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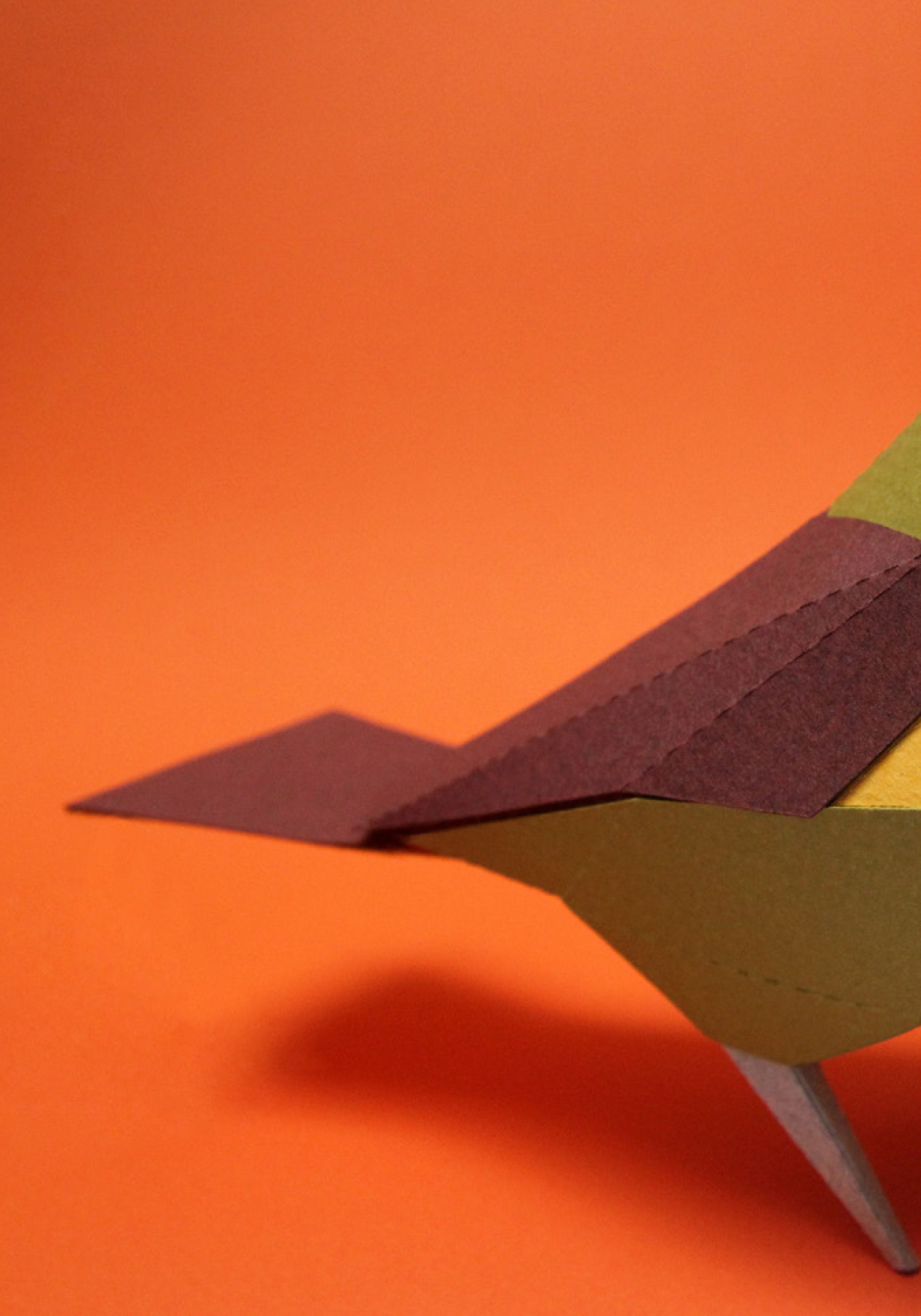

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Cover art

Cover: Rüppell's weaver Flying (*Ploceus galbula*) | Design: Estudio Guardabosques

pp. 2 - 3 & pp. 116-117: Yellow Cardinal (*Gubernatrix cristata*) | Cardenal amarillo | Design: Estudio Guardabosques

Design

Marjan Eggermont

Colin McDonald

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Rüppell's Weaver | Photo: Sergey Yeliseev, 2015 | Flickr cc

What They Left Behind

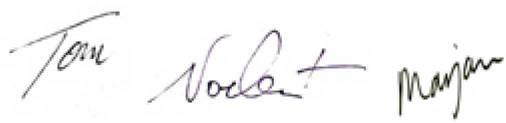
In this issue Heidi Fischer writes of an ancient community in the American Southwest whose relationship with a unique plant, the iconic agave, left a botanical legacy that long outlived its human inhabitants. This is a living legacy some 1,000 years old, perpetuated by the exquisite adaptations of these plants to their home ground, and it took clever scientists to notice it within the complex tapestry of the desert landscape. Her essay reveals as much about ourselves as it does about these prehistoric cultivars.

Our case study depicts another, more modern legacy, that of plastics. Without a doubt, this will be part of the material legacy that this century's humans leave the world. Unlike the persistence of the agave, it is, and will continue to be, harmful to humans and other organisms long after many generations have joined their forebears. We chronicle the Wyss Institute's efforts to change this petrochemical based paradigm.

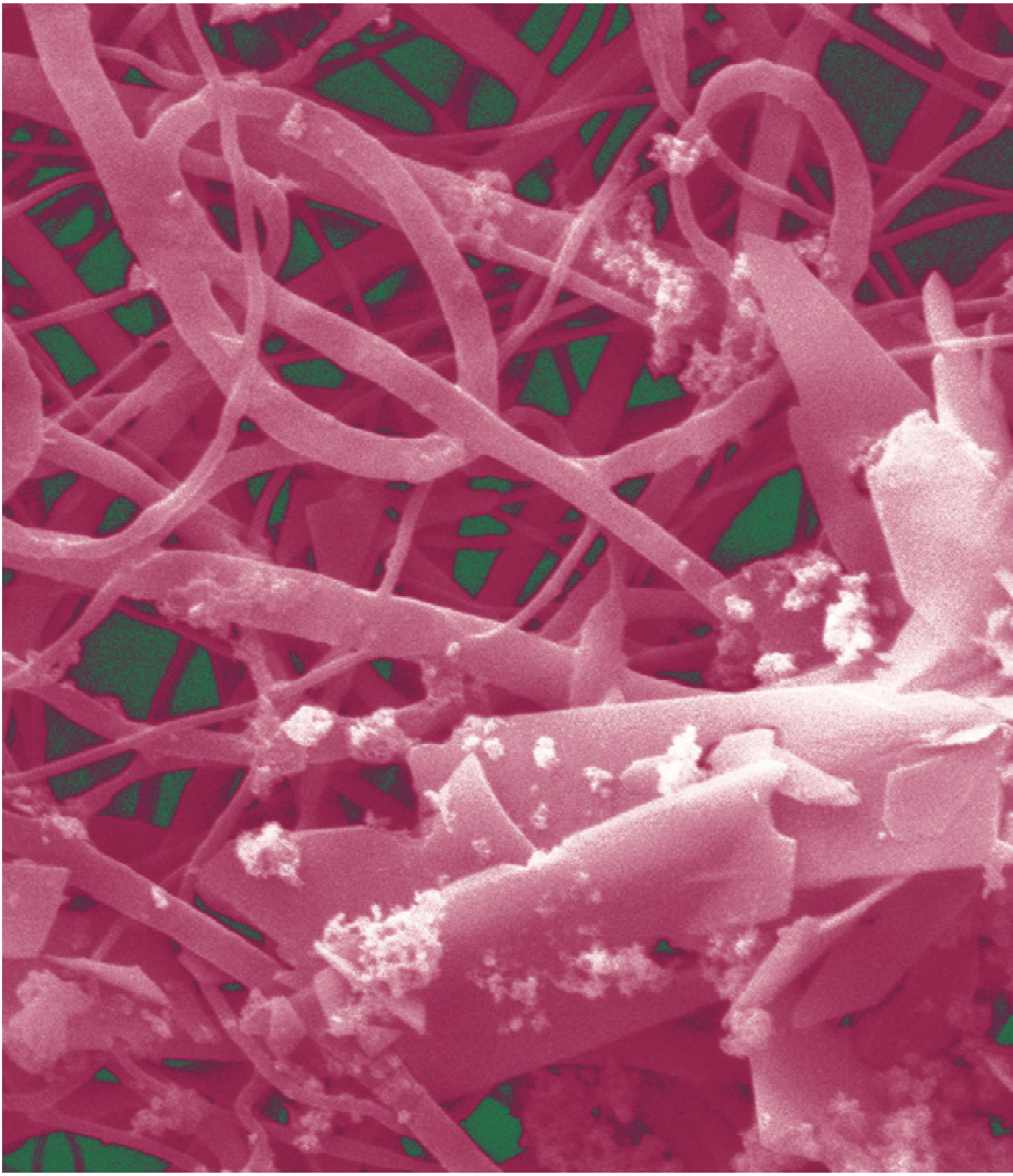
Neither cultural scenario need be the future fate of our civilization: hard-scrabble subsistence and eventual dissipation, nor suffocation in the hubris of material excess. There are other ways into the future, and one of the most hopeful is the emulation of the universal truths of nature. Even the pathway in search of answers for ourselves and our society is likely to yield unexpected results.

Those who follow that pathway is what we are keen to tell you about, whether a scientist like Russell Kerschmann, an observer and chronicler of scientific work like the photographer Felice Frankel, or a young Argentinian partnership who delight in abstracting the essential form of animals. Legacies of knowledge, wisdom and delight are perhaps what we should leave behind, rather than heaps of hazard and woe. We support those who act to create the former and prevent the latter.

Happy reading! ×

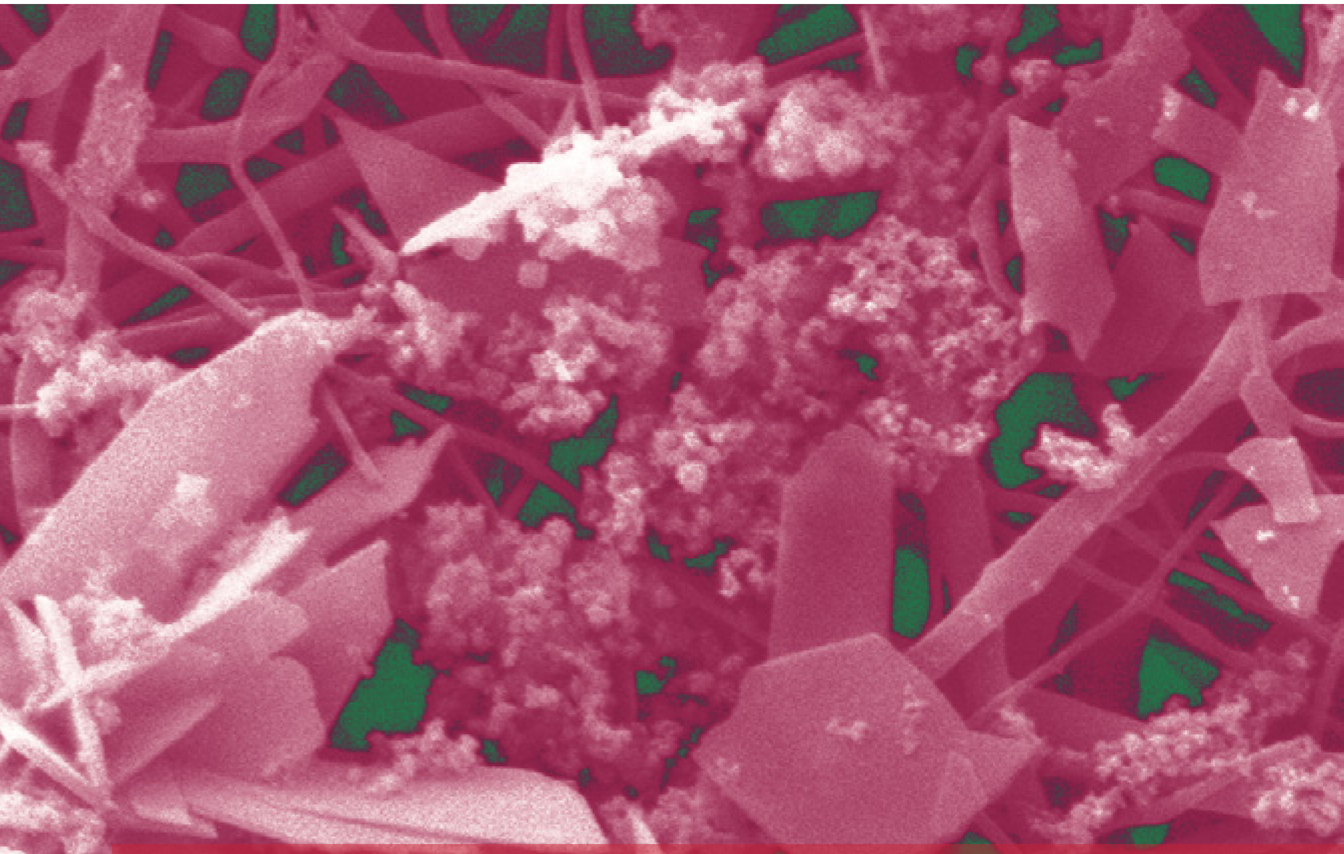


Tom McKeag, Norbert Hoeller and Marjan Eggermont



Mineral Blooms on Electrospun Fibres

Photo: Jenna Shapiro, Engineering at Cambridge, 2013 | Flickr cc



Case Study
Oh, So Plastic!

Tom McKeag

vol 3 | 2015

Case Study
Oh, So Plastic!

Author:
Tom McKeag

Oh, So Plastic!

Advances in the biomedical field form the inspirational basis for an innovative and universal natural replacement for petrochemical-based plastics.

The Problem

We live in the Age of Plastics. Although not as long as the Stone, Bronze or Iron Ages, the plastic age's impact on the natural world has been greater in its short duration than all of these combined. While providing an incredibly useful and sometimes wondrous material, petrochemical based plastic has come with a cost: in energy use, human health problems and degradation of the natural environment.

When Leo Baekeland first combined phenol, formaldehyde and wood flour to make Bakelite in 1907, it is unlikely that he realized the full impact of the material he was introducing. Although he had said that the first thermosetting plastic ever made would have a thousand uses, he could not have imagined how short of the mark he was.

In a little more than 100 years, petroleum-based synthetic polymers have found their way into all aspects of our lives, from the toddler's teething ring to the plastic lined coffin. That reach even extends beyond the grave. Although our mortal flesh will decay, some of its plastic contents, accumulated over a lifetime, will tarry much longer. So it is with our oceans and land.

The world produced approximately 299 million metric tons of plastics in 2013, most of which flowed from east to west. China is the biggest producer at 24.8 percent, followed by Europe at 20 percent, and North America at 19 percent.

Estimates of 2015 global consumption average 45 kilograms for every man, woman and child on the planet. As shocking as that is, this is about three times lower than what it could be. The average consumption in Europe and North America is more than 135 kilograms per capita; only lack of development has kept the rest of the world from following suit. Many aspire to change that, however. The Indian plastics industry, for instance, projects its 2013 domestic consumption total to double within the next five years.

Plastic is light, strong, waterproof, resistant to rot and decay, with high thermal and electrical insulation properties. It can be produced in virtually any color or made clear enough to see through. It can be made it into sheets, rods or just about any shape.

It's also cheap — at least when one omits the environmental and health costs, troublesome externalities missing typically from account books. Moreover, making something out of plastic, rather than glass or metal, often saves a lot of energy, material and subsequent greenhouse gas creation.

The word "plastic" was coined by Baekeland and describes the malleability of the material.

Bakelite telephone at Bletchley Park | Photo: wwarby, 2015 | Flickr cc

Plastics can be more precisely defined typically as organic polymers or chain molecules, usually synthetic and based on carbon backbones derived from petrochemicals with an almost endless variety of side chains which give various different properties to the material. The carbon chains can be combined with sulfur, oxygen or nitrogen, and in most products the polymer is mixed with additives: fillers, colorants and plasticizers. Plasticity (https://en.wikipedia.org/wiki/Plasticity_(physics)) is the general property of all materials that are able to irreversibly deform without breaking and this has become associated with this class of polymer.

While nobody truly knows the full environmental and health costs of plastics use, some simple things are known. Most plastic lasts for a very long time without breaking down and 90 percent or more is never recycled. Much of it contains compounds that are toxic to animals and can leach out when it does break down.

The polymers that form the basis of plastics have high molecule weight, are insoluble in water, and relatively inert when formed. For this reason, they have relatively low levels of toxicity. The additives mixed with them, however, are or greater concern. Plasticizers, for example, are often added to brittle plastics like polyvinyl chloride to increase flow and workability. Traces of these compounds, like adipates and phthalates, can leach out of the product and are toxic.

Some plastics, including polycarbonate bottles and the resin lining of cans, contain plausible endocrine disrupters like Bisphenol A (BPA) and phthalate that are absorbed while eating and drinking. Some 93 percent of people in the U.S. had detectable levels of BPA in their urine, according to the U.S. Center for Disease Control and Prevention. Nearly all adults also had measurable levels of phthalates in their bodies, along with eight out of 10 babies.

One third of the plastics produced are used in disposable packaging, most of it discarded within one year of manufacture. Used only once, these persistent and toxic compounds can remain intact for decades. The energy cost, beyond the degradation of our health and environment, is high. About eight percent of petroleum production is used to make these plastics; half for feedstock and half to power the processing.

Plastic's high malleability has allowed a great number of manufacturing techniques to occur, making a wide range of products. In addition to knowing a chemical formula, knowing how a plastic object gets produced can offer insights for finding alternate materials. Here are the most common ways that plastic articles are made:

- Injection molding: one of the most common techniques for a wide range of products, this process forces resin pellets into a metal mold and mixes and heats them uniformly for a solid plastic object.
- Extrusion molding: similar to injection molding in that it also heats resin to a plastic state, in this technique the malleable substance is squeezed through a die to create a particular shape. This process lends itself to linear stock such as pipes or door seals and uses multiple-setting thermoplastics or single setting thermoset plastics

LegoSpritzguss (Lego injection molding, detail) | Photo: Arne Hückelheim, 2009 | Wikimedia Commons

Wild Giant Otter plays with plastic bottle in the Pantanal
Photo: Paul Williams (www.IronAmmonitePhotography.com), 2011 | Flickr cc

- Blow molding: a hot plastic plug called a parison is enclosed by a mold and then blown against the walls of the mold by air pressure, creating a hollow object like a bottle.

- Rotational molding: a dry plastic powder goes into a mold and is heated as the mold is rotated to coat its interior with a thin layer, thus also making a hollow object. Auto parts, toys and furniture are some of the products typically made this way.

- Additive manufacturing: layers of resin are set (polymerized chemically) using various activators such as heat or UV light and an object is built up into its three dimensional shape by adding these precise computer controlled layers one at a time. Fused Deposition Modeling (FDM) where a heated resin sets on contact with the air, and stereolithography (SLA) where light sets a liquid resin into a solid, are two examples among others.

Elimination of the most dangerous aspects of synthetic polymers will probably require the creation of three things: new formulas that allow sustainable sourcing and recycling; materials that break down in a benign way; and more sophisticated systems of collection, disposal and reuse.

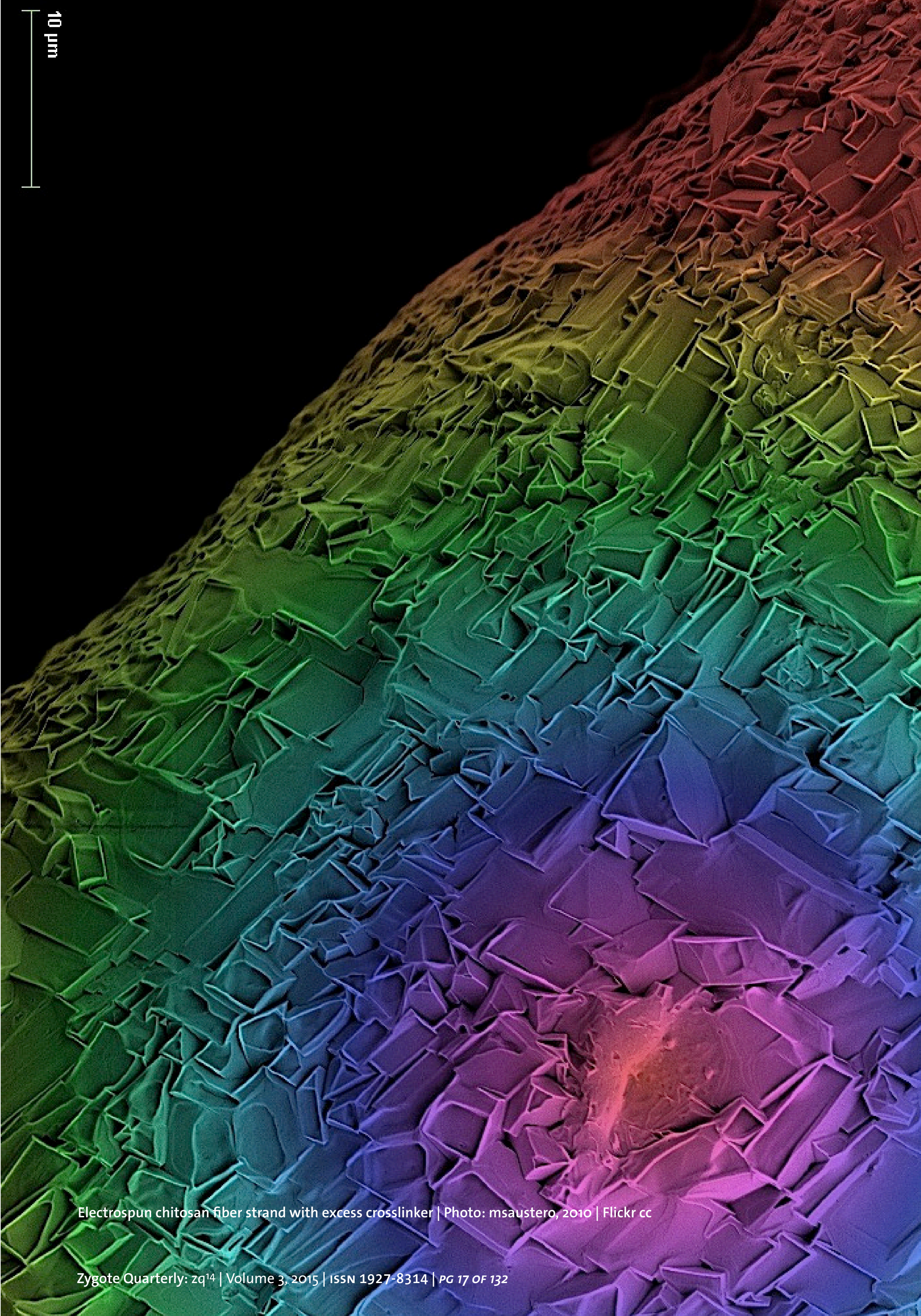
Bio-based plastics have been made for many years but are generally considered to be only a partial solution. They comprise two basic types of material: those that are biodegradable and those that are bio-based but not biodegradable. Examples of the latter are bio-polyurethanes based on polyols from vegetable oils. Proper waste stream management of these substances would typically include waste to energy regimes or recycling. The inextricable combination of ingredients (such as fillers, colorants and plasticizers) in many of these formulations has thwarted attempts to recycle them economically.

Non-degradable substances represent the majority of the current bio-plastic production at 62.4 percent, with biodegradable material comprising the rest at 37.6 percent. Although 2013 worldwide production volume of 1.6 million tons is small relative to oil-based plastics, it is of an industrial scale and is expected to quadruple in the next five years.

While many of these plastics make use of natural materials, such as cellulose, they must be categorized as examples of bio-utilization, not biomimetics. There are, however, materials being developed that attempt to mimic the form and process of nature to build in performance as well as use natural materials.

The Model

One of the sources of these newly developed materials is chitin. Chitin is the second most common organic material in the world after cellulose. It is a polysaccharide, or sugar, found in crustacean shells, insect cuticle, fungi walls, the beaks of cephalopods like squid, and the radulae and nacre of molluscs. It is typically combined with other materials in nature to make strong composites. The nacre of the abalone shell is a case in point. The chitin scaffolding holds protein gels that are then mineralized to make a composite material tougher than any ceramic.



