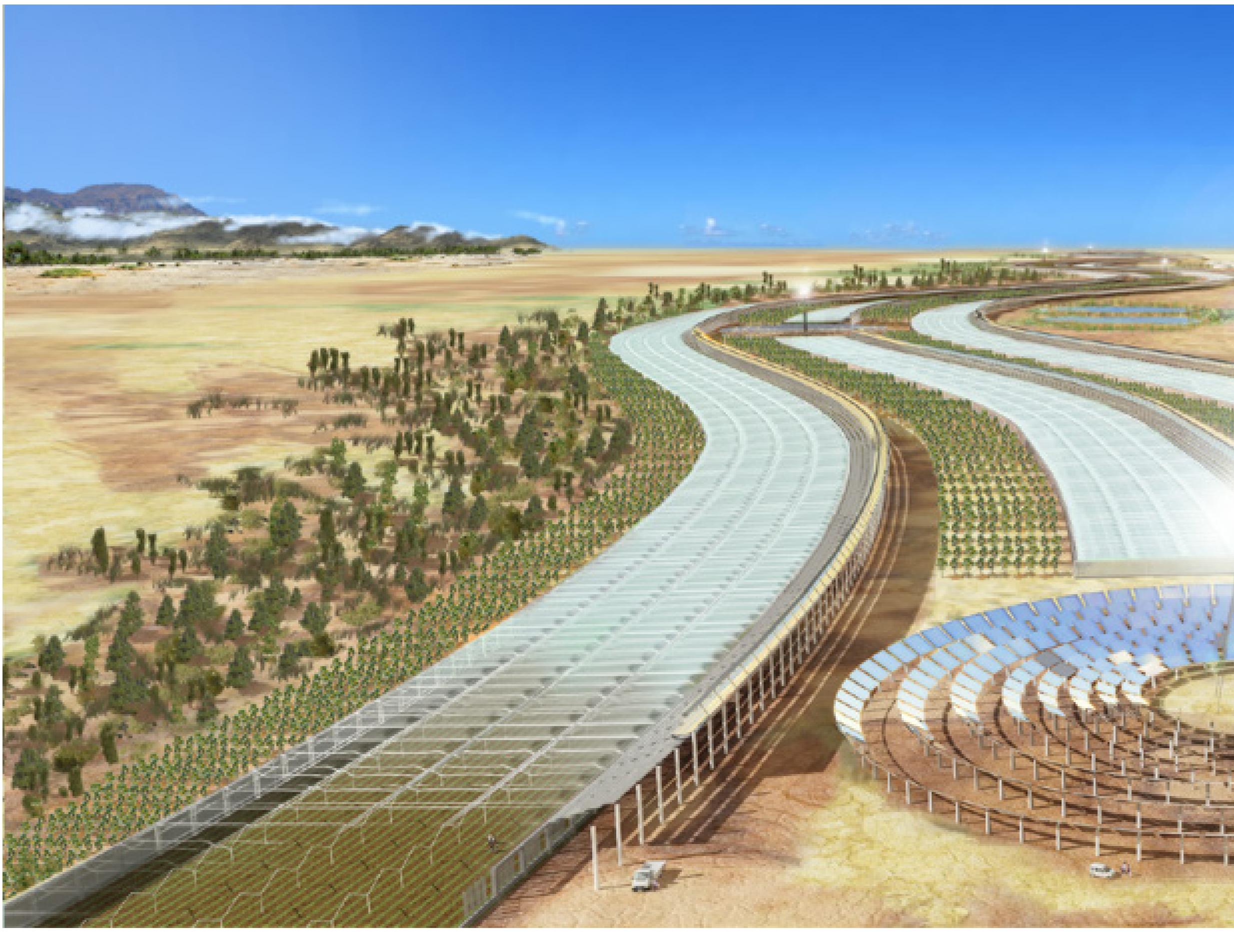
How did you get started in biomimicry/bio-inspired design?

My interest in biomimicry goes back a long way. As a teenager I was torn between studying architecture and biology and eventually chose the former because I couldn't see as much creative potential in biology. I was also quite politicized about environmental issues in my early teens

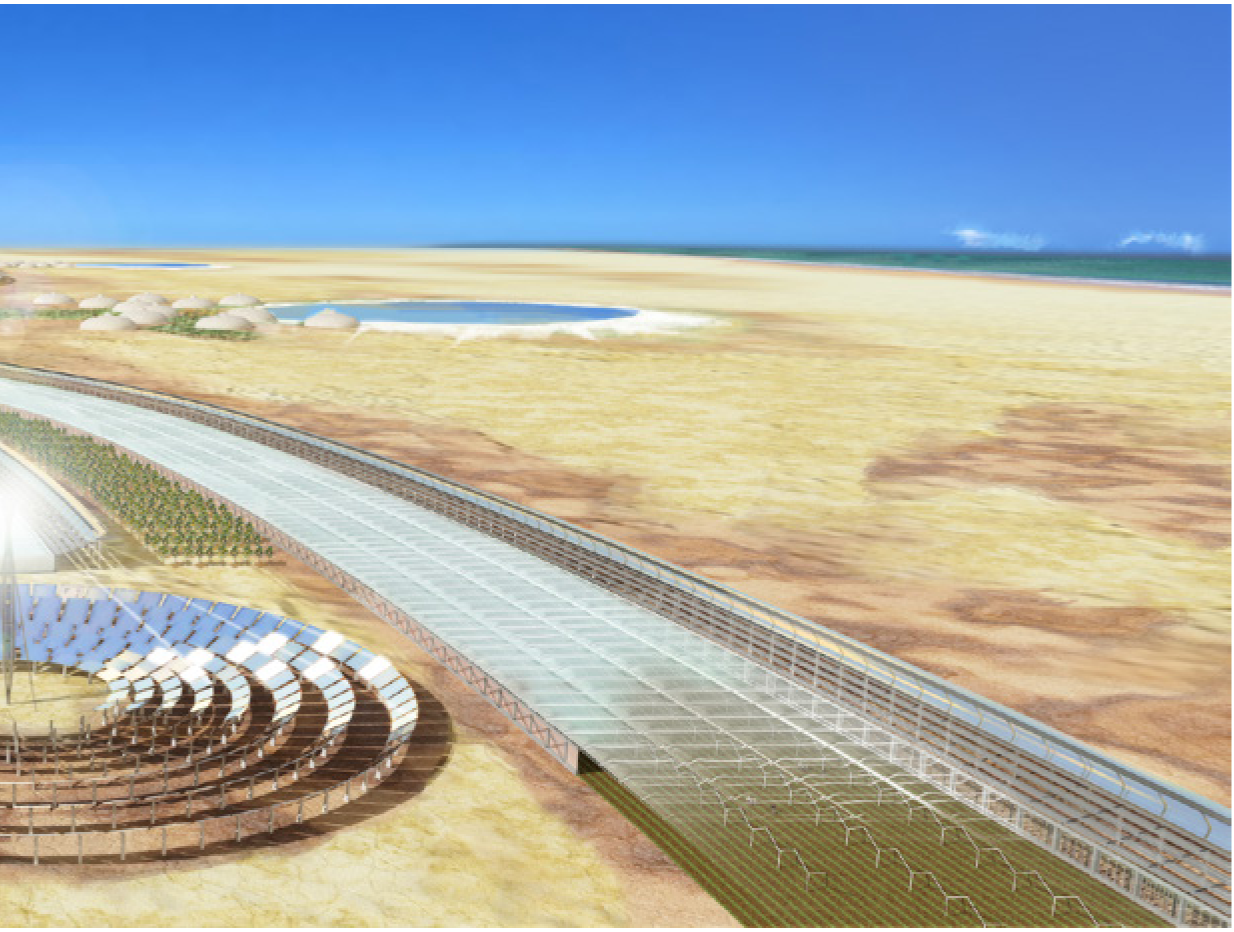


Amazon water lily | Photo courtesy of Exploration

Natural circuits | Photo: Vimal Raveendran, 2008 | Flickr cc



The Sahara Forest Project is a scheme to reclaim desert lands by using solar-powered distillation of seawater to water crops and bands of vegetation. It also includes a concentrated solar power (CSP) element. There is currently a pilot plant operating in Quatar since December 2012, and an agreement with the country of Jordan to host another when construction funds have been raised. | Image courtesy of Sahara Forest Project



when a relation gave me a copy of the Club of Rome's *Blueprint for Survival*. When I joined Grimshaw to work on the Eden Project I realized that there was a way to bring these three strands together in pursuit of sustainable architecture inspired by nature. This emerged even more fully when I went on a one week course at Schumacher College run by Amory Lovins and Janine Benyus – I learned more in those five days than I had in the previous ten years of attending conferences and seminars.

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

When we were researching good examples of biological structures to include in our recent exhibition we found the Honeycomb Cowfish, which has the most amazingly geometrical exoskeleton. We have been trying to find some biologists that have studied it and are able to answer the question that we so often ask – "Why is it the way it is?"

What is your favorite biomimetic work of all time?

I'm a huge fan of Pier Luigi Nervi's 'Palazetto dello sport' in Rome, which was inspired by the beautiful and efficient structure of ribs found on the underside of giant Amazon water lilies. Many of Nervi's projects won in competitions and the secret to his success was his frequent ability to produce the most cost-effective schemes. In a satisfying parallel with the refining process of evolution, the combination of ingenuity and biomimicry led to a remarkable efficiency of resources.

What is the last book you enjoyed?

I thoroughly enjoyed George Monbiot's book *Feral – Searching for enchantment at the frontiers of rewilding*. It's a wonderfully positive look at what rewilding could achieve and nature's amazing capacity for rebuilding ecosystems. He describes some remarkable examples such as the reintroduction of wolves into Yellowstone National Park. Just that one change produced a whole series of further transformations – bigger trees, enhanced habitats for birds, fish and amphibians, more bears and much else besides.

Who do you admire? Why...

There are a lot of people I admire including Ian MacEwan whose novel *The Child in Time* is a modern masterpiece, artists that are committed environmentalists like Cornelia Parker and Ackroyd & Harvey, and two recently deceased heroes - Wangari Maathai and Ray Anderson – both of whom had the courage, vision and determination to lead huge changes. I also admire the countless scientists who continue to reveal biological secrets and those who work in environmentally related fields such as climate science with the highest integrity and do so in spite of the media assault.

What's your favorite motto or quotation?

Buckminster Fuller's is hard to beat as an aim "To make the world work for 100% of humanity in the shortest possible time through spontaneous cooperation without ecological damage or disadvantage to anyone." I also like Ben Okri's assertion that ". . . adversity is not the end of a story

Palazzetto Dello Sport, Rome [by Pier Luigi Nervi, 1957]
Photo: Nathan Bishop, 2008 | Flickr cc

but, where there is courage and vision, the beginning of a new one, a greater one than before." We have a long document of favourite quotations that we refer to here at Exploration and it includes people like Donella Meadows, Margaret Mead, Mahatma Gandhi, Thomas Edison, Albert Einstein and other luminaries.

What is your idea of perfect happiness?

I love cities as well as nature so I guess it would be to live in a beautiful biophilic city, surrounded by good friends and family and to be continually engaged by new ideas.

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

I'm passionate about cinema and would love to make a film as brilliant as Kurosawa's *Dersu Uzala*. ×

For more about the Biorock Pavilion: http://vimeo.com/86747640

For more about the Biomimetic Office Building: http://vimeo.com/86659369

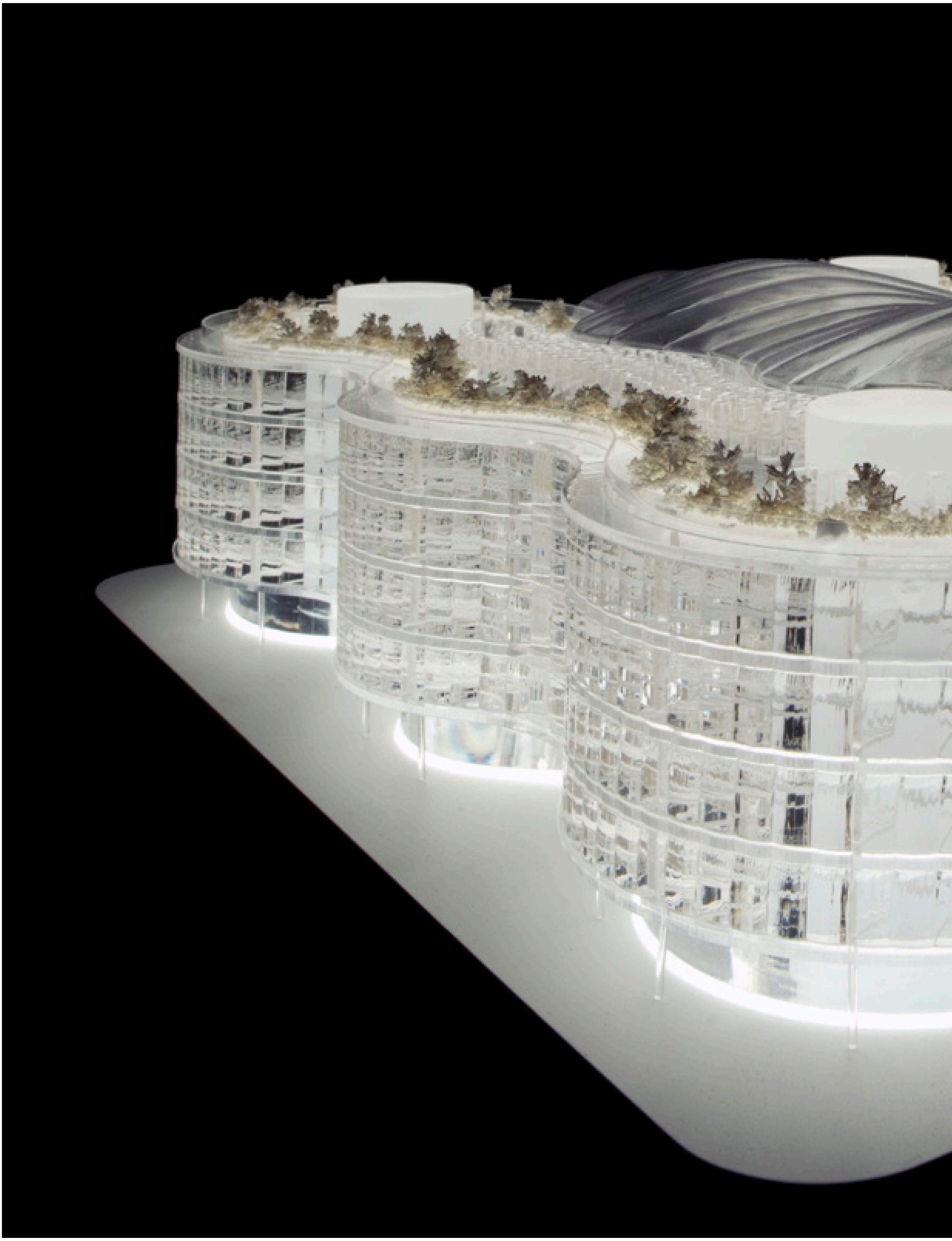
For more about the Mountain Data Centre: http://vimeo.com/86656423

For more about the Sahara Forest Project: http://vimeo.com/86661134

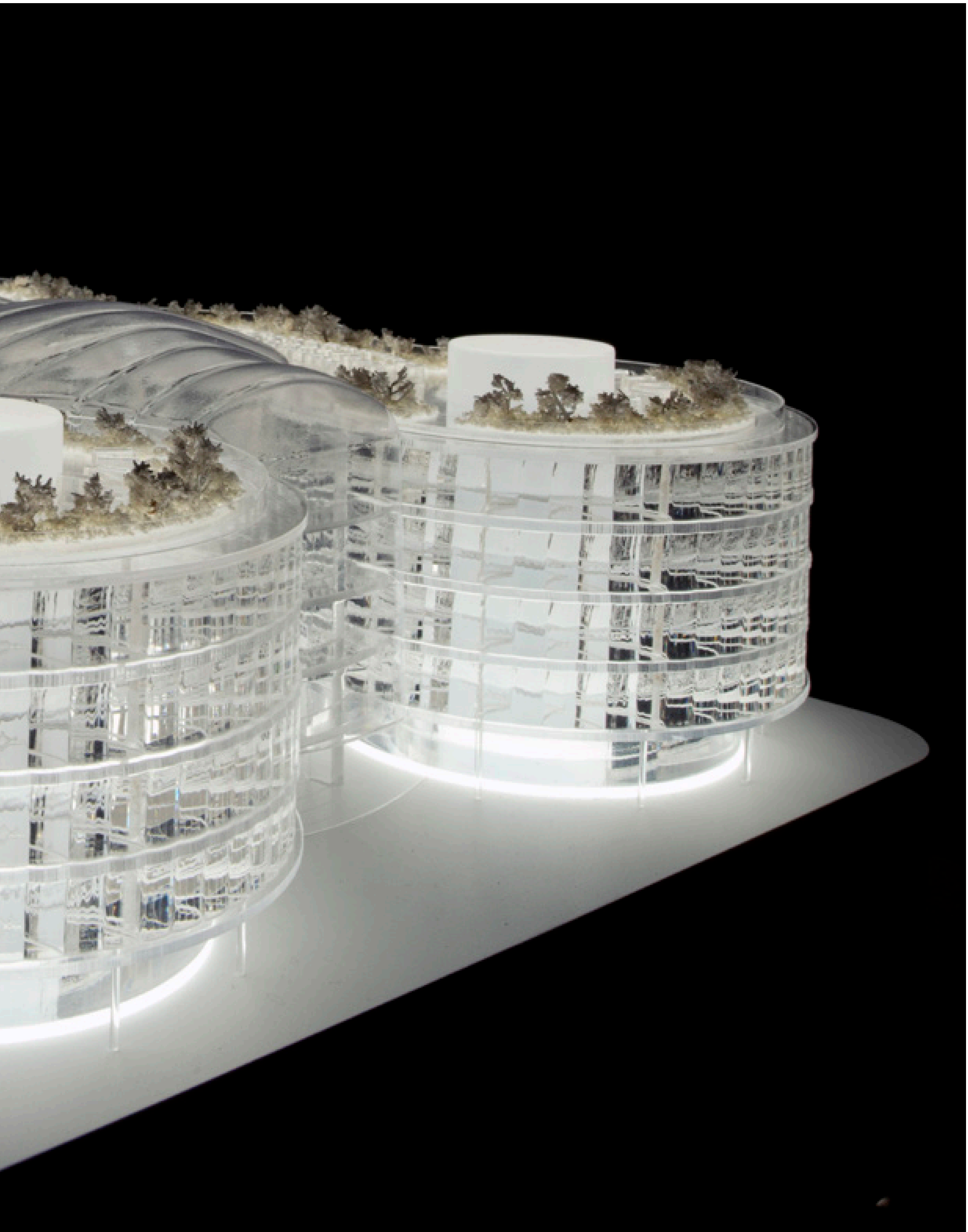
BioRock Pavilion, interior view. Exploration studied the morphology of shells and mathematical surfaces to develop an idea for a pavilion that could accommodate small spoken word performances. The design process started by defining the fixed elements – the seating rake, a stage and a surface for projection – and then used parametric design tools to extend and distort the geometry of the seating into a complete enclosure | Images courtesy of Exploration

