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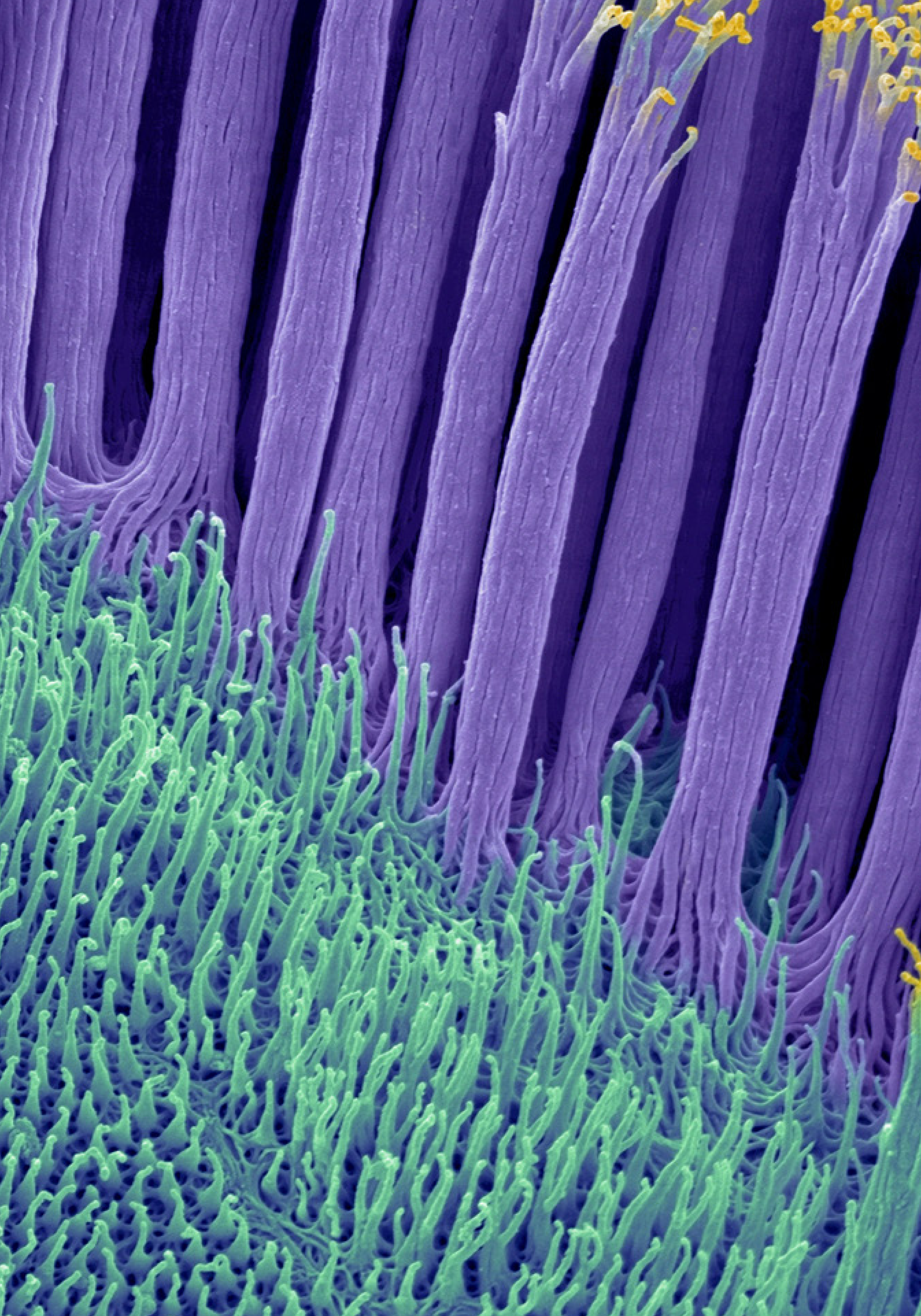

About Zygote Quarterly

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Cover art

Cover *Nematode* | Photo: Zeiss microscopy, 2010 (False-colored male nemotoda, taken with ZEISS SEM. Courtesy of Emil Zieba, Catholic University of Lublin, Lublin/ Poland) | Flickr cc

pp. 2 - 3 & pp. 116-117 *Gecko lizard toe hairs inspired the design of medical adhesives* | Photo: Zeiss microscopy, 2014 | Flickr cc

Design

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Horseshoe Crabs

Photo: Zeiss microscopy, 2012 | Flickr cc

Three years ago three of us got together and decided that it was time to provide something to the world that we thought was missing: a magazine about bio-inspired design that would exist in the space between the peer-reviewed journal and the popular press. It would be understandable to the general reader, but a bit more demanding than the typical news flash. It would also explain things to a level of detail useful to the professional practitioner. Overall it would celebrate the exciting spirit of discovery and creation that we were seeing in the work of scientists, engineers, designers and artists.

Our intent was to cast a wide net for content and to gather as many professional problem-solvers to our publication as we could. This effort is still ongoing, as we have expanded not only our subject matter but our geographical reach as well. One of our most significant accomplishments has been the translation of ZQ into a Spanish edition. This work was made possible by the tremendous efforts of the team led by our contributing editors, Raul de Villafranca of Mexico, and Manuel Quiros of Spain. We have also added a regular product design and world interview section to our offerings. In what can only be compared to receiving manna from heaven, at year two we gratefully accepted the superb writing of Heidi Fischer in her regular column, the *Science of Seeing*. We could not have produced the quality product you have come to expect without the professional work of Kristen Hoeller, our copy editor extraordinaire. Finally, we want to thank all our guest contributors for their time and energy and support. This magazine would not exist without your help.

On pages 12-17 you will find a complete index of all of our guest contributors.

If you have been a regular reader you know that we have been interviewing a wide range of practitioners since we began. We have published 26 interviews and, as you might imagine, the answers to some of our questions have been varied. Among other queries we asked them what they thought the biggest challenge to the profession was and where we ought to focus our energies in the future.

The responses to our question about the biggest challenges facing the profession could be divided into two categories: communication and technical progress. The most common communication answer was that the definition and value of bio-inspired design still needed to be conveyed more clearly. Other responses concerned perceptions but on a deeper level, expressing the belief that changing the basic worldview of people was the biggest hurdle. Those whose answers centered on the technical believed that training and scientific rigor were the most pressing problems, or that solving the technicalities of translation was the primary challenge. Here are some sample responses.

> “Bioinspiration is not yet a scientific discipline in its own right. It lacks a theoretical foundation that would be applicable to all problems of mimicking biology and is at the same time specific to the field. Mature fields of science and engineering have such theoretical underpinnings that have been turned into objective sets of methods for solving problems in the field.”

Butterfly wing, imaged with confocal correlative microscopy

Photo: Zeiss microscopy, 2012 | Flickr cc

"...persuading and teaching the (public) that biomimicry is necessary and desirable (and even profitable."

"...how do we collectively build a design methodology, and supporting practices, services and tools, for goal-directed, problem-driven biologically inspired design?"

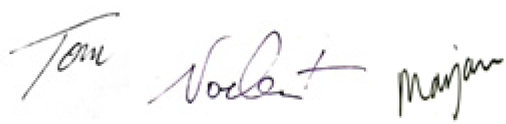
As to where we should collectively focus our energies in the future, our interviewees seemed evenly divided on priorities. Scientific rigor and the support of discovery shared equal priority with education and solving specific world problems. To a lesser extent, respondents thought empowerment (financial and otherwise), was critical to bringing ideas to fruition. Not surprisingly, the specific world problems mentioned comprised the efficient uses of energy and materials to support health and safety.

"Increasing efficiency is clearly a worthwhile goal but needs to be balanced with actively renewing and regenerating systems. We need to find ways of co-creating or co-evolving with natural systems for mutual benefit."

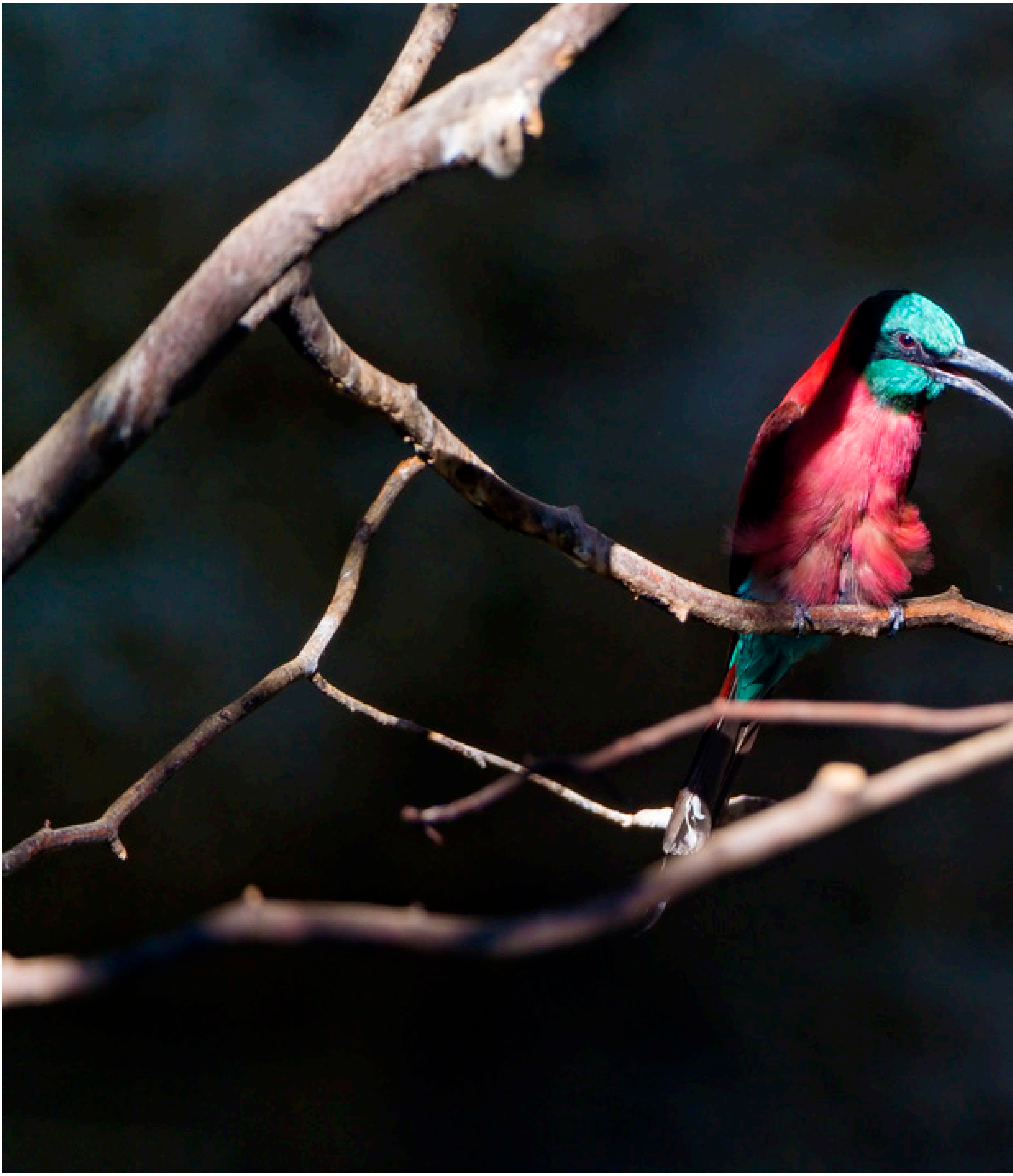
"...anything which raises credibility and generates general principles. At present most people seem to be content to design gizmos (that) hardly change the world. This is trivial."

"A more systematic, mathematic and modeling driven approach that relies on quantitative methods. Currently, there is a lot of ad-hoc and inspirational design happening, some very successful, but we want to apply the power of engineering and science to this field. While some advances have been made, more rigor is needed."