Electrospun chitosan fiber strand with excess crosslinker | Photo: msaustero, 2010 | Flickr cc

Arthropod shells or cuticles are another example. These are nanocomposites comprising chitin and protein tissue containing calcium carbonate crystals in a hard microfibrous shell. The parts of this shell, the exocuticle and endocuticle, are designed to resist mechanical loads, being laid in a twisted plywood structure. This tissue illustrates several structural stratagems of nature: composites, building in a hierarchy of linear scales, and using the geometry of structure or array, rather than material, to resist stress.

Chitin is a derivative of glucose, comprising long chains of N-acetylglucosamine units. It is quite similar to its more common relative, the polysaccharide cellulose, but with one hydroxyl group on each monomer replaced with an acetyl amine group. This allows for increased hydrogen bonding between adjacent polymers giving the chitin-polymer matrix increased strength. While in structure chitin is most like cellulose, the structural component of plant cell walls, in function chitin serves most like the protein keratin, which forms hair, nails and hooves in animals.

Chitin, like cellulose, is used in a wide range of industrial applications: fertilizers, biopesticides, binders for dyes and adhesives, membranes and filters, surgical thread and tissue scaffolding, additives in food processing and in pharmaceuticals.

Chitin is modified typically into chitosan through deacetylation from 75-90%. A common method uses sodium hydroxide in excess as a reagent and water as a solvent. It needs no additive to gel, is heat responsive, and soluble in acidic conditions, but not otherwise. It bonds to metals and proteins, and is the only positively charged polysaccharide.

Chitosan has been researched extensively since the 1980's because of its versatility and promise. In particular, researchers have looked to it as a natural source for hydrogels. Hydrogels are long, three-dimensional hydrophylic polymer chains that can absorb up to 1,000 times their dry weight in water and can be made from a variety of materials.

The typical hydrogel structure is crosslinked, formed by reactions of the monomers in its base spine or by hydrogen bonding. The material will behave somewhat like a solid and not be dissolved by the water because of the three-dimensional cross-linking within the polymer chain.

Examples of hydrogels in nature are cartilage, the vitreous humor of the eye, tendons, mucus and blood clots. Typically these are made from proteins like collagen. Other natural hydrogel materials being investigated for tissue engineering include agarose, methylcellulose, and hyaluron

Hydrogels exhibit some useful properties because of this 3D chemical structure: their swelling can be controlled and activated by environmental conditions like changes in pH, temperature, ionic strength, solvent composition, pressure, and electrical potential. They can be biodegradable, bioerodible and bioabsorbable, and in many situations these processes are tunable. They are therefore used in biomedical applications such as transdermal drug delivery and implant coatings, soft contact lenses, pills and capsules, bioadhesives, wound healing, tissue engineering, cell culture and in electrophoresis, and chromatographic packaging.

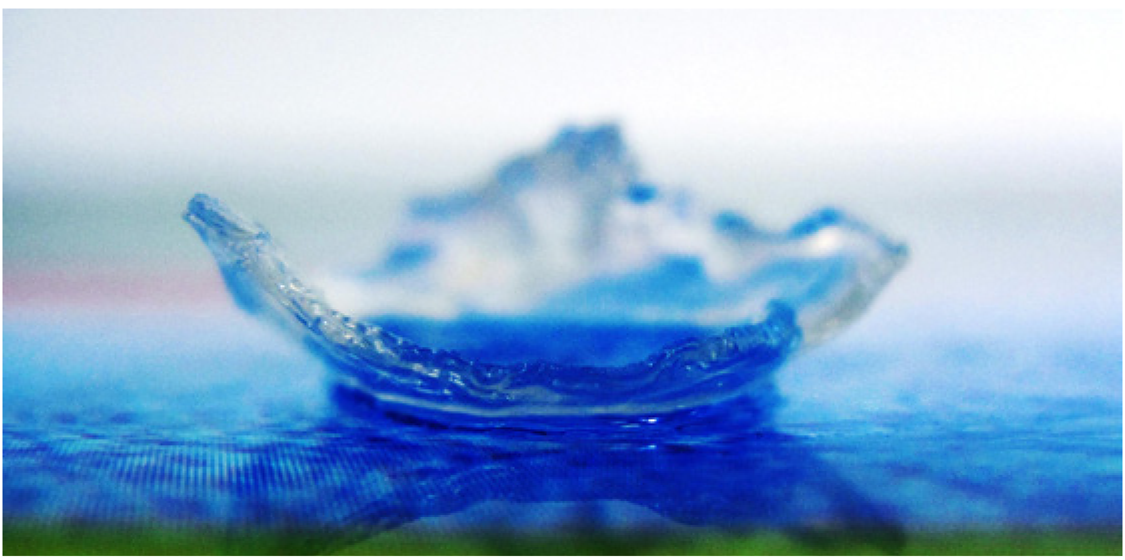
Natural polymers like chitosan are attractive to biomedical researchers because they generally have high biocompatibility, intrinsically interact with cells, are biodegradable, and produce low toxicity byproducts. Researchers have mitigated some of their disadvantages, such as low mechanical strength and relative inconsistency of batch compared to synthetic formulations. Often they have combined relatively benign natural products with the least offensive synthetic ones, such as blending chitosan with methacrylates.

The Translation

The advances made in the biomedical realm have led others to explore more general applications. One of these is Shrilk, a conflation of the words “shrimp” and “silk,” the two sources of material for the plastic. The shrimp provides chitin, the sugar from which the more useful chitosan is made, and insect silk provides fibroin, a protein. These two substances are laid in a composite that takes advantage of the properties of each to make a product that is both strong and durable.

Javier Fernandez, lead researcher and postdoctoral fellow, and Donald Ingber, the director of the Wyss Institute for Biologically Inspired Engineering at Harvard, conceived and developed Shrilk two years ago and published their work in the journal Advanced Materials. Dr. Fernandez is now an assistant professor at Singapore University of Technology and Design.

At the time Shrilk was hailed as “one of the materials that will change the future of manufacturing” by Scientific American, as a “Super-



Artificial cornea on a chopping board | Photo: Khaow Tonsomboon, Engineering at Cambridge, 2012 | Flickr cc

Large three-dimensional objects made of chitosan | Photo: Jgfermart, 2014 | Wikimedia Commons

material" by *National Geographic* magazine, and had been chosen (with graphene) by The Guardian newspaper as one of the "five materials that could change the world."

Fernandez and Ingber had observed the cross-laid nature of abalone and arthropod shells and mimicked it, plywood fashion, at the micro scale. This is a helical structure, in which rafts of chitin microfibrils in a protein matrix form a sheet or lamina. Each sheet is rotated with respect to the one below, in a manner like plywood. Like logs in a raft the microfibrils crosslay the layers above and below, thus making a very strong structure that can resist stress from all angles.

The resultant material was not only bio-based, but also biodegradable and biocompatible. The U.S. Food and Drug Administration had already approved chitosan and fibroin, making them suitable for biomedical applications.

Reporting in March 2014 issue of the journal *Macromolecular Materials and Engineering*, the pair revealed further results. Working exclusively with chitosan, they had been able to demonstrate a scalable production process for a chitosan-based plastic that could be either injection molded or cast like any current plastic.

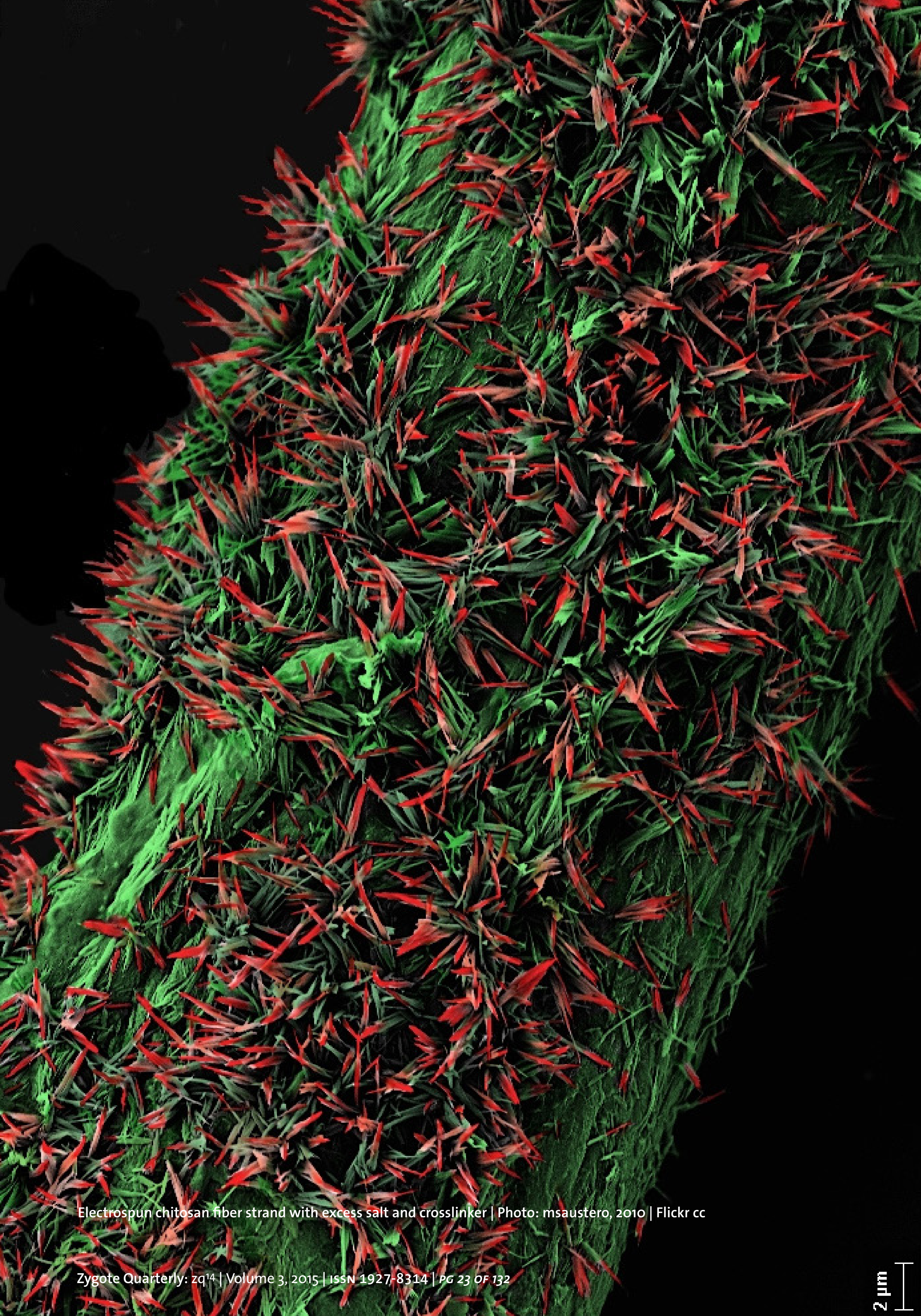
In presenting their work the authors wrote:

> "This chitosan fabrication method offers a new pathway for large-scale production of fully compostable engineered components with complex forms, and establishes chitosan as a viable bioplastic that could potentially be used in place of existing non-degradable plastics for commercial manufacturing."

Key to their innovation was a finely honed process that retained the three dimensional mechanical properties of the chitosan. Despite the remarkable strength of structures like insect cuticle and mollusc nacre, most applications of the material destroyed one of its best attributes. Heretofore, ground shrimp shells had been used widely for fertilizer, cosmetics and food additives, but the crude processing had removed chitin's structure. Almost all of the then current processes failed to produce 3D materials with the organization, ecological integration, or structural properties of natural chitinous systems. Some of the few uses of the material that retained its integral structure were found in the biomedical field as thin films or scaffolds in microfluidic devices and surgical wound dressings.

Rather than freeze drying, chemically changing the polymer or blending it with thermoplastic polymers, the researchers concentrated a dilute solution in acetic acid to form a pliable liquid crystal.

> "An initial solution of 3% chitosan is concentrated until it reaches the viscosity necessary to be molded. To cast the solution, it is warmed up to decrease the viscosity and poured over the mold. The viscosity increase at room temperature helps to keep the polymer on the walls of the mold; the final crystallized form of chitosan is separated from the mold after the remaining solvent evaporates. In the case of injection molding, the polymer (by its own or mixed with a filler) is concentrated to a plastic state and warmed up at 80 degrees C before being injected in the mold. Just after the injection, the mold is open and the fabricated objects removed".



Electrospun chitosan fiber strand with excess salt and crosslinker | Photo: msaustero, 2010 | Flickr cc

Fungus | Photo: racatumba, 2008 | Flickr cc

They were able to demonstrate its utility as a stock for injection molding and casting while still retaining its natural microscale crystalline organization. The reconstituted chitosan uses the structure found in the original substance, rather than more material, to create strength, a basic principle of nature.

Production costs are currently above that of petroleum-based plastics, but the adding of wood flour to the chitosan formula makes the cost comparable. Researchers believe that economies of scale will further reduce unit costs. Chitin, sourced by grinding up shrimp shells or growing fungi, does not impact land-based food production.

The material also gets high marks for recyclability and biodegradability. For one thing, dyes used within the polymer are recoverable, and therefore the plastic does not have to be sorted before being recycled. Chitosan can capture and retain small molecules, a property that had been used in the biomedical field to develop novel controlled-release molecular delivery systems. Water soluble dyes held within the chitosan could be released under a more acid regime and the uncolored chitosan recycled. Additionally, the material will not only break down in a matter of weeks, but will add nitrogen to any soil that it is in, encouraging plant growth.

This development is distinguished by more than a good observation of nature. Befitting the Wyss Institute, the researchers were keenly aware of the application criteria to which their experimentation must hone: scalability, practicality for the manufacturing sector, and an improvement in the sustainability equation.

The process must be simple, able to be done on a large scale, cost effective and a genuine improvement over oil-based and toxic materials.

They seemed to have done it and, although their objective was to demonstrate plausible scalability of a bio-based resin in the processes of injection molding and casting, there is every reason to believe that it can be used in other processes. A team at the MIT Media Lab, for instance, has demonstrated chitosan hydrogel use in multi-chamber extrusion printing. It is exciting to think of a new and improved version of this alternate feedstock growing in use, particularly in the expanding world of additive manufacturing. ×

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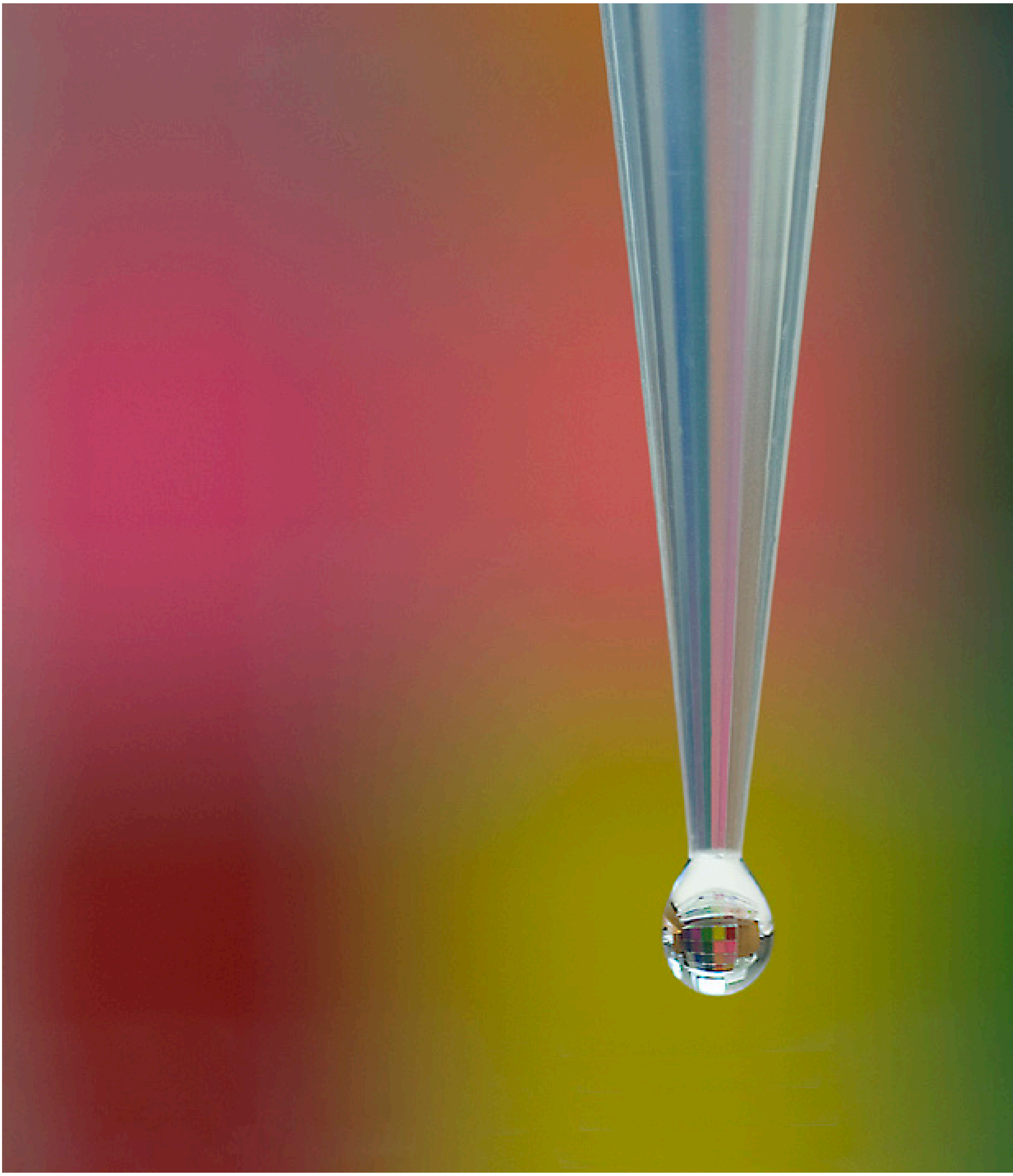


Water drop

Photo: Felice Frankel

Portfolio

Felice Frankel

Could you tell us about your background and how you got started in the field of science photography?

I began in science, right after graduating from Brooklyn College, to work in a cancer research laboratory. Then, through a series of serendipitous events, I became a landscape architecture photographer and then later, back to science—this time bringing in my photographic experience.

What kind of techniques do you use for your work?

Mostly macrophotographic and microscopic imaging. Sometimes, I use more sophisticated equipment—as a scanning electron microscope, however I work with a technician with that equipment. They know more than I, technically, but basically I art direct.

How has your art/style changed since you first started?

Interesting question. Probably, I have become more creative, mostly because I am more confident now. I no longer believe it's accidental that I make interesting images. I must know what I am doing. Finally, I believe that! And so, I now take more chances in my set-ups. However, the rigor and rules that go hand-in-hand with making science images keep me in line. I am not an artist. My intention is NOT to create art. My task to communicate information and so there are various parameters I have to work within.

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

There is no question that I am continually asking more and more questions about nature, i.e, why are things the way they are? My job is to communicate science, visually. And so, I need to understand what I am photographing...a very exciting approach to seeing our world!

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

I have the privilege of working with some of the best researchers in the world. THEY are my inspiration and the work they accomplish.

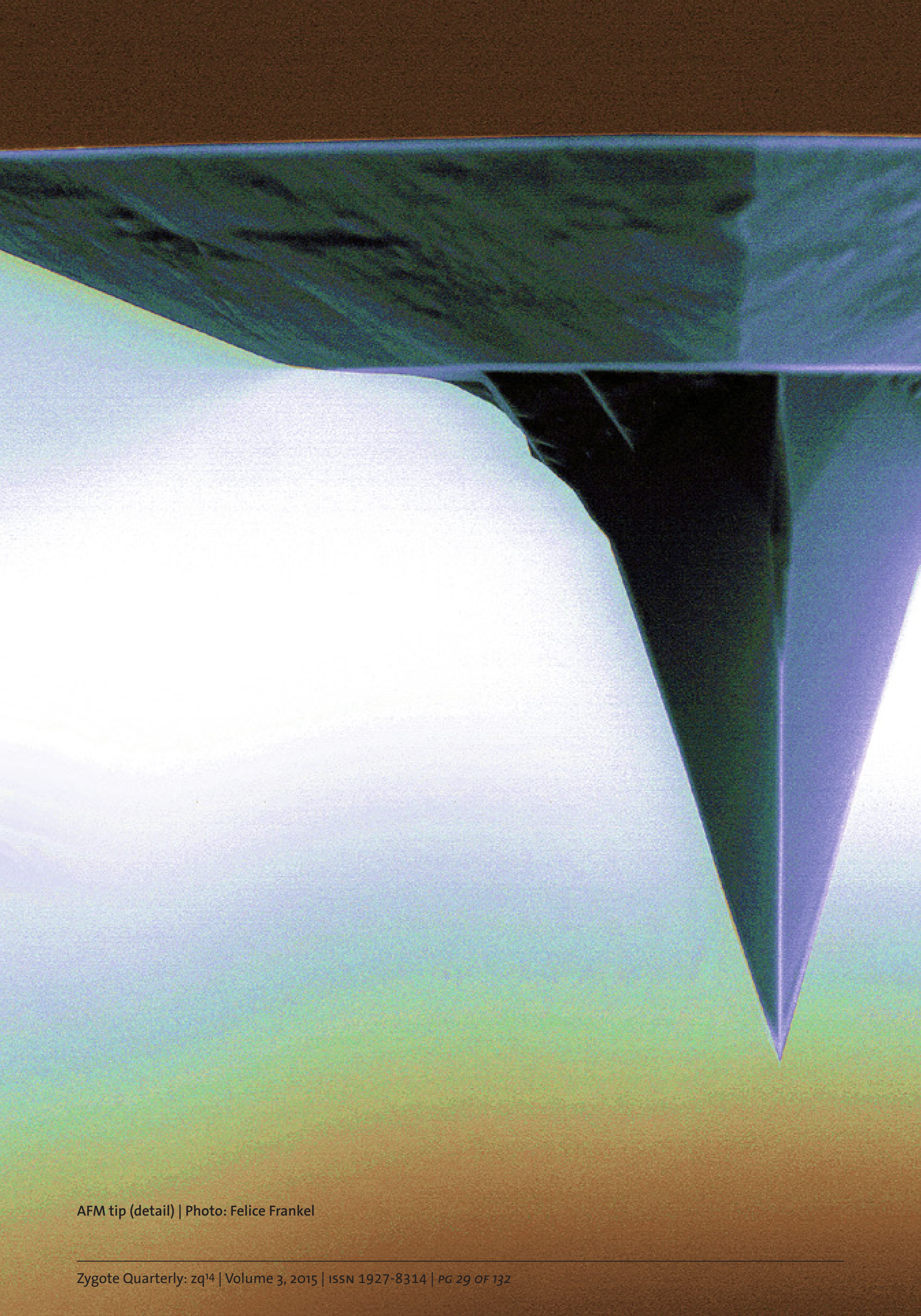
What are you working on right now? Any exciting projects you want to tell us about?