An X-ray a marine “triton” snail, *Charonia*

Photo: Dr Michel Royon, 1978 | Wikimedia Commons



Biomimetic Office Building (three quarter view) | Image courtesy of Exploration

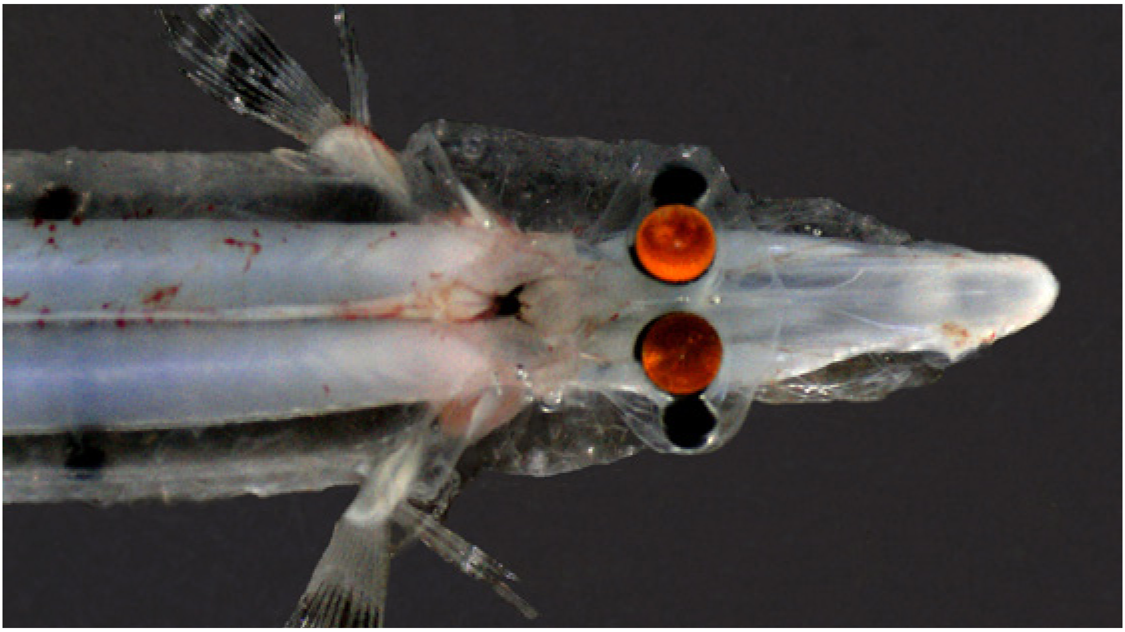


Mimosa pudica (Mimose) | Photo: Werner1122, 2012 | Wikimedia Commons

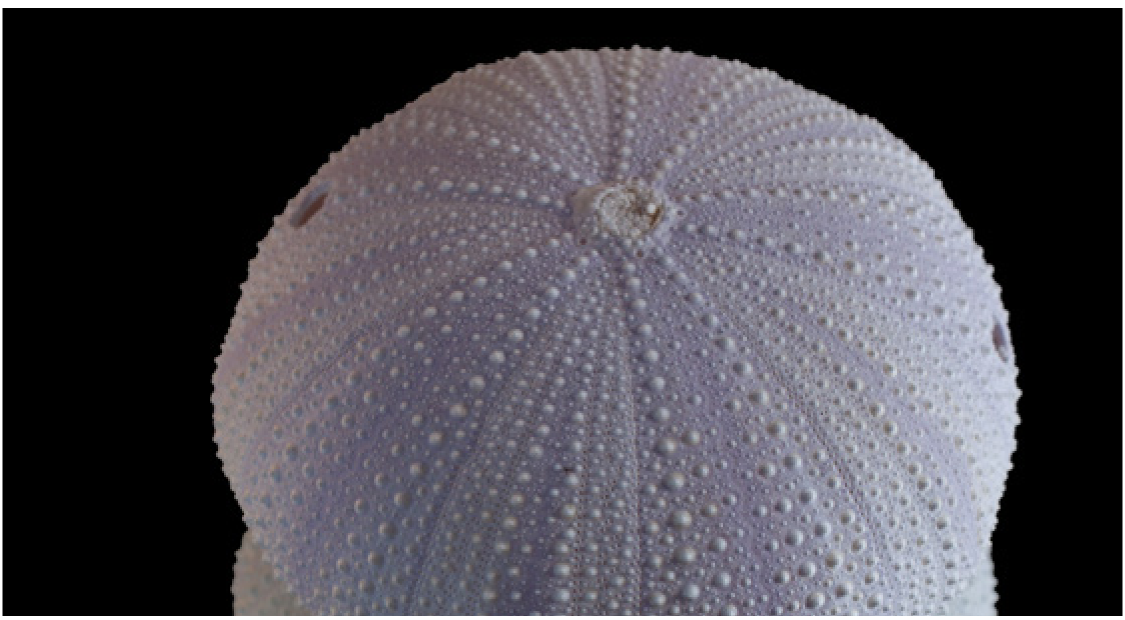
The Sensitive Plant and beetle wings inspired ideas for tuning the light within the Biomimetic Office Building.

Sea Urchin and Brittle Stars

Photo: NEPTUNE Canada/CSSF, 2012 | Flickr cc



Spookfish | Photo courtesy of Tamara Frank | The spookfish has mirror structures in its eyes that focus low-level bioluminescence onto its retina. This led directly to the idea of a large-scale light reflector in the atrium of the Biomimetic Office Building that would bounce light deeper into the lower parts of the building.



Sea Urchin | Photo: Tim Sackton, 2012 | Flickr cc

Biomimetic Office Building, sea urchin: When designing the roof over the atrium, the design team used form-finding software to arrive at an efficient shape that would deliver the same resource-efficiency that can be seen in organisms like sea urchins.

Biomimetic Office Building (aerial three quarter view) | Image courtesy of Exploration

Biomimetic Office Building, perspective of atrium. The entire building system was designed with a biologically-inspired approach by an interdisciplinary team which included biology professor Julian Vincent. Hundreds of different biological organisms were analyzed in the search for new solutions to the challenges of climate control. Exploration claims that, if built, the structure would be almost entirely naturally lit and would be one of the lowest energy expending offices in the world. | Images courtesy of Exploration

Designing With Nature: The vein branching pattern of the Amazon Water Lily (p. 49) inspired the supports for the 3D printed tables provided at the Architectural Foundation exhibition. Soft Kill Option (SKO) software was used as the design tool. Above the table a cabinet of curiosities displays artifacts that inspired the architects either directly or indirectly. | Courtesy Daniel Hewitt and The Architecture Foundation

Designing With Nature | Courtesy Daniel Hewitt and The Architecture Foundation

Designing With Nature | Courtesy Daniel Hewitt and The Architecture Foundation

Designing With Nature | Courtesy Daniel Hewitt and The Architecture Foundation

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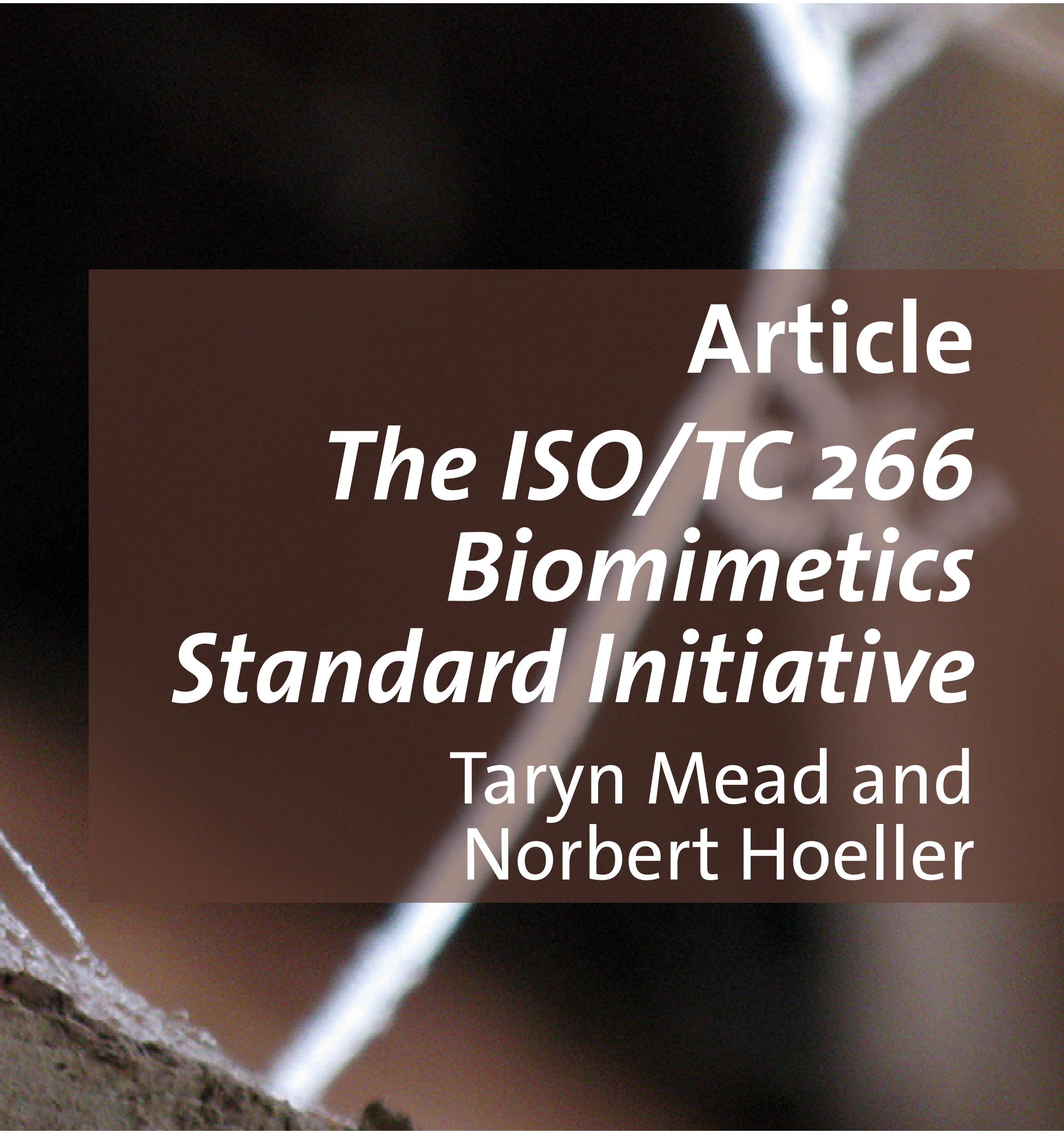
Photo: Emanuele, 2009 | Flickr cc



Article
The ISO/TC 266 Biomimetics Standard Initiative

Taryn Mead and Norbert Hoeller

Biomimetic patent filings have grown exponentially since 1985 [2]. Similar trends have been seen in studies of academic publications across a wide range of disciplines [5]. A 2010 study [3] funded by the San Diego Zoo suggested "biomimicry-based goods and services could account for approximately $300 billion of U.S. GDP by 2025." There are a growing number of significant biomimetic inventions such as SLIPS and commercially available products such as the REGEN Energy™ Swarm Energy Management™ controllers.

In light of this rapid growth in the application of biomimetics around the globe, it seems a natural progression that a standardization process would also emerge as has been the case with many other new innovations and innovation processes. Some countries and organizations have already started creating related certifications in education and biomimetic processes, such as the professional certifications of Biomimicry 3.8 and the process certification of the Verein Deutscher Ingenieure (VDI or the Association of German Engineers) in Germany.

The International Organization for Standardization (ISO) is the leader in developing international standards. ISO was formed in 1947 to "ensure that products and services are safe, reliable and of good quality" across the world. Aside from benefits to the consumer, standards improve business efficiency and "facilitate free and fair global trade." To date, over 19,500 standards have been published through the support and collaboration of 161 member countries. Incorporating bio-inspired principles into its review structure could help biomimetics continue to build momentum in sustainable design and manufacturing but only if the standards represent the range of interests of all affected countries.

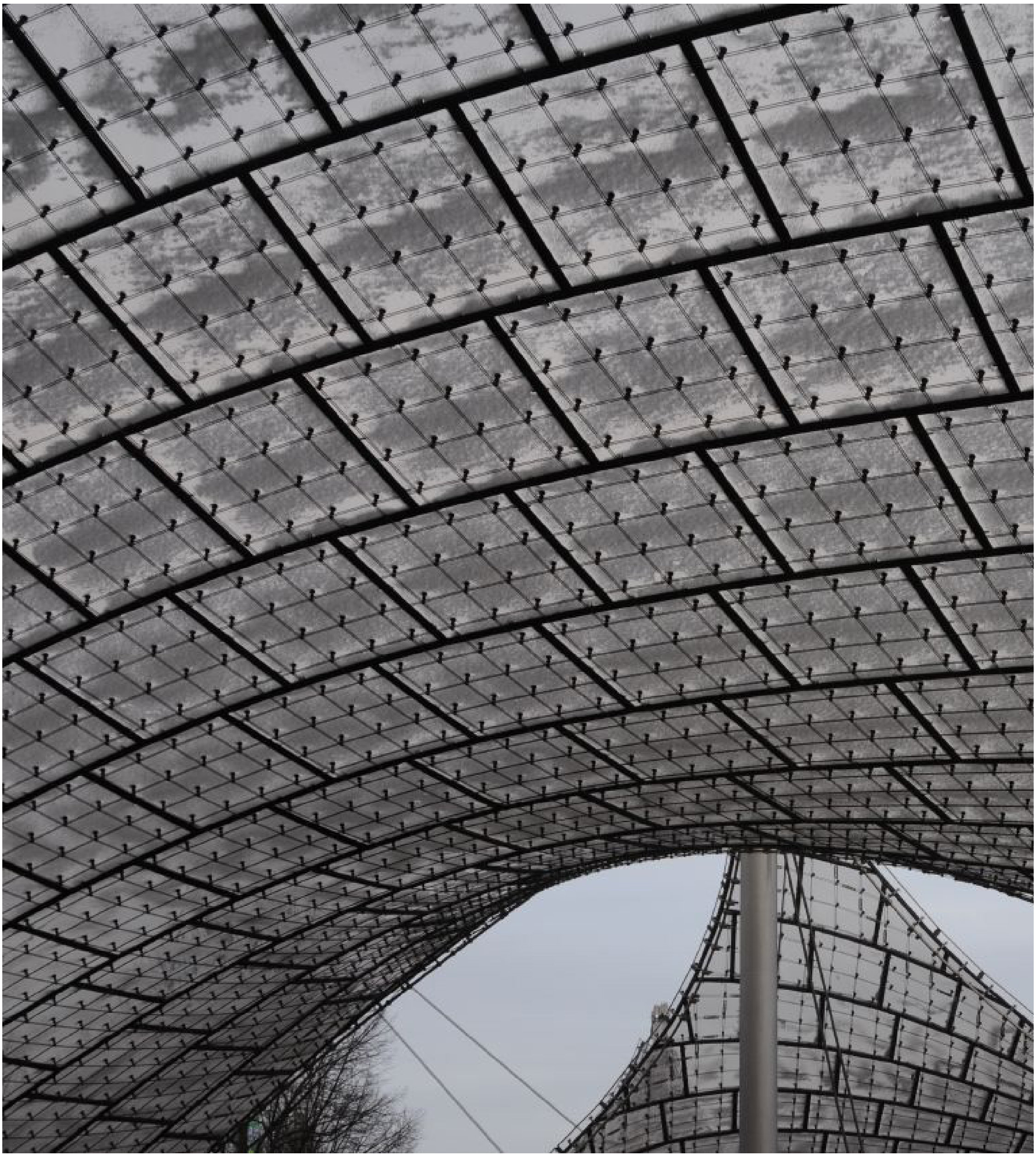
Background of ISO/TC 266

In May 2011, representatives from Germany proposed that ISO form a Technical Committee (TC) with the scope of "... international standardization of biomimetic methods and approaches, incorporating the most recent results of R&D projects." To help launch the initiative, VDI offered to share a number of relevant documents. Key objectives included:

- improving communications through standardized terminology
- describing the potential and limitations of biomimetics in the areas of innovation and sustainability
- facilitating interdisciplinary initiatives that translate biological research into technical products
- improving international cooperation

The proposal was accepted in October 2012 as ISO/TC 266 [1, 6] and three Working Groups were created:

- WG 1: definitions and differentiation from conventional methods and products (based on VDI 6220)
- WG 2: biomimetic materials, structures and components (based on VDI 6223)
- WG 3: biomimetic optimization methods (based on VDI 6224 part 1 and VDI 6224 part 2)



Frei Otto | Munich

Photo: anthony zahner, 2008 | Flickr cc

In May 2013, ISO/TC 266 accepted Japan's proposal to create WG 4 to develop a knowledge infrastructure for biomimetics. The default standards development track for each working group is 36 months from approval to publication with a review every five years, so ongoing engagement from committee members is necessary.

There are currently 10 participating countries (Belgium, Canada, China, Czech Republic, France, Germany, Israel, Japan, Republic of Korea, United Kingdom) and 15 observing countries (Argentina, Denmark, Finland, Hong Kong, India, Iran, Kazakhstan, Malaysia, Netherlands, Poland, Serbia, Sweden, Switzerland, Thailand, United States). ISO/TC 266 meetings have been held in Berlin (2012), Paris (2013) and Prague (2013). The 2014 meeting will be held October 2014 in Liège, Belgium.

Working Group 1 Status

With release of Draft International Standard (DIS) 18458 in April 2014, WG 1 is roughly halfway through the standards development process. The document emphasizes innovation inspired by nature that involves abstraction or

Musmeci 2

Photo: Emanuele, 2009 | Flickr cc

modelling. The focus appears to be on technology products although the boundaries are not explicitly defined.

The Terminology section is more of a glossary with short definitions of selected terms and would benefit from greater breadth and depth along with discussion of the variances in usage amongst different countries. A later section includes a diagram showing the overlap and intersection of various practices related to biomimetics.

WG 1 differentiates biomimetic and non-biomimetic products by applying three criteria (all three need to be satisfied):

- knowledge derived from a biological system (excludes non-biological analogs or similarity on shape alone)
- abstraction from the biological system to a model
- transference without using the biological system

A range of examples are given and further detail is provided in Annex A explaining the reasons for how each example was rated. However, the criteria would benefit from explicit discussion of the nuances involved in applying the three components.