Our path ahead at ZQ seems clear since we consider a large part of our job to be communication and the promotion of nature-based innovation. We will continue to cast our net wider and let it sink deeper as we strive to deliver credible case studies and useful information that informs you about nature, human discovery and problem solving. Please let us know if you think we have been on the right track, what articles have had the biggest impact and what you would like to see in the coming issues. As always, happy reading! ×



Tom McKeag, Norbert Hoeller and Marjan Eggermont



Two bee eaters

Photo: Tambako the Jaguar, 2015 | Flickr cc

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Three Years of Zygote Quarterly

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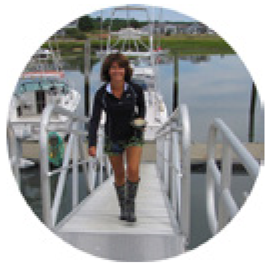

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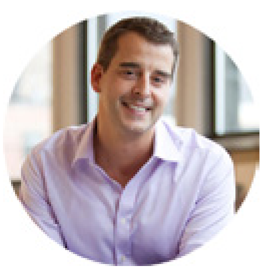

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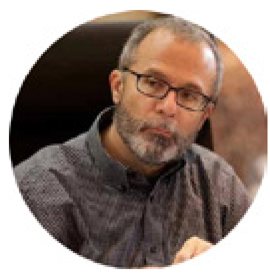

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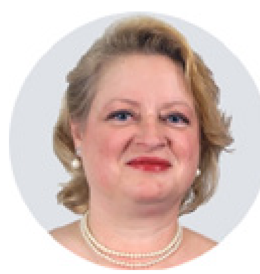

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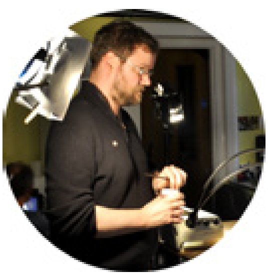
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Gecko

Photo: Studio Tempura, 2010. | Flickr cc

Case Study

Sticky Wicket: A Search for an Optimal Adhesive for Surgery

Tom McKeag

Sticky Wicket

The Challenge

Jeffrey Karp has been on a quest to find a better way to stick material onto things that are wet and gooey and move around. His realm is the micro-space of invasive surgery, in which organs and tissues must be repaired and replaced. The material and functional challenges of this environment are enormous. Any substances must be biocompatible and not rejected by the human body. They must be biodegradable so that the body can absorb them. They must be soft and compliant yet strong and durable. They must hang on tightly in the midst of all sorts of movement, resisting intense shear stresses. Finally, they must help, if they can, to heal the living tissue, by delivering therapeutic drugs or growth aids.

Jeffrey Karp

Dr. Karp is a bioengineer at Brigham and Women's Hospital in Boston, an associate professor in Medicine at Harvard Medical School and he is Principal Faculty at the Harvard Stem Cell Institute and is Affiliate Faculty at MIT through the Division of Health Sciences and Technology (HST) program. He is also the co-founder of a unique company, Gecko Biomedical. A believer in looking to nature for possible solutions, he and his lab have been inspired to innovate by porcupines, geckos and worms:

> "...we've really had to look beyond our own fields and seek out new sources of inspiration.[1] What I find remarkable is when we go outside or go to the aquarium or go to the zoo or start to learn about animals around us, we uncover solutions to incredible problems."[2]

This nature-guided quest has paid off for Karp, garnering him several awards and providing the IP foundation for a new company that he co-founded, Gecko Biomedical. In 2008 he received a TR35 Award, MIT's Technology Review's selection of the best innovators under the age of 35. In 2009, his lab's Gecko Adhesive Technology was selected as one of Popular Mechanics magazine's "Top 20 New Biotech Breakthroughs that Will Change Medicine", and in 2011, he received

American Porcupine | Photo: Tambako the Jaguar, 2011 | Flickr cc the Society For Biomaterials Young Investigator Award. Gecko Biomedical, based in Paris, has recently received 1.3 million euros in advancement funding from Bpifrance, a subsidiary of the Caisse des Dépôts and the French Government. The money will be used to develop further their line of "Bioinspired Surgical Solutions".

Within the sphere of benchtop biomimetics, Karp's single lab has a position and profile worth noting. They are engineers, so rather than starting deep biological research from which application ideas are spawned, the lab instead trolls widely for candidate ideas from nature. All of these disparate candidates must fit the requirements of the core challenge: finding the best way to close wounds and repair tissue. While this "challenge to inspiring organism" problem approach is not new, the breadth of the search and the scientific capacity to test results and bring ideas to application are what set the lab apart.

The divergence of the search and the deep special knowledge required mean that interdisciplinary collaboration is essential and Karp is a strong believer in this approach.

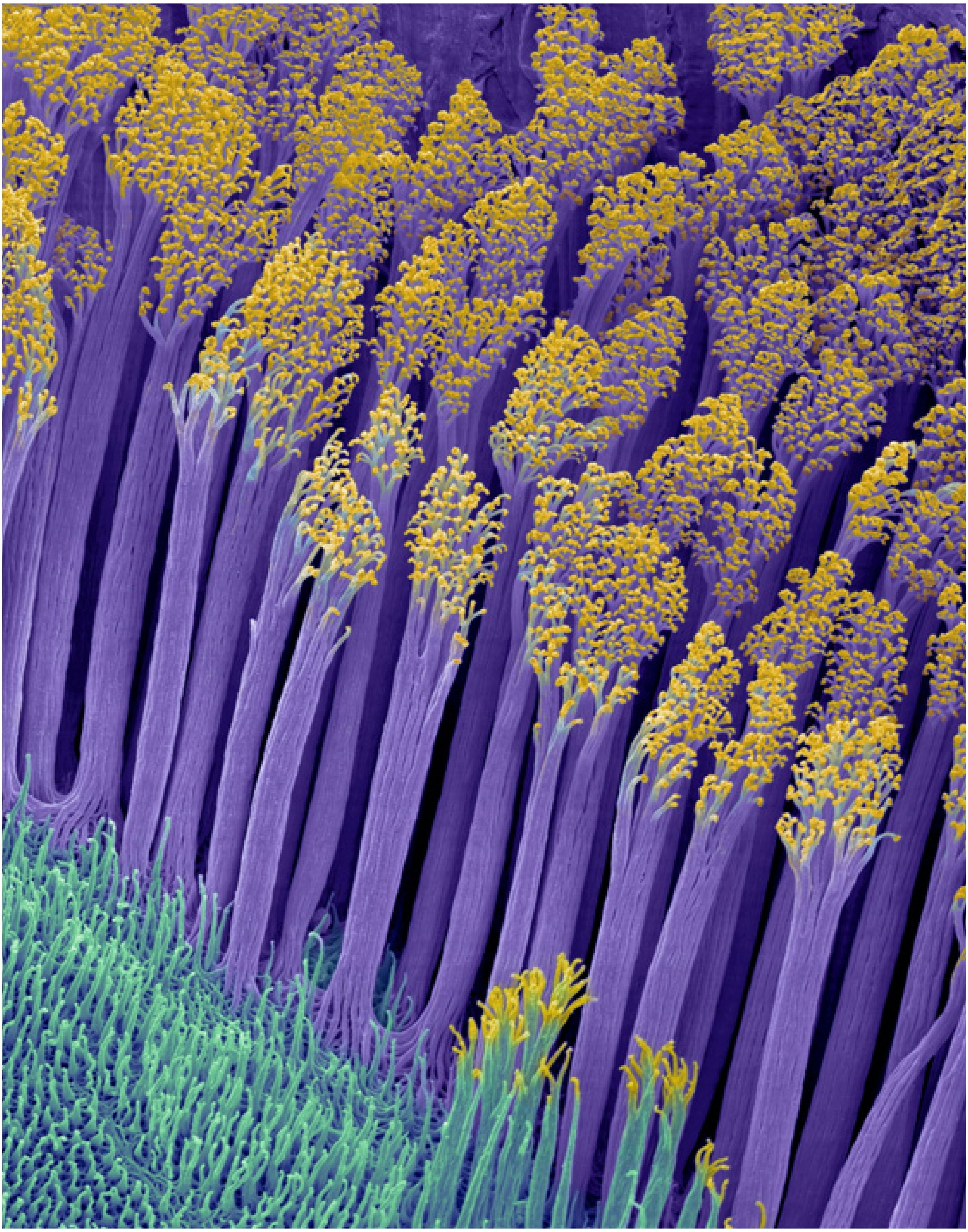
> "I believe that the process of innovation happens at the interface of disciplines. There are many, many steps required to translate a technology into a solution that has the power to help patients and improve quality of life. Each step requires thoughtfulness and creativity, from finding inspiration for a new material to how you create it, manufacture it, run clinical trials, and so on. As bioengineering has gained ground since the 1990s, there has been a realization that you can achieve so much more when you get very different types of scientists, talking and working together with engineers and clinicians. My lab couldn't exist without that."[1]

The Inspirations

Gecko

A Tokay Gecko (*Gekko gecko*) sticks to walls and ceilings by the aggregation of many small forces of molecular attraction, called van der Waals forces, between its feet and the surface it is on. These small forces are sufficient to keep the reptile affixed and are made possible by the hierarchical structure of the gecko's foot. Here fringed toes contain many bristles or setae and these setae are split on the ends and each of these ends has a tiny pad. These divisions through the linear scale from macro to nano multiply up to a huge exposed surface area and millions of pads on each foot. This was first discovered by Kellar Autumn in 2000 and the process explained in the *Proceedings of the National Academy of Sciences* in 2002.

Since that time, many laboratories have joined the movement to capitalize on this extraordinary insight and have produced over 100 patents or patent applications. Karp was one of many to have read the literature on the phenomenon and he began to apply its concepts to his own work in 2005. He believed that there was a great need for a tape-based repair aid for wound healing and surgery. Such an aid could be less invasive than traditional sutures and have more mechanical applications, like wrapping around tissue and being inserted into small incision openings.



Gecko lizard toe hairs

Photo: Zeiss microscopy, 2014 | Flickr cc

In 2007, in the same journal, Karp and his colleagues recounted their procedure for translating the well-known dry adhesive properties of the gecko to challenges of *in vivo* tissue repair in an article entitled “A biodegradable and biocompatible gecko-inspired tissue adhesive”.[3]

Some of their design challenges were different than nature’s. In the case of the gecko, the attachment mechanism is dry, based on a hierarchy of structure that attracts the van der Waals forces for sticking power, and is reversible at lightning speeds on this fast-moving animal. For the medical application, however, the team needed to increase adhesion in a wet environment, and were not interested in reversibility at all, rather an adhesion that remained throughout the lifetime of the tape. This lifetime would be short and part of the design brief was to make a material that would degrade in the body.