I just finished teaching an online course: Making Science and Engineering Pictures. It took 2 years to create 31 tutorials. I worked with an amazing team, teaching students from all over the world how to make more compelling and communicative photographs of science and engineering. The videos are available here:

Making Science and Engineering Pictures, A Practical Guide in Presenting Your Work

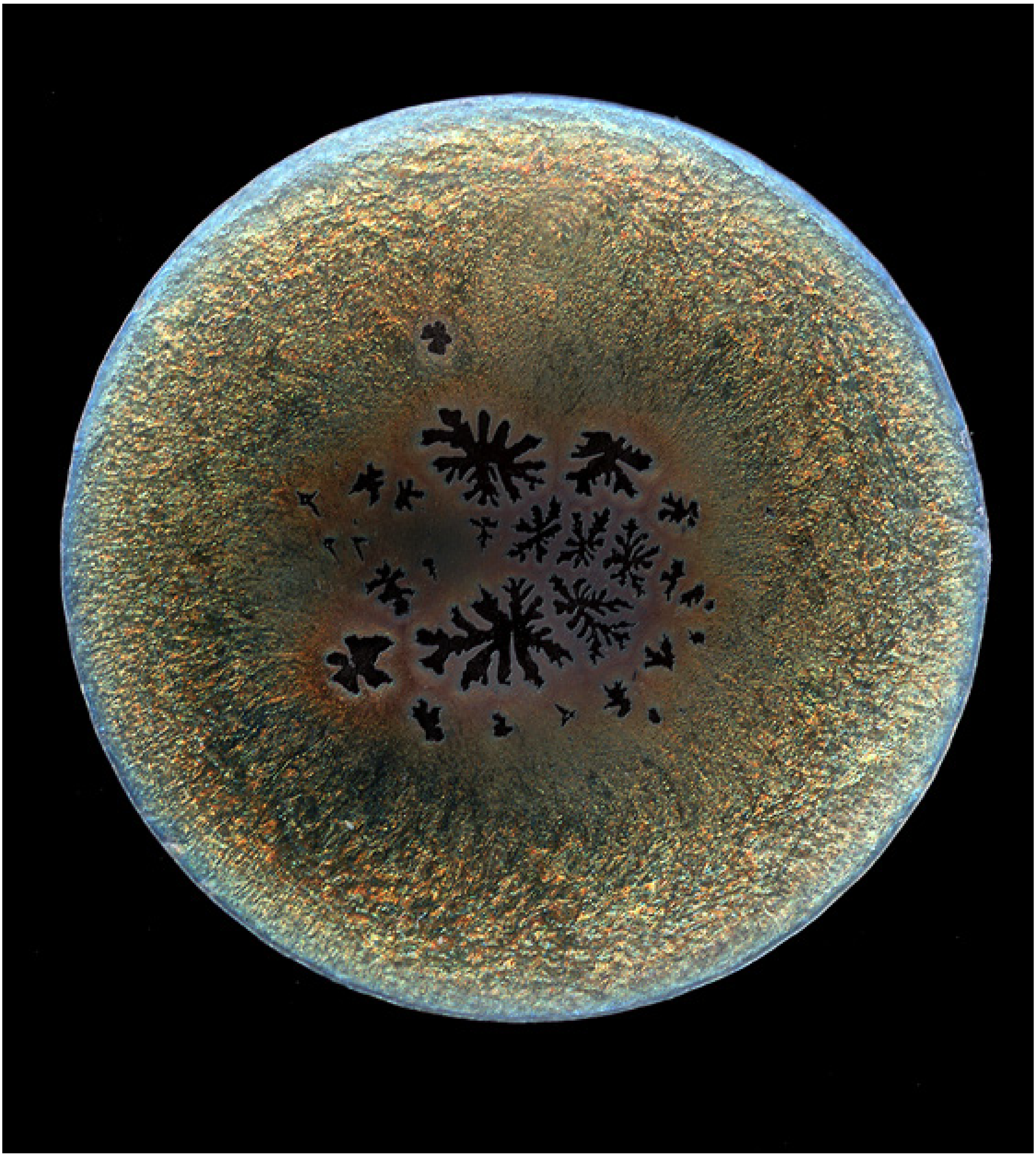
What is the last book you enjoyed?

Hard to say. I guess *The Signature of All Things* by Elizabeth Gilbert is way up there on my list. ×