The description of the biomimetic process is based on a fairly generic design model with a smattering of biomimetic-specific content. There are few references to the real-world processes used by biomimetic designers or the range of challenges they face. Vincent, Fish and Beneski [4] argue that differences in context and the constraints on biological evolution can cause significant challenges in biomimetic knowledge transfer, something DIS 18458 appears to discount. Sustainability is mentioned a number of times but with few metrics or clear evidence that biomimetics increases the likelihood of sustainability.

Working Group 2 Status

In June 2014 WG 2 released Committee Draft 18457 that looks at specific examples of biomimetic innovation in materials and structures with extensive charts and tables comparing biological, biomimetic and traditional materials. The process section overlaps that of WG 1 DIS 18458.

Working Group 3 Status

WG 3 released DIS 18459 in April 2014. The goal is to "...familiarize users with biomimetic optimization methods as an effective tool for increasing the lifespan, reducing the weight of components and to promote the widespread use of these methods in support of sustainable development." The underlying assumption is that principles relating to biological growth in load-bearing situations can be analyzed, modelled and abstracted into computer algorithms that can then be applied to the design process. Algorithms described include Computer Aided Optimization, Soft Kill Option, Computer Aided Internal Optimization and Method of Tensile Triangles.

Working Group 4 Status

To date, this working group has not yet published a Committee Draft. The proposal focuses on reducing communications difficulties between the domains of biology and technology as well as improving data accessibility. Activities include:

- developing a thesaurus that links biological and technological terms
- creating a set of rules to encourage fair and open access to existing knowledge (reward systems to encourage opening up of databases and improving quality of data by detailed tracking back to the source)

North American Involvement

Taryn Mead became aware of the ISO/TC 266 initiative when she joined the Business School at University of Exeter as a Marie Curie Early Career Researcher. Although resident in the United Kingdom, her US citizenship prevented her from being part of the UK mirror committee. Unless a country is a recognized participant, the ISO standards development process makes it difficult to obtain detailed information prior to official publication, influence the content of standard and assess the potential impacts.

Until recently, there has been little involvement or even awareness from North American constituents. The US is one of 15 'observer countries' that have limited access and input into the ISO process. The national standards organisations in the US (American National Standards Institute or ANSI) and Canada (Standards Council of Canada or SCC) were approached by ISO in 2011 but neither ANSI nor the SCC was able to make contact with organisations or individuals with the required expertise and resources to participate in ISO/TC 266.

The membership criterion varies significantly for different countries. Each country has unique circumstances for engaging with ISO with varying degrees of formality and costs. In Israel and Canada, for instance, the national standards organization does not assess any fees for individual and organizations to participate in the process, while the costs for some European countries and the US are quite substantial.

In January 2014, Mead contacted ANSI to explore the steps required to get the US engaged as a participating country. In order for the US to participate in the ISO/TC 266 process, a diverse group of stakeholders from business, academia and non-profit organizations must come together to form a 'mirror committee'. The mirror committee can then participate in the aforementioned Working Groups and contribute to the creation of the standards. The process is intended to be open, transparent and participatory for participating countries who would like to be involved, although access to documents by other countries is limited.

A webinar on March 20th assessed community interest - one suggestion from the group was to explore the ISO process in Canada. As in the US, all Canadian interaction with ISO is coordinated by the Standards Council of Canada (SCC), the national standards body that is the Canadian equivalent of ANSI. Similar to the US, Canada requires that a mirror committee be established that has balanced Canadian representation across geography and stakeholder groups. Mem-

British Museum Great Court roof

Photo: Andrew Dunn, 2005 | Wikimedia Commons

Spiderwebs | Photo: JP Hastings-Spital, 2008 | Flickr cc

bers need to demonstrate practical and relevant experience related to the subject. The mirror committee is expected to develop a consensus position on how the proposed ISO standard relates to Canada's national interests. This in turn determines how the mirror committee responds to requests for comments on ISO documents and voting as required by ISO.

To date, the Canadian mirror committee, led by Norbert Hoeller, has representation from five universities (University of Calgary, Carlton University, University of Guelph, Ryerson University and St. Francis Xavier University), five companies (GaitTronics, Hastrich Design, Powersmiths International, REGEN Energy and Whalepower) and three organisations (Biomimicry Alberta, Biomimicry Quebec and the BID Community). A formal proposal to create a mirror committee was submitted to the SCC early in June and was approved, enabling the mirror committee to access over 100 ISO/TC 266 documents.

The fees required by ANSI and other time constraints have limited the ability for the US to participate in the ISO/TC 266 process thus far. The US contingency, currently led by Mead, includes participants from Georgia Tech, Biomimicry Institute, Symbiosis, Biomimicry NYC and San Diego Clean Tech. The team is strategizing about the best organizational structure to enable participation in this effort and seeking leadership from various stakeholders to support the process.

Although North America may be playing catch-up to Europe and Asia in promoting BID at a national policy level, targeted research is underway in numerous academic institutions and a growing number of companies are actively developing or investigating opportunities in biomimetic design. Participation in the ISO/TC 266 will provide North American stakeholders the opportunity to influence the final standards and ensure that North American organisations can effectively engage in this field both nationally and internationally. This involvement can also create opportunities for growing the biomimetics community within North America, building contacts internationally and increasing North America's credibility through demonstrated leadership in the field.

If you are interested in becoming a part of this process in the US, please contact Taryn Mead or in Canada, Norbert Hoeller. ×

Taryn Mead a management researcher, biologist, sustainability strategist and Certified Biomimicry Professional who has consulted with over 30 corporate, municipal and non-profit clients using biomimicry as a tool for innovation and sustainability. She is currently pursuing a PhD in Management Studies, researching Biomimicry for Business Management Innovation at the University of Exeter in the UK. In addition to biomimicry, her research interests include sustainability-oriented innovation, planetary boundaries and the role of corporations in sustainable development.

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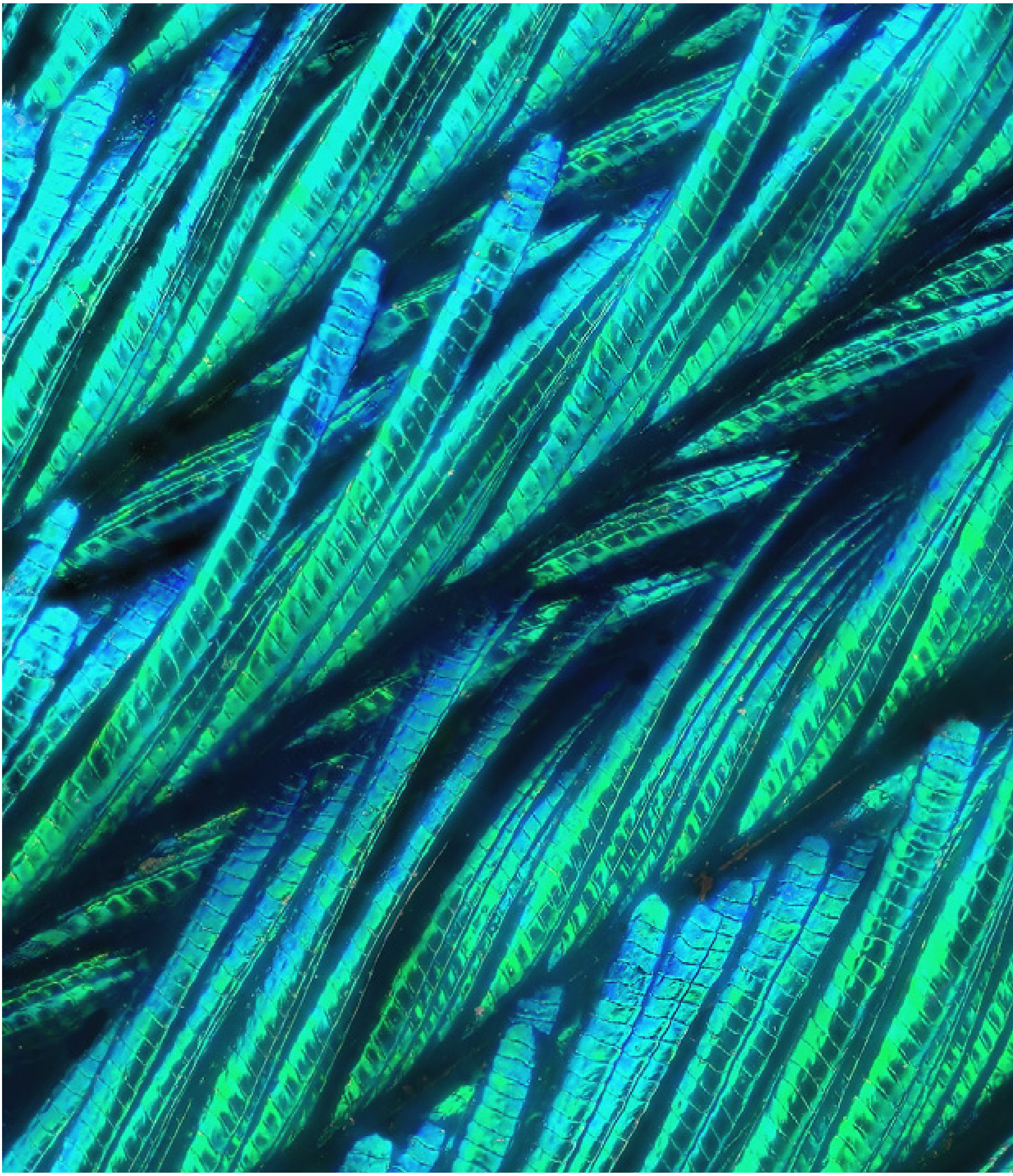
Munich, Olympic Games Tent, View from Olympia Tower

Photo: Detlef Schobert, 2006 | Flickr cc



Peacock feather with microscope lens

Photo: Johan J. Ingles-Le Nobel, 2013 | Flickr cc

People
Interview with
Ray Lucchesi, Tomislav Terzin and Megan Strickfaden

Springs Mountains National Recreation Area - Spring Mountains, Southern Nevada
Photo: Stan Shebs, 2005 | Wikimedia Commons

Interview

Ray Lucchesi

Ray Lucchesi is a Principal with Regenesis who partners with people and their place to regenerate ecosystems and the human spirit. He is an architect, planner, lecturer and university instructor. Ray lives and nurtures both grapes and the soil in Northern California as a means of learning with nature.

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

Based on my experience, biomimicry gets its momentum from biophilia, which helps us relate to nature and reminds us that we are part of nature. Biomimicry shows promise in encouraging us to co-evolve and co-create to mutually enhance both our systems and the natural systems on which we rely for our basic needs. At the same time, the terminology of 'transferring solutions from nature' and a tendency to emphasize 'product' case studies can reinforce our separation from nature. Organizations are now playing with institutionalizing biophilia to leverage workplace and productivity improvements, which can be a good thing at some level, but primarily we continue to develop our built environment without considering how to be in a co-creating and mutually-beneficial relationship with "place".

What do you see as the biggest challenges?

Biomimicry and bio-inspired design processes often work at the level of function, which tends to encourage a focus on efficiency and a mindset of scarcity. This in turn leads to conservation or preservation mindsets which can result in emphasizing the operation or maintenance of systems and prioritizing quantities over qualities and value-adding outcomes. Rather than seeing potential, our actions are limiting our options, or to use the Natural Step metaphor, forcing us further into the narrow neck of the funnel.

Seeing the world through a frame of abundance and potential encourages us to not only seek efficiencies in the operation and maintenance of the system, but also aim to improve the health and resilience of these systems. Learning to be adaptive is essential – we may be the only species that is not moving to higher latitudes or to higher altitudes in response to climate change, a luxury enabled by our prolific use of energy which is a major contributor to that climate change. We need to integrate biomimicry's principles of life into the development process. In addition, we also need to integrate the ecological principles of systems thinking, understand the whole before the parts, see our built places as relationships and not just objects, and consider the context and not just the analysis. As we build our places, how can the capital investment of a building or infrastructure also be intentionally developmental for the people and their community? How can the practice of biomimicry further develop its socio-ecological relationship capability as we leverage the value of learning from nature by being in a co-creating and mutually beneficial relationship with nature?

As a second point to the question, unlike our western culture, many cultures have no word for 'nature' – the concept of being 'outside of nature' simply does not exist in these cultures. The anthropologist and ethnobotanist Wade Davis in his book *The Wayfinders: Why Ancient Wisdom Matters in the Modern World* suggests

Nature Exchange Program, Desert Living Center, Springs Preserve, Las Vegas, Nevada

Photo: Lucchesi Galati Architects

that "the social world in which we live does not exist in some absolute sense, but rather is simply one model of reality." In other words, our cultures hold various views of the world, but no one cultural view is complete.

According to Davis there are about 7,000 languages being spoken on the planet, with each culture's language an expression of, and a way of being a culture, including the way the culture understands its relationship with the world. Davis calls these 7,000 ways of being a culture an "intellectual and spiritual web of life" or an "ethnosphere." Davis also estimates that half of these languages are not being taught to children, which may result in losing half of our languages, and in turn, views of the world - a loss of social-ethno diversity. In simple terms: lose a language lose a culture. According to Davis, today "80 percent of the world's population communicates with one of just eighty-three languages."

I believe that one of the foundational attributes of our species resilience comes from how many lenses or mindsets we hold as a species, and the cultures we often lose are the ones that see themselves as nature, in contrast to western cultures that see nature as external, of which we are not a part. Bio-inspired design will benefit significantly if we see ourselves as nature and work at a bio-being level of relationship.

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

Increasing efficiency is clearly a worthwhile goal but needs to be balanced with actively renewing and regenerating systems. We need to find ways of co-creating or co-evolving with natural systems for mutual benefit. A machine metaphor assumes that entropy rules: everything wears out and runs down. Only living systems can locally generate negative entropy by carefully tapping the constant flow of renewable energy through Earth's systems. The challenge is developing ways of understanding the complexity of nature and then building new relationships within that context. One other thing I would offer is that in order for us to be working at the improving or regenerative level of work, we need to also be developing our potential as human beings.

What is your best definition of what we do?

In the past we have focused on emulating form and process in nature. We have only recently tried to work at the level of systems in an effective and repeatable manner. We can benefit not only from understanding natural systems but also in seeing the human context through the lens of living systems. The journey and the outcome both matter: we need to understand the reason we are intervening and then experiment in ways that maintain the overall integrity of the system.

By what criteria should we judge the work?

Emulation at the functional level lends itself to measurements and the evidence is typically captured through metrics and spreadsheets. Regenerative work is about improving the vitality and viability of living systems (human, social and natural). When a project is based on improving the system (in contrast to operating or maintaining a system), the evidence takes on a long-term temporal and experiential quality and the best evidence is in the stories that emerge. Products and outcomes are still important but need to be balanced with processes and relationships developed through a different way of thinking and connecting. How many capitals (human, social, financial, built infrastructure and natural) and relationships are we improving? What kinds of community-level development are we facilitating that increase health and resilience?

What projects exemplify your approach?

Two projects come to mind. The first is the Springs Preserve in Las Vegas. The site is a 180-acre historic cultural landscape and former artesian springs complex that has been a magnet for wildlife and humans for thousands of years, and was a true oasis in the middle of the Mojave Desert. The site was a major Spanish Trail campsite that was known as "The Meadows" (Las Vegas means "The Meadows" in Spanish).

Desert Living Center at the Springs Preserve, Las Vegas, Nevada

Photo: Lucchesi Galati Architects

Constructed Wetland, Desert Living Center, Springs Preserve, Las Vegas, Nevada | Photo: Lucchesi Galati Architects

The population of Las Vegas in the 1950's was tens of thousands. And by 2010, in less than sixty years, the metro population was about two million people, with 90% of the community's water coming from the Colorado River. The Las Vegas Valley Water District initiated the Springs Preserve project as a way to increase water conservation by the community.

The Springs Preserve is a place-sourced demonstration project to begin to shift attitudes and cultural relationships to become more attuned to its place. Specifically, the project serves to shift a culture from being 'in' the desert to being 'of' the desert. It is also an example of leveraging built and natural capital investment as an investment to increase the community's human and social capability to see themselves as part of their ecological place. The project involved developing a master plan and an interpretive planning process as well as the usual design/build phases. The Springs Preserve is built and operational including a Visitor Center, Desert Living Center and Natural History Museum.

In addition to realizing the functional outcome of delivering seven LEED Platinum buildings at once, the project achieved the higher order of outcomes that the community felt were essential: additional returns in the form of human, social and natural capital. The sub-contractors from the community were introduced to the project goal in a way that allowed them to understand how construction of the buildings positively affected relationships within their community. They demonstrated their appreciation of this broader goal by bringing their families on site to share in the wider aspects of what they were building.

The Springs Preserve became an important place to visit for a community of about two million people. It will take years to assess how this increase in social capital will impact the community's relationship to nature. The national and global press attention that the project received affected Las Vegas' brand identity and social capital by raising important questions about how Las Vegas as a community is beginning to shift its relationship with the desert. This project alone cannot erase the popular image of Las Vegas but can encourage other developmental projects that increase co-evolution of physical structures, social relationships and natural systems.

Lastly, a constructed wetland serves as the wastewater reuse treatment system for the Springs Preserve. Another part of the site was also developed into wetlands by redirecting a "nuisance" flow of surface runoff water. Bird species visiting this new wetlands area increased from two to 200 bird species, including the sighting of a pink flamingo, rare outside of the casino.

The other project is the Middle Kyle Canyon (MKC) Gateway Project in the Spring Mountain National Recreation Area in Southern Nevada. The US Forest Service and the Southern Paiute Tribe partnered in the project with an aim of a place-sourced leveraging of an increase in natural capital to also increase social and human capital and renewed relationships with the land. Both partners had an aim of regenerating a socio-ecological relationship with the land. Biomimicry 3.8 participated in the project and conducted a "Genius of Place" process to deepen the appreciation of the strategies of how life was working in this ecological place.

This project involves development of a 90-acre site including visitor services and educational buildings that are currently under construction. The Springs Mountains interpretative planning process to incorporate the landscape into the transformational goals was woven into the planning and design processes for site and building development.

The Forest Service and the Southern Paiute had different priorities on how they wanted to leverage the land. For the USFS, they wanted to leverage the experience in the forest to foster a shift in visitors from recreation to ownership and partnership. For the Southern Paiute, their aim was to leverage the landscape to help them save their language and their culture. The Southern Paiute language is part of the ethnosphere, the web-of-life languages that Wade Davis is concerned we are losing.

The project provided an opportunity to change how the Forest Service perceived their role, their relationship with visitors and how the visitors related to the forest. The site has particular significance to the Southern Paiute Nation who has a relationship with the place as part of their creation story, and an ongoing part of their culture.