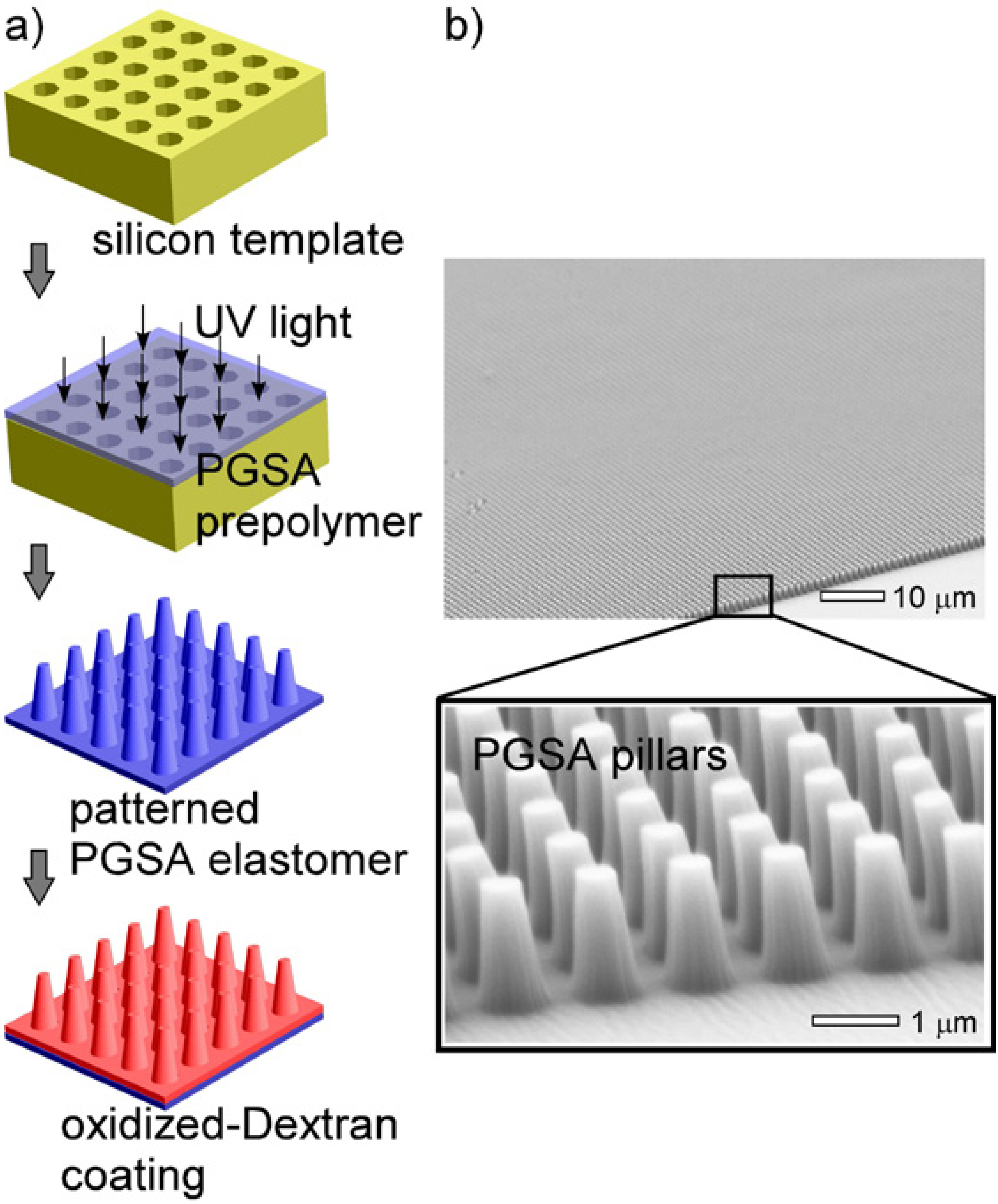
Their strategy was to increase the surface area of the tape using lessons learned from the setae of the gecko, and add a wet adhesive that was both biocompatible and biodegradable. They made a spiky bio-based elastomer and coated it with polysaccharide glue. After testing many different nano-patterned bases they chose the version which conformed the best to live tissue and then added the glue. In tests on sample pig and living rat tissue they found the patterned tape to be twice as strong as unpatterned and the addition of the glue increased adhesion by 100%. The material of the tape and the patterns on it can both be tuned for different purposes and drugs embedded in it for timed delivery as it degrades. This kind of tunability is an important characteristic of successful bioengineering endeavors and maximizes potential applications.

Fabrication of the material followed some of the techniques of photolithography and reactive ion etching used in silicone wafer technology. A mold of cone shaped holes was made of silicone into which was poured a monomer premix for poly(glycerol-co-sebacate acrylate) or PGSA, and this was cured using UV light. The hardened and patterned elastomer made of the cured PGSA polymer was then released from the mold and coated with a layer of oxidized Dextran. PGSA is biocompatible and biodegradable, as is Dextran aldehyde (DXTA). The aldehyde groups in the DXTA cross-link with amine groups in body proteins like collagen and also bond to the glycerol subunit in the PGSA elastomer.

Thus, the engineers had made a highly conformable base, much like a spiky rubber welcome mat, made of nanoscale pillars covered in a sticky glue. The glue was permanent but short lived, covalently bonding with proteins like collagen but then degrading within a range of days.

The work caught the attention of the editors of Popular Mechanics magazine who named the invention #17 in their “Top 20 New Biotech Breakthroughs that Will Change Medicine” in March, 2009.

This effort illustrated the interdisciplinary approach needed to bring an idea to practical testing. The team was led by Karp and his colleague and former postdoc mentor, Robert Langer, both of whom share positions at the Harvard-MIT Division of Health Sciences and Technology (HST). Research assistance came from the University of Basel, Switzerland as well as MIT, and engineers from the Draper Laboratory made the necessary nanomolds, while researchers at Massachusetts General Hospital performed the testing on ani-



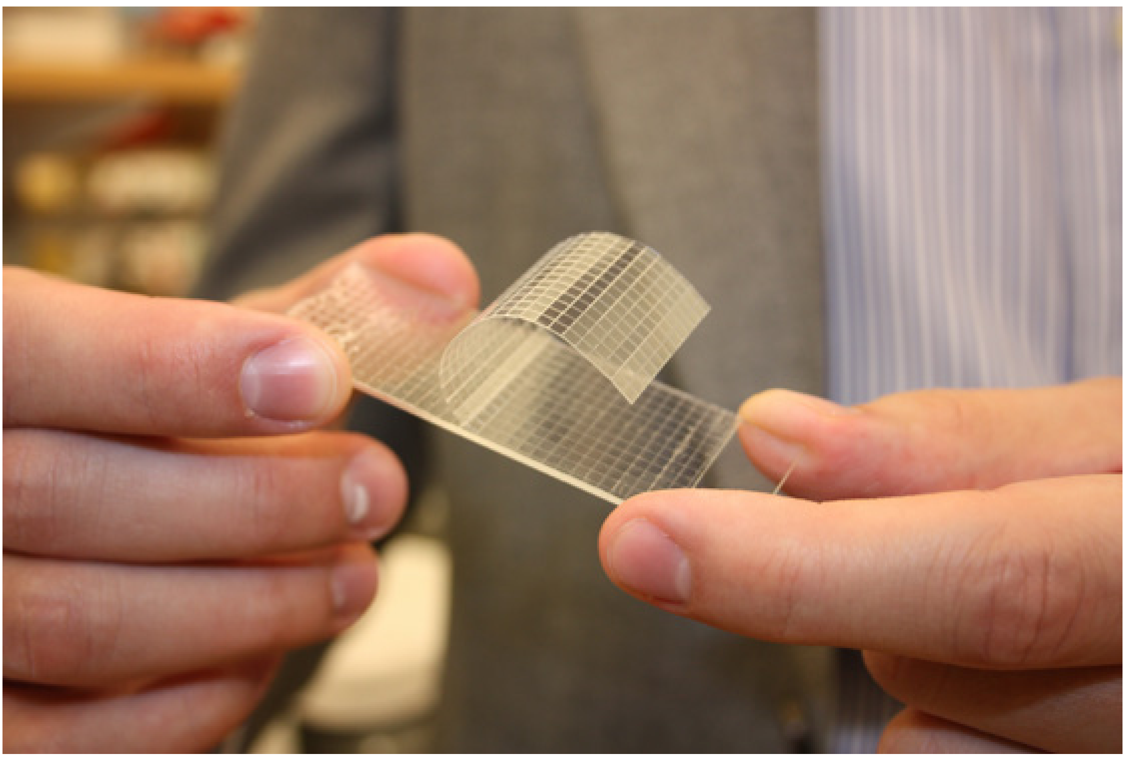
Fabrication process of “a biodegradable and biocompatible gecko-inspired tissue adhesive”

Photo courtesy of Jeffrey Karp

mals. (1) Dr. Langer runs a well-known lab in the Department of Chemical Engineering at MIT, is a winner of the US National Medal of Science and US National Medal of Technology and Innovation. He holds over one thousand patents granted or pending and has cofounded 26 companies, including Gecko Biomedical.

In 2012, Karp and Langer submitted results for another iteration of the gecko tape, this time to solve the problem of skin injury from medical tape removal. This problem is especially acute for newborns and the aged. The contradiction that they were trying to solve was one that the gecko already does: sticking tightly but unsticking at will and without loss. In the medical application newborns who were, for example, premature and needed help breathing would typically be fitted with tracheal tubes that could be anchored securely only with tape to the body. Neonatal skin has not had time to keratinize or form a tougher outer epidermis so is vulnerable to tearing and in some cases scarring for life.[4]

Their approach was to make an intermediate layer of material between the wet adhesive of the plaster and the fabric backing. At removal the fabric backing is pulled away easily from the so called release layer and the adhesive is left to wear off without trauma. Key to the solu-



Quick Release Medical Tape

Photo courtesy of Jeffrey Karp

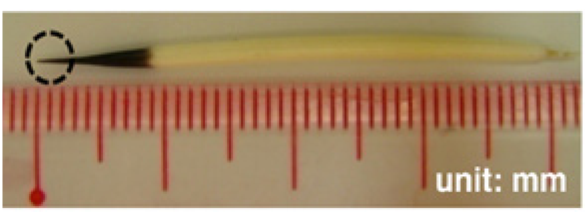
tion was the transfer of the mechanical lessons of the gecko, rather than mimicking the structure or material. They had recognized that they needed a layered material that had high shear resistance and would not slip around, but with low peal resistance. The gecko achieves this by muscular action that changes the angle of placement of its toes and peals up all those millions of nano-scale pads. The researchers created a gridded material that serves the same purpose when pulled up: the force is localized to the edge of peeling and therefore does not spread its upward pulling force to the entire surface of the adhesive causing injury.

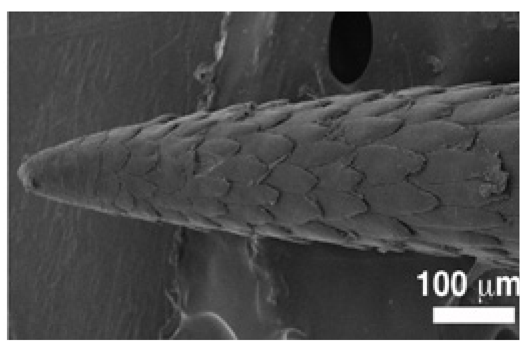
Porcupine

The quills of the North American Porcupine (*Erethizon dorsatum*) are extremely difficult to remove because of the flaring backwards barbs at their ends. The Karp lab took a closer look at this structure and adapted it to applications in the medical field: adhesives, needles or surgical staples for example.

What surprised the team was that the structure of the barbs made going into skin or muscle (sometimes both!) much easier as well. No one had taken the time to analyze the microstructure of the quills before, and what they discovered was that the ends of the barbs had a precisely honed geometry that made penetration possible at very low forces. Within the space of about 4-5 mm, the black tips of the quill exhibit a gradation of edge diameter facilitating the cutting of tissue. Like the tip of an arrow, the multiple barbs, all from 100-120 microns in length, become larger as they are arrayed rearward. The team plotted the forces needed to insert and remove the quills from a tissue in a so called penetration-retraction test. They compared this to several controls including an 18 gauge hypodermic needle and barbless quills from other species of porcupine.

The key investigative issue for penetration became stress concentration and in their results the team likened the barb array to the larger scale serrations on a kitchen knife. Barbless needles would first deform material before the compressive force of pushing overcame resistance and the needle would puncture the skin. Like the serrations on a knife the barbs would serve to concentrate stress in very local areas and from





Natural quill: Digital photo and SEM

Photo courtesy of Jeffrey Karp

Porcupine | Photo: USFWS Mountain Prairie, 2006 | Flickr cc

that could further propagate the cracks cut open. This not only makes the work less but reduces damage to the material.

During retraction the team observed the greater drag inducing qualities of the natural barbed quills contrasted to those they had made with polyurethane. The barbs on the natural quills would often become bent and this increased drag significantly over relatively long displacement of the quill. It is still unclear whether the barbs are mechanically deployed to result in this or whether they are randomly bent by circumstance. Whatever the cause, the team noted the importance of this bending in the design of any synthetic barbed device.

In addition to fabricating control test needles of polyurethane, the team also made a micro needle patch made of silicone (PDMS) as a testing prototype.[5]

Interestingly, the idea of a bio-inspired serrated microneedle has been explored in other labs by observing very different animals. Engineers from Kansai University in Japan, for example, had published results in 2010 for a needle based on the mosquito proboscis. In the animal, two jagged-edged maxillas surround a smooth labrum. The maxillas serve to cut the skin, making intrusion so clean that it is usually not felt, and the labrum moves down within them to pierce and siphon the blood. The researchers fabricated a similar three part mechanism.[6]

Spiny-headed Worm

The spiny headed worm (*Pomphorhynchus laevis*) lives in an environment very much like the one surgeons have to operate in: wet, plastic and full of movement. It is an endoparasite that feeds on the intestines of teleost fish and Karp and his colleagues chose it for investigation because they saw from its image that it had the right tools for the job.