AFM tip (detail) | Photo: Felice Frankel

Artist:
Felice Frankel

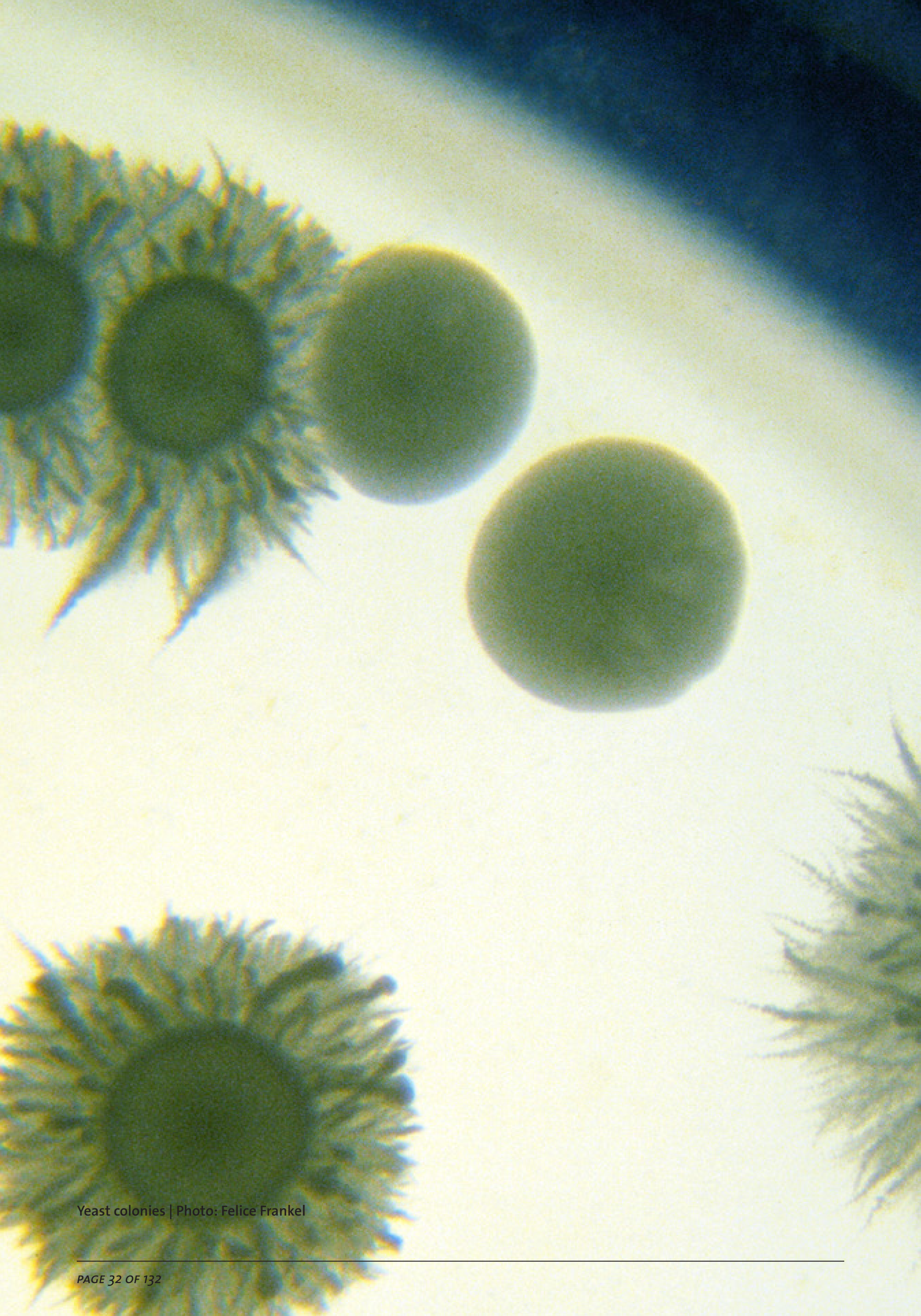


Block co-polymers

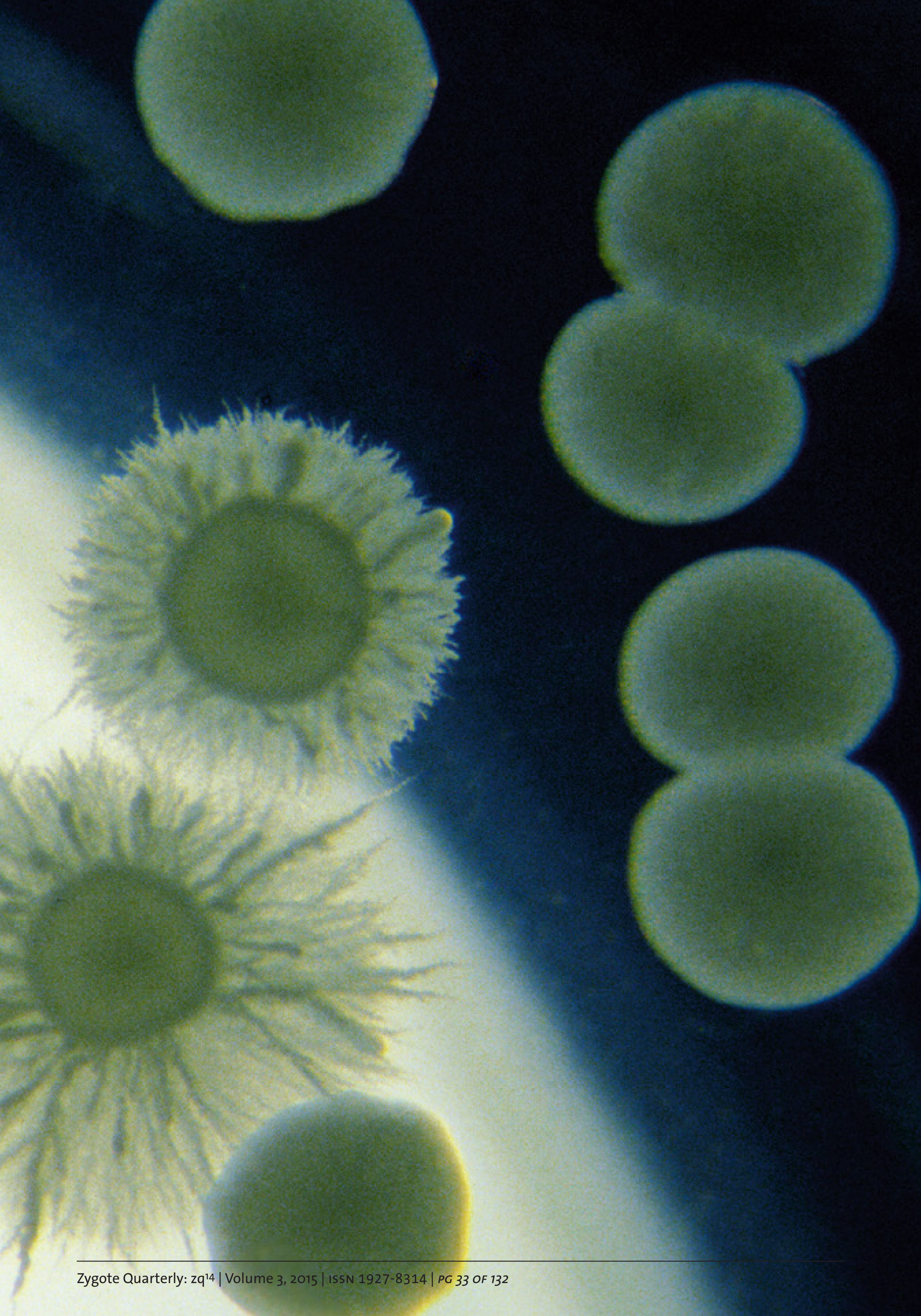
Photo: Felice Frankel

Yeast colony

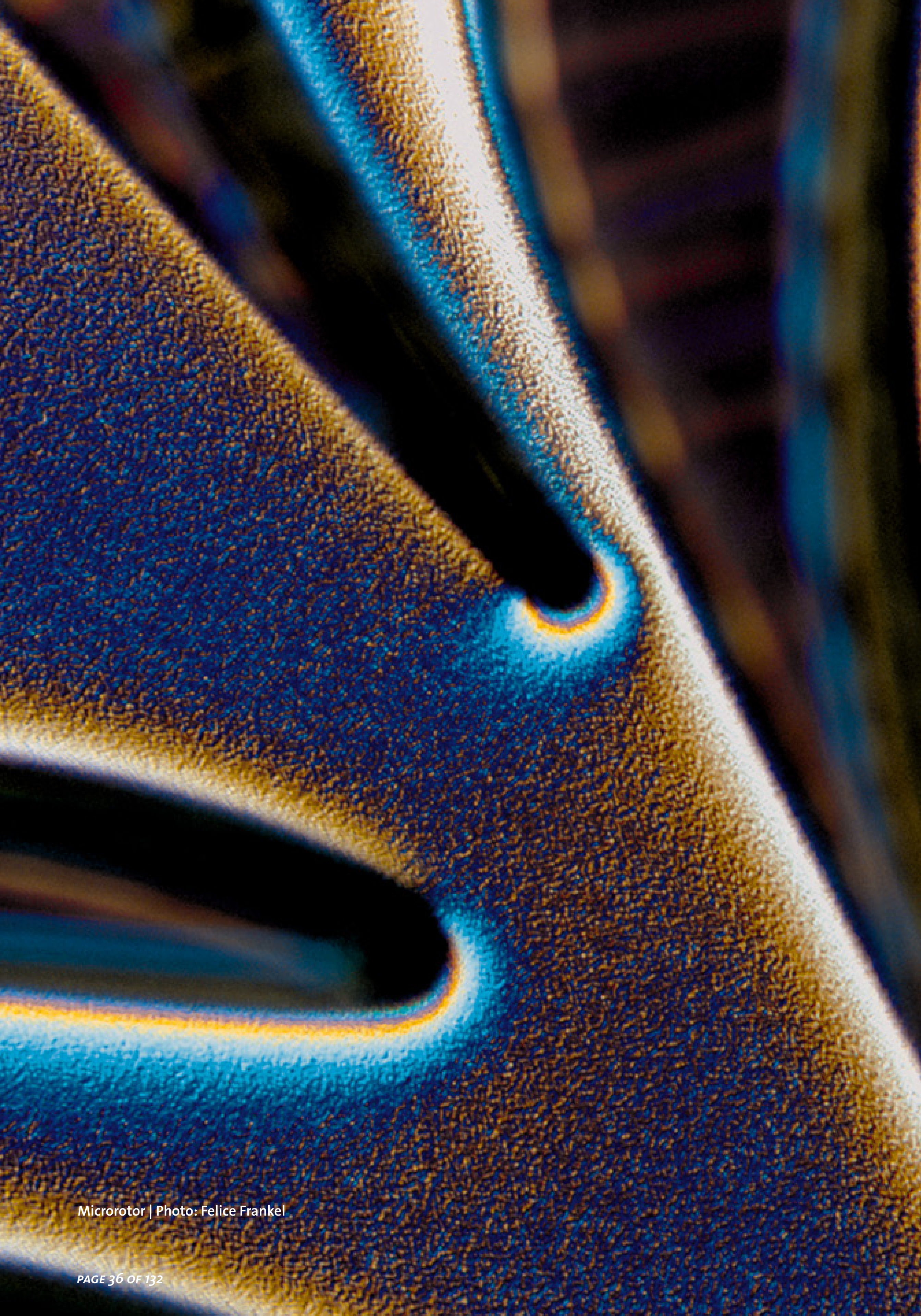
Photo: Felice Frankel



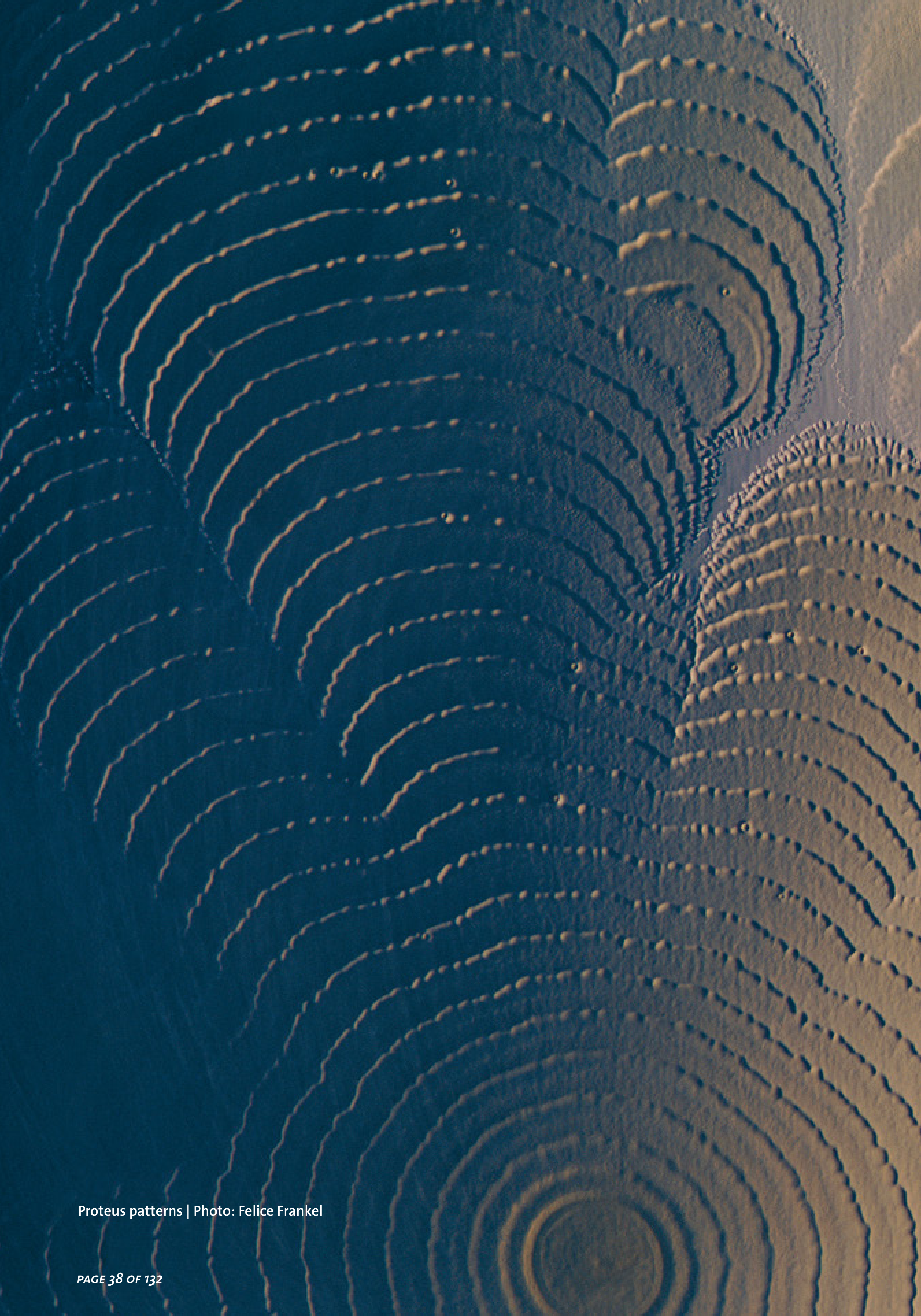
Yeast colonies | Photo: Felice Frankel



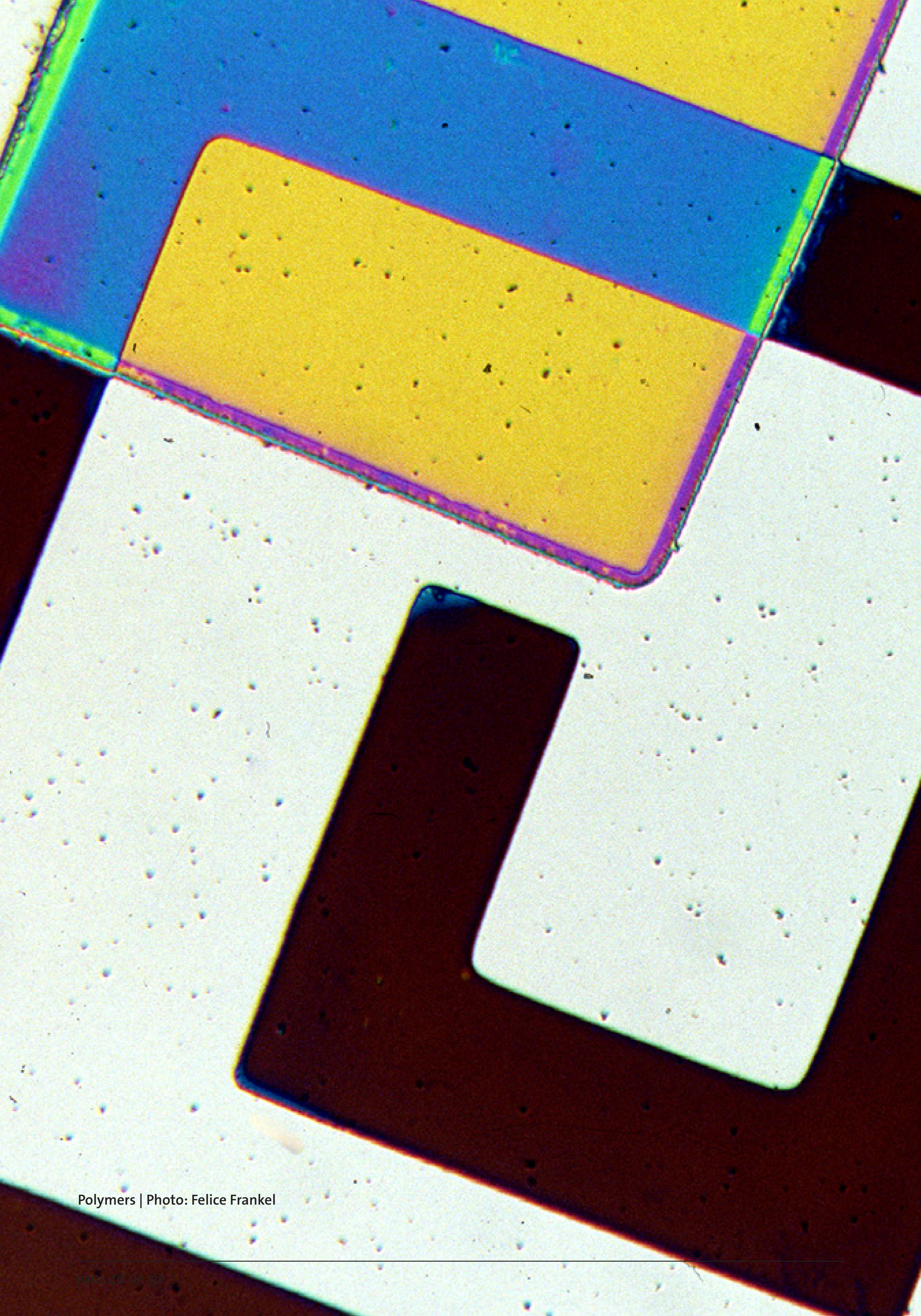
Ferrofluid | Photo: Felice Frankel



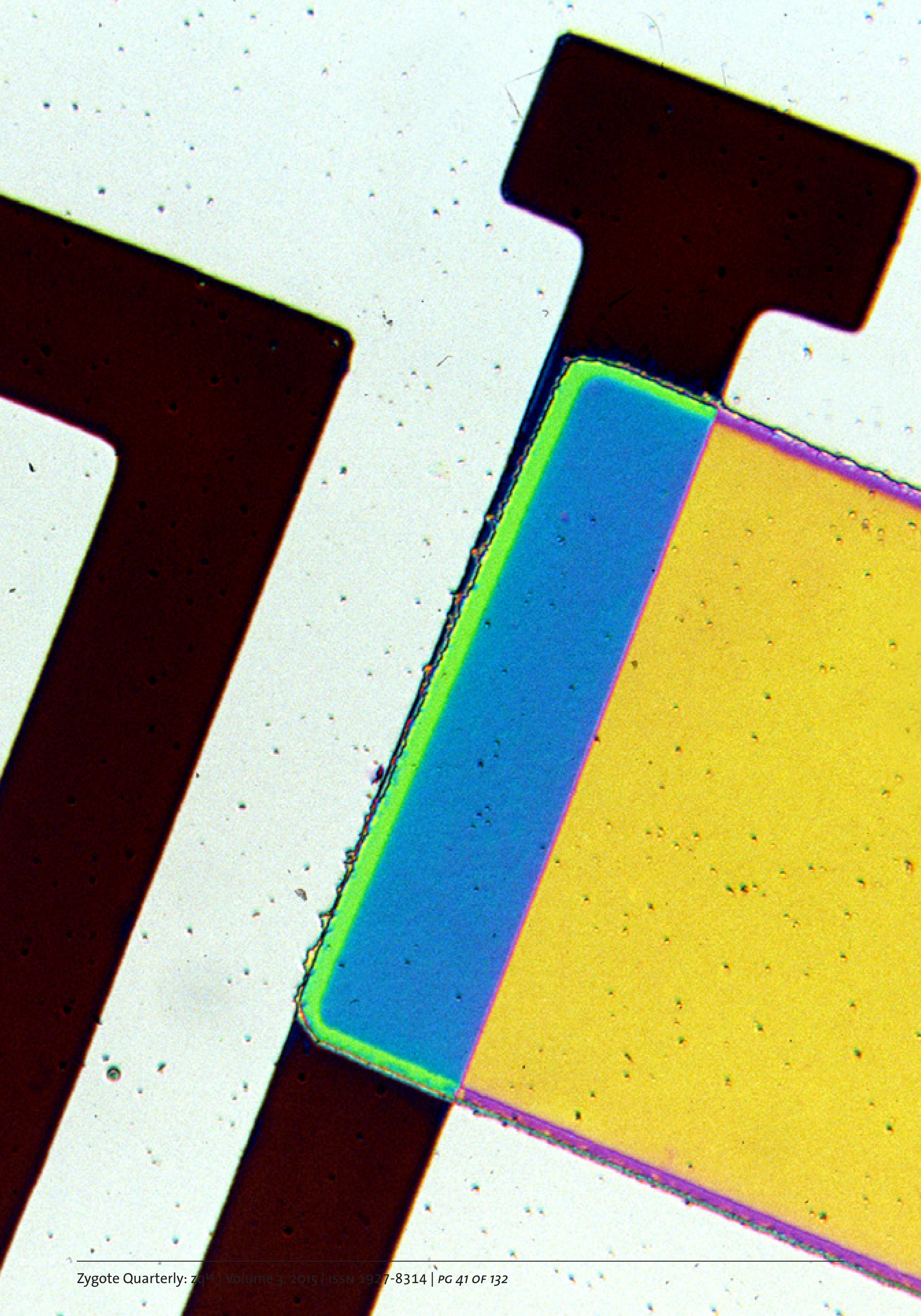
Microrotor | Photo: Felice Frankel



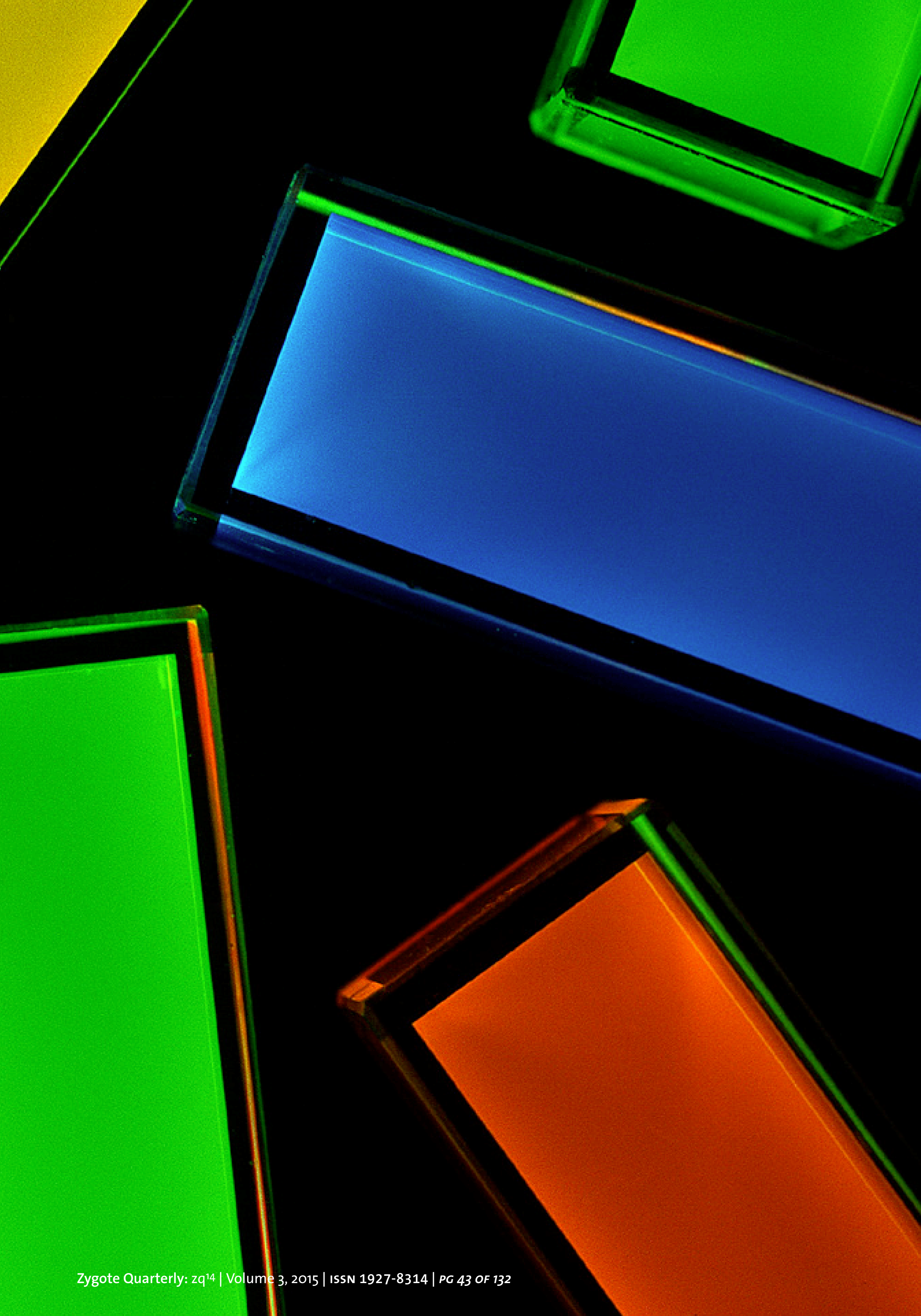
Proteus patterns | Photo: Felice Frankel

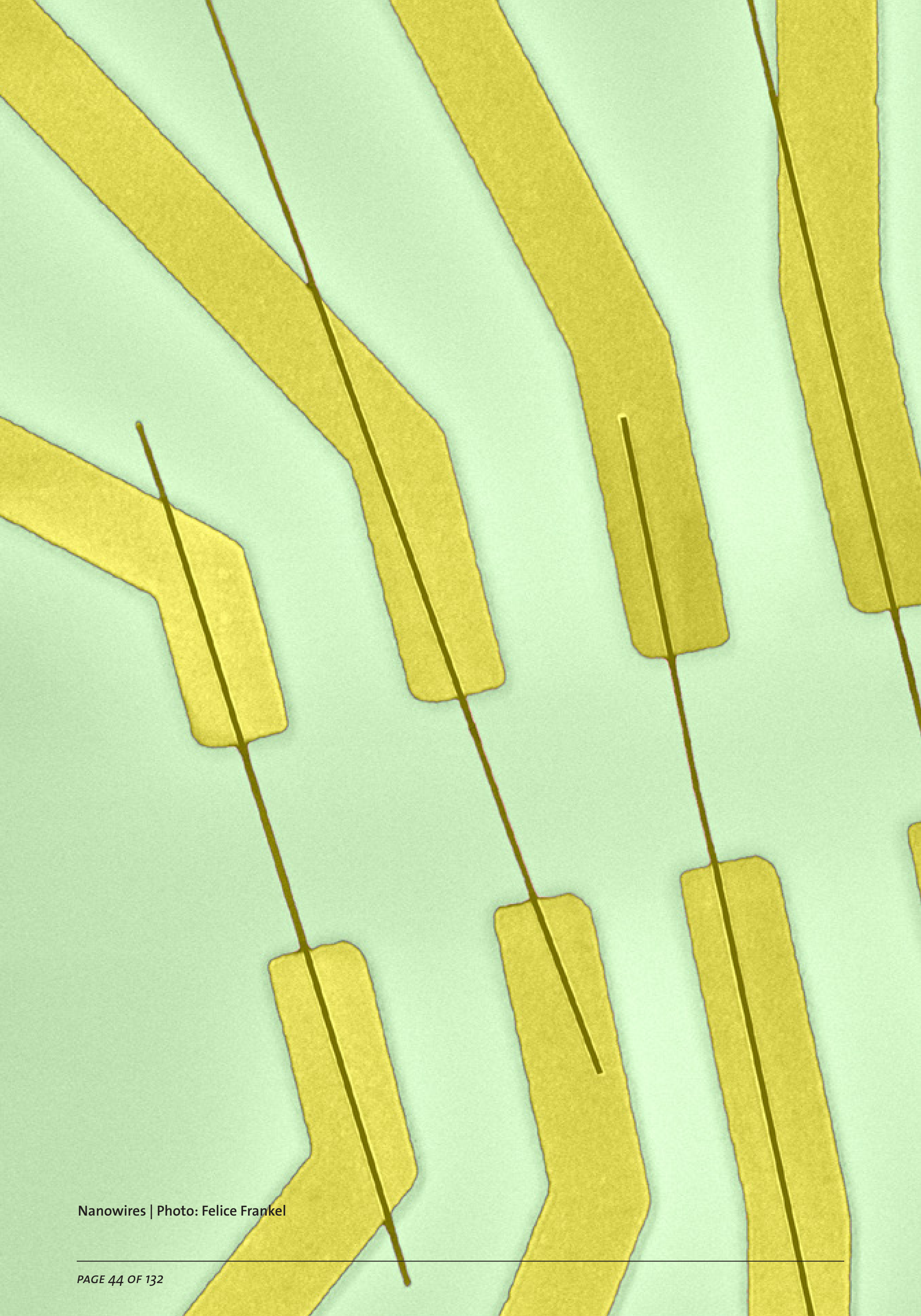


Polymers | Photo: Felice Frankel

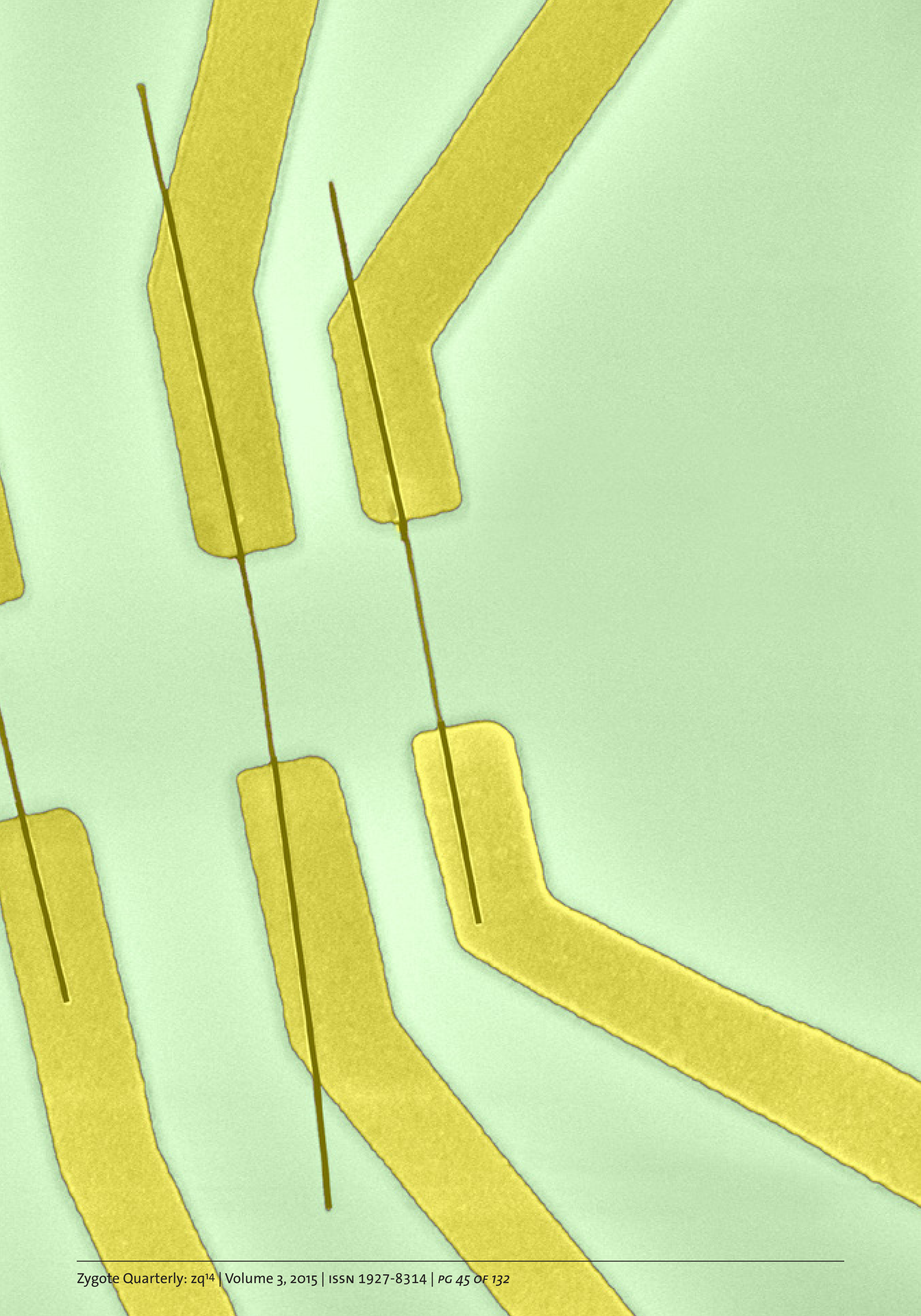



Nanocrystals | Photo: Felice Frankel



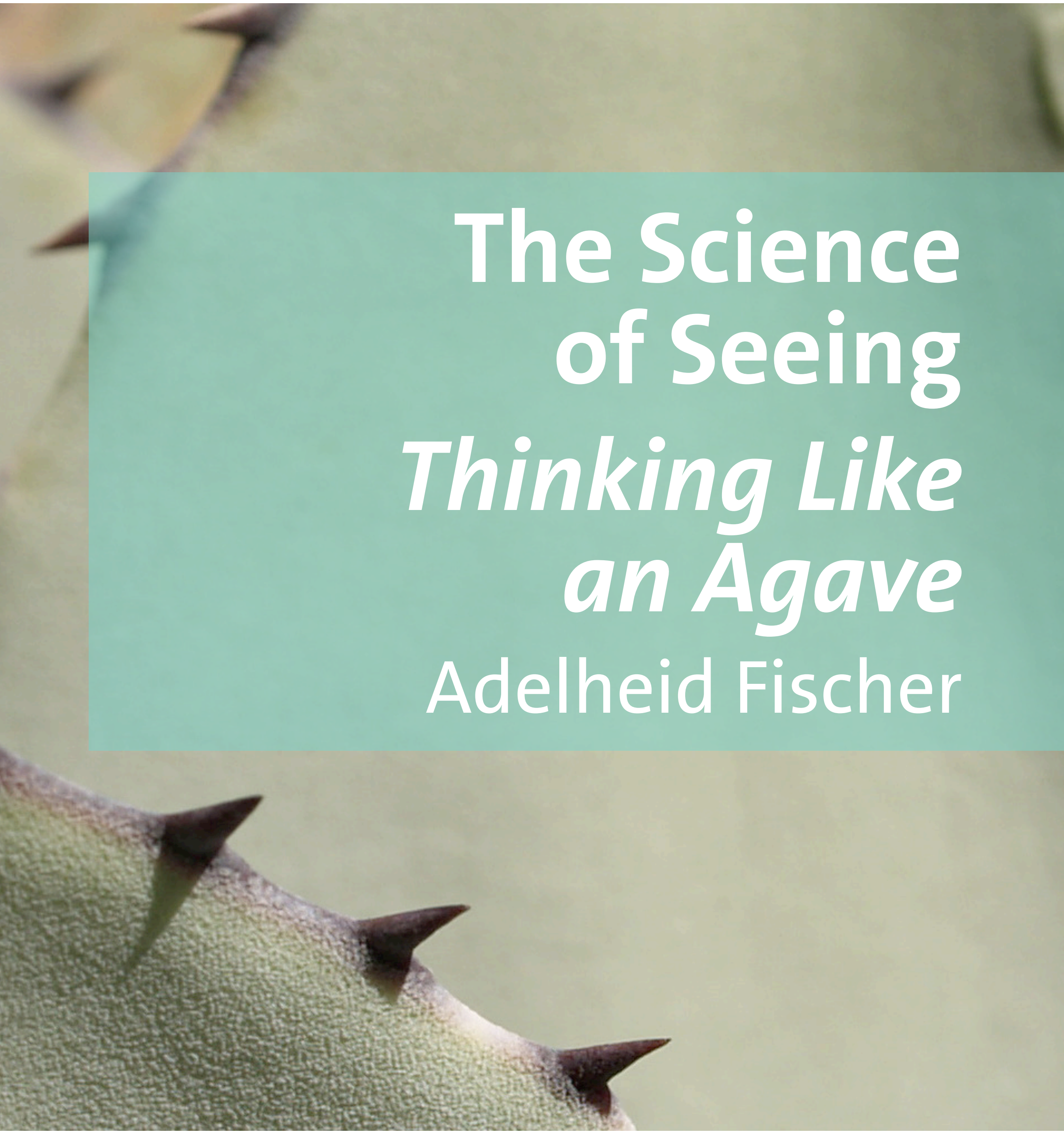


Nanowires | Photo: Felice Frankel



Agave parryi

Photo: mcgrayjr, 2008 | Flickr cc



The Science of Seeing
Thinking Like an Agave

Adelheid Fischer

Thinking Like an Agave

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

5:40 a.m. I catch the tail end of the day's weather forecast on the radio. The temperature is already pushing 90 degrees. My heart sinks. June is living up to its reputation as the hottest month of the year. For the past week Arizona has been in the grip of a heat wave, with the thermometer climbing past 115 nearly every day in the City of Phoenix where I live. It looks as if today might break another record.

I throw an extra water bottle into my backpack as I prepare to head into the field with botanists from the Desert Botanical Garden (DBG). Although our destination is Sedona, two hours north and several thousand feet higher in elevation, temperatures there will still be toasty. To make matters worse, we'll be hiking out in the open, bushwhacking to exposed ridges through thickets of spikes where plants go by such names as shindagger, horse crippler and crucifixion thorn. I rifle through a stack of folded trousers on my closet shelf and pick fire-engine-red pants made of a thick, tightly woven cotton, the closest thing I have to Army-issue canvas. I pull them on, look at myself in the mirror and chuckle aloud. Oh well, by the end of the day I may be comatose from heat and exertion but my crimson pants can at least guide the rescue helicopter to my impaled remains in the desert brush.

I meet up with the carpool at Wendy Hodgson's house. All morosity dissipates as I catch sight of Wendy, with an ear-to-ear grin, strolling down the driveway. She calls out her signature greeting, "How ya doin'?" as she grips me in a bear hug. Petite but sinewy, Wendy has lost none of her athleticism since her college days on a golf scholarship. She later earned a graduate degree in botany at Arizona State University in the 1970s. Maintaining physical strength and stamina has been critical to her career since most of her 40-plus years as a DBG researcher have been spent out in the wilds of Arizona.

She has had adventures that leave me bug-eyed and stuttering with envy: rappelling down a Grand Canyon wall to pluck a cliff-edge plant from the Coconino sandstone or shooting the rapids of the Colorado River to collect plants from a remote side canyon. Then there's the time she bivouacked with colleagues in the cinder-cone deserts in the southwestern corner of the state. While pitching their tents, a man walked right out of the horizon and spent the night around their campfire. Their guest turned out to be the famous desert writer Edward Abbey.

Ask Wendy about what tops her list of outdoor adventures, however, and she's most likely to name her longtime love affair with the agaves of Arizona. Great pinwheels of fleshy, spear-like leaves, agaves range widely throughout the

Gila Woodpecker on Agave Blossoms | Photo: desertdutchman, 2008 | Flickr cc

Agave | Photo courtesy of Wendy Hodgson

state, growing on the desert floor in the shadows of saguaro cactus and all the way up to 8,000 feet in forests dominated by ponderosa pine. To date, researchers have tallied 23 taxa of native agaves, more than half of which are endemic; that is, they occur only in Arizona.

The final tally, however, is far from complete. In the 1930s, when botanists first began to conduct formal field surveys in Arizona, they noted some odd agaves, recording their sightings of these curious anomalies in letters or as hunches on plant lists. Unfortunately, documentation was spotty. The official filing of specimens in herbaria, like the one at the DBG, requires the inclusion of plant parts such as flowers along with leaf samples. Since many agaves bloom during the torrid month of June, when it is torturous, if not dangerous, to be roaming out in the open, the early botanists often encountered these outliers only during the cooler offseason.

In the 1970s, researchers began to suspect that a collection of anomalous agaves near archeological ruins along the Mogollon Rim in north-central Arizona could be remnants of the cultivated gardens of pre-Columbian people. Interest grew and additional plants were discovered. By the late 1980s, two new species of ancient agave cultivars had been named.

Around this time, Wendy too caught agave fever. Then in 1992 she struck gold. While reviewing a plant list for the Grand Canyon in preparation for a collecting trip, she noticed that *Agave parryi*, a native species, was on the list. Wendy knew that the plant had been misidentified since *A. parryi* did not occur in the Grand Canyon. She consulted botanist Art Phillips, her colleague at the Museum of Northern Arizona (MNA), Flagstaff. Art recalled the plant and was able to direct Wendy to its exact location. Sure enough, when she hiked down into the canyon, Wendy found not *A. parryi* but an agave that was unlike any that she had seen before.

As you move north in latitude, agaves typically grow smaller and more compact as a protective response against colder temperatures. This specimen, however, defied the rule. The Grand Canyon agave was large and its leaves widely arrayed. Nearby were some archeological ruins. Her heart began to pound. “That was my smoking gun,” Wendy says. “I knew that it would not have evolved in the Grand Canyon in that form with its big and looser rosettes. It was brought in by people.”

After hours of careful comparative analysis with other agaves in the DBG herbarium, Wendy declared the plant a new species and officially christened it *A. phillipsiana* in honor of her MNA colleague. Subsequent genetic tests by fellow DBG botanist Andrew Salywon have confirmed Wendy’s designation.

Due mostly to Wendy’s field research and Andrew’s molecular sleuthing, the tally of domesticated pre-Columbian agaves continues to grow. To date, five species have made the list. The official botanical christening of additional agaves is currently in the works.

As our van finally crunches to a halt on a long dirt road in Sedona’s red-rock backcountry, Wendy jumps out and surveys her surroundings. Every outing is a chance to find a new clue in the landscape that can help piece together a picture of a mysterious and fascinating past. To stum-

Archeological ruins, Sedona | Photo courtesy of Heidi Fischer

Agave flower stalks| Photo courtesy of Wendy Hodgson ble across a new species, especially one that is tied to the lives of ancient people, "is exciting," Wendy says. "It is like YES!"

She raises her arms and begins to shout into the fierce heat of the day. "I love the way this looks, the way it feels, the way it smells. In my next life," she declares, "I want to come back as a field botanist."

Sedona is renowned for mesas the color of fresh paprika which rise out of the rolling chaparral of juniper and pinyon pine in the north-central part of the state. I am standing on the top of one of these mesas, looking out over a series of cliff faces, forming what look like basting stitches across the land. At my feet are rows of tumbled rocks, the linear ruins of a prehistoric field house. Eight hundred—maybe even a thousand—years ago, someone took shelter here from the sun or the wind or the rain to keep watch over a hillside planted with agave. The guard would likely have kept a pile of palm-sized stones or a slingshot near at hand to pick off the gophers and packrats foraging for the more tender young plants.

Wendy and Andrew are ecstatic. The two botanists have examined so many agaves up close that even a cursory look at these specimens suggests that they may be candidates for new species status. Many of the agaves are in bloom, which will allow the researchers to bring complete sample sets of leaves and flowers back to the DBG for later analysis. They snap photos and write down the GPS coordinates for each plant. Using long-handled pruning shears, they also snip a blossom from the towering flower stalks. Armed with a sharp knife, Andrew gingerly buries his hands into the rosette to hack off one of its thick leaves, taking care to avoid the serrated teeth along the leaf edge and sharp terminal spine on the end. Ancient pictographs in Mexico show how Mayans inserted these spines into the flesh of children as a form of discipline. Wendy shakes her head at the cruelty of it. On a field outing weeks before, a terminal spine embedded itself in the knuckle of one of her fingers. Measuring almost one centimeter long, the spine caused serious swelling and pain before it had to be surgically removed.

As Wendy and Andrew tend to their plant-collecting regimen, I sit down to examine these plants up close. For ancient people, agaves were one of those all-in-one plants that provided a cornucopia of products. In her book *Food Plants of the Sonoran Desert*, Wendy lists the following benefits of agaves: "food, alcoholic and nonalcoholic beverages, syrup, fiber, cordage, clothing, sandals, nets, blankets, lances, fire hearths, musical instruments, hedgerows (including boundary demarcations), soap, medicine and ceremonial purposes."

In this list of human services, one of the most important was food. During a late stage in their development, agaves flip a metabolic switch and begin to divert huge amounts of energy to the center stem of their rosettes. The plants build this carbohydrate-rich tissue to fuel the growth of a massive flower stalk. Prehistoric people would short-circuit this process by hacking off the rosette of leaves just as the flower stalk formed and began to drain the precious store of nutrients. The size of a basketball, the heart then could be roasted in underground fire pits for several days until it was tender enough to eat.