For the Forest Service, the project created opportunities for building a partnership with the Las Vegas community that traditionally sees the forest as a place for recreation. The Forest Service wanted to leverage the experience of being 'in the forest' to help move the community towards ownership, stewardship and partnership in the operations and management of the forest with the ultimate goal of transformative shifts in organizations and people through a renewing

Springs Mountains National Recreation Area - Spring Mountains, Southern Nevada

Photo: Stan Shebs, 2005 | Wikimedia Commons

Middle Kyle Canyon Gateway Project Site - Spring Mountains National Recreation Area, Southern Nevada

Photo: US Forest Service

and reciprocal relationship with the Spring Mountains.

For the Southern Paiute, the project represented a pathway for the Tribe to re-engage the mountain so that the youth would learn the Paiute language and re-engage the Tribe to this place. In their cosmology and belief structure, the Spring Mountains is an integral part of their creation story, and the mountain only knows Paiute. If no one is talking to the mountain in Paiute, the mountain will die. Over time if the Paiute youth cannot speak Paiute, they could lose their culture. As with the Forest Service, the tribe had a goal of a transformative shift in their people and their relationship with this place.

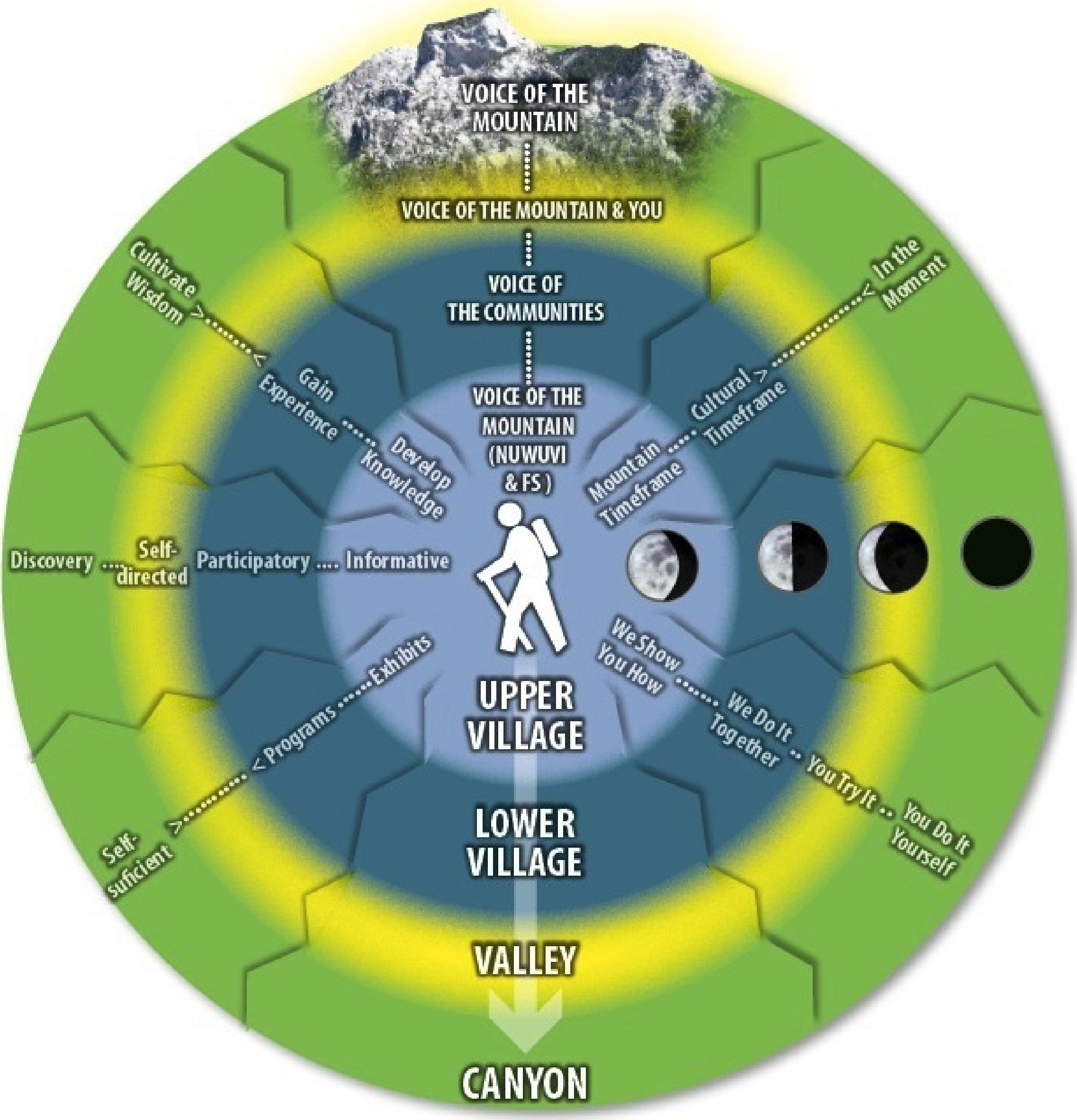
Both the Forest Service and the Southern Paiute Tribe saw this project as a means to achieve a higher order of outcomes that were essential to the vitality and viability of their organizations and culture. For the Tribe, this project was an investment to help them retain their language and consequently their culture. Evidence of this shift will take time to be revealed, often through subtle signs.

One interesting aspect of this kind of work is that whether an organization or community understands "why" the project is being built is a powerful influence on the viability of the project and its ability to increase human, social and natural capitals. In additional to the usual metrics of on-time and on-budget, it is important to assess if the project is still "on-purpose" and leveraging all the capitals so that the project achieves its potential.

As an example of how "on-purpose" works, well into the planning and design process the Forest Service cut the project budget in half. Normally that kind of reduction is difficult to achieve without significantly impacting the quality of the project. Not so in this project. It was easy to achieve the cuts by eliminating a portion of the visitor services building because the essential transformative experience (shifting from recreation to partnership, helping a Native American culture to survive) is in the landscape, not the building.

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

A good portion of my career was spent practicing architecture in the Mojave and Sonora desert biomes – I love nature and have always preferred passive design approaches. In the 1990s I was on step six of a 12 step program moving away from architecture as building 'things' to architecture as a way of building relationships. In one sense I was already well on the way to integrating biology, sociology and anthropology into an architectural design process when I came across Janine Benyus' book *Biomimicry*. I was very attuned to the book's message – nature has been a highly adaptive system that has thrived for 3.8 billion years by building and benefiting from a complex web of relationships. Biomimicry has created opportunities to broaden my personal contacts and relationships and to think more deeply about how we can be in stronger relationships with nature and also humans. We need to encourage and build on loving nature so that we can build capabilities to actively care for nature, which implies nurturing and regeneration. We need to move from "making place" to "improving place" that renews



Tiers of Experience Mandala, Spring Mountains National Recreation Area, Middle Kyle Canyon Gateway Visitor Experience Report, Southern Nevada

Image: AldrichPears Associates, Lucchesi Galati Architects

ENCOMPASSING THEME

The Spring Mountains are alive – we sustain and renew each other.

SUBTHEME 1 – A PLACE OF CONSTANT CHANGE:

The Spring Mountains host a constant and dynamic dance between cultural and ecological factors, despite the appearance of stability.

SUB
A GATH

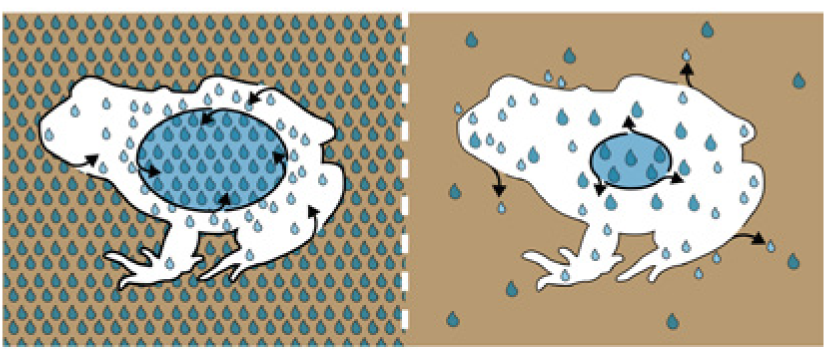
For past
this day,
the Spri
sustain life

Tying the Place Together

The Patterns of Place and Genius of Place collectively assess social and environmental histories. Together, they allow us to foster relationships for a sustainable future for all species by designing as nature might.

Transitions

The Patterns of Place reveal that the Spring Mountains are a place of many transitions – geographically, biologically and culturally. The Genius of Place highlights many organisms that have mastered various transitions, as evidenced through behavioral and physiological adaptations. For example, although most toads are not adept at surviving in the desert, the red-spotted toad is one of the few organisms that can expand its bladder to considerable size during wet times to store the water it absorbs through its skin. During dry times, it can then pass water directly through the bladder membrane into the rest of its body to cool its skin through evaporation.



Cooperation

Cooperation is an additional pat
Place. It evokes a discussion of p
partnerships and simply giving b
this place are found to excel at c
example is the piñon pine, upon
in a convoluted food web. This w
that eat tips of pine branches, th
(when they hide them), and eat
spores are spread in their scat, w
pines.

THEME 2 –
ERING PLACE:

millennia and to
people gather at
ng Mountains to
, relationships and
culture.

SUBTHEME 3 –
A PLACE OF REFUGE:

The unique physical, ecological and geographic conditions of the Spring Mountains create a refuge for specialized plants, animals and an indigenous culture, and today provide an escape from the urban environment for recreation and spiritual renewal.

SUBTHEME 4 – THE
POWER OF PLACE:

The Spring Mountains landscape inspires stewardship, exerting a profound influence on those who know it and allow it to know them.

tern revealed by the Patterns of
romoting community, fostering
back. Champion organisms of
ooperation. One exceptional
which multiple species depend
web includes ground squirrels
en eat and plant the seeds
all the symbiont fungi, whose
hich inoculates the host piñon

Renewal

The Spring Mountains serve as a place for human cultural and spiritual renewal and as a place to which organisms retreat seasonally. Physiological adaptations include the ability for an ephemeral wildflower to emerge once a year, going from seed to seed in a very short time. Behavioral adaptations include that of Clark's nutcracker. This bird accomplishes cyclical renewal by returning to the same spot every year. It buries seeds from the Great Basin bristlecone pine and has an exceptional knack for remembering where it planted the seeds the prior season. This bird renews the pine population by planting its seeds in extremely rocky terrain that is not very suitable for seeding without intervention.

communities at the social, cultural, economic and natural context.

What is your favorite biomimetic work of all time?

In terms of my favorite work that has occurred in my lifetime, I am impressed by Peter Steinberg's research on understanding the critical role of biofilms and identifying novel and potentially important applications. Unfortunately, it appears that he was not able to continue with his work, which underscores the challenges of a funding and financing model that focuses on narrow outcomes rather than the ecology of innovation. In terms of my favorite of "all time", probably the egg. Oh, and by the way the egg came before the chicken, since egg evolutionary technology is older than chicken evolutionary technology.

What is the last book you enjoyed?

Positive Development: From Vicious Circles to Virtuous Cycles through Built Environment Design by Janis Birkeland.

Who do you admire? Why...

Anyone who chooses to make a difference in their community in a way that builds capability in their human, social and natural capital of their place as they also realize an increase in the invested financial capital. When one chooses to engage their place as a living system, and they invest their time and resources in relationship to their place across the capitals, they build capability in their community and in themselves. In turn, returns increase across the various capitals, and not just in more built or physical community. An effective financial return on invested capital is essential for vital and viable communities, but if we do not also invest in and integrate all the capitals into building our communities and improving our places, the vitality, viability and quality of life we seek in our places cannot be sustained.

If you could choose another profession or role, who/what would you be?

I have not left architecture in the strictest sense, and believe I still practice architecture, but do not seek work that results in only a building or infrastructure. I have shifted my emphasis from the physical and functional outcomes, to an emphasis on the human, social and ecological developmental potential in the project. Who I am becoming seems to be attracted to projects that are complex and involve working at all levels of value, not just on-time and on-budget, but also on-purpose, and seeking to realize the potential the project holds. I don't know what to name this state of being, but at Regenesis we call ourselves Regenerates. ×

Previous page: *Encompassing Themes and Subthemes*, Spring Mountains National Recreation Area, Middle Kyle Canyon Gateway Visitor Experience Report, Southern Nevada | Image: AldrichPears Associates, Regenesis, Lucchesi Galati Architects

Patterns of Place, and Genius of Place Integration, Spring Mountains National Recreation Area Middle Kyle Canyon Gateway Visitor Experience Report, Southern Nevada | Image: Biomimicry 3.8, Regenesis, Lucchesi Galati Architects

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Las Vegas Springs Preserve

Photo: Roxanne Ready 2012 | Flickr cc

The detail of an elytron (wing case) of *Chrysina spectabilis*, a member of *Rutelinae* sub-family of beetles from Honduras. *C. spectabilis* has unique golden depressions on its green wing cases. The diversity of surface design among 400,000 species of beetles seems to be almost limitless. | Photo courtesy of Tom Terzin

Interview

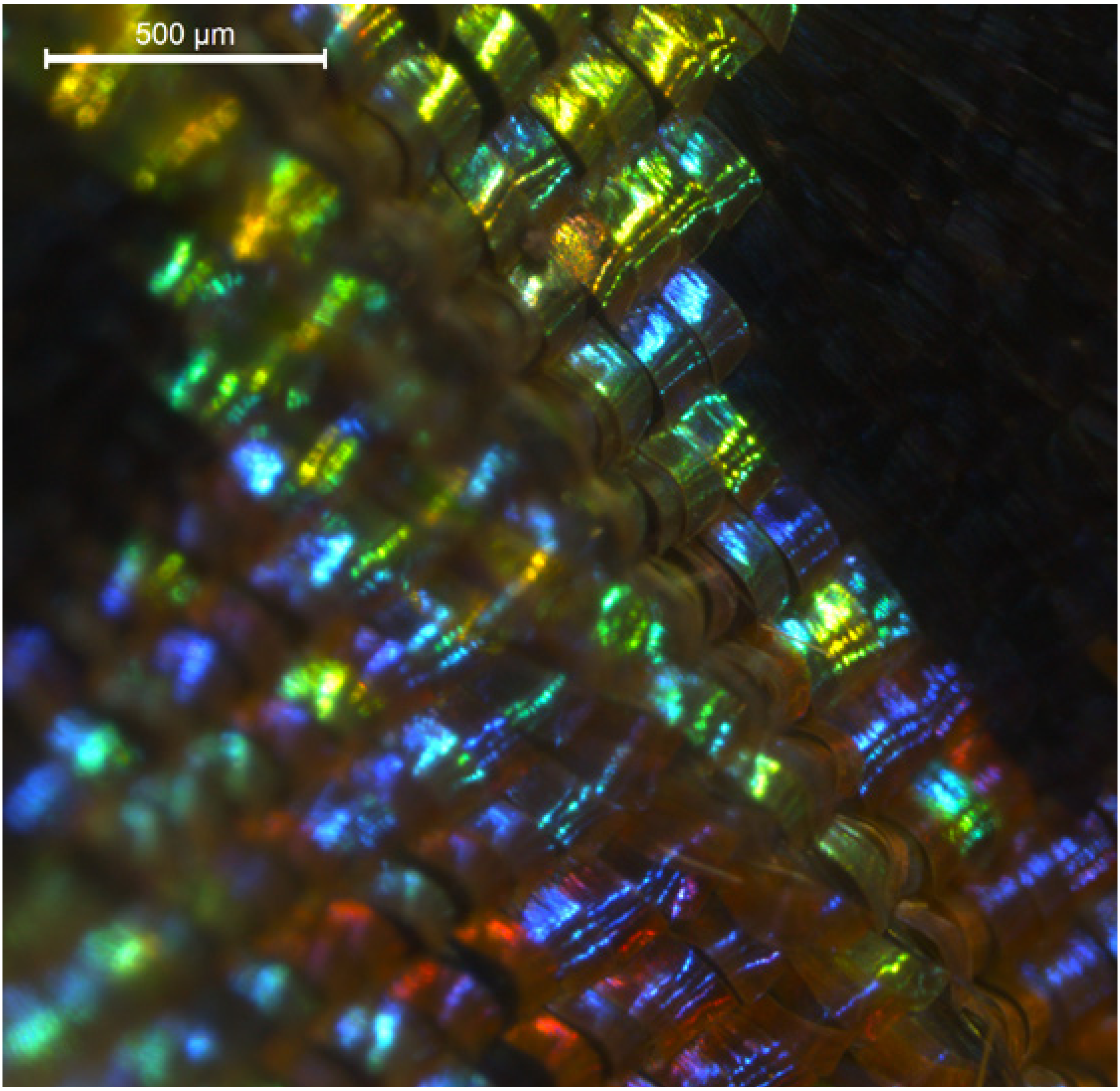
Tomislav Terzin and Megan Strickfaden

Dr. Tomislav Terzin is an assistant professor of biology at Augustana campus, University of Alberta. He was born in Serbia in 1971, where he completed a Bachelor of Science degree in molecular biology and physiology at the University of Belgrade. From 1996 to 2001 he was a researcher at the Institute of Molecular Genetics and Genetic Engineering in Belgrade. In 2001 he immigrated to Canada with his wife Nevena. In 2003 Tomislav completed a Master of Science degree in zoology and in 2007 he received a PhD from Western University in London, Ontario, while working on the development of parasitoid wasps. His most significant scientific work was published in the journal *Nature* in 2004 (*Nature*, 432: 764-769). In 2008 he joined the Biodiversity institute in Guelph, working on insect DNA barcoding. In 2009 Tom joined University of Alberta, where he teaches genetics, developmental biology and the evolution of development (evo-devo). His current research is in the field of colour pattern formation in butterflies and beetles and the evolution of mimicry. He conducts interdisciplinary collaborative research with Dr. Megan Strickfaden on using biological colour patterns as inspirational sources in textile design.

Megan Strickfaden studied anthropology, people-centred design and sustainability at the University of Alberta (Canada) where she obtained a BA specialization with a double major in Art & Design and Anthropology and an MDes in Industrial Design in sustainable design practice. Dr. Strickfaden obtained her PhD in Humanities & Social Sciences from Napier University (UK) with a study investigating potential sociocultural influences on the design process and the cultural milieu of design teaching environments. Prior to completing her MDes, Dr. Strickfaden worked for 12 years as a designer with various firms in Canada. Since then she has engaged with many industry collaborations towards innovative product development and as a result holds several patents. She has taught design for over 20 years at 7 different design schools in the USA, UK, Europe and Canada. Dr. Strickfaden's research involves numerous international collaborations and continues to investigate sociocultural complexities within educational and professional design environments. Specific projects include exploring the sociocultural capital of designers and design educators, influence and inspiration in the design process, design for/with people who are disabled, and design of products for specialized markets such tactile paintings for people who are blind and clothing for protection from steam and hot water. In sum, Dr. Strickfaden's work is both applied and scholarly, where she is involved in product development and in expanding knowledge, particularly in the area of supporting health, safety, wellbeing and quality of life.