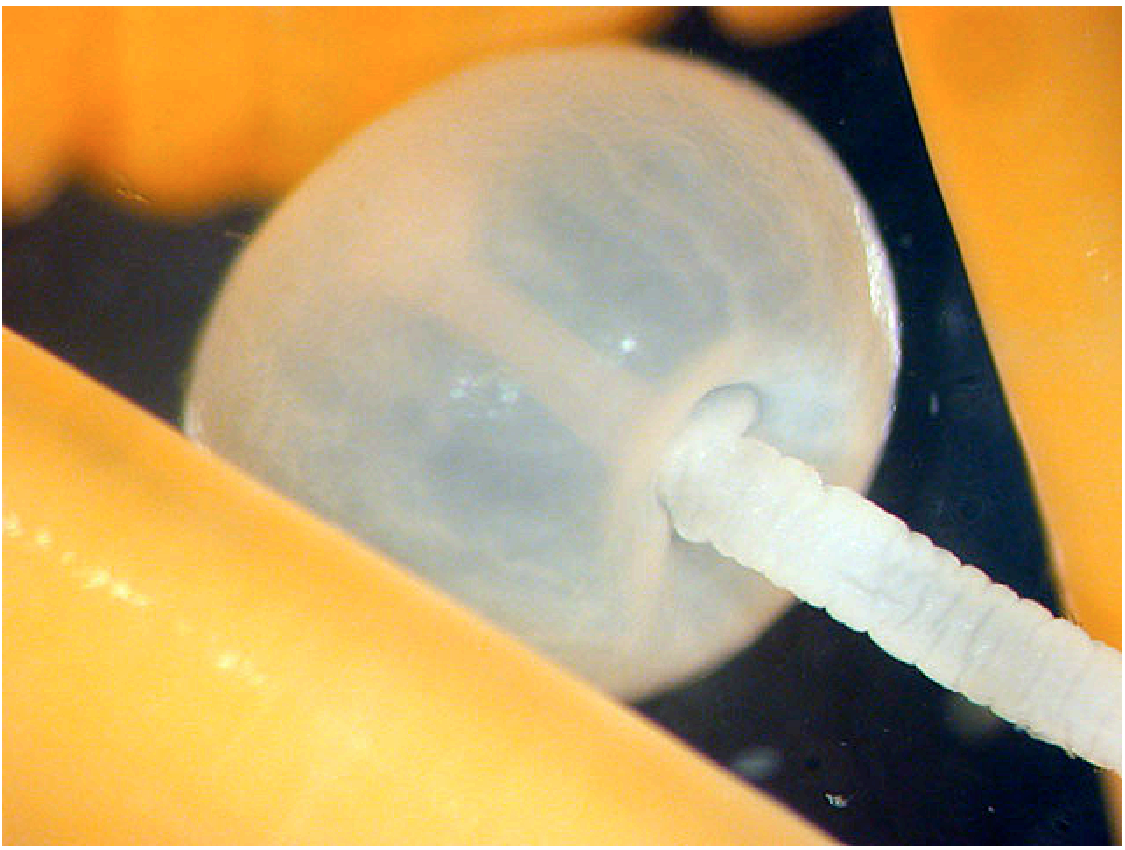
The source of Karp's initial interest was a study by biologists whose concern was more purely academic.[7] For them, the worm's taxonomy and it role in the ecosystem were the most valued information and its apparatus for attachment viewed mainly as a morphological aid to identification. The purpose of the biologists' study was to establish a clear phylogenetic tree for these species and they were mainly interested in sorting out clades by DNA tests. Additionally the parasitic worms were seen as possible model organisms for studying host-parasite co-evolution. The Karp team saw something different, however.

The worm is in the phylum Acanthocephalans. Acanthocephalans come in 83 different genera and 594 species but share some common features. The worms have no mouth so absorb nutrients that their host has already digested directly through their bodies. This means a great deal of hanging out and to do this they have a wide variety of hook arrays, most being recurved and arranged in spirals along an extendable proboscis. In the case of *P. laevis* a bulbous extrusion is inserted into the walls of the host tissue and then expanded; a friction fitting, if you like, similar to expanding or toggle bolts used in construction or rock climbing.

To achieve the same kind of holding mechanism the researchers made a core of polystyrene with an outer layer of conical tips of a combination of the polystyrene and polyacrylic acid, a highly absorbent material used typically in baby diapers. Used in a patch, the microneedle array can be applied to tissue with easy insertion and when the tips swell is kept tight against the material, resisting pullout.

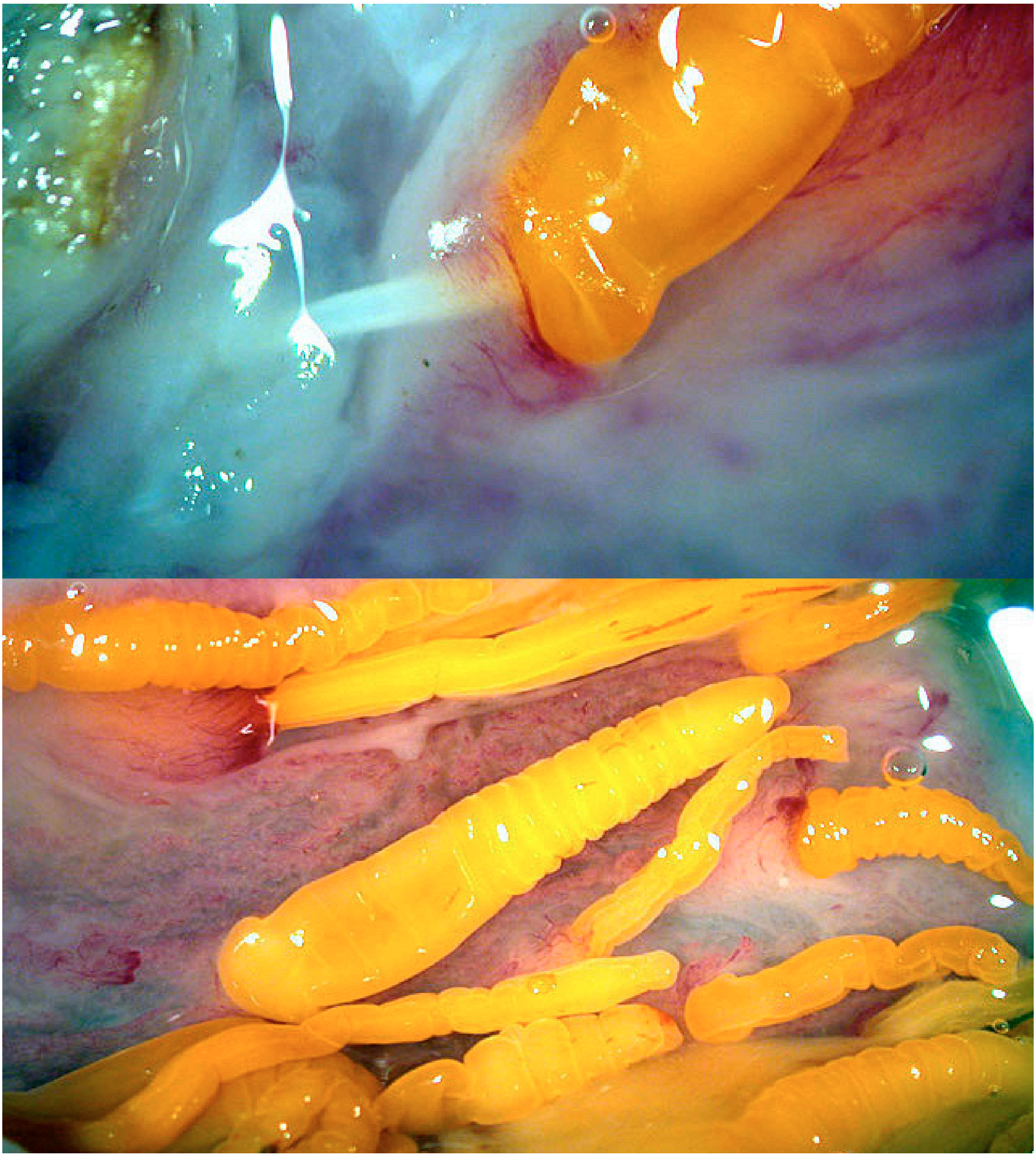
As in the gecko inspired tape, the swellable microneedles patch has basic advantages over other methods according to the researchers: ease of application in minimally invasive procedures, conformability in soft tissue, a reduced risk of infection found in traditional staples, less traumatic removal, minimal damage on application and the ability to deliver drugs as well as repair a wound. The device shows good performance: they have recorded a 3.5 fold increase in adhesion strength over staples typically used in skin grafting, an application area that they consider the most promising.

To date, the team has tested this biphasic device on animal tissue and intend to conduct further investigation to judge the feasibility of clinical



Friction fitting: Pomphorhynchus from Bluefish (*Pomatomus saltatrix*)

Photo: fishdisease.net, 2007 | Wikimedia Commons



Acanthocephala Pomphorhynchus

Photo: fishdisease.net, 2007 | Wikimedia Commons trials. Karp cautions, however, that promising devices fabricated in the lab are still a long way from commercial products.

> "Before we can advance to clinical testing, we have to understand what would be required to replace existing technologies. You have to know all the practicalities. There are a lot of cool technologies but many just can't be mass-produced with consistency, or may cost too much to integrate into practice, and so on."[1]

Sandcastle Worm

The Sandcastle worm (*Phragmatopoma californica*) is a Pacific Ocean polychaete worm that exists in the dynamic environment of the intertidal zone. As part of its strategy for survival against the mechanical forces of waves and the prying of predators, the worm uses a glue to affix bits of shell and sand particles together to make a tube home. Colonies of these tubes can be several meters across. During the exposed low tide the worm remains beneath its operculum seal and when the tide is high the worm extends its tentacles to catch food within the water. It is not alone in using an underwater glue; mussels, oysters and barnacles all use this strategy in the marine environment.