For prehistoric farmers, agaves must have seemed a kind of miracle food. They grew more labor-intensive crops such as corn, beans and squash in low-lying fields with easier access to irrigation. Agaves, on the other hand, flourished in the thin, rocky soils of the hillsides that overlooked their fields. Aside from the need for pest control of gophers, the plants were fairly self-sufficient. Although agaves reproduce sexually (hence the production of nectar-rich flowers that attract bats, bees beetles and birds), the primary mode of propagation is through cloning. The plants produce genetic copies of themselves via underground rhizomes. Indeed, adult plants at the end of their lifespans are routinely encircled by young clones, known as "pups." Because these young plants are remarkably tough and could survive overland travel in a backpack, they were traded over long distances by people in prehistoric times. Indeed, Wendy suspects that the progenitors for many of the domesticated species of agaves in Arizona came from Mexico. These forgotten species have either become extinct or have yet to be discovered there.

The realization that the plants before me are copies of the very same agaves that prehistoric people tended nearly a millennium before makes me grow flush with wonder and admiration. How have these clones persisted here?

For one thing, their form is well adapted to desert conditions: wide swings in temperature, which can range from triple digits to below freezing, and scant and unpredictable rainfall. Agaves are collecting dishes whose guttered leaves capture this moisture and funnel it to its shallow roots. Plumped-up with rain, the leaves double as storage tanks. At the same time, the rosette pattern protects against water loss as overlapping leaves partially shade each other from the desiccating sun and drying winds in a strategy known as phyllotaxy, in which each leaf spirals off the center at a slightly offset angle in order to balance the need for both sunlight and self-shading. For added measure, a waxy cuticle covers the surface of the leaf, retaining the hard-won moisture.

The plant also draws on a bag of tricks that are invisible to the unaided eye. Its stomata, or "breathing" pores, are recessed, rather than flush with, the leaf's surface. This buffers contact with the dry air that could increase water evaporation during photosynthesis when the stomata are open in the give-and-take of absorbing carbon dioxide and releasing oxygen. During drought periods, some arid-land plants such as agaves practice an alternate method of photosynthesis known as Crassulacean Acid Metabolism (CAM). Stomata open at night, instead of during the day, to minimize water loss. CAM photosynthesis conserves water but dramatically slows plant growth. When moisture is more available and they can afford to forego greater water loss for faster growth, however, agaves can switch back to opening their stomata during the day.

Then, of course, there is the sheer beauty of these plants: the scallops of fine, regular teeth that run along the edges of their sturdy leaf spears, the attenuated arc of each leaf tip which is every bit as beautiful as the curve in a dancer's wrist as she holds it aloft in space above her head. It is a plant that can flourish in thin soils and sparse rains and yet be of great service and star-

Agave with Wendy Hodgson

Photo courtesy of Wendy Hodgson

tle with its grace. These are precisely the qualities to which I aspire in my own brief tenure on the planet. I find myself wondering: 1,000 years ago, was there another person here on this very spot, gazing out at the red-rock cliffs who, like me, was astonished and grateful and happy to just quietly sit in the company of these plants?

Wendy and Andrew carefully bag and mark each plant sample in paper grocery bags and then gently load them into the back of the van. On the ride back to Phoenix, the van begins to fill with the aroma of agave blossoms: a sweet and musky smell.

It doesn't take long before we cross the frontier of urban sprawl that creeps ever northward from Phoenix to Sedona. As far as the eye can see, a crust of red-tiled roofs is overtaking the desert. In the fall of 2014, this region of Arizona was hit hard by record flooding. Dry washes suddenly raged with floodwaters that jumped their banks and lofted homes off their foundations, pummeling them until they broke into pieces. Cattle and horses swam alongside sofas and empty SUV's.

The desert is adapted to the floods that follow boom-and-bust cycles of rain. Current modes of human development, however, have outstripped the capacity of the land to effectively mitigate storm flows. Instead of designing structures that intercept water onsite, like agaves, saguaro cactus and other desert plants, we armor nearly every surface of our developments, shunting rainfall from roofs, driveways and high-

Glenn Murcutt, Magney House, Bingie Point, New South Wales, Australia. 1982-84 and 1999.

Photos : Anthony Browell | Courtesy Architecture Foundation Australia.

ways. Hydrologists estimate that these impervious urban surfaces send four times the amount of stormwater across the land than undeveloped desert. Some of these urban flows course into holes in the ground known as retention ponds. More often than not, they are odd, leftover spaces carved out of already anonymous landscaping. Occasionally, these excavations have been integrated into recreational developments, doubling, for example, as ball fields under dry conditions and catchments for stormwater overflow in floods. Yet, in major flood events, even the most thoughtful designs can brim with a murky urban soup which is laced with motor oils, backyard pesticides and the fecal wastes of birds, dogs and cats. Compared with the agave's elegant fit of design to circumstance, our designs often are crude, clumsy and ugly.

What if human-built structures functioned more like agaves, capturing stormwater and discreetly directing it to a storage area where it could service localized needs? What if, in the process, we could marry utility to beauty, which agaves so perfectly model? As an example, I might point to the designs of one of my favorite architects Glenn Murcutt. In his native Australia, water often is as scarce as it is in the deserts of the American Southwest, and so his houses typically incorporate features for rainwater harvesting and storage. The designs for this exterior plumbing, however, are no slam-bam, get-the-job-done affairs.

Take his Magney House in New South Wales. Canted roofs, like the guttered leaves of the agave, funnel rain into a central trough and from there into an underground tank. The rain spout flares in what looks like a receiving bowl or cupped hands. To my eye, it is a beneficent gesture, as if the design were striking a blessing pose, assuming a position of gratitude for the gift of water in dry places.

What if our buildings and roadways, like the Magney House, like the agave, routinely intercepted rainfall onsite before it flowed across the land and conjoined with other flows to form destructive floods? What if they received water as the gift that it is, rather than sloughed it off as a nuisance?

What if our designs, like the agave, could help us flourish in an age of resource scarcity? What if they could be of great service and, at the same time, startle us with their grace? ×

For more about Glen Murcott's work see:

https://www.murcuttfoundation.org

Glenn Murcutt, Magney House, Bingie Point, New South Wales, Australia. 1982-84 and 1999.
Photos : Anthony Browell | Courtesy Architecture Foundation Australia.

Glenn Murcutt, Magney House, Bingie Point, New South Wales, Australia. 1982-84 and 1999.
Photos : Anthony Browell | Courtesy Architecture Foundation Australia.

Eurasian Hoopoe (*Upupa epops*)

Design: Estudio Guardabosques

Product design
Estudio Guardabosques
3D Paper Models

Product design
Estudio Guardabosques

Designers:
Carolina Silvero and Juan Nicolás Elizalde

Could you tell us about how you are inspired by nature?

Guardabosques in Spanish means “forest rangers”, so even from the start, from the exhibition of the same name that gave birth to the studio, we always knew that nature and its endless possibilities was something that we would want to explore when working together. We take nature as an infinite source of inspiration: the colors, textures, shapes, scales, movements, it never ends, and you always discover something new and exciting.

Most of the things that we do are experimental, and even if most of our work seems to end up as 3d paper representation, we are always trying new stuff.

Obviously we approach our pieces from the aesthetic side, but our intention is not to make a shallow product. We like to use them as means to share our love for nature with others, to show the existence of some animals and in some cases try to create some awareness, as is the case of our paper birds and the idea to be able to have the birds in your home without cages and enjoy the real ones free in their natural habitats.

We get our inspiration from the internet but also from taking field trips or walking to parks and taking pictures or drawing. It’s really a different experience when you are there and you can feel, watch and smell all the subjects. But when you don’t have that option, it’s amazing how many references you can find online.

Also, it’s curious how you can learn by making 3d models: for example, observing that we always used the same colors for all the mammals that we have made, realizing that about the colors of the mammals in general, googling it and learning about melanin.

Can you tell us about Estudio Guardabosques and the work you do?

Guardabosques is a studio based in Buenos Aires, Argentina, formed by Carolina Silvero and myself, Juan Nicolás Elizalde. Carolina is a graphic designer and works as an illustrator and textile designer, and I’m an audiovisual designer and I usually work as an art director, illustrator and animator. After I graduated as a designer, I started studying natural sciences, and a lot of inspiration comes from those classes. We both work in advertisement, but most of the work that we show on our site is mainly personal projects. The paper birds for example started as a project to decorate the Aves Argentinas (Argentine birds, the national ornithology institution) headquarters where I study, so we investigated our local birds and started making our first models. From that first research effort a lot beautiful birds were left in our references folder, and with time we started doing all of those and more. Then came mammals, cetaceans, and dinosaurs.

Most of the animals were inspired by photos we saw online and were made just for fun, for the joy of translating those animals to 3d and spend some time crafting them in paper, but when we started publishing them online, they went viral for a while, and that brought amazing opportunities like being invited to make a local bird exhibition at KAUST (King Abdullah University of Science and Technology) in Saudi Arabia, or

Gray fox | Palacio San Miguel | Design: Estudio Guardabosques

Product design
Estudio Guardabosques

Designers:
Carolina Silvero and Juan Nicolás Elizalde

Designer Carolina Silvero
Estudio Guardabosques

travelling to India to work for a couple of weeks. We love that, and we hope more of those experiences come up in the future.

What kind of techniques do you use for your work?

Most of our work is done in paper. We have two ways to handle it.

Our most popular work is the 3d paper animals; those are designed in 3dsmax in lowpoly style, then translated to paper with Pepakura, and finally cut via cutter plotter and assembled by hand. It's really a long process for each piece.

The other thing we like to do is to illustrate with paper, sketching, cutting big blocks of colors, then refining it to cut what we need and then draw on top of it. Both process are really different but we enjoy both of them.

We have also been experimenting with cardboard and needle felting.

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

We tend to take our inspiration more from the nature side than the design side.

A lot of the inspiration comes from biology websites or Facebook pages that we follow, that keep posting amazing discoveries, unusual animals, landscapes, macro photography, etc. Also from books, documentaries, magazines like yours, photos, museums, it never ends (and we like it that way!). And also from real life: we love to

go to parks and natural reserves to take pictures that we may use as references for the works we are doing.

Bill Bryson's *A short history about nearly everything* was a huge eye opener to biology and I personally recommend it to anyone who's getting interested in the subject. We love Richard Feynman and we even opened a few workshops with his "Ode to a flower" bit as an inspiration. We could go on forever with the people we admire.

We also take a lot from illustration, we have a few authors that we love because of how they interpret nature, such as Charley Harper, Eyvind Earle, Alice & Martin Provensen, Ariane Dewey & Jose Aruego, Mary Blair, and on the serious side Douglas Henderson or James Gurney.

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

We just finished collaborating on a big organ donation campaign for the United Kingdom that launched in early September, this time not in paper.

We are also doing new birds for our 'Papercraft birds to assemble' collection, and getting ready to hopefully launch it with English instructions soon.

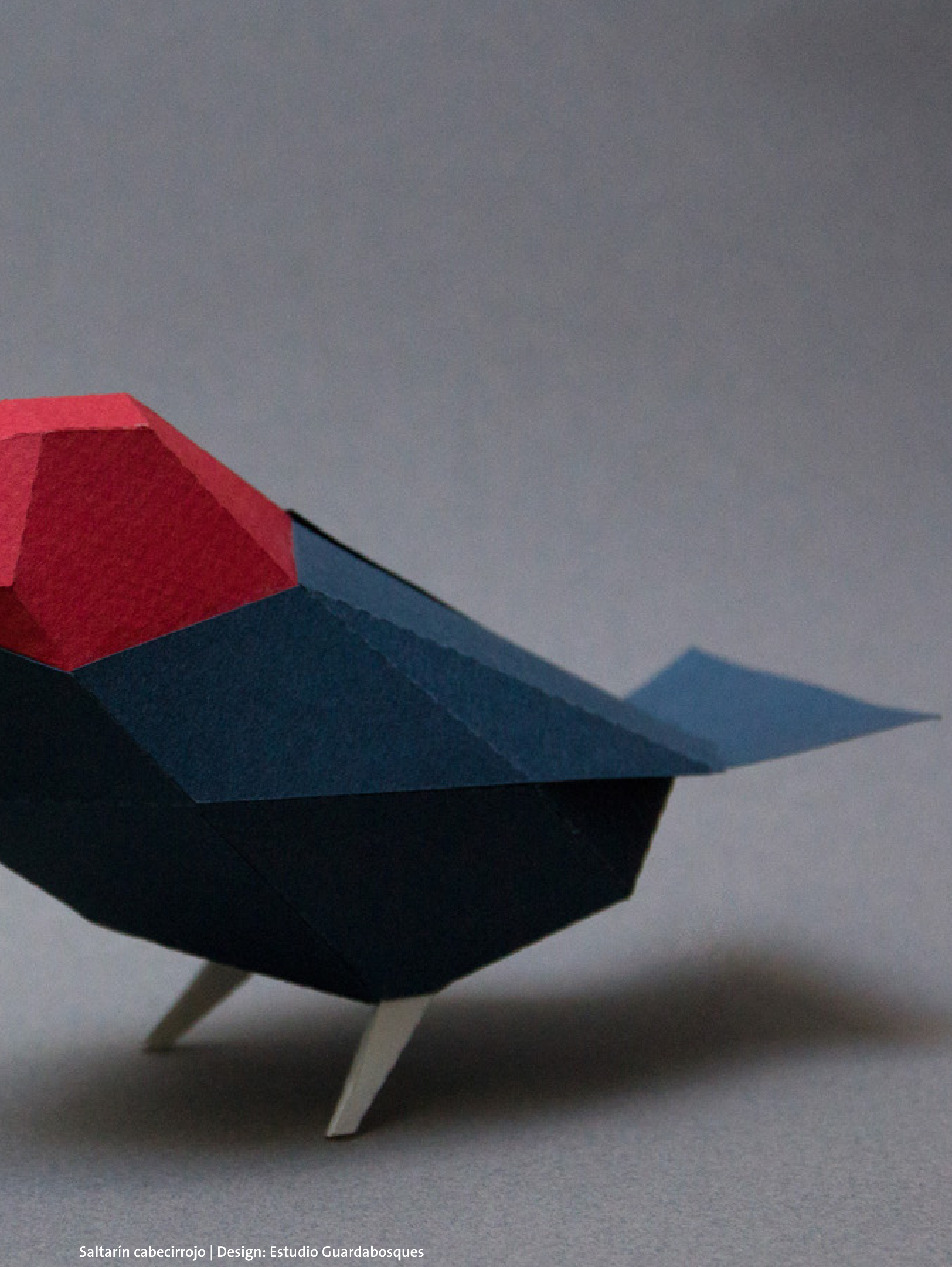
Also on paper we are really excited with our new project of paper dinosaur skulls to assemble, we have been doing a lot of research on that to make it as scientific as possible while having our aesthetic at the same time, and we have more than 20 dinosaurs already, it will be hard to make a selection!

Besides that, we are also planning a bird app, like a field guide but with a different interface, in which people from all ages, even kids, would be able to tell what bird species they are looking in the park or in the city, and learn some information in a playful way. We think that getting to know what surround you is the first step to start taking care of it. ×

https://guardabosques.mitiendanube.com

Designer Juan Nicolás Elizalde
Estudio Guardabosques

Crimson-hooded manakin (*Pipra aureola*) | Saltarín cabecidorado || Red-capped manakin (Pipra mentalis) |



Saltarín cabecirrojo | Design: Estudio Guardabosques

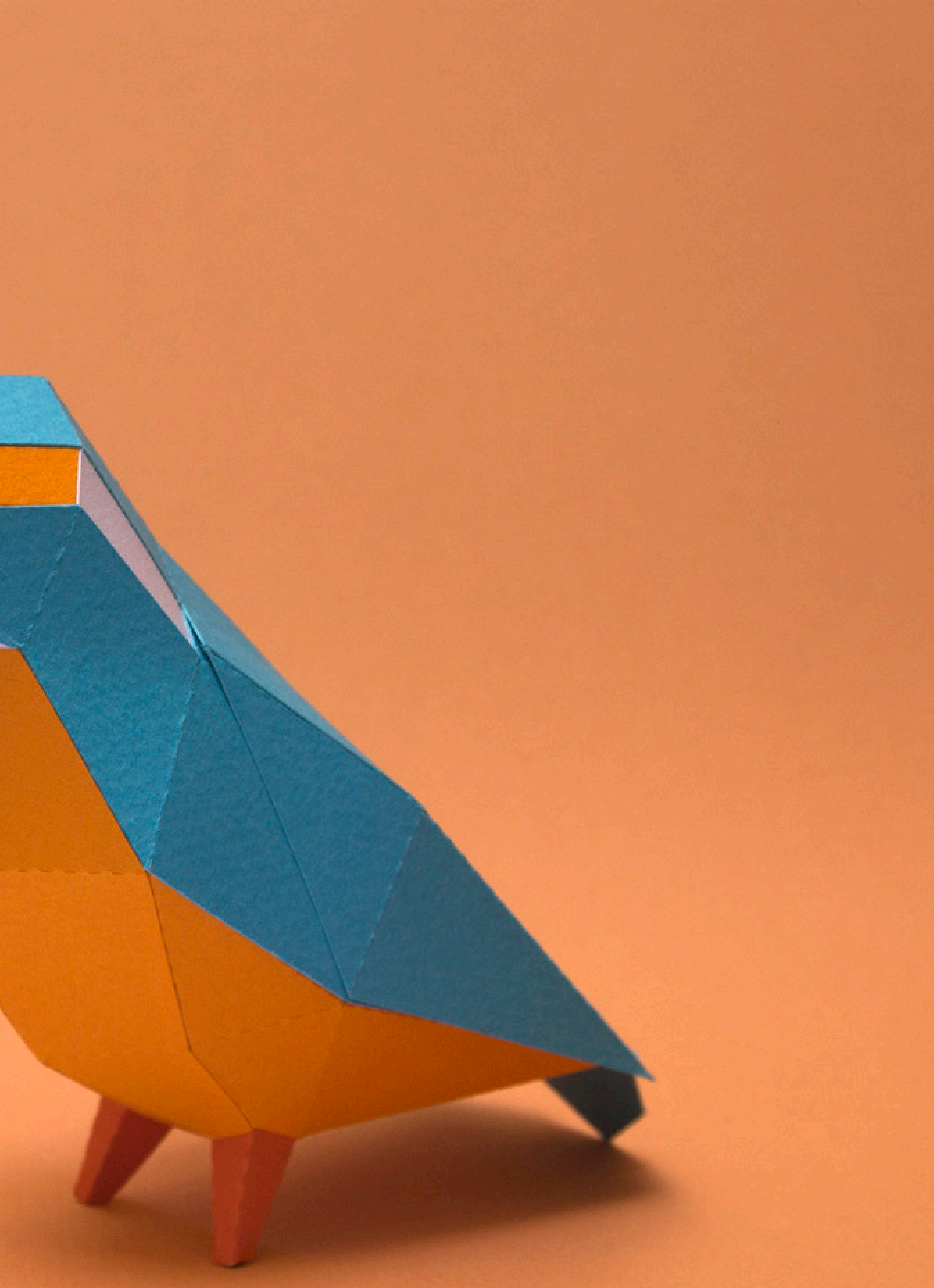
Red-capped robin (*petroica goodenovii*) | Design: Estudio Guardabosques

Red-flanked bluetail (*Tarsiger cyanurus*) | Ruiseñor coliazul | Design: Estudio Guardabosques

Purple-crowned fairywren (*Malurus coronatus*) | Maluro coronado | Design: Estudio Guardabosques

Green-barred Woodpecker (*Colaptes melanochloros*) | Carpintero Real | Design: Estudio Guardabosques

Kingfisher (*Alcedo atthis*) | Design: Estudio Guardabosques



Scarlet-headed blackbird (*Amblyramphus holosericeus*) | Federal | Design: Estudio Guardabosques

Narcissus flycatcher (*Ficedula narcissina*) | Papamoscas narciso | Design: Estudio Guardabosques

Red-crested cardinal (*Paroaria coronata*) | Cardenal común | Design: Estudio Guardabosques

Backstage | Design: Estudio Guardabosques

Green bee-eater (*Merops orientalis*) | Design: Estudio Guardabosques

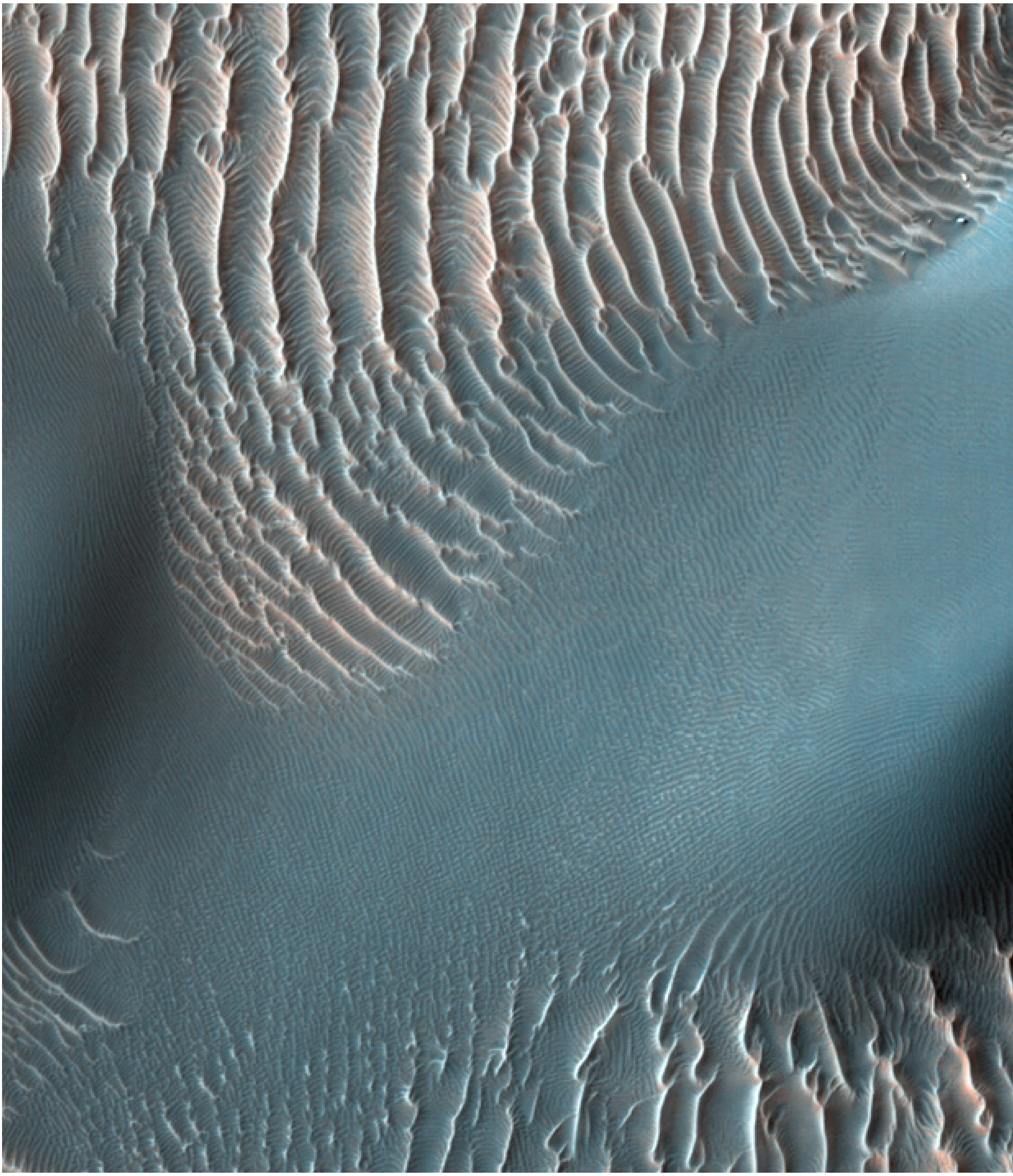
Rüppell's Weaver (*Ploceus galbula*)

Photo: Sergey Yeliseev, 2015 | Flickr cc

People

Interviews with

Russell Kerschmann, Pete Foley and Shannon Royden-Turner



Sand Dunes and Ripples in Proctor Crater, Mars
Photo: NASA/JPL-Caltech/University of Arizona

Interview

Russell Kerschmann

Dr. Russell Kerschmann is an M.D. pathologist with 30 years' experience in executive management, clinical practice, biomedical device development, and molecular pathology industries. From 2004 to 2009 he was chief of the Space Biosciences division at NASA Ames Research Center, where he initiated programs in radiation biology and lunar dust toxicology and supported missions with the Russian Space Agency. Dr. Kerschmann continues as a subject matter expert consultant to the NASA Engineering and Safety Center (NESC).

You tend to refer to 'nature-inspired design' (NID) – how does it differ from biomimicry/ biomimetics/bio-inspired design?