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

T: There is a large and growing community of researchers in biomimicry. My impression is that many researchers involved in biomimicry are not aware of their involvement, or were not aware until a certain point. It seems that the field of biomimicry is self-emerging from many areas of research. Through different forms of communication people sooner or later realize: "hey, I am a part of this!" That happened to me. So, to publicly communicate the basic concepts of biomimicry is essential for further advancement. Another impression I have is that the biomimicry movement is a giant who is not aware of its strength. With more structured organization and worldwide networking, biomimicry has a potential to become one of the most influential



The detail of the ventral wing surface of a sunset moth *Urania ripheus* from Madagascar. This species of day-flying moth is arguably one of the most beautiful insects. Dark wing scales contain pigment melanin while metallic ones produce structural colours. While pigmented dark scales are flat to efficiently absorb light, metallic scales have completely different morphology, being bent and looking like aluminum foils. The curvature of metallic scales produces amazing optical effects reflecting light in different directions. This particular species was used as an inspirational source for textile design in our research project. | Photo courtesy of Tom Terzin.

factors of global progress. Research-wise there is a huge ocean of natural inventions on all levels, from molecules to biosphere, which wait to be applied for the good of humankind. I would say we are only at the beginning of one long and exciting development. And as with science in general, I cannot see the end. It seems to me that nature is an unlimited source of usable ideas.

M: Since becoming aware of biomimicry in 1999 I feel that the field has evolved considerably. There are many more scholars and practitioners working in the area, concepts have evolved and been defined, and there is a great deal of diversity in the 'things' that have resulted from biomimicry and bio-inspiration. Naturally, the internet has aided in spreading the word about biomimicry.

What do you see as the biggest challenges?

T: I have a bit of an unorthodox understanding of living nature. I look at it as a mechanism, a very complex one. I see nature as a complex natural technology which is beyond individual human comprehension, but can be understood step by step through the joined endeavor of millions of humans, through the enterprise we call science. The technological character of living nature is so advanced and on such a miniature scale that it was not recognized as such until recently when the advancement of human technology moved us toward the nanoworld. Scientific tools are a part of the overall technological advancement and such tools have allowed us to see the biological macromolecules in action. Molecular machines are everywhere inside living cells of all organisms, from bacteria to humans. There are machines which replicate the DNA molecule, machines which harvest light energy in green plants, molecular walkers which transport molecules to their precise locations within living cells etc.

Based on this new knowledge, I see two main challenges in the field of biomimicry. The first challenge is theoretical: in order to reproduce natural technology, we first need to see it, to admit it and to accept it as such. Many scientists refuse to see or to think about biological life as a manifestation of very advanced technology.

The second challenge is practical. At the current state, biomimicry mostly reproduces the macro-aspects of life. An example is a chair with a built-in backbone for additional support or adopting general principles that we have learned from eco-systems. The increasing trend of the application of nano-technology in biomimicry is encouraging, but even on that nano-level we play with simple materials in order to achieve extraordinary features seen on the surface of biological entities like the gecko lizard adhesive setae or metallic butterfly wing surface mimicked by materials which will be used for personal documents or money bills because they are difficult to be forged. The real challenge, however, is to be able to design molecular machines in a way living cells do. Once we become technologically capable for such deeds, that will be the beginning of a new chapter in human history that will bring unimaginable changes in human society and everyday life. The ultimate challenge is to make artificial life, or self-replicable machines.

There is one very pragmatic challenge: how to convince oil, plastic, car and military industries

Research on colour patterns 1

Photos courtesy of Tom Terzin and Megan Strickfaden to voluntarily stop making a profit by the destruction of our planet and to switch to clean and sustainable technologies. They do have money and even knowledge to do so. I wonder, did anyone nicely asked them to stop? Maybe they would? I have no better idea than to try to educate people who are in charge that what we do on a global scale is suicide. I believe that we all love our children and grandchildren, and that we all, no matter how rich or poor we are, would like to leave a habitable planet to them once we are gone.

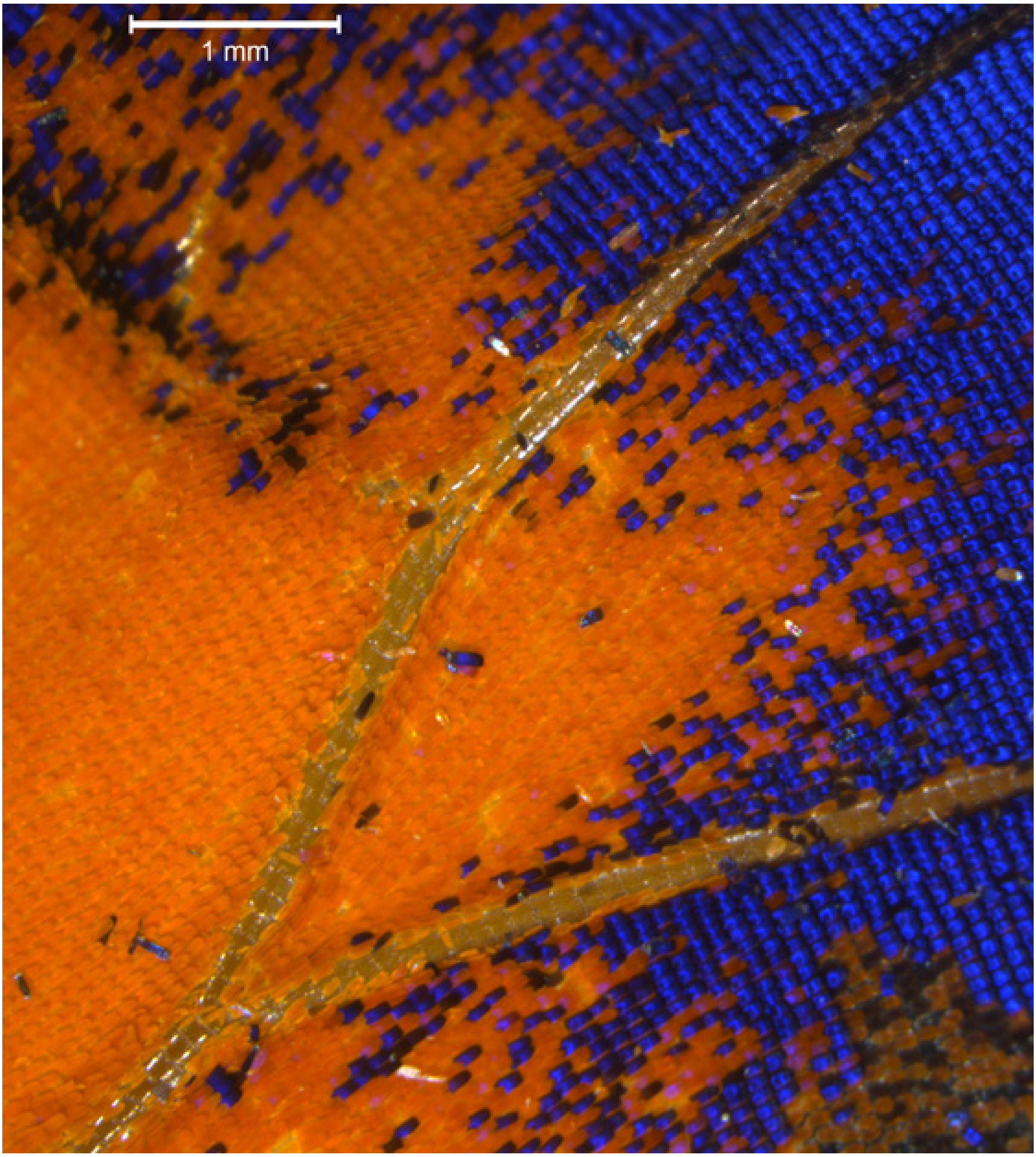
M: The biggest challenge I see about biomimicry is in how it is perceived and defined. I feel that everyday people don't really understand what biomimicry is. They relate the term to bionics or other more mechanically-based concepts. The term biomimicry is clear to someone like myself, but in teaching design I find that students really don't connect with the term. I've heard comments like: "is it engineering?" or "is it about robots?" which I think is interesting because these ideas are almost contrary to the very things that biomimicry is trying to bring forth. In terms of how biomimicry is defined, I find that the definition is still pretty wooly. It has helped considerably to add the term bio-inspired, which aids in clarifying what it is. Therefore, one of the biggest challenges is how the general public perceives biomimicry and how it is defined within the academy. There is still work to be done on identifying clear concepts to fit with the terms and perhaps even to expand the terminology by being very focused and specific.

Another challenge for the field of biomimicry is in the limitations of technology. I believe that over the past few decades there has been a focus on technology solving the issues of the world. I believe that this is not the case, and this needs to be expressed to young designers and scholars so they will seek various solutions including those that are technology-based and those that are not.

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

T: It is not correct, and fortunately it is not possible to limit the freedom of the human spirit and to force biomimicry research in a certain direction. However, at the same time, the world is facing big challenges, and I believe that the most useful and ethically justified direction biomimicry should advance towards in this moment is the one which can help us to solve or at least to reduce some of global problems. I believe that we should focus on development and world-wide application of clean sustainable technologies based on efficient recycling of matter and clean energy production in a way natural eco-systems work.

M: I believe that biomimicry as a field needs to continue to focus on the creation of things that relate to health, wellness and safety. These kinds of products are for niche markets, however, these are the products that make a big difference for people. This attitude harkens back to design innovators like Victor Papanek, who, in my opinion is one of the first people to work in biomimicry. Papanek's unfailing dedication to create things that really mattered to people, society and humanity is very admirable.



Butterfly *Agrias amydon furniere*. Detail of the ventral side of the upper wing. Preformed insect wings resume their full size very quickly, when adult organism emerges from a pupa. Hollow tubes (veins) visible on the image like Y shape structure, temporarily accept large amount of body fluids using hydraulic pressure to spread the wings. After few hours fully grown wings dry, and fluids return into the body. This technology could be used for assembling large flat surfaces previously being packed in a small volume. As in all butterflies and moths, the wings are covered with microscopic scales. Blue colour is produced as an optical phenomenon (structural colour) while orange is deposited pigment. These two very different types of wing scales somehow have adjusted colour tints and shades in order to maximise the contrast between orange and blue. | Photo courtesy of Tom Terzin

Research on colour patterns 2

Photos courtesy of Tom Terzin and Megan Strickfaden

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

T: As a child I was a bug collector (as I am today). Since toys were expensive, I used to play with bugs as if they were tiny robots. And that is exactly what they truly are! Insects are amazing self-replicating natural robots and that early realization was my ticket to the world of biomimicry. But it was a long way from the observation of natural technology to the participation in the biomimicry community and research. Recently, as a newly hired assistant professor at Augustana campus of University of Alberta, I met the right people and with Dr. Megan Strickfaden got involved in the interdisciplinary research on colour patterns. This year I also joined the advisory board of Biomimicry Alberta in order to become more active in biomimicry.

M: My interest in biomimicry and bio-inspired design began in 1999 when I 'bumped into' Janine Benyus' book. I was studying 'green design, eco-design or sustainable design' which was a topic that was very controversial at the time. Benyus' book opened up a world of ideas for how to continue as a designer when I felt as though the marriage of design to business was a huge failure. It provided a philosophy that I could relate to, especially when it came to considering ecologies, networks and learning from nature. Whether that learning from nature is directly related to the design of things or the relationship of things within a system, this way of thinking resonated strongly with my lines of thinking. These interests in biomimicry have influenced the way that I think about design processes, particularly the complexity of how designers design. This complexity is not unlike the complexity of nature.

What is your best definition of what we do?

T: We rightfully steal ideas from nature, and apply them in human technology and design, in order to improve the quality of life and the sustainability and health of our environment.

M: Scholars and practitioners in the field of biomimicry look to nature to explore, describe, explain, critically analyze or create things in built world.

By what criteria should we judge the work?

T: We should judge the work based on the consensus-definition of biomimicry we adopt. For example, if we go with the above definition, good work should be based on one or more natural inventions and would have positive application with a neutral or positive impact to the environment and with a low risk of misuse. Unfortunately, our species is adept at the misuse of things rather than the use them for good, so the obligation of those who develop new technologies is to think ahead about the possible consequences. All biomimicry work should be low risk.

M: Judging work is always a challenging thing. When we make judgments we are creating a frame of reference that is more about the judger than the judged. That being stated, biomimicry and bio-inspiration is best judged by considering the source (what aspects or things of nature) that is applied/referred to in the development of the new concept or thing. If the source and outcome are placed together, then there is a space to consider that thing or idea that is new.

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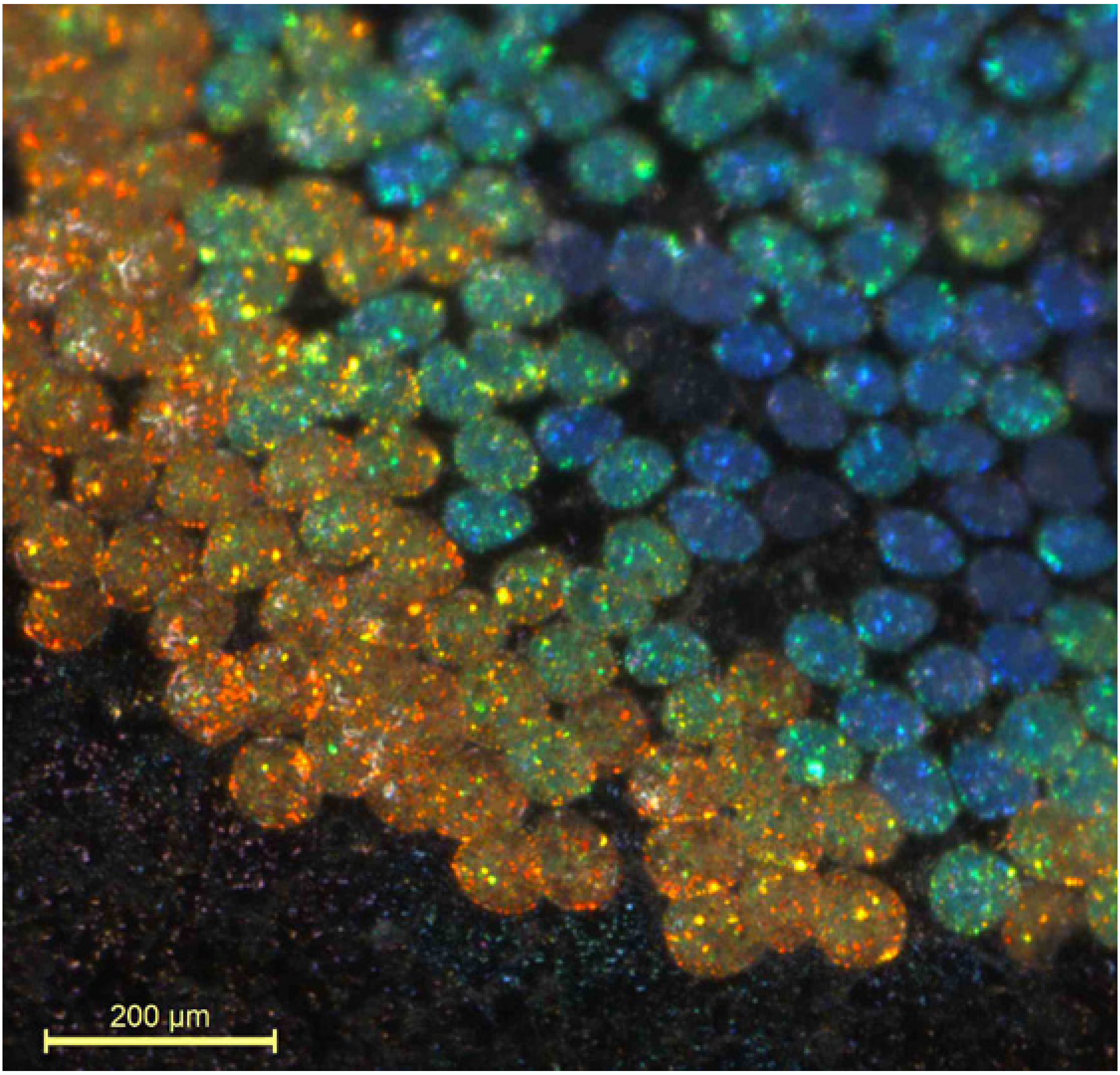
People:
Interview

Authors:
Tomislav Terzin and Megan Strickfaden



The detail of an elytron of weevil beetle *Eupyrgops sp.* from Philippines. The surface of these beetles is decorated with microscopic scales which reflect metallic colours. Unlike in butterflies, these scales are of round shape and thick, resembling tiny shields. This particular species belongs to a mimicry ring where several unrelated or distantly related species share similar patterns to signal their unpalatability to potential predators. Notice that the scales of various structural colours are organised in concentric rings forming a pattern similar to false eye of a peacock feather. | Photo courtesy of Tom Terzin

What are you working on right now?

T: I'll leave it to Megan to say more about our research. Beside bio-inspired design, I study actual mimicry in insects and teach developmental biology at Augustana. Being a developmental biologist, I find the name of your journal quite interesting and symbolic. For sure, it is a right place for one developmental biologist to be!

M: I have a number of projects on the go, which is not unusual for me. I am a scholar with a background in being a designer and as such I continue to design things while exploring sociocultural concepts that are significant to being a design practitioner. My interests are in influence and inspiration, which is deeply linked to the philosophy of biomimicry. In my scholarly work I look at sociocultural issues that are often marginalized in society such as disability and sustainability. I believe it is important for designers to understand pertinent issues, particularly those that are intrinsically part of society and require acknowledgement. I think it is particularly important to take my findings back to design educators in order to influence future generations of designers. One of the projects I have recently worked on is the Textile Designer's Inspiration from Nature project with Dr. Tom Terzin and Lesley Stafiniak. In this project we tracked the ways that designers use nature (biological specimens) towards textile designs. This project provided some incredible insights into the creative process whereby it is understood that designers use sources of inspiration at every part of the design process and that sometimes the final design does not have any attributes related to the original source. Design projects that I have been involved in developing in the past few years are clothing to protect from steam and hot water, tactile paintings and an accessible metro. In particular, the metro was seen as a network or system with many nuances and complexities that can be related to nature. When considered this way, it was much easier to make it accessible for people who are blind and visually impaired.