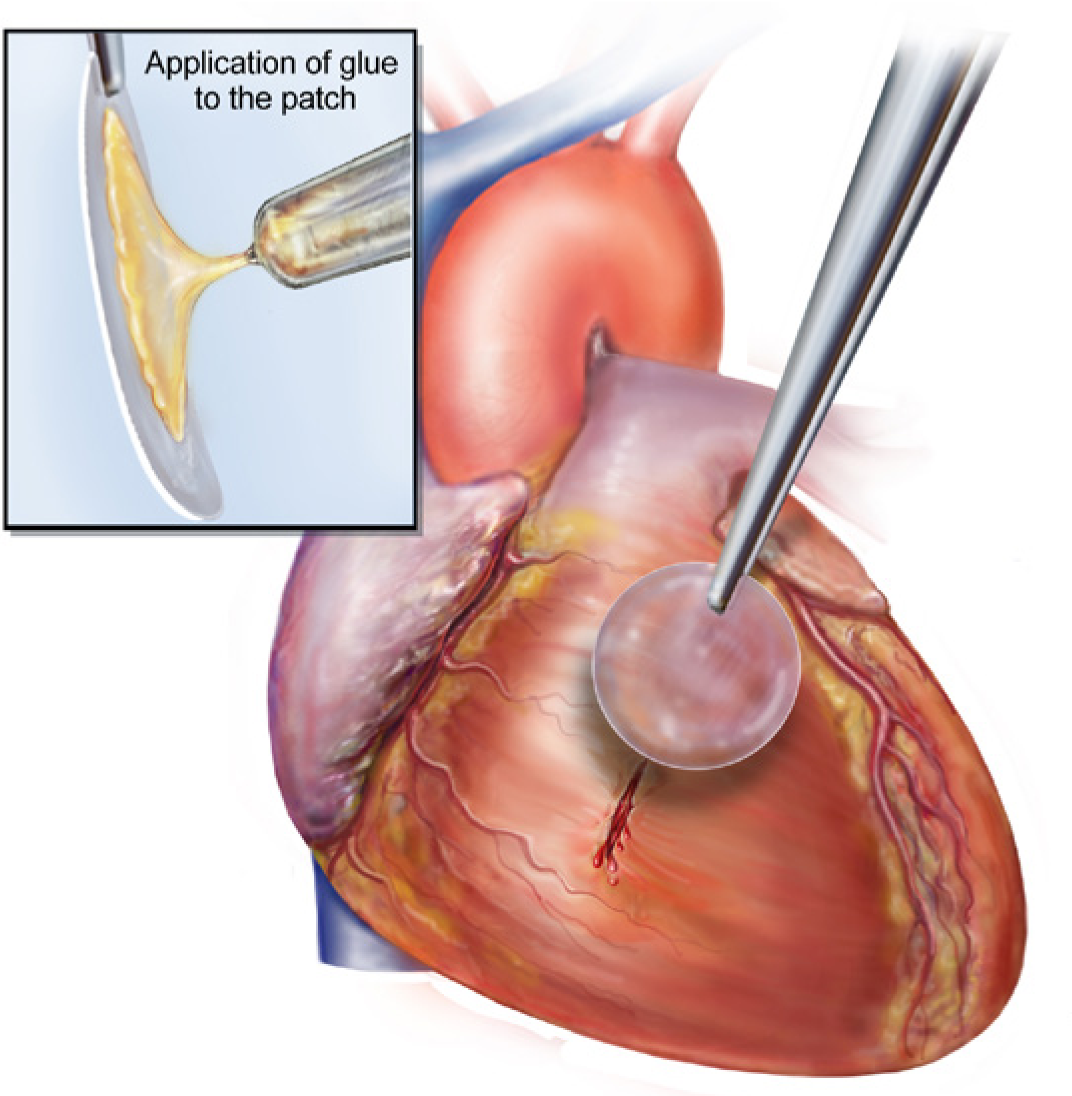
The makeup of the glue has been an object of research for some time and in 2005 a team from J. Herbert Waite's lab at the University of California, Santa Barbara was able to sequence the protein structure of this bioadhesive and describe how it sets. Not surprisingly, the proteins are similar to that found in mussel byssus and belong to a small group called the polyphenolic proteins. The glue as made and dispensed is very much like a two-part epoxy; different proteins and associated adhesion-forming side groups formed separately and then mixed as they are secreted from a gland. The glue sets underwater in 30 seconds and cures in about six hours. Researchers think that the setting is triggered by the meeting of the acidic protein mix and the base seawater.

In 2009, Russell J. Stewart's lab at the University of Utah was able to make a synthetic version of the glue. This group was able to achieve similar results without slavishly imitating the chemical structure of the natural version. The combination of side chains for cross-linking and the forming of a complex coacervate, a hydrophobic array, was important in developing this viscous, immiscible liquid.[8]

The Karp group reported their development of a new type of surgical glue in the January, 2014, issue of Science Translational Medicine, "A Blood-resistant Surgical Glue for the Repair of Vessels and Heart Defects.".Their stated goal was a non-toxic, strongly binding adhesive that could work in the wet and dynamic environment of surgery. This was for the purpose of improving minimally invasive reconstructive cardiovascular surgery. Key design criteria were that their substance be a "...biomimetic, stable, water-insoluble precursor that could resist washout in vivo, be cured in situ via light activation, and achieve a watertight but flexible bond."

Current clinical methods include the use of medical-grade cyanoacrylate ("super glue") or fibrin sealant and both have serious drawbacks, being either toxic or weakly adhesive and prone to be washed out by blood flow before being affixed.

Honeycomb Homes (sandcastle worms) | Photo: kqedquest, 2007 | Flickr cc



Application of glue to patch

Image courtesy of Jeffrey Karp

Other adhesives under development depend on specific chemical interactions that make their applications limited, and their catalyzing sequences make prepositioning difficult.

While the group mentioned initial inspiration from several animal-inspired formulas including the synthetic glue inspired by the sandcastle worm, they chose for their base a synthetic adhesive they had developed as a biocompatible elastomer in 2007, poly(glycerol sebacate acrylate), PGSA. It contains components already in the human body: glycerol is a foundational component for lipids and sebacic acid is a metabolic intermediate for fatty acids. Both are approved by the U.S. Food and Drug Administration. PGSA can be photocured in five to thirty seconds, making it a good candidate for medical procedures.[9]

The results of their experimentation was a hydrophobic light-activated adhesive (HLAA) made up of the PGSA precursor and a photo initiator. They tested this in vitro and in vivo, using, among other things, pig tissue and rat hearts. They reported excellent biocompatibility, good adhesion to soft tissue and, importantly, no washout or degrading of the adhesive properties due to blood flow. The advantages over current methods and materials were many, since there are now no procedures that allow positioning of hydrophobic prepolymers and such quick curing which avoids potential damage from lightsource heat. Moreover, the researchers claim to be able to tune the mechanical properties of the substance by adjusting its formula and controlling cure time and light intensities.[10] Recently, the researchers have been able to scale manufacture of the adhesive by 100x, and intend to test it in live pigs in 2015.

A sandcastle worm (*Phragmatopoma californica*) in the laboratory of Russell Stewart, University of Utah, making a tube out of sand (yellow) and beads of zirconium oxide (white).

Photo: Fred Hayes for the University of Utah | CC BY-SA 3.0 via Wikimedia Commons

The Market

The performance success of the HLAA is buoying the prospects of Karp's new company, Gecko Biomedical, a Paris based biotechnology start-up. Gecko Biomedical is privately owned and has been funded by a group of investors that include Omnes Capital, CM-CIC Capital Innovation, and CapDecisif Management. Series A financing totaled eight million euros. The company is a confluence of the scientific talent at MIT, namely Dr. Langer and Dr. Karp, the iBionext Network founded by Dr. Bernard Gilly, and centered in Paris around the Institut de la Vision, and the capital investors. Dr. Karp serves as Observer of the Board of Directors and Chairman of the Scientific & Clinical Advisory Board.[11]

The market focus for the company is minimally invasive procedures (MIP), where an instantly curable glue that can stand up to the demands of the *in vivo* environment has great advantages.

Lined Leaf-tail Gecko - Exotic Reserve Peyrieras, Madagascar | David D'o, 2008 | Flickr cc

Gecko foot on glass

As described in the above scientific paper, the HLAA might also become a new standard option for all sorts of tissue repair.

Much remains to be done before this glue becomes a regular feature of operating rooms. Its development is in the pre-clinical trial position, meaning that it has not been tested on humans yet, but the company has been able to scale the material for production, stabilized the formulation and intends to begin human trials in 2015, or early 2016. New formulations; fine-tuning of characteristics like viscosity and adhesive strength and an exploration of how to better incorporate bioactive therapeutics into the mix are all ongoing. Beyond that, toxicity and safety studies will have to be done to pave the way for the clinical phases. One possible early path to human testing envisioned by the inventors has been as a hemostatic agent for suture line bleeding or small lacerations, since the glue seals so well. This more limited performance and safety testing might come before the more complex and longer-term studies needed for internal tissue repair like patches to the heart.

From geckos to porcupines to worms, the Karp lab has pursued some of the more arcane forms and processes of nature, but always with the intent to better the medical profession and improve people's lives. They have focused on a single category of mechanical challenge and a single application venue, but within that sphere the challenges have been so demanding that they have found a wide search in nature not only useful but necessary. Their success can be attributed to a keen focus on applications in problem-solving, an openness to divergent ideas in interdisciplinary teams and an ability to look deeply and test rigorously when investigating some of nature's better ideas. ×

Notes

1. http://www.newscientist.com/article/mg22429900.400-what-id-ask-spiderman-mascot-of-bioinspiration.html

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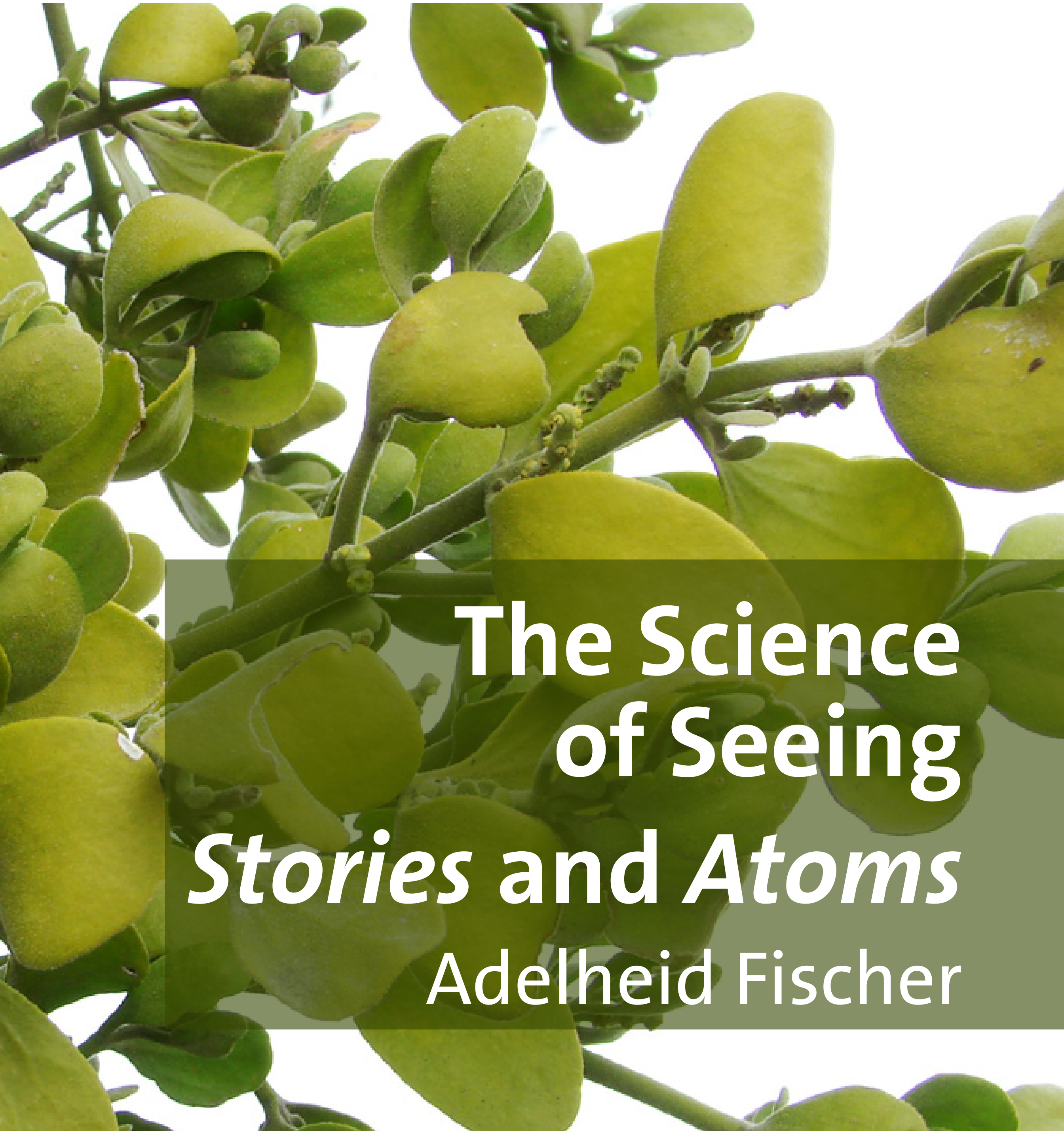
Additional Links

www.karplab.net

http://tedmed.com/talks/show?id=309658

Eastern Mistletoe (*Phoradendron leucarpum*) in Northeast Texas

Photo: David R. Tribble, 2009 | Wikimedia Commons



The Science of Seeing
Stories and *Atoms*

Adelheid Fischer

Stories *and* Atoms

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

One of the best things about life is that you never know when a jewel might drop from the brown wrapper of an ordinary day and present an exquisite new pleasure that you savor for the rest of your life.

Just such a jewel fell into my lap on a mid-summer day in 1995. I had traveled 300 miles due north from my house in Minneapolis to Mallard Island on the U.S.-Canada border. Mallard is a tiny brooch of rock pinned onto a sprawling lacework of islands that spans the 360 square miles of Rainy Lake. It was home to the late Ernest Oberholtzer, an arctic explorer and Minnesota conservationist whose activism in the 1930s and '40s helped preserve the border-lakes environment.