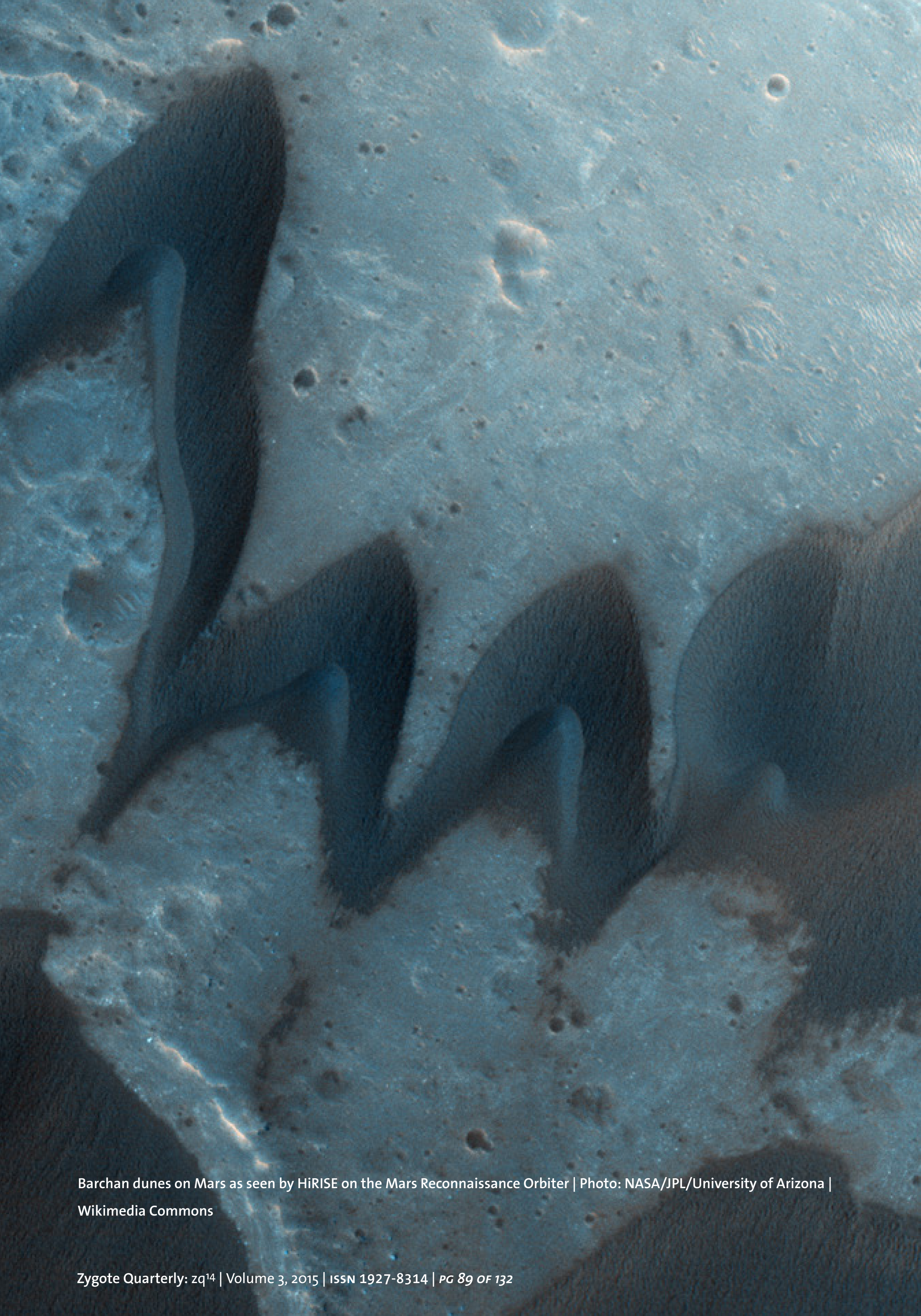
It's one of the goals of our NESC subgroup to try to broaden the scope of bio-inspired design to include other sciences. Although the bulk of the biomimicry/biomimetics/bio-inspired design research tradition has focused on biology, there is value in including the full breadth of natural systems, such as geology, meteorology and other disciplines. To date, other natural sciences have not been studied extensively as sources of engineering concepts and ideas. However, some non-biological applications in space robotics might include designing light-weight shelters on Mars that resemble the shape of dunes to prevent wind-damage, or even that rely on Martian wind patterns to accumulate actual dunes around the structure to provide additional radiation shielding. In other areas researchers have modeled computer algorithms on inorganic chemical reactions to increase computational performance. Biology has the tremendous advantage that it's based on a well-structured data storage and execution mechanism, DNA. What the equivalent of that might be for, say meteorology, is anyone's guess.

What are your impressions of the current state of nature-inspired design?

In my opinion, the field is lightly scratching the surface of the potential, and it's still in search of a persona. Natural systems display a wide range of characteristics that could help make robotic and manned spaceflight systems safer and more reliable. Natural systems, particularly biological systems, are highly autonomous, fault tolerant, cooperative, and adaptive to environmental changes. Biological systems often involve self-assembly and self-replication, and display low weight, low power consumption, integration and multi-functionality, resulting in high levels of efficiency. However, few formalized NID solutions have been incorporated into NASA or other spaceflight projects.

What do you see as the biggest challenges?

Although the life sciences have accumulated massive amounts of data, there appears to be what you might call an "impedance mismatch" that prevents engineers from easily accessing the biological knowledge stored in massive literature databases. It may be that the biological data is not properly structured for engineering solution-oriented search. Part of this may be due to the fact that in comparison to engineering, the life sciences tend not to manipulate their concepts in the realm of high level mathematics, although this is may be changing in the field of genetics. Another issue is that biologists tend



Barchan dunes on Mars as seen by HiRISE on the Mars Reconnaissance Orbiter | Photo: NASA/JPL/University of Arizona | Wikimedia Commons to be discovery-oriented while engineers are requirements-driven. Typically engineers have limited input into these requirements and it can be very difficult to change requirements once they are locked in. Providing solutions that exceed requirements can increase project complexity and risk while raising questions about how to compare competing solutions. Lastly, NID solutions are often very sophisticated, requiring tools and methods that may be unavailable to most engineers.

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

The tendency in NID to date has been to emulate or copy biological structures. However, it has been said that nature is more than a collection of objects – it does things, and does them in ways that are often unfamiliar to engineers, so that NID can produce surprising results beyond what any human might create. We should embrace this process-oriented approach and spend more energy exploring the processes in nature (such as evolution, development and interaction of the organism with the environment) that led to the natural structures and systems we observe. Natural processes are fluid and dynamic – they are a 'means to an end', which is one definition of a tool. Modeling these processes could provide engineers with novel ways of delivering solutions that meet their project requirements. This pathway shows potential for enabling a new level of engineering design sophistication.

Secondly, NID must become more requirements driven. Although solution-oriented biomimetic designs predominate, few appear to have progressed beyond the demonstration stage, or 'low Technology Readiness Levels' at NASA. Developing methods and tools that allow NID to be applied to specific engineering needs can lead to innovative solutions even though they may not necessarily resemble any biological organism or phenomenon.

How can we deal with complexity in both natural systems and today's engineering challenges?

Complexity is the major hurdle to advancing the field of nature-inspired-design and engineering. Some might think that nature-level complexity is so overwhelming that it is an insurmountable barrier to full implementation of NID for producing entire multi-component systems, such as using NID to design an entire jet engine. It could be said that without mastering the complexity problem NID has to remain a curiosity that might only be useful for much simpler components, like jet fan blades.

However, we do know one thing: that Nature itself has solved the complexity problem. I personally believe that the human mind has limitations and I don't believe that human beings will be able to master complexity on an element-by-element, logically-derived basis. The way we will surmount the complexity issue is by finding methods to apply NID itself to that solution. I believe this "judo" approach may have to be done "blindly": we may never have the satisfaction of understanding completely how our NID tools have solved a complex solution. This will irritate the pure scientist and the mathematician, but similar to physicians, what matters most for engineers is that the result is satisfactory and it does the job.

How have you developed your interest in nature-inspired design?

I have had a long standing interest in space exploration and while on the faculty at the University of Massachusetts worked on a chicken embryo project that flew, and was lost with Challenger. We re-flew it two years later and made some significant discoveries. Subsequently, I was Chief of Life Sciences at Ames Research Center from 2003-2008, working on life sciences payloads on shuttle, International Space Station and Russian Bion spacecraft (http://www.russianspaceweb.com/bion.html). When I retired, I joined the NASA Engineering and Safety Center where technical teams evaluate mission safety and ensure new technologies are not overlooked due to cultural or political inhibitors. Nature-inspired design fits well with the NESC mandate to keep focus on new technologies and could also improve safety by helping make systems more robust, self-contained, and resilient.

I helped form a sub-group within our NESC Robotic Spaceflight Technical Discipline Team (TDT) three years ago to focus on NID, working with Dr. Joel Levine (professor at William and Mary College, principal investigator and chief scientist of the proposed ARES Mars Airplane Mission), George Studor (Johnson Space Center) and Michael Simms (Principal Research Scientist, NASA Ames Research Center). I gave presentations at IEEE and AIAA to popularize NID within a NASA context but also the wider engineering discipline. Through his work at Langley Research Center, Joel has promoted natural systems in the NASA organization, and George Studor started a Natural Systems Working Group within the International Council on Systems Engineering (INCOSE) and started a very successful INCOSE webinar series in natural systems.

What is your best definition of what we do?

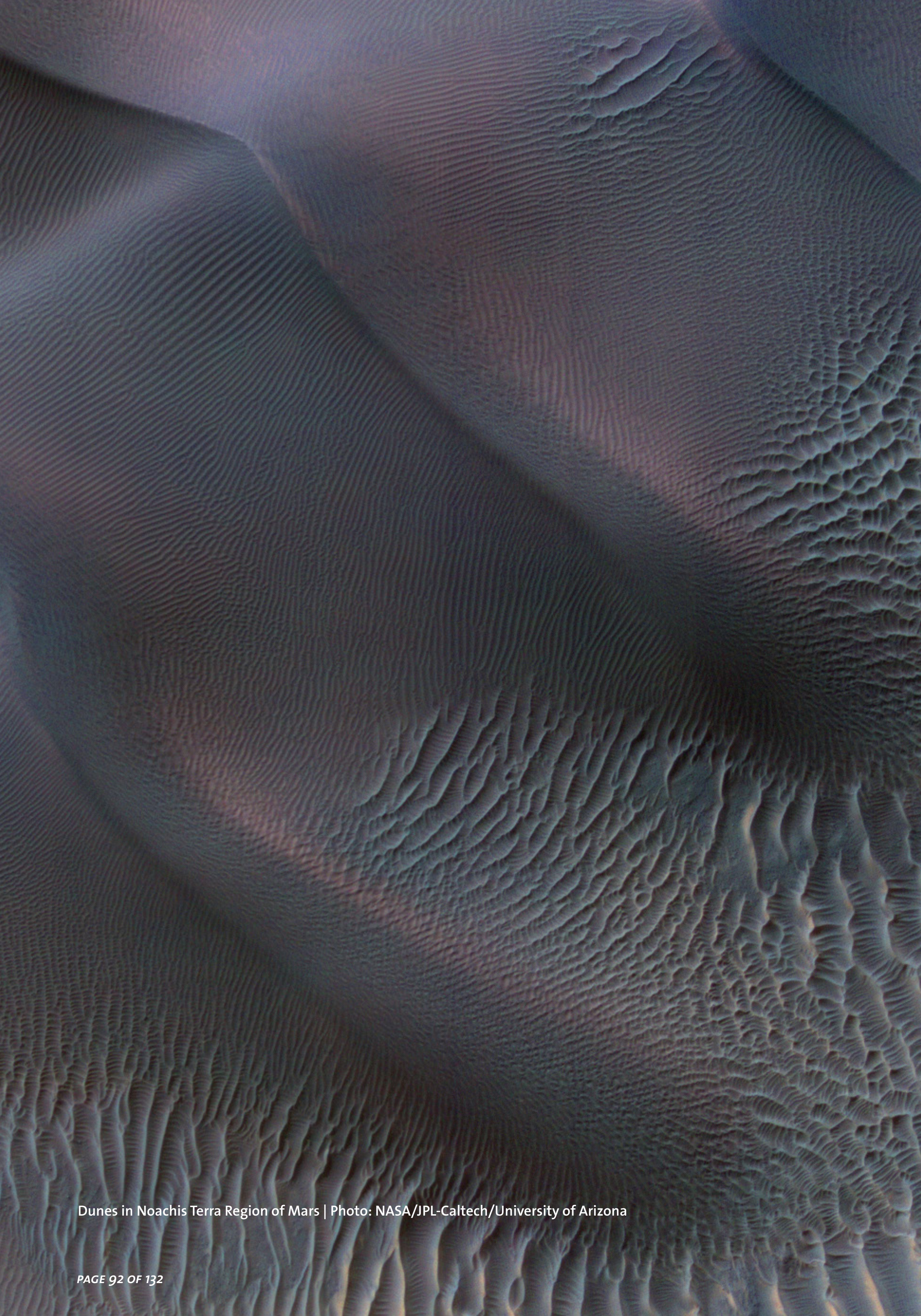
Although living things and our machines interact all the time, we don't often consciously use the design examples present in the natural world to direct the design and construction of these machines. Beyond transferring knowledge between the domains of nature and engineering, we need to bridge expertise and insights within these domains through education programs where people are steeped in both fields and motivated to do true nature-inspired design. Although I switched from electrical engineering to neurosciences during my undergraduate studies, my life science work has a strong engineering orientation.

By what criteria should we judge the work?

I would say the one criterion that will signal that we have hit upon something great in this area is the element of surprise. When experts in a field see something that startles them by way of new function and efficient design, that's meaningful.

What are you working on right now?

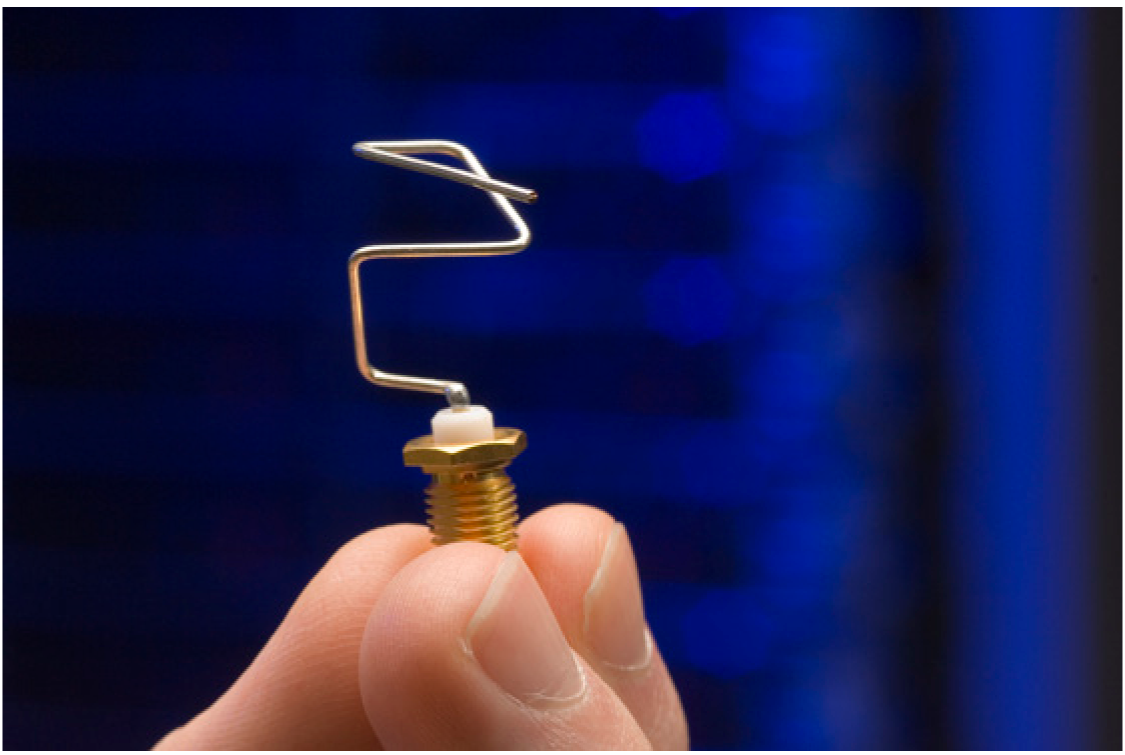
Our NESC Robotic Spaceflight TDT subgroup is working hard to get more people in NASA interested in this subject of natural systems design. Although some NASA centers and researchers have done work in natural systems, the Agency proper has never developed a major funded program for NID. At the same time, newly minted bio-inspired design programs at major institu-



Dunes in Noachis Terra Region of Mars | Photo: NASA/JPL-Caltech/University of Arizona

tions such as Georgia Tech, CalTech and Harvard will be turning out young engineers who will be looking to NASA for opportunities to apply what they have learned. In order to get this topic elevated within NASA, we are working to include NID in the NASA Systems Engineering Handbook, a project that will benefit from George Studor's INCOSE initiative.

On a more scientific level, I have been exploring the Phylogeny (evolution), Ontogeny (individual development) and Epigenesis (interaction with the environment) or POE model developed by Moshe Sipper and his colleagues as a way of organizing and making sense of natural processes. The Sipper group conceived of POE as forming the three dimensions of a natural systems process space, where each axis has unique characteristics that can also be viewed as different information processing modalities. Evolution builds a recording of historical events in DNA and this depends on errors called mutations. Ontogeny reads this evolutionary recording to create an individual living organism, but unlike evolution this is very fault intolerant, requiring mechanisms that avoid, detect and rapidly repair errors. Epigenesis involves the resulting animal, plant or microorganism's response and adaption to environment changes, often through



Ames Evolved Antenna

Photo: Ames Research Centre, NASA

some form of memory, such as the nervous and immune systems or structures (like bone) that develop through growth under stress. Much as the Cartesian system revolutionised the field of geometry, the POE model suggests opportunities for advancing engineering design in natural systems processes by exploring each axis as well as the interaction within the POE space.

What is your favorite nature-inspired design of all time?

The shining example of successful bio-inspired design in spacecraft engineering has to be the Ames Evolved Antenna (http://www.nasa.gov/centers/ames/news/releases/2004/04_55AR.html), a project led by Jason Lohn (Carnegie Mellon University, Ames Research Center) that used a nature-inspired design process to meet a specific engineering requirement. A conventional antenna had already been designed for an Earth orbit mission called Space Technology 5 (ST5) mission. ST5 was intended to demonstrate new technologies, providing Jason an opportunity to propose an alternative novel antenna design created by using a genetic algorithm (phylogeny) that met all requirements but was different from anything seen before in both engineering and nature. Due to subsequent changes in the ST5 mission design, revised specifications were issued which could have seriously delayed the project because a conventional antenna would have no longer performed adequately. Hardware designs are often 'baked in' early in the design process and redesigns can be both expensive and time-consuming, but Jason was able to rapidly design and develop a revised antenna within a month, allowing the ST5 project to remain on track.

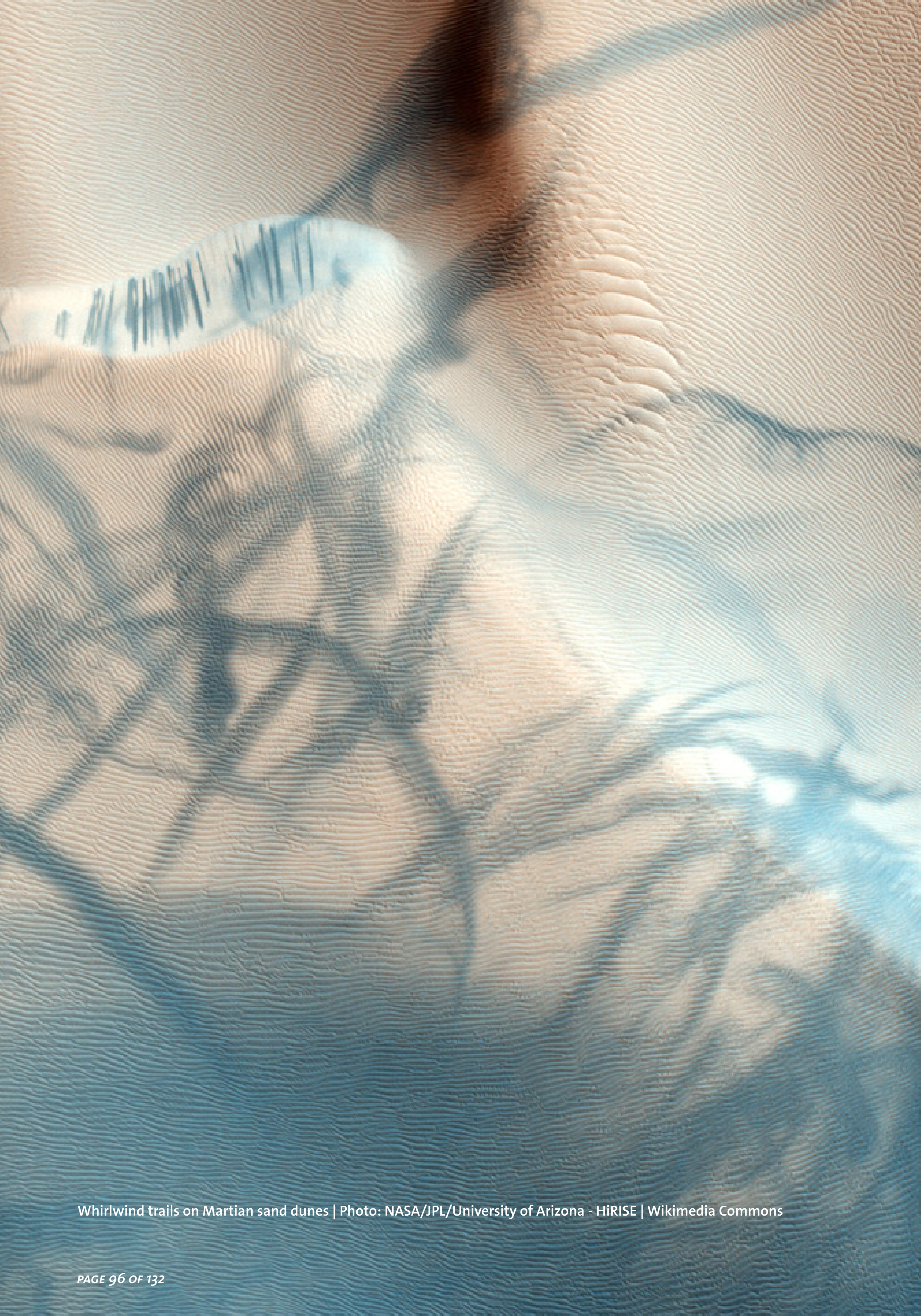
Although the goal was not to develop a better antenna but one that only met conventional design criteria, Jason Lohn's design process based on evolutionary algorithms was able to deliver solutions more rapidly than conventional approaches, which is critical when requirements change. The Ames Evolved Antenna has flown on two other missions that did not have a technology demonstration component: the LADEE lunar orbiter (http://www.nasa.gov/mission_pages/ladee/main/) and the IRIS mission (http://www.nasa.gov/mission_pages/iris/index.html). Jason co-founded the start-up X5 Systems (http://www.x5systems.com/) to commercialize his design method.

What is the last book you enjoyed?

Consciousness: Creeping up on the Hard Problem, by Jeffrey Gray.

Whom do you admire? Why...

That's a tough one: I have met many great people. I would say that out of the many the three that come to mind are my mentor, the late Dr. Guido Majno, Chairman of Pathology at the University of Massachusetts Medical School. If I hadn't by some stroke of chance early in my medical education attended one of Dr. Majno's lunchtime U. Mass lectures on the history of medicine, my career would have been radically different. Also, Apollo 17 Astronaut Jack Schmitt, who I worked with on the lunar dust project while I was Chief



Whirlwind trails on Martian sand dunes | Photo: NASA/JPL/University of Arizona - HiRISE | Wikimedia Commons

of Space Biosciences at Ames Research Center. Somehow Jack was able not only to go to the moon, but become a successful US senator, making him one of the most accomplished people I've ever met. And the third would be the late Jim Connolly, who was my Chief Engineer at the Ames Space Biosciences division and much loved at the Center. Jim once said to me, "The thing I'm most proud of during my time at NASA is that I have been able to get something done." I think the ability to somehow get things done in the face of uncaring bureaucracy and organizational inertia is what I admire most in any professional. It's too easy to find a comfortable niche in large organizations and not get something done.