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

T: From the very beginning of my professorship in 2009, I was looking to all possible venues to make use of my research collection of tropical insects and seashells. Being a biologist, but also an artistic soul, I was opened to interdisciplinary collaborations with artists and designers. I met Megan at a new professors' orientation in Edmonton, exchanged ideas with her and that is how it started. In that time, I was not aware of the biomimetic aspect of our collaboration. I was focused on the application of biological patterns in textile design, not trying to classify the nature of that research. It was when I met a PhD student of design, Carlos Fiorentino, who was deeply involved in biomimicry, that I actually realized that what Megan and I do qualifies for what biomimicry/bio-inspired design stands for.

M: I began as a design practitioner creating things that considered the environment as a factor, meaning that I used methodologies of production, deconstruction or recycling that would be better for the environment than counterparts in the past. For instance, I designed a solar panel that had only 16 parts compared with ones with 100s of parts. Following this I began to think about design processes relative to nature and investigated factors that were under-explored by other researchers. For example, I looked at how designer's backgrounds related to the design process. In this way, I was looking at the design process not as a closed system but as an open system that had ambiguities and extreme nuances. Then more recently I looked at inspirational sources (bio-inspiration)....and so the story goes.

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

T: The discovery of a biological gear mechanism in the leaf hopper (see this issue's case study). Usually in biomimicry we copy natural inventions, but for the gear mechanism we humans proudly claimed "copyrights" not being aware that the gear mechanism also exists in nature. So this is a rare case where we invented something not watching how nature does it, but later found it in nature. The garden leaf hopper uses a gear mechanism to interlock its hind legs when jumping. That ensures that both legs give propulsion at the same time, producing maximum thrust. Amazing stuff!

M: I still think that one of the best examples of bio-inspired designs are the development of artificial prosthetic limbs. The so-called "Cheetah Leg" also known as the flex foot is an incredible design that moves humanity into a different realm. Imagine an artificial limb that out performs human legs...this is the flex foot limb. This is a design that not only changes the way a person moves, it also changes the way that people in society view that person. Now, a person with a disability can be seen as powerful, strong and almost superhuman. How cool is that?

What is your favorite biomimetic work of all time?

T: Leonardo da Vinci's work on the flying machine. Although Leonardo was not successful in designing a flying machine, I think there is no better and more obvious example than watching a flight of a bird, or a dragonfly, and trying to imitate it with a mechanical machine.

M: Classics are great! To be honest, I still love the Victor Papanekian and Buckminster Fullerian products....

What is the last book you enjoyed?

T: *The Nature of Technology* by Brian Arthur. There are many books about particular technologies, but it is very difficult to find a book, which deals with the nature or essence of any technology. I highly recommend this book to all who would like to gain a better understanding of what technology is. That knowledge is useful for biomimicry since in one or another way many of us apply our findings in some sort of technology. Since my thesis is that living nature is a highly sophisticated, self-replicating technology, I naturally wanted to see what the definition of human technology is in order to make a comparison. At this point, I am not going to reveal my conclusions but I am looking forward to an eventual ZQ article on that theme.

M: There are many, many books that I've enjoyed in the past month, but I will choose one that I believe is incredible. The book is: *The Black Book*

A detail at the border between upper and lower right wing of a large *Fulgoridae Homopteran Phrictus sp.* from Costa Rica. Unlike in butterflies and moths, pigments in these wings are injected in between two layers of the wing membrane like a tattoo. The number of veins (tubes) is much higher, and their network is way more sophisticated than equivalent structures in butterfly wings. Many wing fields are completely enclosed by veins to prevent diffusion of pigments. Butterflies do not have such need since their pigments are contained in the scales. | Photo courtesy of Tom Terzin *of Colors* by Menena Cottin and Rosana Faria (2006). This book describes color tactilely for sighted and non-sighted readers and is aimed at children, but is fabulous for all audiences. It articulates color as it relates to the natural and human-made world. I find this book very inspirational because it pushes the status quo of ability and questions how the world is defined.

Who do you admire? Why...

T: Undoubtedly Carl Sagan. He was an excellent scientist, a better writer and an even better educator and public proponent of science and the application of scientific skepticism in society. He is my role model in many ways. But even he was not perfect and made some obvious errors (not many), like his famous statement that: "extraordinary claims require extraordinary evidence." What is "extraordinary" for one person is a subject of brain chemistry, not objective reality, therefore the statement is empty. But he was only a human, and I simply love him. He was a planetary scientist and arguably an astro-biologist. As an educator he made a huge positive impact and was an inspiration for one entire generation of scientists worldwide. His TV series *Cosmos* was broadcasted in Yugoslavia when I was a child. He is, and always will be, my greatest teacher.

M: Professor Tim Ingold for bringing movement, the dynamic, and temporality to the forefront of anthropological studies.

What's your favorite motto or quotation?

T: "If you wish to make an apple pie from scratch, you must first invent the universe" - Carl Sagan in *Cosmos*.

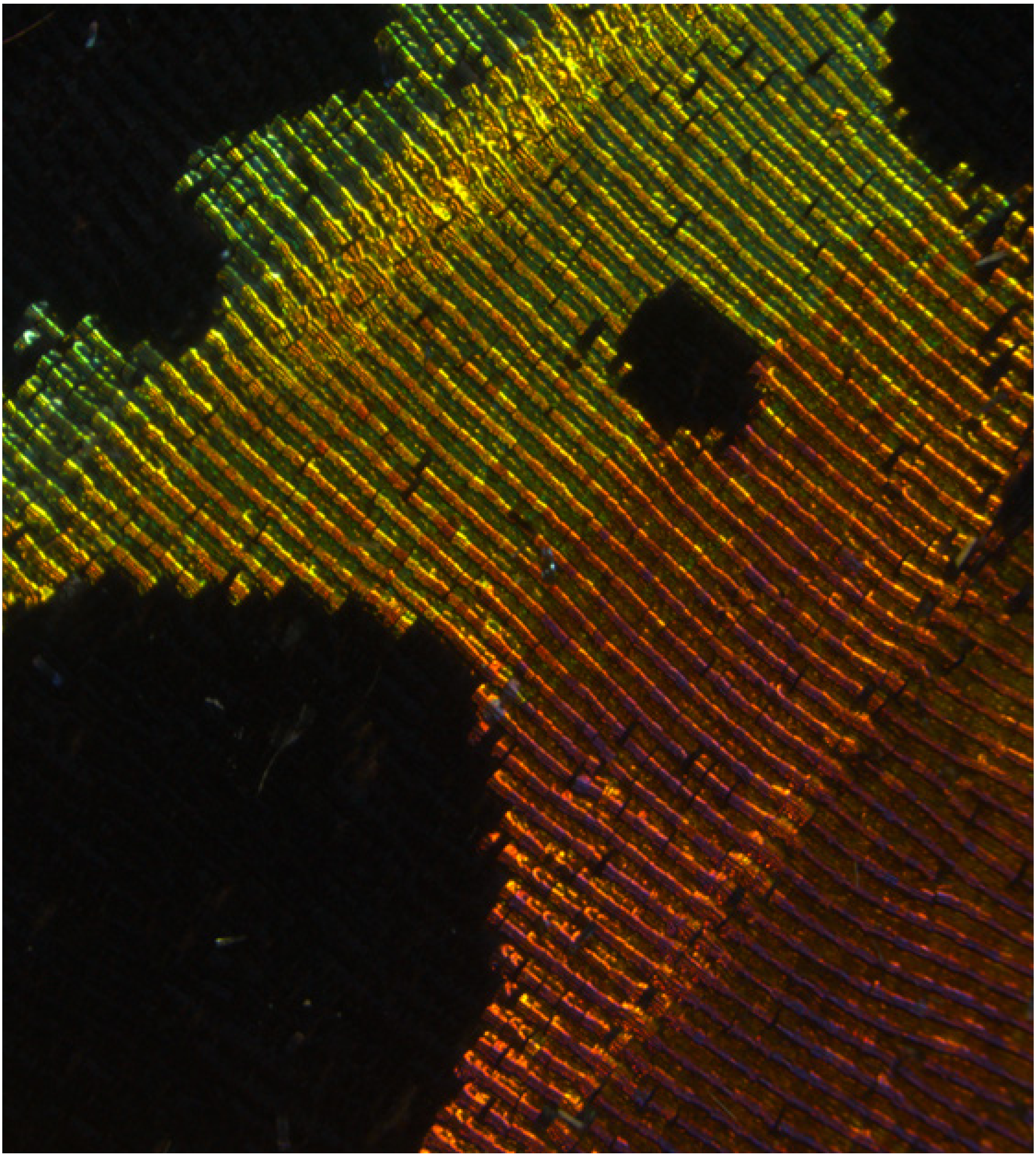
Sagan is reminding us that we all just play with already made matter and energy. We can even turn one into another in nuclear reactors, but we cannot make it out of nothing, and even if we could do it on a small scale in CERN or Fermilab, by that act we still would not set the physical laws which allow the making of an apple pie, because it also requires space, time, the Solar system and life. As a biologist, I can tell you that we do not possess the knowledge to make even a single apple cell from scratch. I think entire book or even books could be written based on this Sagan's quotation. Truly remarkable.

M: "It's not the destination, it's the journey" - Amanda Marshall, songstress, from Ralph Waldo Emerson "Life is a journey, not a destination."

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

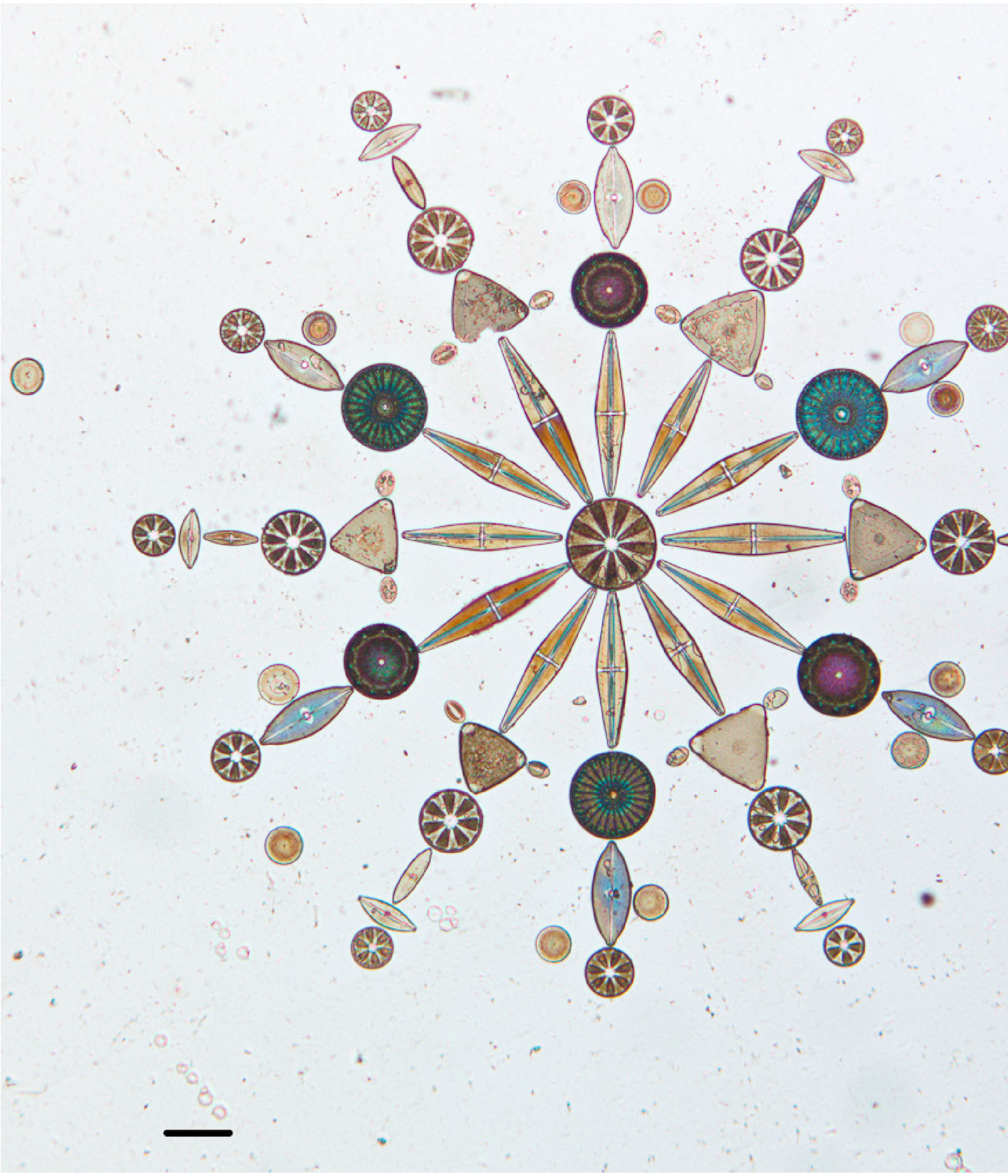
T: I would be an artist, making paintings of the natural world or a writer writing novels that explore the deep meaning of life. In both cases I would be very hungry because the world recognizes only pragmatic values, and in most cases art becomes a pragmatic value only after the death of an artist.

M: I would be a nanny. Children are pure, creative, true to themselves, love to learn, free to explore, say what they see, and view the world as inherently beautiful. Who wouldn't want to be surrounded by that all day long? ×



The detail of the dorsal wing surface of a sunset moth *Urania ripheus* from Madagascar

Photo courtesy of Tom Terzin



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Photograph of diatoms arranged on a microscope slide by W.M. Grant, 2013 | Flickr cc

Book

The Systems View of Life: A Unifying Vision by Fritjof Capra and Pier Luigi Luisi

Reviewed by Janet Kübler, Michelle Y. Merrill and Randall Anway

vol 3 | 2014

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The Systems View of Life: A Unifying Vision by Fritjof Capra and Pier Luigi Luisi

Fritjof Capra, *Lawrence Berkeley National Laboratory, Berkeley, California*

Fritjof Capra is a founding director of the Center for Ecoliteracy in Berkeley, California, and serves on the faculty of Schumacher College (UK). He is a physicist and systems theorist, and has been engaged in a systematic examination of the philosophical and social implications of contemporary science for the past 35 years.

Pier Luigi Luisi, *Università degli Studi Roma Tre*

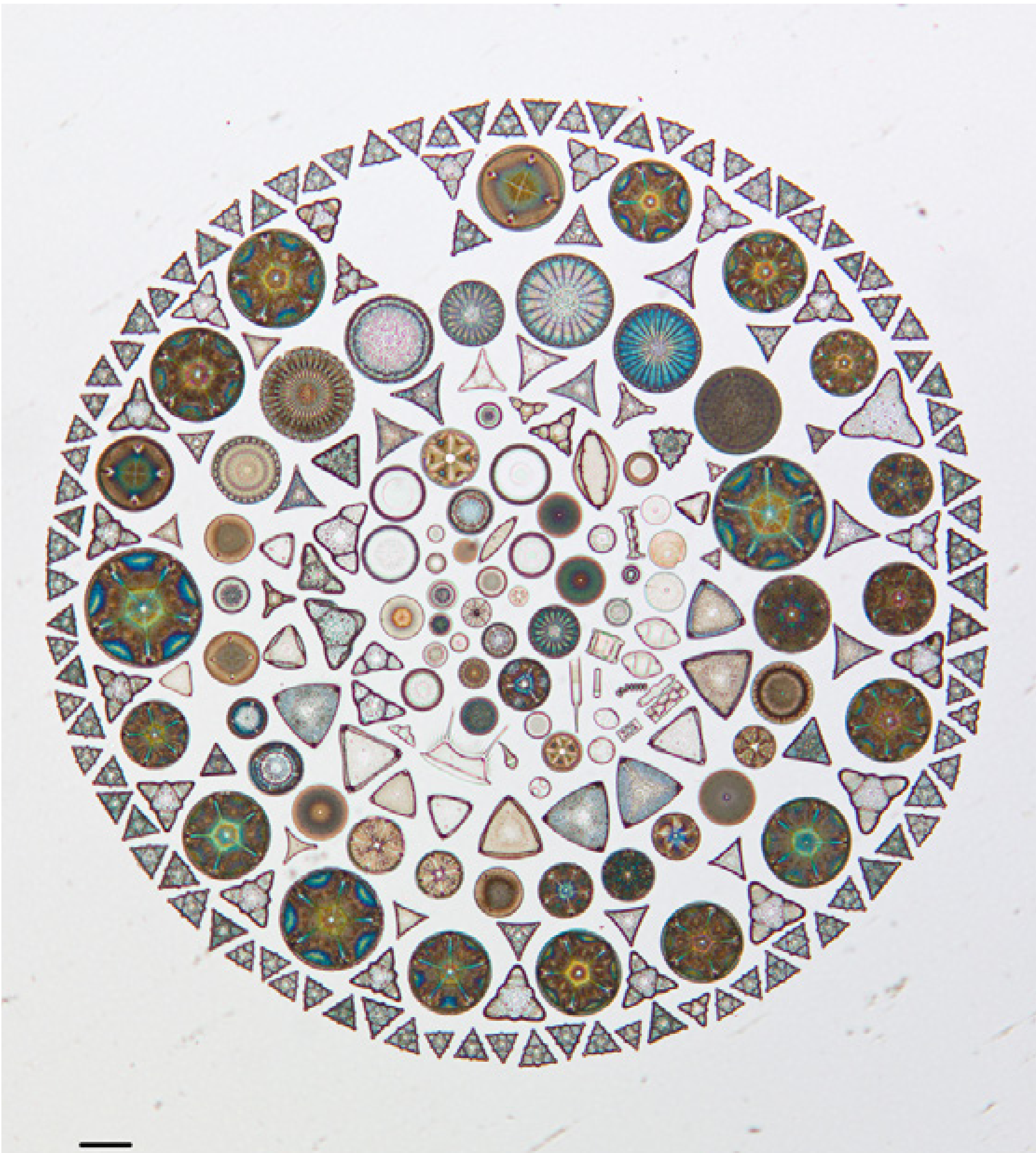
Pier Luigi Luisi is Professor in Biochemistry at the University of Rome 3. He started his career at the Swiss Federal Institute of Technology in Zurich, Switzerland (ETHZ) where he became full professor in Chemistry and initiated the interdisciplinary Cortona-weeks. His main research focuses on the experimental, theoretical and philosophical aspects of the origin of life and self-organization of synthetic and natural systems.

Keywords: complexity, networks, cognition, systems biology, history of science, science and spirituality, evolution

Fritjof Capra has described his latest book as "... a multidisciplinary textbook that integrates four dimensions of life: the biological, cognitive, social and ecological dimensions... [and] discuss[es] the philosophical, social and political implications of this unifying vision." It is an interdisciplinary conversation between polymaths that defies easy categorization. The authors have the admirable ambition of providing a landmark synthesis of systems thinking and convincing the world of its utility for addressing some of our most complex challenges. Time will tell if they can build enough critical mass willing to turn concepts into practice and deliver on the promise.