American explorer, author and conservationist Ernest Oberholtzer (right) with dog Skippy and Ojibwe trapper and guide Billy Magee (left) holding cabbage. | Wikimedia Commons

By the time of my visit, Ober, as friends and admirers knew him, had been dead for nearly two decades and the island had turned into a place of learning for people like me who were interested in the history, culture and ecology of the north country. Ober's presence was still palpable, nonetheless, particularly in the whimsical structures that the landscape architect, educated at Harvard under Frederick Law Olmsted, had designed and tucked under the trees. Over the decades, they had housed family and friends as well as fellow soldiers in the conservation trenches who plotted legislative battles around the mess-hall tables in Wannigan, a former barge that had been dry-docked on the north end of the island and converted into a communal kitchen.

One afternoon during my retreat on the island I found myself in Big House, Ober's personal residence. Stacked with gables, Big House was built atop a great outcrop of Canadian Shield granite, like building blocks balanced on the back of a gray whale breaching the surface of Rainy Lake. The ceilings had trapdoors that led to private reading nooks and secretive screened porches that clung like barnacles from second-story lookouts. Best of all was the living room that featured a bulging hearth of lake cobbles built by

Common Dodder

Photo: Dendroica cerulea, 2014 | Flickr cc

Weasel

Photo: Borderslass, 2012 | Flickr cc

an Ojibwe neighbor, Charlie Friday, whose spirit is said to have taken up residence in the mason's handiwork after his death. Stashed in the rafters was the beloved canoe that Ober and another Ojibwe friend, Billy McGee, had used on an arctic river journey to the Barren Grounds of Hudson Bay in 1912. Some of the black-and-white photographs from this epic trek rested on a large piano whose notes, along with those from Ober's violin, had disappeared long ago into deep drifts of winter snow.

It was here in the dim, sepia glow of this northwoods parlor, its heavy timbers steeped in the smoke of warming fires, that my friend Jean Replinger, then-program director of the Oberholtzer Foundation, introduced me to Ober's collection of vintage natural history books. An avid reader with encyclopedic interests, Ober had converted nearly every square inch of wall space in the island's structures (outhouses excepted) to store his library of 11,000 volumes, including the many on natural history. Jean, who was in the midst of a multi-year project to catalogue the books, knew of one that might help us identify a low-slung animal that we had spotted nosing around the shores of the island next door. Was it a pine marten, a mink or a common weasel? Jean pulled out a hefty tome, its gilt lettering stamped into a jacket of furrowed brown leather: *Cassell's Popular Natural History*. Volume 1: Mammalia. London: 1860. Much to our surprise and delight, there was an entry on common weasels. So we settled into some rocking chairs, and I began to read aloud. It soon became clear, however, that *Cassell's Popular Natural History* should have been titled *Cassell's Fanciful Natural History* since the entry on weasels quickly moved into what can only be called Victorian infotainment. Like a fairy tale, the story opened innocently enough:

> *One fine summer evening the father of Captain Brown, the naturalist, was returning from Gilmerton, near Edinburgh, by the Dalkeith road. He observed on a high ground, at a considerable distance, betwixt him and Craigmillar Castle, a man, who was leaping about, performing a number of antic gestures, more like those of a madman than of a sane person. After contemplating this apparently absurd conduct, he began to think it might be some unfortunate maniac, and, climbing over the wall, made directly towards him; when he got pretty near, he perceived that the man had been attacked, and was defending himself against the assaults of a number of small animals, which he at first took for rats, but which in fact turned out, on getting closer, to be a colony of from fifteen to twenty weasels, and which the unfortunate man was tearing from him, and endeavouring to keep from his throat. He joined in the combat, and having a stick, contrived to hit several of them, and laid them lifeless. Seeing this, the animals became intimidated, and speedily fled towards a rock hard by, and disappeared in its fissures. The gentleman was nearly overcome with fatigue and exhaustion, having been engaged in his struggle with the weasels as far as he could guess, upwards of twenty minutes; and but for the fortunate and timely assistance he received, he said he must have inevitably fallen a victim to their fury, as he found himself quickly losing strength from the violence of his exertion. His chief attention was turned to keeping them from his throat, to which they seemed instinc-*

> *tively to direct their course. He was a powerful man, otherwise he must have sunk under their ferocity. He had squeezed two to death while tearing them from him. His hands were much bitten, and were streaming with blood from the wounds.*
>
> *The account he gave of the commencement of the affray was, that he was walking slowly through the park, when he happened to see a weasel; he ran at it, and made several unsuccessful attempts to strike it with a small rattan he had in his hand; on coming near the rock above mentioned he got betwixt it and the animal, and thus cut off its retreat; the weasel squeaked aloud, when an instantaneous sortie was made by the whole colony, and the attack commenced.*

Where to begin to sort the kernels of truth from the chaff of embellishment? In the interest of telling a compelling story, the writer conveniently ignores the fact that adult weasels are not colonial but largely solitary animals unless mating or rearing pups. It is true that when threatened weasels can mount a fierce defense. A friend, whose canoe once strayed too close to the shore of a Minnesota lake where a mother weasel and her three offspring were hunting, recalls how the adult female swam out from shore to give their canoe a solid thump of warning before attempting to lacerate the hull with her teeth. Regardless, even in the unlikely event that the man on the Dalkeith road had been ambushed by a guerilla force of vengeful weasels, he could have easily avoided his bloody, twenty-minute brush with death by simply walking away. But who wants to read about an exercise in common sense? In this account of questionable natural history, the narrator uses nature as stage furniture and weasels as anonymous extras in his heroic fantasy drama. My guess is that he may have been a former British military officer long retired from the colonial wars who found country living a bit too hum-drum. In the absence of a bona fide enemy, even a weasel may be counted upon to raise the red flag of stranger danger lurking within an ordinary pile of field rocks and make a hero out of an occasional hiker.

Nonetheless, the writer achieved his purpose brilliantly, despite the biological gaffs and the artificially leavened drama. Two decades later, Jean, now in her 80s, and I can recall vividly how captivated we were by the account that we seemed to have read it from start to finish in a single breath and howled with laughter until we wept. I had been so charmed I even went on to collect vintage natural history books of my own, writers such as Jean-Henri Fabre and Neltje Blanchan, not to mention, of course, my own multivolume copy of *Cassell's Popular Natural History*.

What do I love about these writers? Some of them, like Fabre and Blanchan, are crack naturalists with extraordinary field-observation skills. Often cheeky and cunning, they have the linguistic daring of trapeze artists and use it to take wild leaps of original writing. Take, for example, Blanchan's brilliant description of a north-woods plant known as Indian Pipe. This wildflower is classified as an epiparasite; that is,

Indian Pipe

Photo: Greying Geezer, 2014 | Flickr cc

Juniper mistletoe

Photo: chloesview, 2013 | Flickr cc

Indian pipe taps into the nutrient-exchange network of another so-called parasite, mycorrhizal fungi, which colonize the roots of other plants and survive on their stores of photosynthetic products such as carbohydrates. Obtaining its nutrients through this underground web, Indian pipe has dispensed with the need for chlorophyll that is essential for carrying out photosynthesis and so has a kind of waxy-white translucency.

Yet Blanchan makes clear that she isn't buying Indian pipe's lily-white "chaste charms." It is, she charges, a "branded sinner."

> *Doubtless its ancestors were industrious, honest creatures, seeking their food in the soil, and digesting it with the help of leaves filled with good green matter (chlorophyll) on which virtuous vegetable life depends; but some ancestral knave elected to live by piracy, to drain the already digested food of its neighbors; so the Indian Pipe gradually lost the use of parts for which it has need no longer, until we find it to-day without color and its leaves degenerated into mere scaly bracts....Among plants as among souls, there are all degrees of backsliders. The foxglove, which is guilty of only sly, petty larceny, wears not the equivalent of the striped suit and the shaved head; nor does the mistletoe, which steals crude food from the tree, but still digests it itself, and is therefore only a dingy yellowish green. Such plants, however, as the broom-rape, Pine Sap, beech-drops, the Indian Pipe, and the dodder—which marks the lowest stage of degradation of them all—appear among their race branded with the mark of crime as surely as was Cain. No wonder this degenerate hangs its head; no wonder it grows black with shame on being picked, as if its wickedness were only just then discovered!*

In her damnation of the miscreant Indian pipe, Blanchan concedes only one small point of redemption. Curved at the tip when newly emerged, the plant straightens as it matures. "When the minute, innumerable seeds begin to form," she writes, "it proudly raises its head erect, as if conscious that it had performed the one righteous act of its life."

The writing is so good—and so wrong, a cognitive dissonance that isn't particularly jarring for astrophysicist and popular science writer Chet Raymo who, like me, is a devoted fan of this period nature writing. In his 1994 essay "Drunk on Honey: Seeing Ourselves in Nature," Raymo quotes a line from the poet Muriel Rukeyser: "The universe is made up of stories, not atoms." He asserts that "telling stories is the writer's business" and that contemporary science writers have much to learn from these early nature writers, especially the liberties they take in anthropomorphizing the world around them. "Nature writers today are more sparing of allegory," he charges. "We resist drawing moral lessons from flora and fauna. We are hesitant to stray too far from the aseptic, impersonal prose of science, fearful that we'll squander our credibility, afraid of not being taken seriously. But why? Nature writers are not scientists. We are writers. Scientists know by dissection; their method is reductive, analytic, single-visioned. Writers know by weaving such a web of likeness that the world is seen whole again. Nature writers

Indian Pipe | Photo: crimfants, 2009 | Flick cc

should not feel beholden to science; our aim is esthetic, moral, synthetic. Anthropomorphic prose can serve our purpose."

Now, Raymo is one of my favorite natural history writers, and I would follow his prose to the ends of the earth but the premise of this essay leads onto thin, slippery ice that gives me great unease. To look out into the nonhuman world and see it populated with sinners and saints, virgins and whores, honest wage earners and welfare cheats, Gandalfs and Darth Vaders, is to deny the sovereignty of other beings. As my friend, the Minnesota plant ecologist Chel Anderson, put it bluntly, "Plants are not us."

Furthermore, seeing other beings as extensions of ourselves has, in some cases, led to disastrous ecological consequences. The most egregious example may be the centuries-long persecution of wolves, which stories from the Brothers Grimm and others have helped to legitimize. We can thank hard science—and not more stories—for revealing a far more profound and truthful narrative. Take the recent research to come out of Yellowstone National Park. The restoration of wolves to the park in 1995 has reintroduced what Oregon State University botanist William Ripple calls an "ecology of fear," particularly for animals such as elk. Wary of the new predator on the block, the elk now redistribute themselves more widely, allowing vegetation such as willows and cottonwoods to regenerate from the pressures of overgrazing. This, in turn, has provided the suite of animals that rely on them with greater opportunities for feeding and breeding, nesting and resting. The ecological resurgence has astounded scientists.

There are many other examples that may not enjoy such high-profile character rehabilitation in the popular press. Take the case of mistletoe. For years now on my regular hike in the Sonoran Desert, I have passed an ironwood tree that hosted a thick tangle of mistletoe in its branches. One day this past summer I noticed that some "Good Samaritan," in what appeared to me to be a fit of righteous indignation, had ripped off every stem of mistletoe and left them in a heap at the base of the tree. When not in use as a romantic lure during the holidays, mistletoe, like Indian pipe, is viewed as a freeloader that lives off the honest labor of others. The plant is indeed parasitic in that it does derive nutrients and water from its host plant. The prevailing wisdom, however, is that mistletoe can't be trusted to dine with polite restraint but instead turns into a greedy vampire that eventually kills its host.

Results of research published in 2012, however, show that this narrative may be far more complicated than previously believed. Indeed, mistletoe in the woodlands of Australia may be vital to forest health, according to ecologist David Watson and Matthew Herring of the Charles Sturt University in Albury, New South Wales. The scientists removed mistletoe from 17 study plots. Surveys taken three years later showed declines in reptile species and some mammals. More important, though, was the loss of bird species, which had dropped by a third. This was a critical red flag since bird diversity is used as a gauge for ecological diversity overall. Particularly hard hit were animals that rooted for insects on the forest floor. Watson and Herring took a closer look at the dynamics of the forest floor and made some surprising discoveries. They found that mistletoe's host plants, like deciduous trees worldwide, drain leaves of their nutrients before dropping them. But mistletoe plants are far less frugal. Because life is easy-come for mistletoe plants, it is also easy-go. The plants not only shed leaves that are still rich in nutrients, but they also drop them throughout the year, providing all kinds of animals on the forest floor with a reliable banquet.