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

Most of the kids in my generation wanted to be astronauts, and I was no different. But I'm proud that I was able to meet and even work with some of the best of NASA's astronaut team.

What is your idea of perfect happiness?

Judging from past experience, taking my daughter to a science museum.

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

If I had somehow been born with the talent, to have been a composer of Hollywood film scores, like John Williams or Henry Mancini. ×

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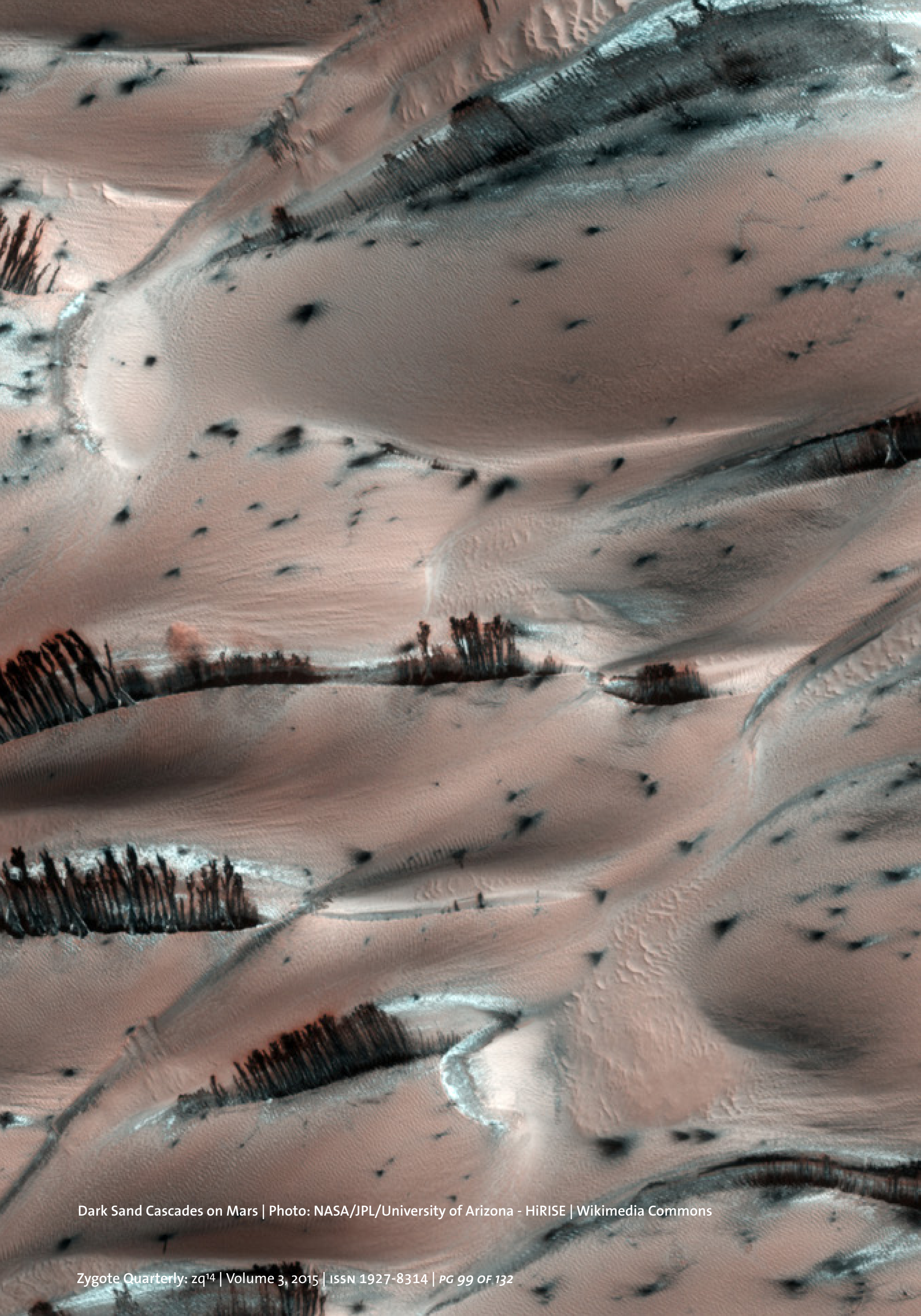


Dark Sand Cascades on Mars | Photo: NASA/JPL/University of Arizona - HiRISE | Wikimedia Commons

Osaka Castle | Red-flanked Bluetail (Ruribitaki)

Photo: ken--, 2005 | Flickr cc

Interview

Pete Foley

Pete Foley is an Innovation Consultant who specializes in applying Psychology, Behavioral Economics and Perceptual Science to business challenges. He draws on experience gleaned from 25 years as a serial innovator at Proctor&Gamble where he published over 100 patents, and spent 8 years working with some of the world's experts in the Behavior Sciences to apply their insights to business needs.

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

I see enormous passion and potential, and certainly a lot more information readily available than there was a few years ago. However, despite this, I think it remains somewhat underutilized, and not as mainstream as it deserves to be as an approach to innovation. Looking at nature should be a default when we are looking to solve difficult challenges, but it remains more of an exception, rather than business as usual.

What do you see as the biggest challenges?

We are not yet sufficiently mainstream within the broad innovation community, and face too many barriers to trial in comparison to more popular innovation processes such as Design Thinking, brainstorming, or open innovation challenges. This means we have to work disproportionately harder in comparison to these methods in order to gain innovation customers. Making the jump from being a relatively small, niche innovation approach to a top of mind, default method can have huge benefits in this respect, so I think achieving this is both the biggest challenge and the biggest opportunity we face.

Innovation methods operate in a marketplace, and as with any marketplace, market leadership creates a "virtuous circle" of trial and repeat that can drive further increases in market share. Basically the big tend to get bigger. This process is driven by feedback loops that are fueled by a combination of availability, awareness and default behaviors. Market leaders tend to be better known, more readily available, and are most likely to have been encountered in the past, and people have a bias to select what they know, what they have heard of, what is readily available, and what has worked for them before. Familiar choices also possess a host of other advantages that can also feed this cycle. For example, they come with more success stories and relevant examples. The more stories there are, the more chance that some will closely match the needs of an organization. Relevant examples can be very persuasive in and of themselves, but they are also great enabling tools for people who are sponsoring a new method within an organization. Passionate, skilled and informed sponsors are often the difference between success and failure when introducing something new into an organization, and so this kind of ammunition can be invaluable. Familiarity also breaks down cultural and organizational barriers to adoption. It leads to shallower learning curves, reduced skepticism, and a lower perceived opportunity cost for selecting the new over established methods that have a proven heritage of success. As a result, more familiar methods are easier to secure funds for, align behind, and if things don't work out, carry less career risk for the innovators who advocate for them.

While we hope innovators are more open to new ideas than the average, they are still human,

Osaka Castle | Narcissus Flycatcher (Kibitaki) | Photo: ken--, 2005 | Flickr cc

Osaka Castle | Red-flanked Bluetail (Ruribitaki) | ken--, 2005 | Flickr cc

Splendid Fairy Wren, Lake Cargelligo | Photo: Nevil Lazarus via Cas Liber, 2005 | CC BY 3.0 via Commons work in human organizations, and are hence subject to defaults, habits, risk aversion, and other cognitive biases that drive convergence on proven, established methods. So, as with any new product, I believe we need to work out how to create sufficient critical mass to step into this virtuous circle, and reap the benefits of being an obvious, default choice in the innovation marketplace.

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

We need to focus on areas that are most likely to infiltrate and fuel this cycle. This probably doesn't mean doing anything completely new, but there are areas we should focus more on if we want to kick start the cycle. These include collecting more and better case studies, and framing them to appeal to the skeptical and uninitiated. We can also integrate ourselves more into existing methodologies, ride opportunities provided by disruptive technologies that are synergistic with nature, and confront and learn from failure in ways that resonate with potential innovation customers.

1. We need more and better stories. We already have many great examples of how nature can inspire innovation, and the general case for the value of 3.8 billion years of pre-existing innovation should be undeniable. But we still need more examples that innovation teams in industry can empathize with, and project their challenges into. I believe this means more problem-based, end-to-end case studies. These need to show how we can take a very specific challenge, and apply insights from nature to it in a systematic way, using well defined processes, to create significant commercial wins. We have a lot of parts of this story, such as databases, process structures, examples of solution led innovation, and reverse engineered examples. We also have case studies, but very few show how all of these parts fit together into a whole story, with a specific problem definition, a process, and examples that show how to tackle the tricky problem of translating inspiration and ideas into actual examples, all within the constraints of a business challenge. Of course, this is not easy, confidentiality will always limit the examples that can be shared. Real world innovation is also messy, meaning that the kind of cut and dried stories that we need are only a small fraction of our successes. However, if we are to achieve the critical mass needed to jump start these cycles, collecting these stories needs to be an area of focus. I do believe that having all of the parts of the story is key, but based on personal experience, having problem-based examples may be the most important. The excellent, entrepreneurial examples of solution based innovation we have will help to attract venture capital, but we also need to attract innovation spending, and that tends to be problem focused. Problem-based examples are the entry point for answering the question I hear more than any other when trying to persuade a team to try a bio-inspired process: "how will we use this to solve my problem?"

2. We have a huge opportunity to leverage new, high momentum technologies that are potential enablers for bio-inspired innovations. In particular, nanotechnology and 3D printing should allow us to more effectively mimic both the scale and flexibility inherent in natural innovation. Nature's insights should also be enablers for the commercialization of these technology

Petroicidae | Red-capped Robin | Photo: sunphlo, 2013 | Flickr cc

waves, so there is a lot of potential for synergy, collaboration, and riding these waves into the mainstream.

3. We need to become more routinely integrated into established innovation processes. Bio-inspired innovation should not be isolated from mainstream innovation processes. Targeted, biomimicry and bio-inspired workshops certainly have a valuable role to play, but there is also a huge opportunity for inspiration from nature to become a default part of Design Thinking. This, and actively engaging in open innovation challenges are great ways to channel more resources into the field, increase awareness, and reduce barriers to adoption that can arise if there is a forced, either/or choice between investing in bio-inspired versus more established methods. We are already seeing some design firms actively driving this, and I think we need to aggressively support this, and engage the broad innovation community as a whole via their blogs, conferences, and communities.

4. Talk more about success rates, and do more to leverage learning via mistakes. Innovation is really difficult, and not every innovation session is a success. The same goes for bio-inspiration, and I've been involved in sessions that both have and haven't worked. I suspect the same goes for all of us. Success of course very much depends upon expectations, and even the best ideas require work, and usually additional innovation, to reduce them to practice. I think the broad innovation community has done a great job of embracing fast failure and uncertainty. I think there may therefore be an opportunity inherent in having more discussion around our struggles, and our success and failure rates. This could be a way to engage the innovation community, improve our processes, and also help set realistic expectations around what we can and cannot achieve, and on what time scales. To this point, I have found Steven Vogel and Robert Full's insights into the challenges associated with translating nature's designs into human technology extremely helpful. This translation challenge is certainly one of the big problems I've personally encountered. It is one reason I like using bio-inspiration and biomimicry to develop processes or systems, as reduction to practice can often be faster, and require less investment than with mechanical or functional products. However, I've also seen teams struggle in other areas, including effective problem definition and the process of making viable analogical connections between their domains and the natural world. I am a fan of Ashok Goel's work, trying to find ways to use Artificial Intelligence or Intelligence Augmentation to more systematically make these kind of connections, but I wonder if we could also benefit even more from the extensive experience the design and broad innovation community have with fast failure?

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

I passionately believe that most problems can be solved by taking pre-existing solutions from other domains, and reapplying and adapting them to ours. I was already using structured problem definition and analogy to search for and reapply pre-existing innovations from places with very high R&D investment, such as medicine, pharma, or the military. A meeting with the San Diego Zoo many years ago first introduced me to bio-inspired innovation. 3.8 billion years of in-

Blue-gray Tanager (*Thraupis episcopus cana*) | Photo: Dominic Sherony, 2010 | Wikimedia Commons

Superb Fairywren (*Malurus cyaneus*), Male, Peter Murrell Reserve, Tasmania, Australia

Photo: JJ Harrison, 2013 | CC BY-SA 3.0 via Commons

novation dwarfs even military or pharmaceutical innovation budgets, so it was obvious to reapply some of the concepts I'd been borrowing from psychology to bridge between innovation in different industries, and apply them to bridge between nature and the world of innovation.

What is your best definition of what we do?

I prefer a broad definition of taking pre-existing concepts, technologies, systems, and processes from nature, and adapting them to solve human centered design problems, which is probably best described by the term bio-inspired design. However, within that broad scope there are lots of extremely valuable, more specialized approaches, including bio-utilization, bio-assisted, biomorphism, biomimicry, bionics, and biomimetics. As with any field, we need specialists who can dig deeply and develop expertise in specific areas, and generalists who can look for ways to connect different, complementary approaches, knowledge, and expertise. I am an innovator who is an advocate for bio-inspired design in general, and to be honest, when trying to solve a problem, I am somewhat agnostic as to whether we have mimicked and adapted nature, been more loosely inspired by her systems, found/used/created a supply of a previously unutilized natural resource, or adapted and modified an existing one. If nature has helped us find a solution to a tough problem, then that is a win, and one that will encourage people to look to nature for future innovations. Ultimately, that will improve lives, but also increase awareness about the value of nature and the importance of conserving it. There is nothing like enlightened self-interest to drive human behavior, and the more people who realize conservation directly benefits them, the more we will see sustainability become a part of everyday thinking and behavior.

A final thought on definitions. Biomimicry clearly has far more equity and name recognition than any other terminology in this space, thanks to Janine Benyus and the host of people who have done amazing work under that umbrella. That familiarity means it often gets used as a category descriptor in ways that extend beyond its precise definition, especially with people who are less engaged in the space. This can cause some problems in terms of understanding scope, but given how important a role I believe familiarity has on decision making, that recognition has massive value, and is key to feeding the "virtuous circle" I mentioned earlier. I'm not sure exactly how to best leverage it, but I think it is important for us to look for ways to use that conceptual popularity to bring new people into the opportunity space.

By what criteria should we judge the work?

Does it work? Are we creating innovation that people want, will use, and will buy? That is ultimately the key to becoming a default method of choice for the innovation community, and business as a whole.

I know there is a lot of passion to leverage our innovative capability to create sustainable innovations with improved environmental footprints. I agree with that, but I also think how we frame this is crucial. If we try to sell sustainability first and innovation second, we risk becoming a niche. Cost effective, high performance innovation that just happens to bring sustainability along for the ride is the fastest way to become mainstream, and hence have the biggest, fastest positive impact on the environment possible. It is great if we can contribute to sustainability on a case-by-case basis, and for many I know it is the price of entry into an innovation project. While I prefer to do it all, I can live with a "do no harm" approach, providing it comes with a significant increase in broad awareness around the value that nature can bring to us. Ultimately, that enlightened self-interest will impact behavior that goes beyond just innovation. It's a harder benefit to quantify, but it is also hard to overstate how important that bigger picture enlightenment is to us all in the long-term.

What are you working on right now?

I'm consulting, speaking and blogging on innovation (including biomimicry and bio-inspired innovation), behavioral economics, and the application of psychology and behavioral science to deliver breakthrough innovations, as well as creating sustainable innovation processes and cultures.

What is the last book you enjoyed?

Steve Pinker's *A Sense of Style*, combined with a re-read of his wonderful book *How the Mind Works*. He is a brilliant communicator, and getting a chance to understand a little of his process was priceless. I'm aware that citing him is fraught with risk, as my prose is probably an example of what not to do based on his insights, but I'm learning!

Whom do you admire? Why...

I'll probably give you a different answer on a different day. Nelson Mandela and Churchill come to mind most often, but Lauren Hill, the Cincinnati basketball player who recently succumbed to brain cancer was a wonderful example of how an ordinary person can have a huge impact, and turn terrible adversity into something that at least has some positive elements. Her example puts our little daily frustrations into clear perspective.

What is your idea of perfect happiness?

Happiness is far too complex to ever be perfect, at least in my lifetime. However, I believe understanding ourselves can make us happier, and that we spend too much time worrying about the happiness of our future selves, and not enough time simply enjoying the moment. I strongly recommend reading Daniel Gilbert's *Stumbling on Happiness*, Jonathan Haidst's *The Happiness Hypothesis*, or Dan Ariely's *The Upside of Irrationality* for far better insights on this topic than I can provide.

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

I've already worked as an accountant, musician, scientist, and in corporate management and consultancy. I enjoyed them all, but never planned for any of them. So I think I'll just see what happens next. ×

Excerpt from SmartCity Nigeria Centenary Celebration

Image courtesy of Shannon Royden-Turner

Interview with
Shannon Royden-Turner

vol 3 | 2015

People:
Interview

Authors:
Shannon Royden-Turner and
Tanya Sakamoto

Shannon Royden-Turner is the Founder of In Formal South, an urban design consultancy. She loves to design and facilitate processes to translate nature's solutions to address many of our most complex systemic urban challenges.

In Formal South focuses on creating strong partnerships with a number of organizations that support this vision. In Formal South is the South African partner to Cordaid, a Dutch NGO focused on enabling social resilience through multi-stakeholder processes, and Play the City, an innovative company focused on serious gaming for urban planning. Locally she is partnered with Biomimicry SA as a key-implementing partner for biomimicry in the urban environment, and Global Carbon Exchange whose focus is on supporting corporate South Africa to realize sustainability.

First, tell me more about how systems thinking influences your work.

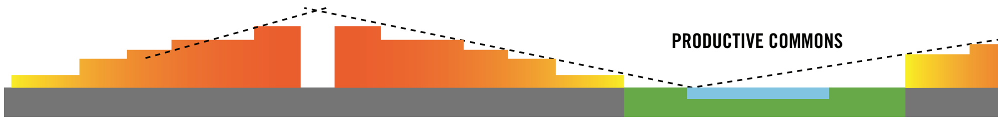
I design and facilitate multi-stakeholder decision making processes; with the aim of finding win-win solutions based on what I consider to be the universal laws of nature. I work globally to bridge the social and ecological divides, understanding and making use of the dynamics of power to establish systems that support the wellbeing of all life giving systems. Systems thinking offers a powerful new perspective, a specialized language, and a set of tools that I use to address wicked problems. For me, it is a way of understanding reality that emphasizes the relationships among a system's parts, and not only the parts themselves. In its simplest sense, systems thinking provides me with a more accurate picture of reality, so that I can work with a system's natural forces in order to achieve the highest possible outcomes. It also encourages me to think about problems and solutions with an eye toward the long-term view. I values systems-thinking as it offers great insight into the causes of systemic failure or success, as well as offering tools for identifying the highest-leverage points for intervention in any system. In Formal South applies systems thinking and systems thinking tools to create integrated urban infrastructure, spatial design and urban management frameworks for regenerative urban futures. Biomimicry thinking is systems thinking informed by 3.8 billion years of optimized systems solutions by nature.

My work focuses as much on the understanding of natural systems as it does on the human system itself. Much of the change that is needed today requires a deep engagement with human behavior, and I believe I now have tools to master this aspect of city making.

How do you accomplish this kind of engagement around urban design?

Bringing about change and initiating innovation within cities or neighborhoods calls for a far more engaged form of social participation. A growing sector of society is seeking to become more engaged in the decision making process that create our cities. There is a need to move from accountability to responsibility, where there is collective ownership of the successes and failures as we move along a learning journey to maturity, and this requires new forms of collective decision-making.

Excerpt from SmartCity Nigeria Centenary Celebration
Image courtesy of Shannon Royden-Turner



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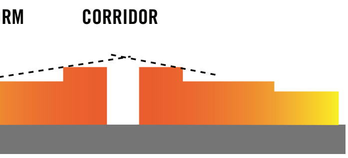
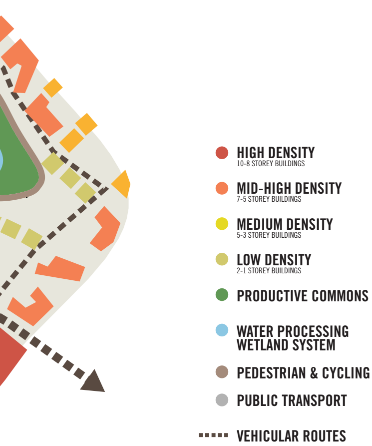


CYCLICAL ABOLISMS

The urban cell system

Each urban cell has a productive component related to food production, biodiversity maintenance and water filtering and infiltration. The built form surrounding the productive commons creates a low edge ensuring that maximum sunshine reaches the central area, increasing in height as it moves out towards the movement corridors where the buildings create urban corridors capable of supporting high levels of activity and socialisation.



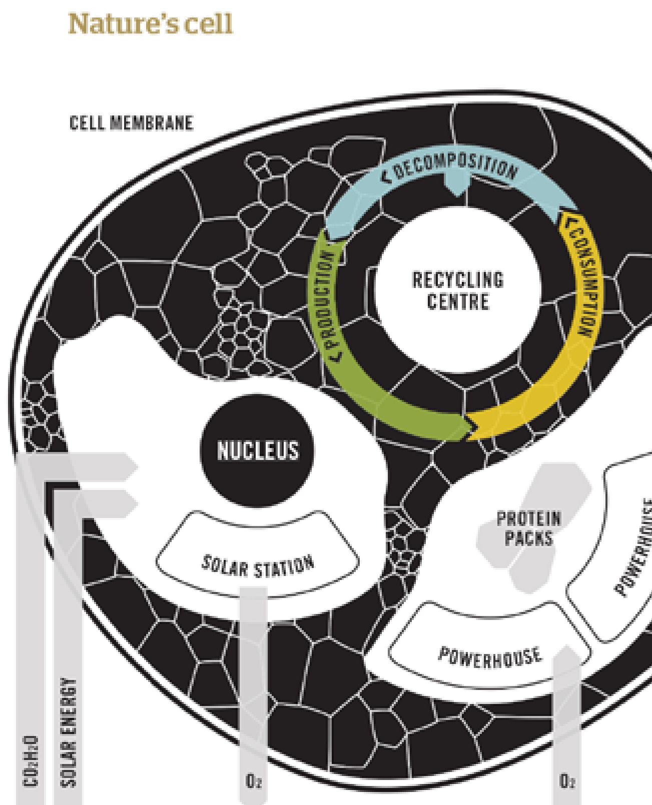
Excerpt from SmartCity Nigeria Centenary Celebration

Image courtesy of Shannon Royden-Turner

I consider active citizenship, driven by the power within each of us, an imperative in creating systems that are optimised to meet the many complex needs, demands and uncertainties of the future. I understand that citizens want to be actively involved and inspired to co-create and shape their communities and define the kind of future that they would prefer to live in. I also understand that every member of a system or community has this potential – and the choice of using it – to lead themselves and thereby make a contribution towards the understanding of our complex reality, enabling people to deal with the uncertainty of the challenges of our time. Leadership is becoming participatory and situational and I allow space for this kind of citizen participation from the earliest inception of an urban process.

Who are some of the partners you have worked with in these engagement processes?

I have had the privilege of working with many inspiring leaders to develop innovative visions for the future. I am currently working with Tongaat Hullett Developers, Dube Trade Port and eThekweni Municipality to break through an age-old conflict between development and ecology by applying biomimicry and systems thinking to the 9000hc new growth area surrounding King Shaka International Airport in Durban. This project is a global pilot to test this innovative new methodology for thinking about cities. I have travelled to Haiti to advise the President on urban renewal opportunities, and work for the Western Cape Premier to develop innovative solutions to waste water, stormwater and solid waste in informal settlements. I have



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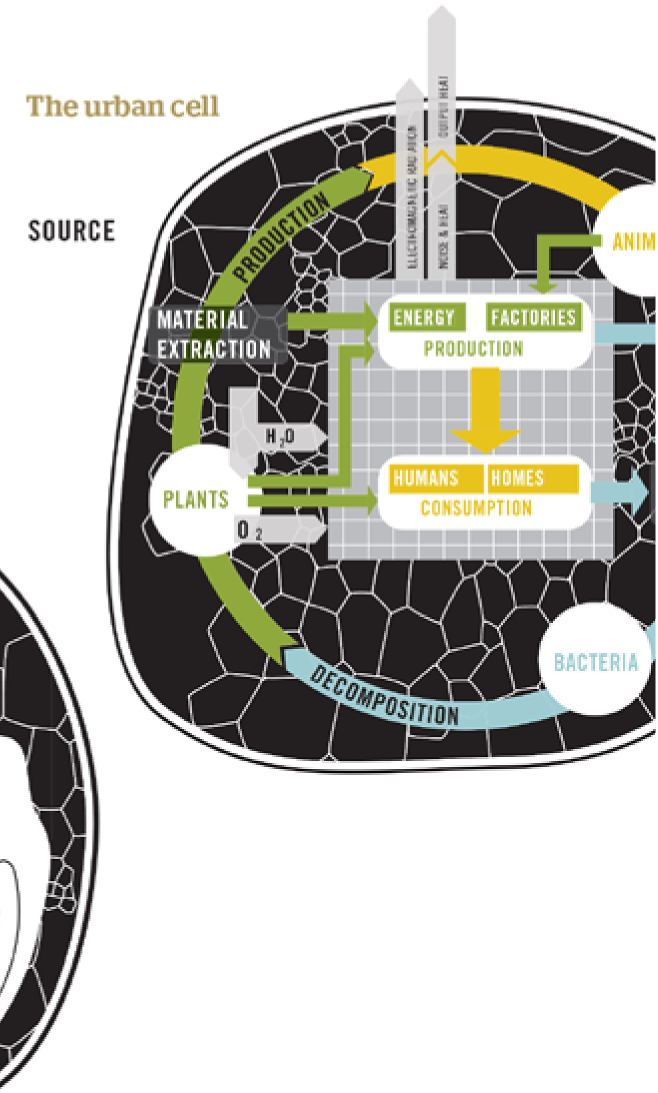


partnered with Dutch social enterprise, Cordaid, as the South African representative and work as a process coordinator and multi-stakeholder facilitator for projects as diverse as domestic violence and the roll out of public transport to the in the Cape Flats.