According to the publisher's notes, this book is intended for undergraduates, graduate students and researchers "interested in understanding the new systemic conception of life and its implications for a broad range of professions - from economics and politics to medicine, psychology and law." Although appealing for those willing to undertake a discipline-specific intellectual journey, the wide-ranging technical language can make it difficult to adopt as a textbook in most university curricula. Excerpts could be used in the classroom setting but the book's holistic journey through the connections between traditional fields is most beneficial taken as a whole.

While no single-discipline scholar will feel satisfied that their subject has been sufficiently covered, the strength of the book is in linking diverse ideas. In our review we have looked beyond



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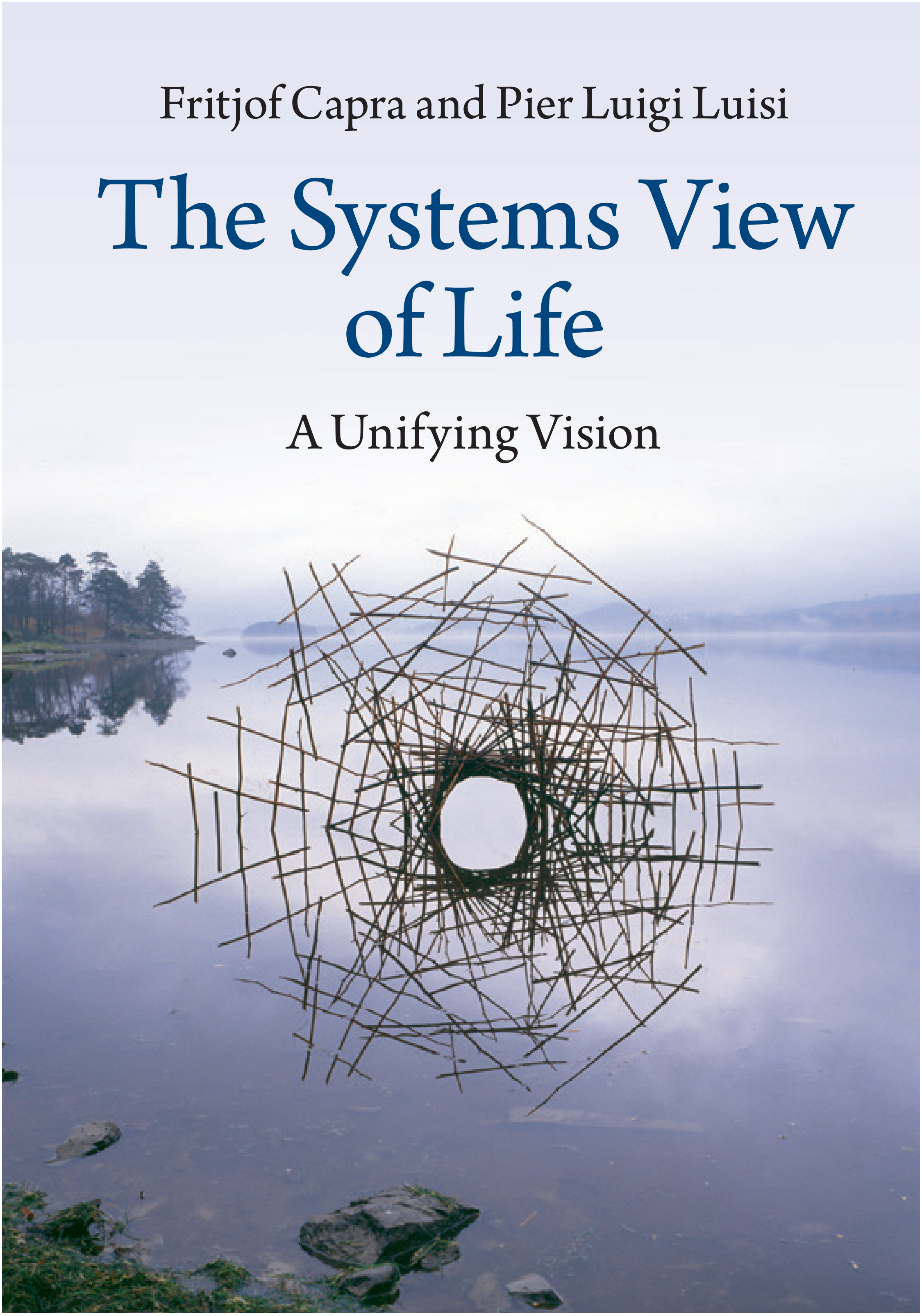
Photograph of diatoms collected in Russia and arranged on a microscope slide in 1952 by A.L. Brigger, 2013 | Flickr cc



Cover *The Systems View of Life: A Unifying Vision* | Courtesy of Cambridge University Press, 2014 the book's value as an academic platform and explored its structure, interpreted key themes and how they relate to each other, and then applied systems criteria from the book to itself. This was done partly to test the utility of its concepts but primarily to communicate our observations.

Structure

The book is organized into four sections:

I. The Mechanistic Worldview

II. The Rise of Systems Thinking

III. A New Conception of Life

IV. Sustaining the Web of Life

The authors provide the backdrop for discussing the character and implications of a unifying view of life integrating biological, cognitive, social, and ecological dimensions. They do this by mapping the development of the predominant worldview on phenomena of life from the Scientific Revolution and Newtonian physics, through Keynesian economics and management theory, to general systems theory and nonlinear dynamics.

Roughly half the book (over 200 pages) is devoted to explaining a view of life that includes both its prebiotic origins and scientific attempts to model it. This brings up many engaging questions, from what makes us human, to what the mind is, to the nature of health and more.

Capra and Luisi argue that the systems view of life enables us to ask detailed and principled questions that reveal the structure and functioning of diverse networks and communities. This shift in perception is exhibited in a review of leading edge practices currently found in management, healthcare, ecology and economics. By increasing our ability to read and respond to complex webs of relationships we become better able to scientifically formulate concepts of quality in complex systems.

The authors suggest that the role of such conceptual formulations in economic and political critiques is central to realistic discussions of how to redesign webs of relationships and overcome systemic problems in a manner consistent with an ethic of ecological sustainability. Many emerging proposals and alternatives to predominant academic, business, and government structures are discussed. The rationale and emerging impacts of these initiatives are described in comparison to activities that lack the systems perspective.

The book falls short of expectations in places upon closer inspection of the component parts. Several chapters did not have the right balance of accessible language and sufficient depth, particularly when viewed as introductions to the diverse fields of study. Moreover, some lacked current references and ideas from the discipline. Chapter 8, "Order and complexity in the living world", has a potentially daunting amount of jargon and diagrams for those with limited experience in chemistry. After an admirable discussion of the contingent nature of evolutionary outcomes in Chapter 9, the authors slip into more deterministic and linear metaphors regarding human evolution in chapters 10 and 11 ("The quest for the origin of life on Earth" and "The human adventure"). Much of chapter 11 neglects important findings and debates in evolutionary anthropology in recent decades such as the contexts for the evolution of tool use and bipedalism. The final chapter relies on references more than ten years old regarding genetically modified crops, despite an explosion of new data on herbicide resistance in weeds and the effects of herbicides on animals. While the book was written in a rapidly changing landscape of scientific ferment, the authors might have included a wider range of more current voices.

Yet the chapters are not the book, as the parts are not the whole. More interesting than these individual chapters are the themes that run through them.

What the book is about: Major Themes

Woven into the linear structure of the book are recurring themes that highlight the authors' intentions. How important themes are revealed across chapters seems more illuminating to us than the individual chapters themselves. Below is a look at the coherent ideas that form the links between the book's components and a map of the book as a whole rather than a dissection of its parts. We will examine the interactions between these themes in the subsequent section.

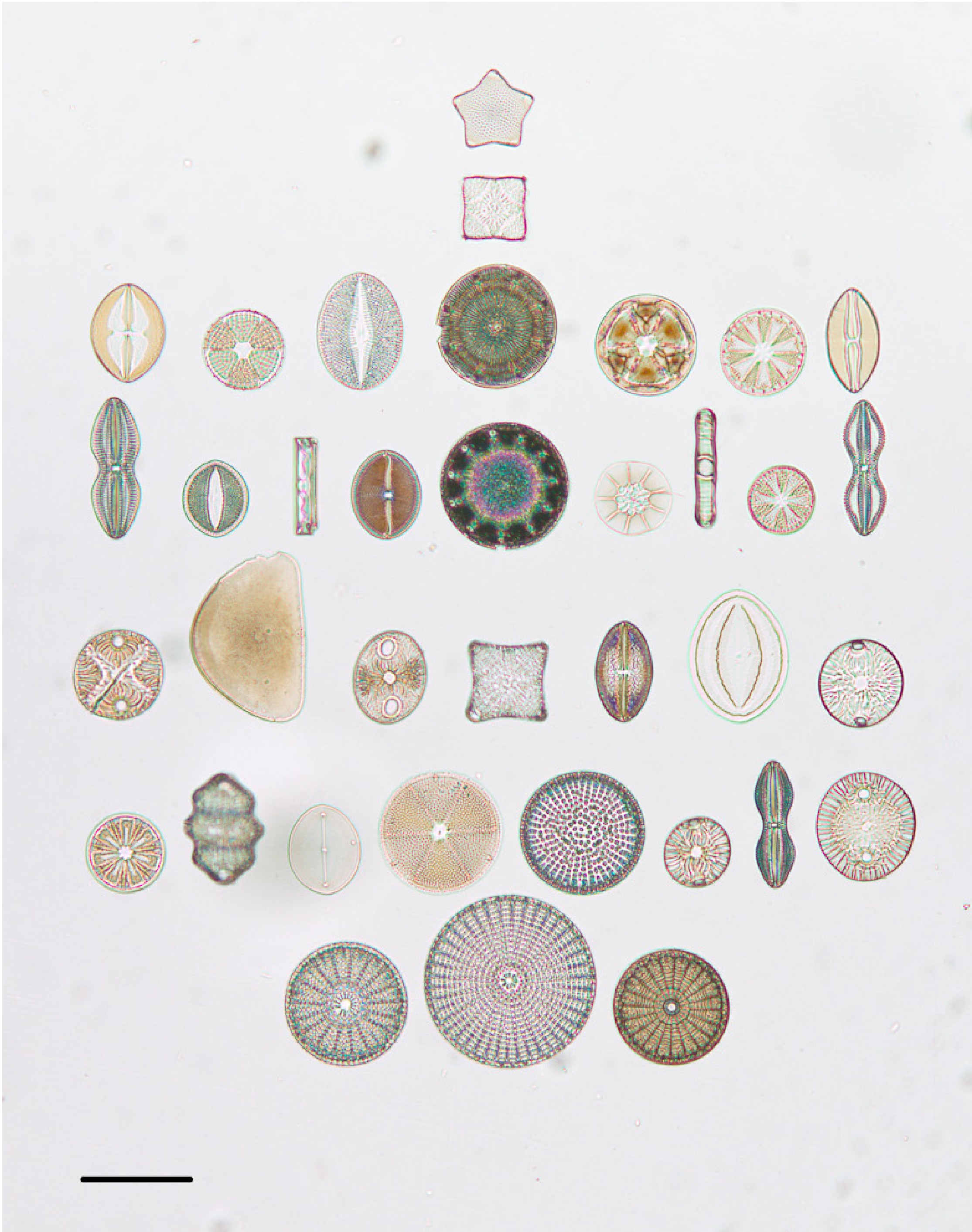
Progress in Science

The book allots much space to progress in science. The first quarter of the book details the rising competition between the mechanistic and systems views. It outlines the emergence of scientific methods and makes the case for expanding the application of systems approaches. The authors cover a lot of territory, starting with a review of science history and progression over roughly the last half-millennium examined through new eyes: a physicist converted to an entirely new interpretation of physics and a biochemist studying the origins of life. The progress made over the last three decades suggests that scientific and other communities have begun to transcend the boundaries of outmoded, mechanistic thought and to shift toward dynamic systems paradigms. Tracking the limitations and strengths shown in prior scientific thought provides a potent backdrop for the main arguments for an emerging synthesis.

Making Sense of Complex Systems

The authors define an emerging 'systemic conception of life' through a comprehensive synthesis and discussion of foundational principles, patterns, and exemplars. They indicate landmarks in a long progression of thought away from a 'mechanistic worldview' toward the systems view. While thoughtfully examining root causes of our current global situation, they develop a new synthesis through drawing upon a wide-ranging bibliography. This synthesis involves four key scientific dimensions of human life: biological, cognitive, social and ecological.

On complexity theory and non-linearity, Chapters 6 and 8 address fundamental concepts with a smattering of mathematical ideas. In practice, these tools are used to describe and predict patterns in living systems and hence are essential elements of the systems view. They also help distinguish the systems view from the mechanistic paradigm which appears insufficient for fully understanding the complexity of living systems. Too schematic for a rigorous course, these chapters offer primarily a qualitative introduction to an important field.



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Photograph of diatoms arranged in October 1974 on a microscope slide by R.I. Firth, 2013 | Flickr cc

According to the Santiago theory of cognition, information is encoded throughout the structure of living organisms as they continually self-organize (the process of autopoiesis, or 'self-making'). The developmental and metabolic processes of any organism can therefore be considered a form of cognition, storing knowledge about how the organism interacted with its environment in the past, in a way that will affect the responses of the organism in the present and future. This interpretation of the cognitive dimension is foundational to the authors' portrayals of all complex living systems, from their envisioning of the earliest proto-cells to their views on ecological and social interactions within and between species.

The relevance of the systemic conception of life to the complexity of global civil society is brought to the forefront in Chapter 17. When considering human social networks from this complex perspective, the authors acknowledge systems level work in science, management, and healthcare - systems facing multiple crises. They further recognize that humans often do not behave predictably according to natural laws (as was asserted in the mechanistic frame).

Important distinctions are drawn between living systems and machines. In the realm of organizational management, the authors note a corresponding conceptual shift of the exercise of power, which involves the role of meaning in social autopoiesis. Touching on Etienne Wenger's 'communities of practice,' a qualitatively different approach to management is outlined. Earlier references to the work of Arne Naess on 'deep ecology' also help connect spirituality to the ecological systems perspective. A key insight is that the essence of the authors' shift in thinking involves feeling connected with the web of life, which has important implications for recovering essential meaning in all sciences and professions.

Perceiving the 'Reality' of Our Current Situation

Underlying this novel integration are two essential elements of thought: the mathematical tools of complexity theory and collateral insights about non-linearity in living systems, and the notion of autopoiesis in cognition. The authors integrate these elements with the assertion that all biological systems are inherently cognitive. It is only through cognition that human beings (e.g., scientists, managers, medical professionals) can 'spiritually' appreciate the order in the complexity of living systems. That is, appreciate it as an expanded 'self' embracing life-preserving and life-furthering values and be able to address crises from within an appropriate conceptual framework.

The authors also attempt to illustrate how failures to think systemically have led to many of the crises that currently plague us. For instance, the rising price and declining satisfaction with the American health-care model can be attributed in part to prevailing mechanistic and reductionist models of health and illness. These excessively narrow models, according to the authors, result in ever more expensive diagnostic and treatment procedures that neglect mind-body interdependence (as demonstrated by the well-documented but poorly understood 'placebo' and 'nocebo' effects) and the many economic, environmental and social benefits from lifestyle changes that promote wellness.

Ethical Action, Spirituality and Deep Ecology

Ecoliteracy and "the profound interconnectedness of all phenomena," central features of the philosophy known as 'deep ecology', are recurring themes throughout the book. There is an especially important section on the spiritual dimension of education in chapter 13, an audacious but essential chapter on the tension between science and spirituality. The authors conclude by proposing broader education to bring forth a new generation of world leaders, critical for profoundly transforming academic institutions and predominant social values. The main perspective of this reformist vision seems to be a spirituality carefully distinguished from religion and just as carefully connected with a philosophy of consciousness and deep ecology: the systemic 'conception of nature' or 'view of life'. According to the authors such a philosophy forms a basis for ethical action and in essence affirms the legitimacy of the activist scaffolding described in the final chapters of the book.

Integrating Complexity as a Practice

After a 'grand tour' through the history of science and systems and a fairly comprehensive synthesis of an emerging integration of physical and life sciences, the authors discuss the application of this new integrative view in the book's final section.

The potential for a comprehensive practice of systemic understanding exists in clusters of challenge- and task-oriented organizations offering system-level solutions to global issues. Details of the solutions offered by various NGO's in the cognitive, social, and ecological dimensions of the systems view are discussed. The authors outline some of the crises in numerous global systems and discuss proposals informed by systemic thinking for addressing energy, climate change, poverty, population, technology, and economic structures. They also address the politics of sustainability. From their perspective, the roots of the current global situation are deep and systemic, and the implications far reaching. A more-sweeping-than-detailed reformist agenda is described at length. Their proffered solutions and examples from around the world include agroecology, industrial ecology, generative ownership, ecodesign, biomimicry and other applications of 'whole-systems' structures and processes deeply connected with the web of life.

While this palette of solutions demonstrates that conceptual and technical hurdles can be cleared, "ecologically literate leaders, capable of thinking systemically" are needed in centers of power in order to move toward a sustainable future. In the end, the answer to such existential questions is perhaps not one of mechanistic certainty, but of living hope.

A Systems View of Life* *Through a Systems Lens

We find it useful to view this book itself as a system. We use its authors' list of the characteristics of systems thinking as a framework to reflect on the book and to see how well these criteria are met by its contents.

Shift of perspective from the parts to the whole

A careful dissection of the book will reveal flaws in many of its component parts. It is only when regarding the book as an interacting whole that its importance and usefulness becomes evident. Readers will likely be familiar with classical system dynamics and concepts like fractals, chaos and simple systems. They are less likely to have considered the connections to cognitive science, spirituality and health. The whole, here, is enormous, and the individual subtopics do pale in comparison. The authors give an unusually humanistic and historical perspective on system dynamics that provides context to the ways systems thinking can be applied to diverse problems.

Inherently multidisciplinary

The authors present a multidisciplinary journey through time and across silos of the traditional fields of physics, biology, cognitive science, social sciences and philosophy to reach a systemic view of human ecology. What sets this work apart from other ecosystem-focused environmentalist texts is the large section on cognitive philosophy and human spirituality beside the "hard science" view of systems. The brave and ambitious breadth of this book may be the most important thing it has to communicate, and provides an eloquent sketch of how that might be accomplished.

From objects to relationships

Capra and Luisi are constrained by the hard-copy book medium, which is necessarily a set of ideas arranged linearly rather than as a network. The authors attempt to overcome this by frequent internal cross-references. The e-book versions may improve on this somewhat through hyperlinks in the text. These cross-references are one way the authors draw attention to the relationships between the book's sub-systems. We can also see the relationships between the systems view presented in the book and earlier scientific approaches in Part I, and how the systems approach can used to connect various disciplines in Parts II-IV.