Arizona scientists Ron J. van Ommeren and Thomas G. Whitham have discovered that mistletoes in the juniper trees of northern Arizona provide similarly important benefits. Junipers, for example, produce berries in boom-and-bust cycles. The mistletoe plants that colonize them, on the other hand, produce a far more consistent crop. Surveys showed that three times the number of juniper seedlings germinated in patches with mistletoe plants than in those without. The reason, say the scientists, is that the steady production of mistletoe seeds continued to attract birds to the junipers in lean years, an important benefit for the tree since processing of seeds in the digestive tract of birds increases the likelihood of juniper germination by a factor of ten.

What writer needs to resort to fiction when she has such glorious facts? Still, I won't be giving away my library of vintage natural history books any time soon, even if they often perpetuate transparent lies through fables of irresistible charm. The question remains: how do we discover our likeness in the world, as Raymo asks us to do, without giving in to our urges to tame, our tendencies to fear, our default propensity for bipolarizing the world into virtues and vices? I think we do it by pledging a vow of faithfulness to the way the world really works, by letting atoms tell their own stories. Their narratives are our narratives: tales of ingenious complexity, restless adaptation and a beauty that may silence even our impulse to speak. ×

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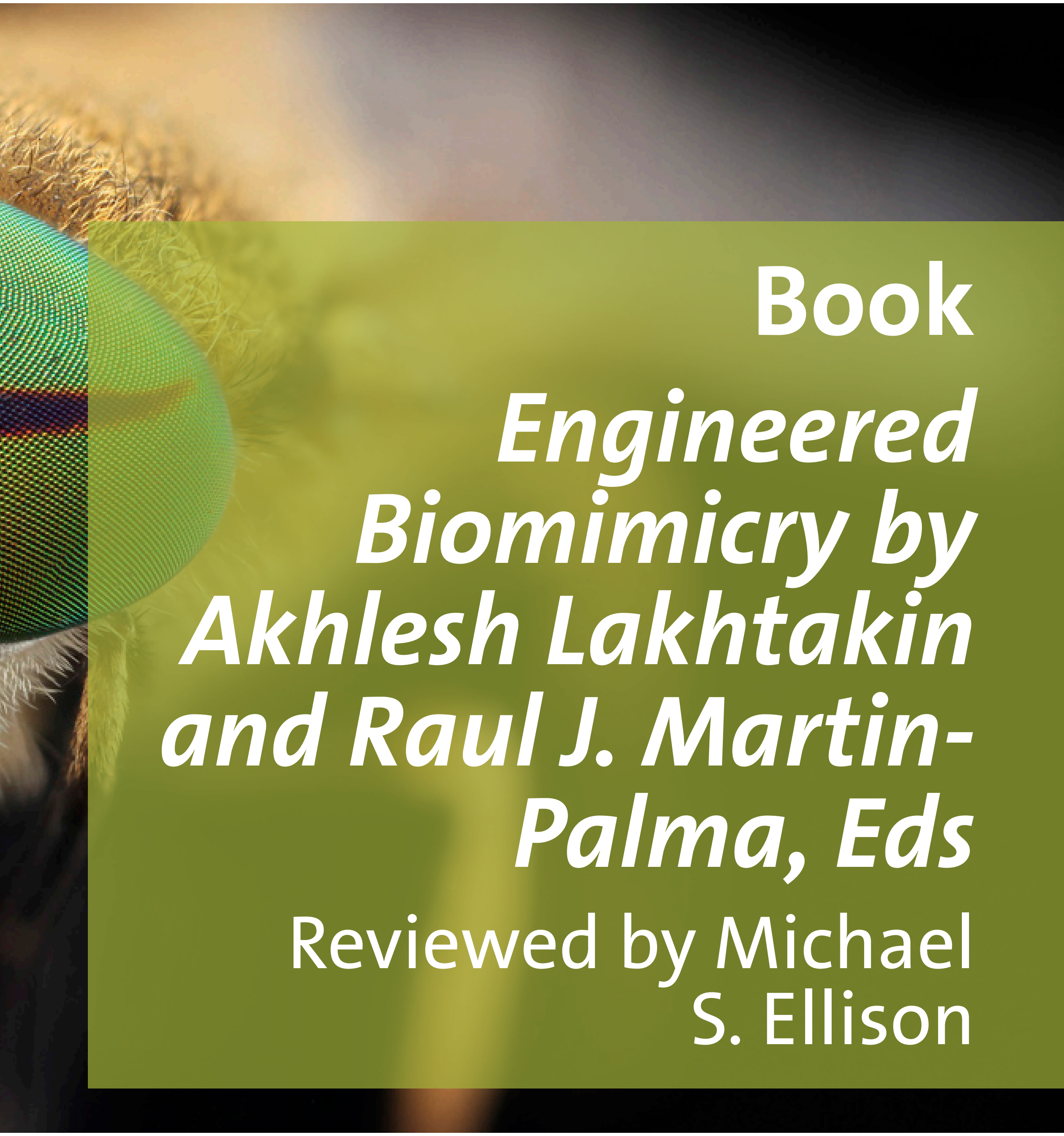
Weasel

Photo: Sergey Yeliseev, 2015 | Flickr cc

Horsefly

Photo: Macroscopic Solutions, 2010 | Flickr cc



Book

Engineered Biomimicry by Akhlesh Lakhtakin and Raul J. Martin-Palma, Eds

Reviewed by Michael S. Ellison

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Book:
Engineered Biomimicry by Akhlesh Lakhtakin and Raul J. Martin-Palma, Eds

Reviewer:
Michael S. Ellison

Engineered Biomimicry by Akhlesh Lakhtakin and Raul J. Martin-Palma, Eds

Michael S. Ellison, Ph.D., is a professor emeritus in the Department of Materials Science and Engineering at Clemson University, Clemson, South Carolina, USA, and is author of one of the chapters ("Biomimetic Textiles") in this book.

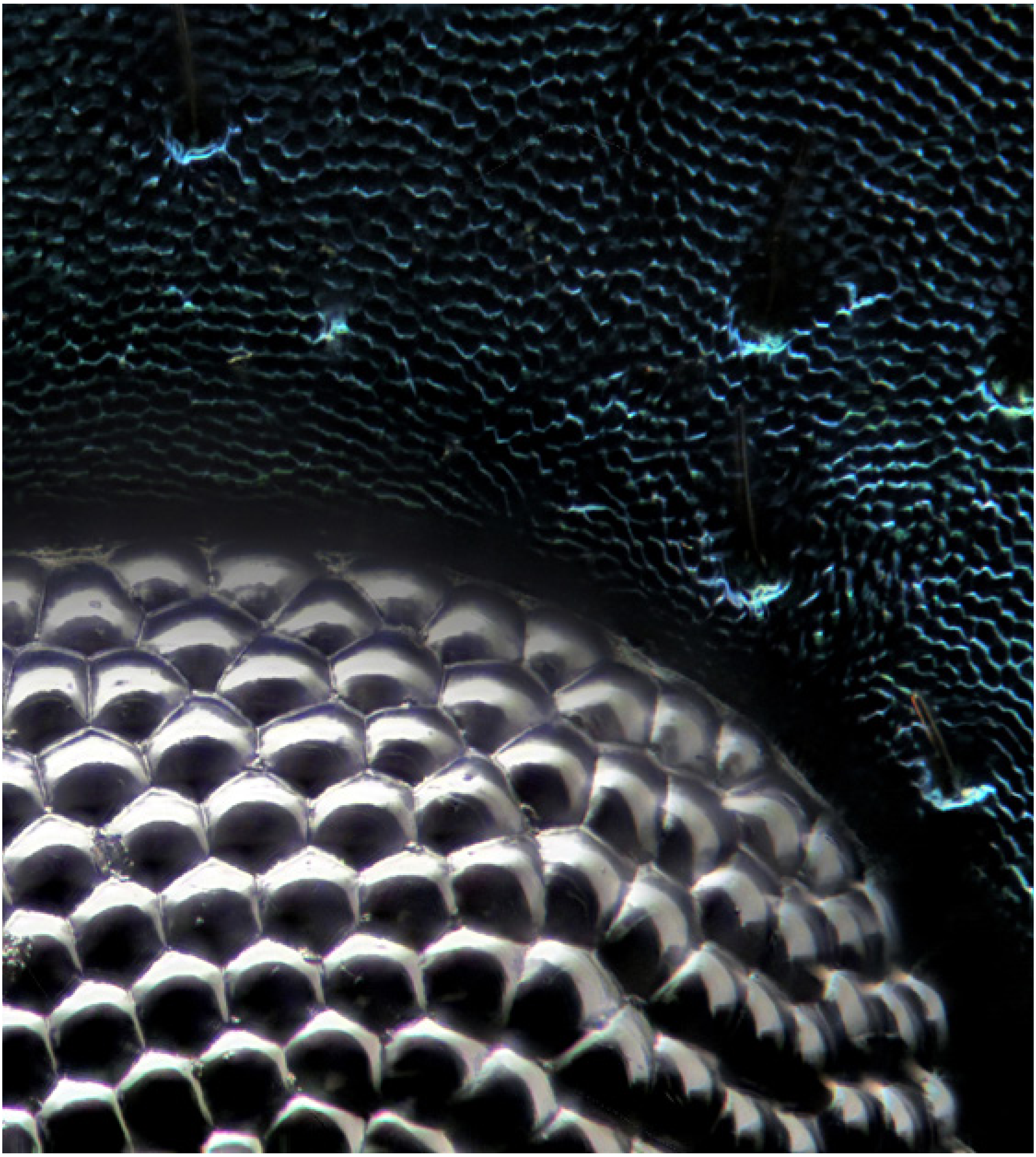
Introduction

This book is primarily, but not exclusively, addressed to engineers working in development of new materials and in devising novel systems as solutions to pressing societal problems (such as sustainability). Many of the current solutions in themselves are problematic and thus require new approaches to materials development. Natural systems are inherently sustainable and, as the contribution by H. Donald Wolpert ("The World's Top Olympians") reveals, often result in organisms possessing remarkable properties. Using Olympic sporting events as a metaphor, Wolpert provides the reader with animal performance metrics, many of which are astonishing. I, for one, had no idea that the white-throated swift is capable of level flight at 217 mph! There are many other such champions in that article, but I will leave it to the reader to enjoy their stories.