In Formal South, in partnership with Cordaid, is currently enabling the development of a Community of Change to focus on water and waste issues within Hout Bay, a suburb of Cape Town. Hout Bay is divided into several neighborhoods of different incomes and degrees of formality. There is a curious but fragile sense of camaraderie and community present among its residents. Our collective aim is to improve social integration, the uncontrolled expansion of informal housing, the limited opportunities for development, localized pollution and associated health implications.

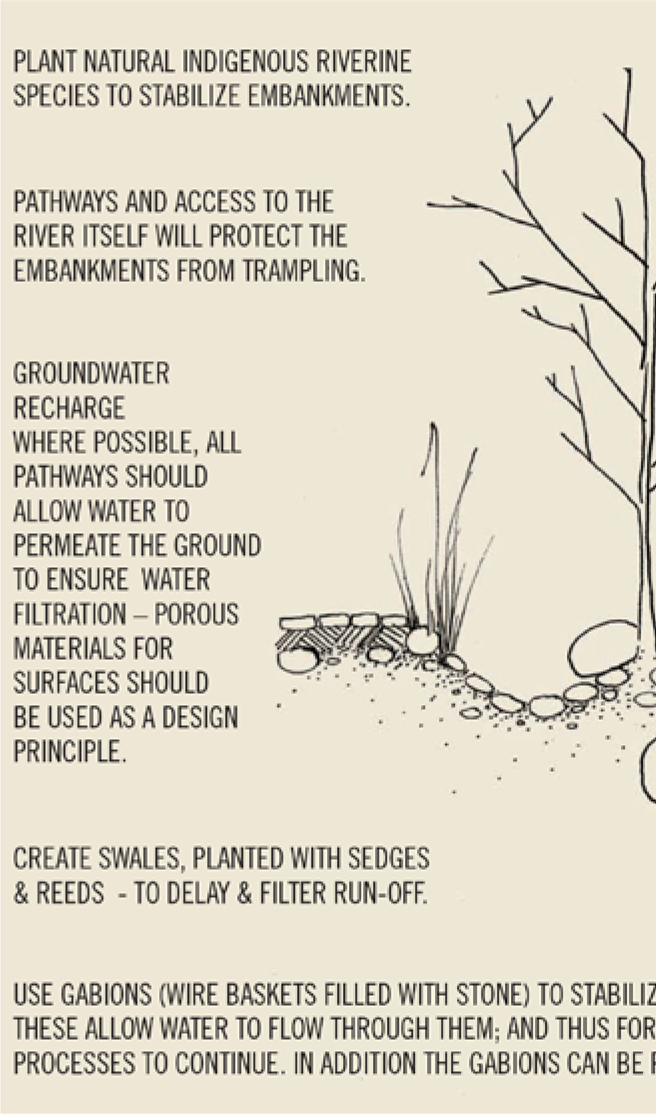
Describe for me some of the urban systems projects in which you have been involved.

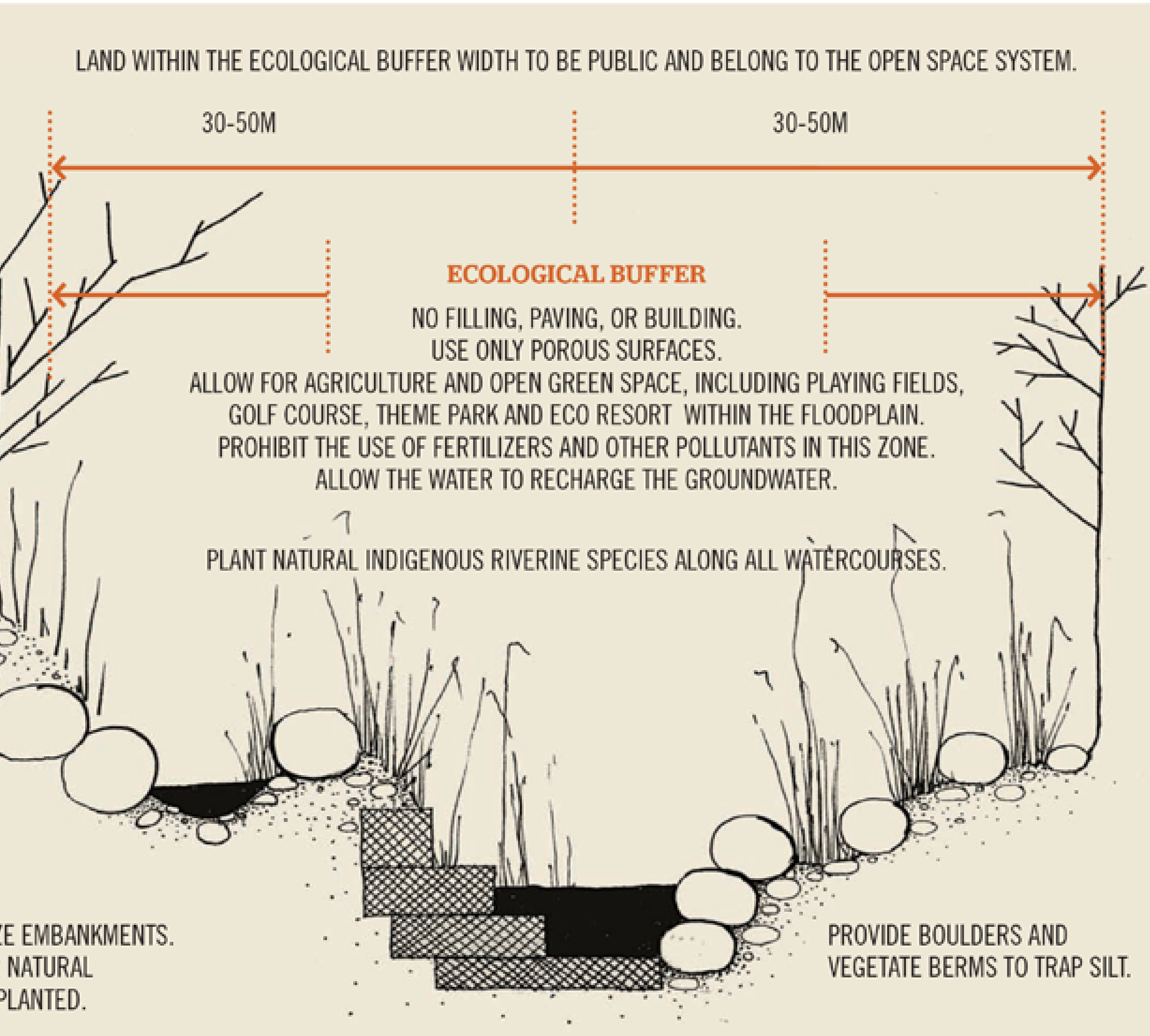
In Africa the partnership between In Formal South and BiomimicrySA has been instrumental in making significant headway into applying biomimicry to urban systems. Together we have completed several projects that have applied a number of different biomimicry methodologies to solving some of our most pressing urban challenges.

In a project close to home, we have been applying biomimicry systems thinking and technology to develop innovative solutions to waste water, stormwater and solid waste in Langrug informal settlement in the Western Cape. This has been an incredible project to work on. One of the highlights was when the Municipal Engineer wrote the following quote to me: “There are potholes on the road less travelled. Some deep, some not so deep, some you dig yourself. Most are filled with mud. Many contain rocks. Once in a while, however, you’ll be walking along and step in one a bit more accommodating... shabby, green, and pulsing with life. It’ll tickle your feet, like clover.”- Ray Blackston.

This is such an apt description of the response we are typically getting about this type of work. People realize that it is not the easiest path to choose, but there is a sense that a reality filled with pulsating life is possible, and they are inspired to deal creatively with the challenges they need to address. This, for me, is the most rewarding part of working within this field. This field of work is very much in its pioneering stage but the idea that our challenges have already been solved offers people a new potential paradigm away from the doom and gloom of the past paradigm. The doom and gloom paradigm tends to disable people, where I find that the idea that nature has already solved the challenges that we are facing is far more inspirational and enabling to people.

Our project in Langrug was awarded a position in the top ten for the GreenTec Awards which was very encouraging. This project has gone through a high level strategy phase, concept and detail design phase and is about to start the construction phase. We have been fortunate to be working with both Provincial and Municipal government on this project, and their support for innovative systems thinking approaches has been amazing.





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Shannon Royden-Turner and
Tanya Sakamoto

In Durban we have been working in partnership with Janine Benyus and Biomimicry 3.8 to develop a resilience framework to inform urban planning and design in the Northern Spatial Development area. It has been such an inspiration to work with and learn from Janine. The project applied two key biomimicry methodologies: ecological performance standards and keys to resilience. The ecological performance standards were generated using an inVest model . The analysis work lead into the development of a wetland protection, restoration and mitigation policy for the area. Management guidelines for development surrounding the defined ecological infrastructure have been informed by the ecological performance criteria for example; how to manage stormwater by mimicking natural hydrological flow cycles for a healthy functioning system.

What do you see as the biggest challenges?

In our work on the Durban project, the biggest challenge was that the project proposed an innovative methodology using biomimicry methodologies that I had not yet worked with, in a context that was highly contentious and politically charged. Directing a project when you have no clue what the outcomes are going to be or how they are going to be used, with a client body made up of three parties who have been locked in conflict for the past 15 years was somewhat intimidating. So a big challenge for me in working in this field is becoming comfortable with the unknown and trusting the process.

When working with biomimicry at the systems level it requires a shift in worldview away from understanding the universe as disconnected parts, towards one of understanding the universe as interconnected and interdependent. Shifting people's worldview is one of the greatest challenges facing us in our work today, and is one that we don't always make adequate allowance for during our proposed processes as it is not an easy sell to clients. It needs to be carefully integrated into all stages of the project to ensure that by the end people start to view the world differently, recognizing the interconnections and interdependencies.

Within the South African context one of our challenges has been to ensure that this work remains easily understandable to the people that we are working with. Given that biomimicry is a science, the language can quickly become inaccessible to people, especially when we are working within the context of informal settlements. To accommodate this we developed a training module for the residents of the informal settlement to help them to understand why we think there is benefit in asking nature to help us solve our problems. It was a great day as we watched people start to grasp the concept, and today if you go into the settlement people casually refer to biomimicry, which gives me great joy. This community is likely one of the only informal communities to have received biomimicry training. People typically feel intimidated by processes that they are not familiar with, so we need to constantly watch that we are not using language that further ostracizes people from the processes.

What areas should we be focusing on to advance the field of biomimetics for urban systems?

In South Africa we have been particularly focused on water issues, which is slowly starting to show results. This is a critical area in South Africa over the coming 5 years if we are to avoid a looming crisis. From a technical perspective there are a number of biomimetic solutions available, but the biggest challenge remains an institutional and organizational one. We need to focus on developing an appropriate institutional model for the management and ownership of new and innovative biomimetic systems, as this is where most of the blocks are experienced. As our challenges become more complex there is a real need to deepen our understanding of the interconnections and interdependencies between government, communities and infrastructure. Most of the decisions regarding infrastructure choices are still made within a framework of hard engineering, which tends to consider all challenges as linear and simple. Inter-departmental collaboration within government also remains a challenge. Essentially we need to focus on the area of human behavior, organizational change management and decision-making processes as an enabler to implementing some of the biomimetic solutions that already exist.

I also believe that we need to focus on the area of transport and land use planning. I have been considering that if we are able to design cities that function like a mature ecosystem, then the notion of defining an urban edge comes into question. Currently we need to contain development, as it is largely destructive. So our approach is to clearly define the edge of the city, and look to densifying the city within that boundary.

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

My interest in biomimicry can through studying systems thinking, and in particular Fritjof Capra's book *The Web of Life*. In the book he compares human and natural systems, and this was the first time that I really contemplated the notion that our industrial systems function in a different way to nature's more mature systems. My master's thesis focused on a material flow analysis in an informal settlement to try to understand the notion of the linear metabolism vs. the circular metabolism. After completing my master's degree, I discovered Biomimicry South Africa and immediately started with all the courses they had to offer. It was such a refreshing paradigm to enter into as it was filled with potential and solutions rather than despair and problems. Claire Janisch, who started BiomimicrySA, and myself developed a great working relationship and we have been collaborating and driving biomimicry within the urban innovation space ever since.

What is your best definition of what we do?

I design and facilitate win-win solutions for complex urban challenges using biomimicry, systems thinking and multi-stakeholder processes.

By what criteria should we judge the work?

These are the questions I ask myself to ensure that I remain on track:

Did the process create a win-win solution?

Did we apply a whole systems approach?

Did we inspire people to see the world as an interconnected whole?

Did we strive to impact the well being of all living systems?

Did we design the most creative, practical and viable solution imaginable?

Did the process teach people to cooperate?

Did the process maximise human potential using passion and responsibility within a framework of principles and values?

Did we design ways to help people meet their needs in ways that serve [or at least do not undermine] the needs of the larger community and world?

Did the process and solution optimise the freedom of all people in the system?

Did we inspire people to see the possibility of an abundant and flourishing world by helping them to better understand nature's genius?

Have the processes and solutions successfully applied life's principles? ×

Whilst all of the natural systems have relevance to the eco-structure for planning purposes – however, the geological and hydrological systems are briefly discussed, although the others have been broadly analysed and are included in the synthesis of information.

Constraints & Opportunities

Areas that should be conserved and are unsuitable for intensive development:

Drainage courses; steep valley walls and 25%+ slopes – not suitable for development.

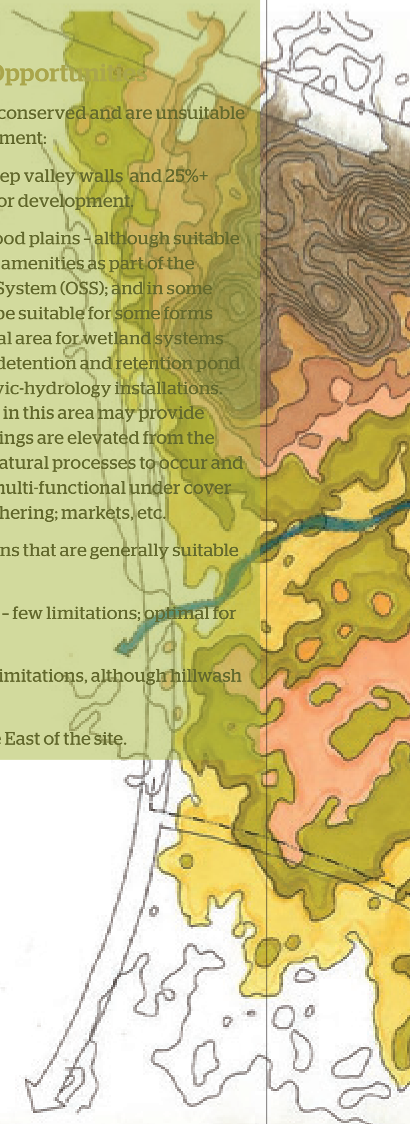
Flat river terraces / flood plains – although suitable for low impact public amenities as part of the broader Open Space System (OSS); and in some circumstances, may be suitable for some forms of agriculture. Optimal area for wetland systems and bio-filtration via detention and retention pond systems and other civic-hydrology installations. District development in this area may provide for areas where buildings are elevated from the ground, to allow for natural processes to occur and would thus provide multi-functional under cover outdoor areas, for gathering; markets, etc.

Areas of few limitations that are generally suitable for development:

The fairly flat plateau – few limitations; optimal for development.

The toe-slopes – few limitations, although hillwash may be of concern.

The mid-slopes in the East of the site.



Geological Syst

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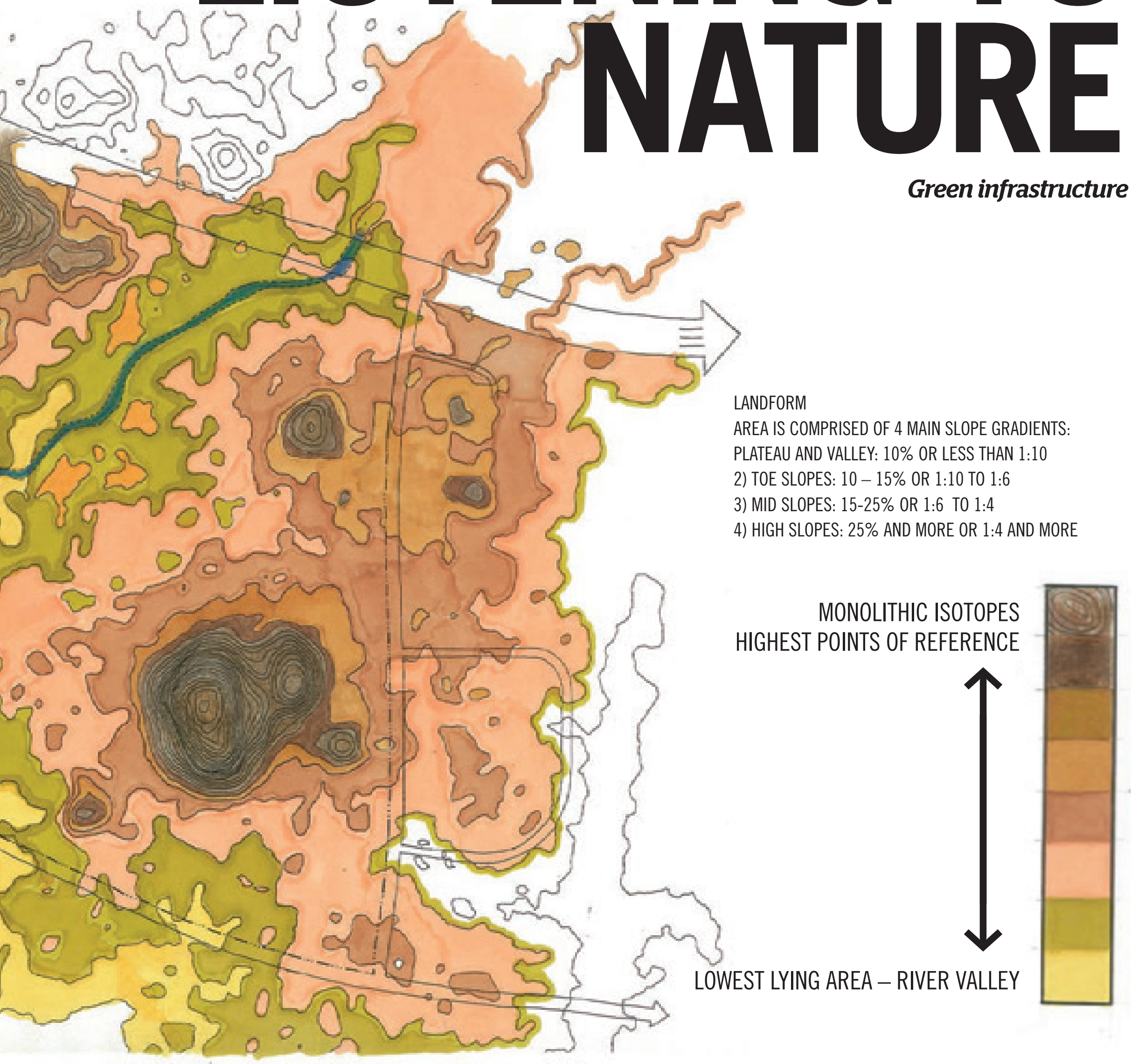
LISTENING TO NATURE

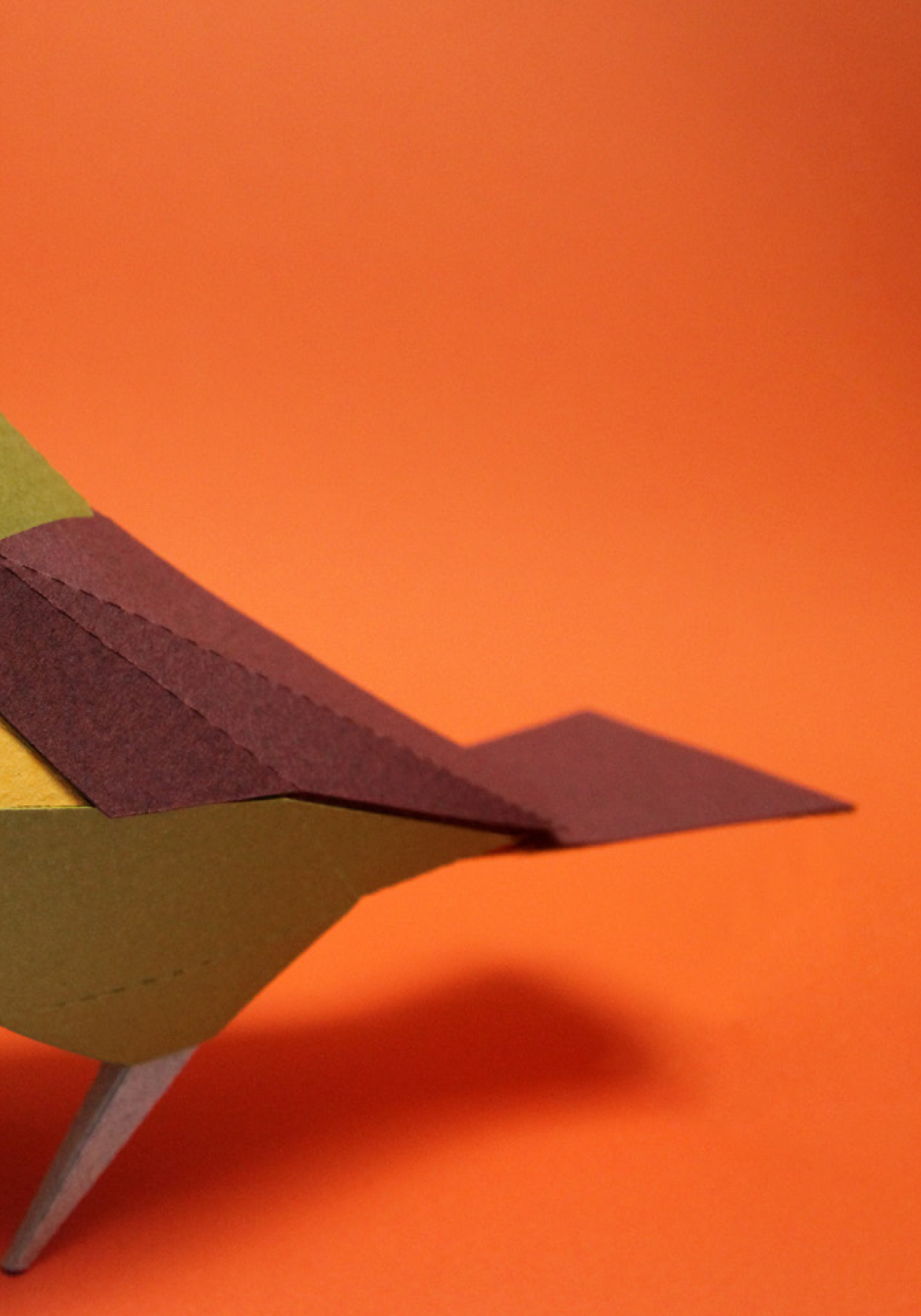
Green infrastructure



em Land Form Pattern

Excerpt from SmartCity Nigeria Centenary Celebration

Image courtesy of Shannon Royden-Turner



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