From measuring to mapping

We have attempted to map this book according to the major themes that are woven throughout its chapters. An explicit verbal, or better yet, visual map of the themes provided early in the book, possibly in place of a linear table of contents, would have been helpful. We challenge readers to map the systems of their local and specific concerns, drawing upon multidisciplinary perspectives informed by systemic thinking.

From quantities to qualities

Unlike more readable texts such as Donella Meadows' *Thinking in Systems*, this is not an easily accessible introduction to the systems view, nor does it give a thorough review of how systems perspectives are currently used in different fields of research. The authors emphasize the qualities of systems rather than evaluation and comparison of their sources. The final chapter, "Systemic Solutions", still relies heavily on the impact of quantities to elicit the qualities of feasibility and hopefulness.

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Photograph of 42 diatom species from Oamaru, New Zealand, arranged on a microscope slide in September 1947 by R.I. Firth, 2013 | Flickr cc

From structures to processes

The physical book is a structure and the reading of it a process that transfers ideas. If, by the process of its replication and distribution, systems memes proliferate and indeed transform human activities, the ecosystem will embody the results of that process. Are there transformations whereby a book can become more organic, and operate in ways that reflect the cognitive and metabolic processes of living systems?

From objective to epistemic science

The authors are clear that they are not abandoning standard scientific practices but recognize the importance of incorporating multiple perspectives. Particularly when dealing with complex systems, understanding how knowledge was attained is as important as the knowledge itself. A weakness of this book is how selective the authors have been in their examples and arguments. We can follow their journey through a series of concepts, but not how they chose particular illustrations supporting their arguments. The narrow range of viewpoints may limit the resilience of the text-as-system to cope with new or contradictory information.

From certainty to approximate knowledge

Systems and uncertainty are evident in all aspects of human endeavor. This book gives an approximate knowledge of the nodes and relationships in the network that make up its field of view. We see Capra's previous work (especially *The Hidden Connections* and *The Web of Life*) as earlier approximations, whose insights have been incorporated and further developed in this volume. Even the weak points of the book provide a good argument for why science textbooks need frequent revisions. The authors illustrate both a soft focus on each field and openness to the possibility that any node in the network of ideas may not be correct, yet the work as a whole provides value. All descriptions of our universe are necessarily abstractions, reminding us that uncertainty is realistic and that determinism is rarely a practical approximation.

Conclusions

The Systems View of Life goes a long way toward embodying its own recommendations. Within the linear constraints of the written word, it maps an inverse funnel from the thin threads of systems in the history of science, spiraling out to include the human spirit, consciousness in all life and examples of works being done in full awareness of the connections among living, non-living, intellectual and cultural ecosystems.

The book has audacious scope and importance and we commend the authors for their unique and brave work. The historical reflection will benefit academics in many fields. Those in science, engineering, technology and math fields will be reminded of the value of a systemic approach to problem solving. Those in social sciences and humanities will gain an appreciation for their connection to the natural sciences and the ongoing shift to systems thinking. Those active in policy or industry will gain valuable insights into the ways that their fields interact with larger social and ecological systems, and how systems thinking can enhance their capacity for meaningful and sustainable transformation.

A unique property of the systems view in general and this book in particular is that they reach fearlessly across disciplines to reveal often-hidden connections. Embracing this entails an ongoing critical need for deep and extended dialog, particularly among those engaged with health, management, and science systems in transition.

Achieving the full benefit of the authors' insights will require a great deal of work:

- Encouraging breakthroughs in achieving the fundamental change of metaphor from machine to network;
- Testing the systems view as a framework for recovering essential meaning in work;
- Shifting outmoded thinking to more appropriate conceptual frameworks of quality in complex systems and evolving palettes of 'living solutions' with emergent properties of local and global sustainability;
- And most significantly, encouraging and supporting ecologically literate and systems capable leadership.

The Challenge

Merely becoming familiar with the outlines of *The Systems View of Life* does not necessarily translate into turning the tide of unsustainability. In our own small way, we attempted to apply some important messages of this book in how we developed our review. We offer as an illustration that the uncomfortable work of abandoning an outmoded metaphor is secondary to a shift in perception and spirit, or feeling.

Capra and Luisi invite serious readers and thinkers to derive lessons from the systemic perspective, particularly at the intersections of critical disciplines experiencing rapid change. This could occur through small-group discussions around local issues or online via communities of interest. Readers of this review may wish to answer this call to earnest dialogue by capturing, sharing and building on these initiatives within and across communities of practice.

The editors and reviewers welcome your comments, insights and experiences via email to SVoL@zqjournal.org ×

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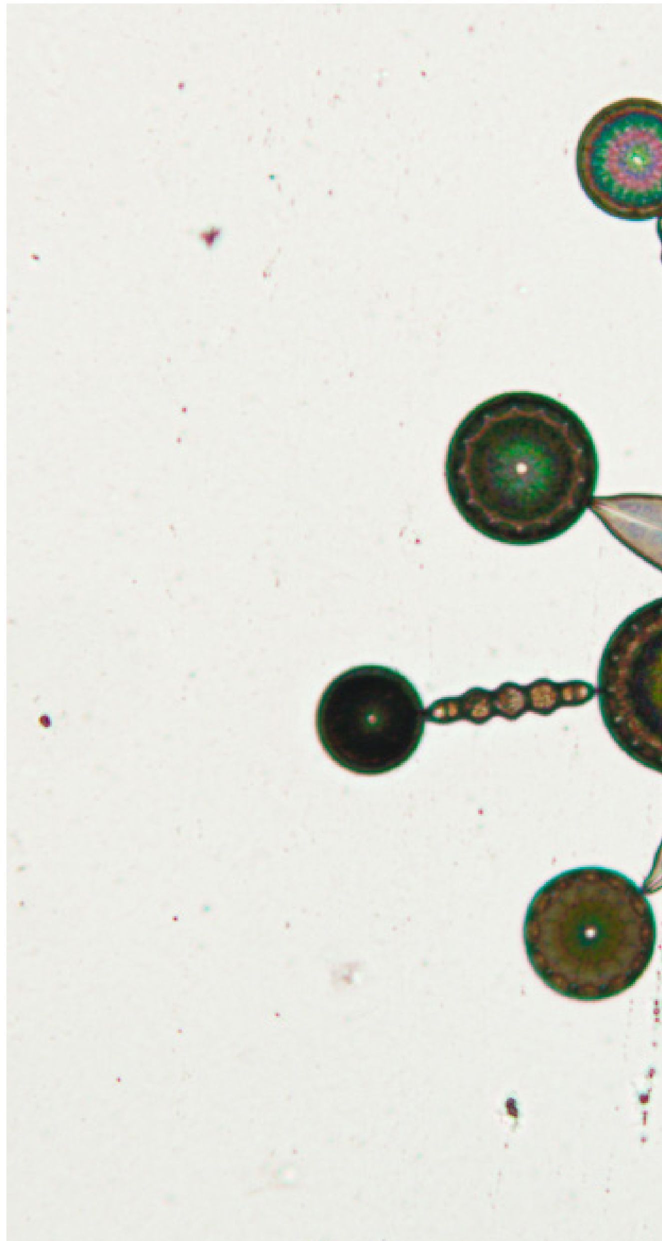

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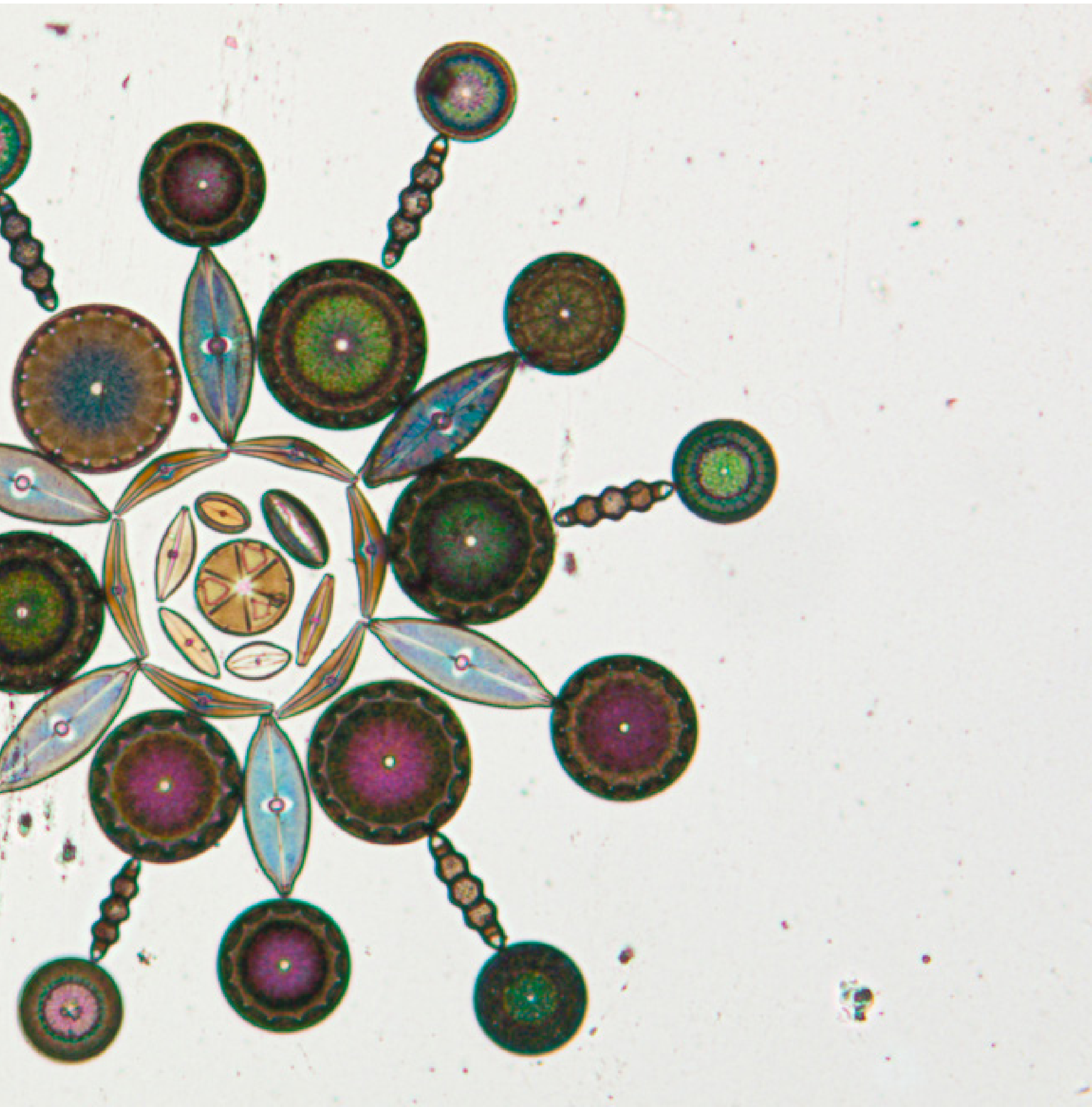
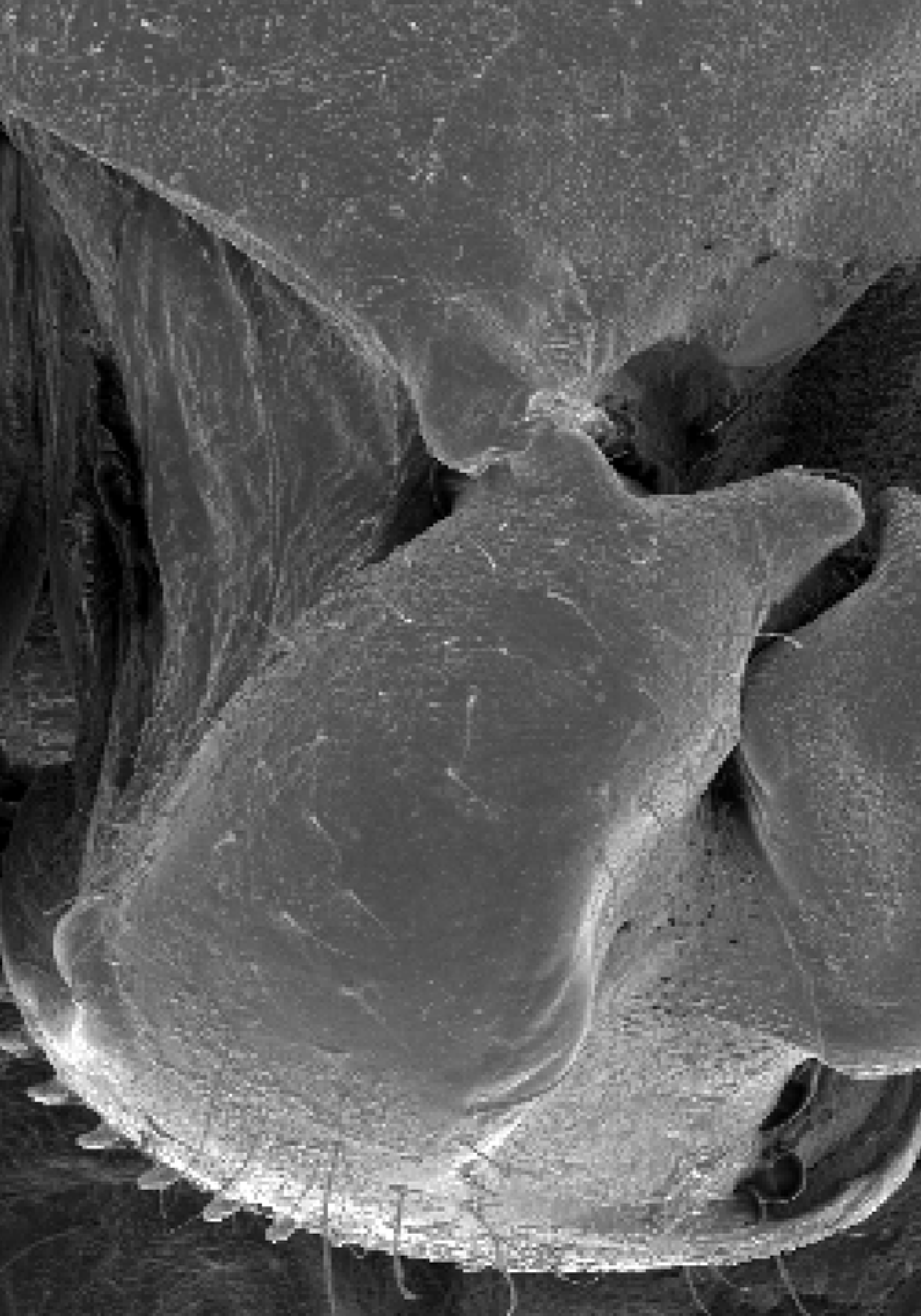
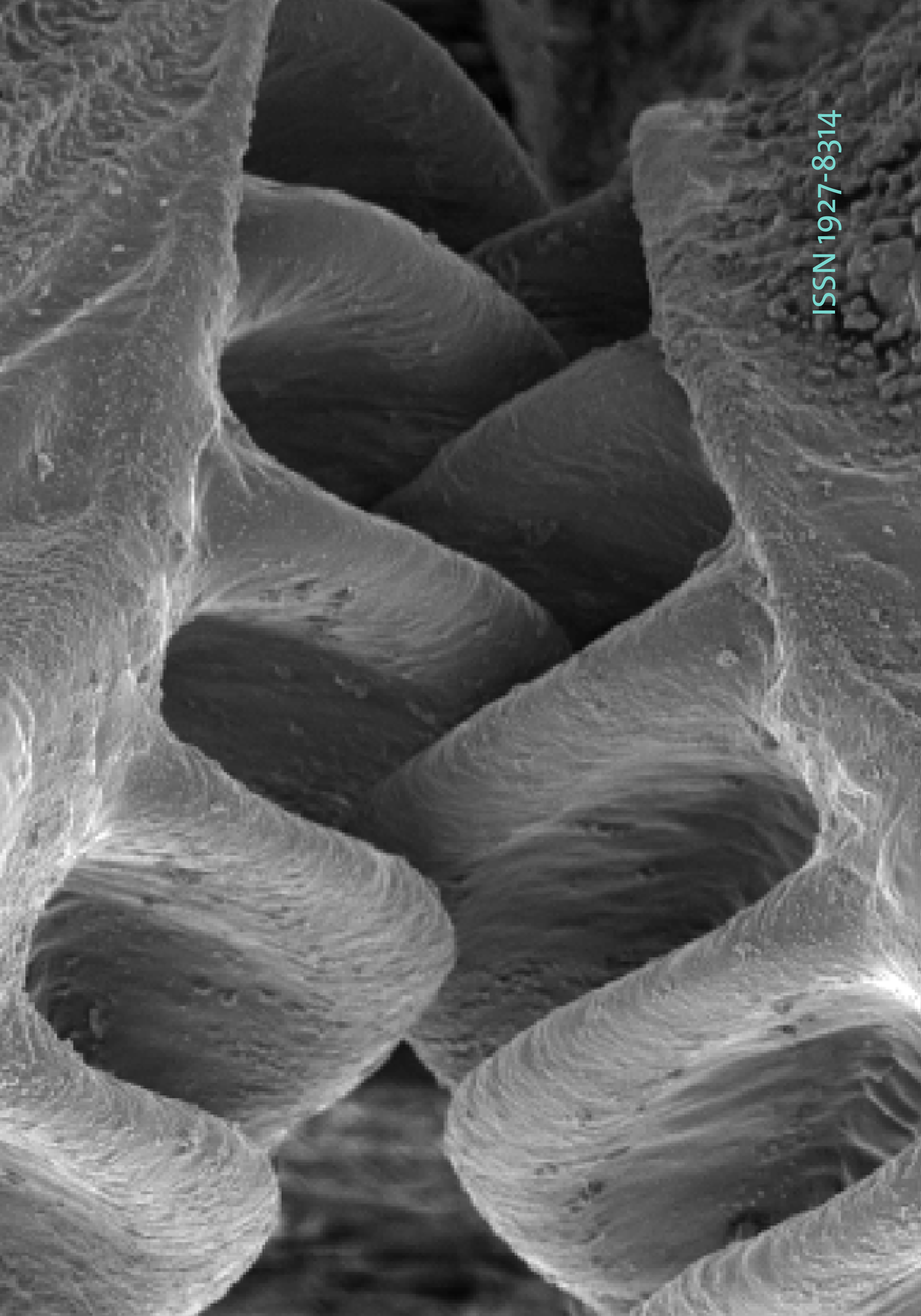


Arranged Diatoms on Microscope Slides in the California Academy of Sciences Diatom Collection

Photograph of diatoms arranged on a microscope slide by W.M. Grant, 2013 | Flickr cc





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