Main thesis of the book

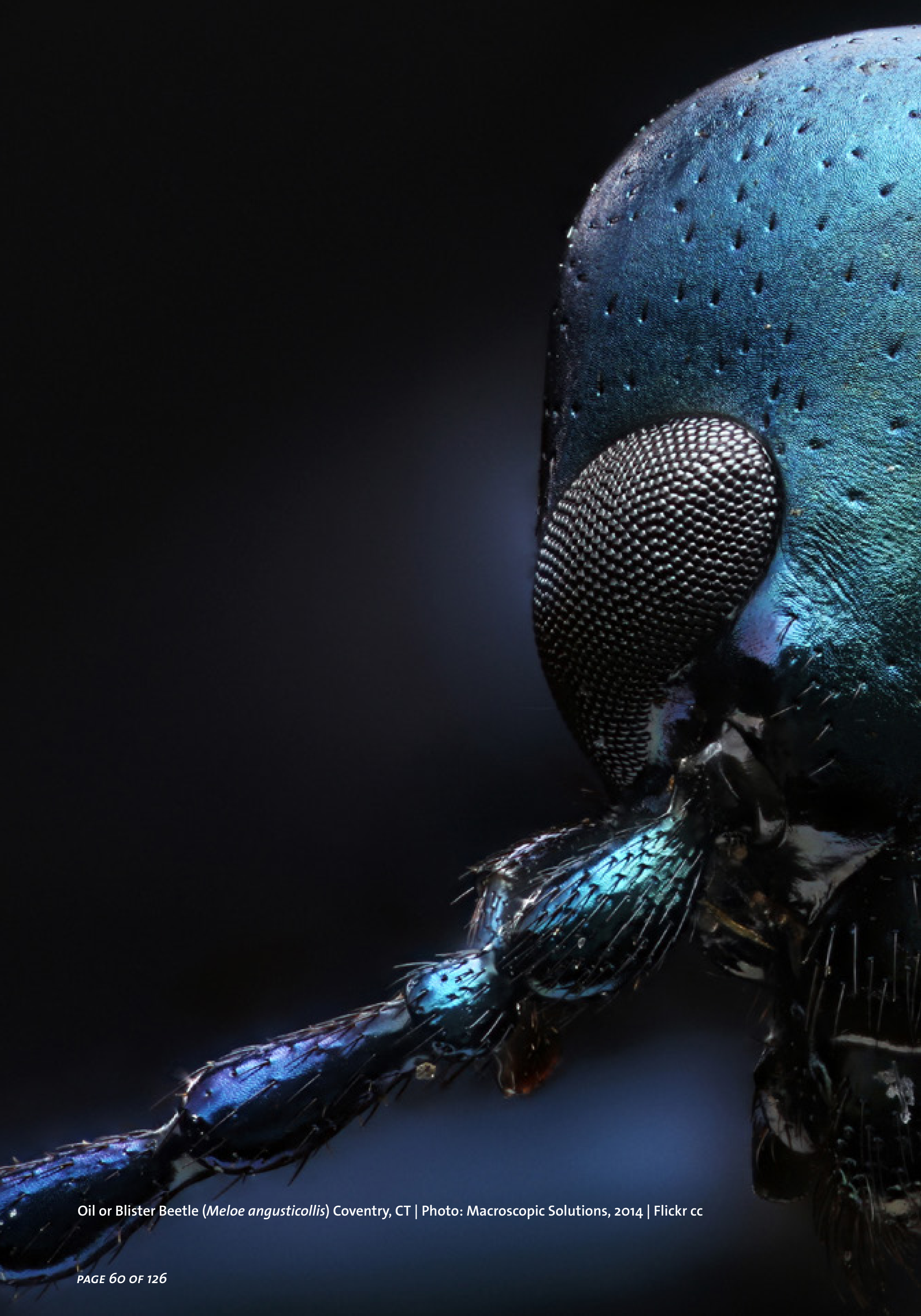
Most discussions of how science and engineering differ yet overlap eventually settle on something like the following. The pursuit of science comprises building an orderly system of knowledge that is derived from multiple observations. These observations are formed into hypotheses, then tested and communicated to other people for further verification. Engineering is the application of these scientific principles in creative and often transformational ways to build materials and systems in support of society.

The objective of this book is to support an engineering paradigm shift, or at least an expansion of the resources used in the engineering community, from solving problems by the application of knowledge from the chemical and physical sciences to solving problems by including application of the life sciences knowledge base. While the Paradigm of Science, as proposed by Thomas Kuhn in *The Structure of Scientific Revolutions* (University of Chicago Press, 1962), may shift as a result of an anomaly or crisis, the shift in the engineering paradigm envisioned by the editors of this book would seem to be facilitated by opening this relatively new box of tools for engineers to use. This revolution has been enabled by advances in all of science, which provide a more detailed understanding of structure and



Oil or Blister Beetle, *Meloe angusticollis*, Coventry, CT

Photo: Macroscopic Solutions, 2014 | Flickr cc



Oil or Blister Beetle (*Meloe angusticollis*) Coventry, CT | Photo: Macroscopic Solutions, 2014 | Flickr cc

function of biological entities. These advances include high resolution, low-damage electron imaging; surface topography by scanning probe microscopy; accurate, high-resolution proteomics; precise nucleotide sequencing; detailed computer modeling; and improved resolution in laboratory measurement techniques. There are other advances, some of which are presented in the various chapters in the book. Combined with the wealth of information about the biology of organisms, including all-important taxonomy as well as the objectives of specialized functions, we are now poised to exploit (intending an affirmative use of the word) materials and systems found in the natural world.

Content and organization

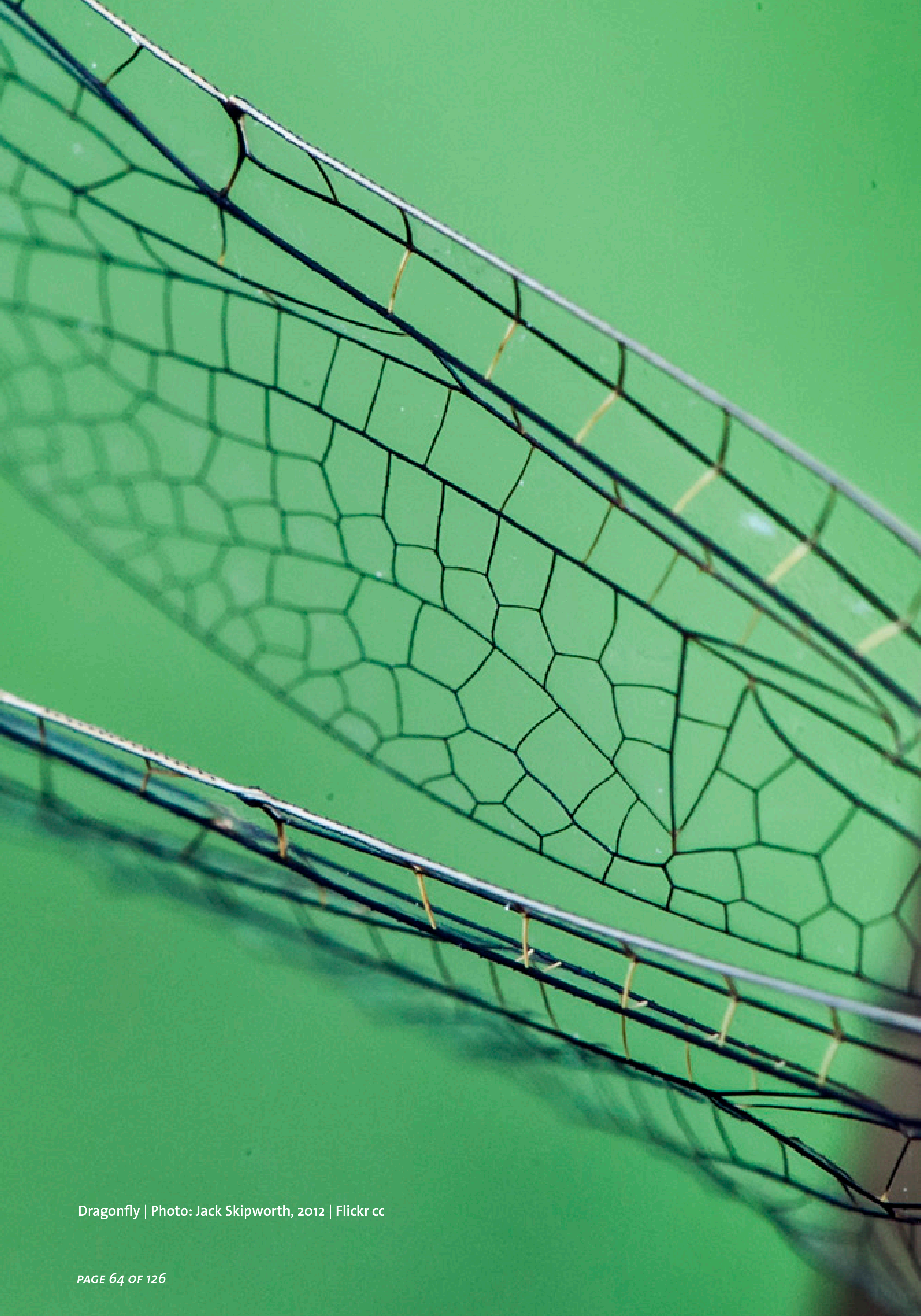
Engineered biomimicry is defined in the preface to the book as having three non-exclusive elements: bioinspiration (inspired by), biomimetic (mimics of), and bioreplication (replicates). The book is then loosely organized around these three intertwined concepts, such that the three elements are not separated as sections comprising chapters, but the elements are in fact also intertwined. For example, bioinspiration is the broad theme of six of the chapters while eight cover biomimetics, but of two contributions addressing sensors, one takes the approach of mimicking nature while the other is inspired by nature. These are chapter one and chapter two in the book. This style of organization is not at all distracting and in fact maintains the coherence of the content.

As noted, there are two chapters on sensor systems that have analogs in nature. One of them, by Cameron Wright and Steven Barrett (University of Wyoming), provides us with an introduction to optics relevant to biomimetic vision sensor development. Understandably, this is followed by discussion of the broad range of eye organs found in animals, from single lens eyes of humans to the compound eye of insects. Topics include motion sensing (analyzed as gradient, phase-based, and energy models) and response to light levels. Case studies are provided and the process required to develop a biomimetic vision sensor is presented. The sensor contribution by Thamira Hindo and Shantanu Chakrabartty (Michigan State University) covers the detection of the physical phenomena of sound vibration, fluid flows, and electric fields. Figure 2.1 characterizes the use of these phenomena by flies, crickets, and fish. The approach of the chapter is a presentation of the neurobiology of a sensor system, complete with figures and images to help explain the key concepts, including neuronal signal generation and propagation. As in the prior chapter, these authors report on case studies and on the development of a sensor for source localization inspired by the study of the natural systems.

Systems and materials from nature that have superior mechanical properties, including hardness and toughness, is the topic of the chapter entitled “Biomimetic Hard Materials.” While most synthetic materials sacrifice toughness to achieve hardness, there are examples in nature that run counter to this model. The contributions of component size and composition that result in the hard yet tough material of teeth and nacre are thoroughly analyzed. These analyses are then used in the design of some methods for fabricating biomimetic hard and tough materials.

House Fly, Coventry, CT

Photo: Macroscopic Solutions, 2014 | Flickr cc



Dragonfly | Photo: Jack Skipworth, 2012 | Flickr cc

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Reviewer:
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Robotics inspired by natural systems is the subject of the contribution of Ranjan Vepa (University of London). Robotics must include locomotion and as well as sensing, so there is a common thread running through the sensor contributions discussed above, the chapter on synthetic muscles (discussed below) and this chapter on robotics. The robotics chapter presents sensing and signal processing from the perspective of bioinspired robotics and some of the engineering requirements for designing manipulators that mimic natural systems. In addition to models of a forearm, controlled change in shape of an airfoil is discussed in the context of controlled morphing. The chapter concludes by presenting some bioinspired solutions to activation and control of human limb prostheses.

Further discussion of biopolymers for use as muscle-mimetic actuators is the subject of the chapter "Muscular Biopolymers." Following an introduction to muscle anatomy and physiology, including the sliding action energy source (ATP/ADP cycle) of muscle contraction, we find an in-depth review of the several types of synthetic muscles, beginning with electroactive polymers (EAP). The bases of the muscle-like action in EAP include electrostatic interaction, ionic mobility, and chemical potential changes occasioned by pH changes or redox reactions. Temperature can be used as the initiator in electrets and in liquid crystal phase changes, through the use of resistive heating. The chapter closes with a discussion of possible methods for fabrication of artificial muscles.

A chapter associated with bioinspiration and biomimesis is "Bioinspired and Biomimetic Microflyers." This chapter takes an approach to bioinspiration that differs from others in that grouping. Here we find several macroscopic mechanical models of small flying objects. The mechanisms used to achieve flight of the models are drawn from observations of large insects and small birds. The author presents ample engineering data on flight dynamics and aerodynamics of different wing profiles, and considers rotating wings and flapping wings along with some combinations. The author presents several model microflyers based on those two types of locomotion in concurrence with observations of natural microflyers.

Bioreplication is explored in contributions addressing sol-gel chemistry and various deposition techniques. Recognizing that language is paramount to understanding, Aditi Risbud and Michael Bartl (Lawrence Berkeley National Laboratory and University of Utah) provide an important discussion of some terms used in bioreplication, and then focus on the sol-gel chemistry route of replicating photonic crystals, which are present in butterfly wings (the book contains a chapter on structural colors) and weevils. Bioreplication by vapor deposition and atomic layer deposition are discussed and applications considered in two chapters. Among the other topics in the book are discussions of self-organization and tissue engineering based on biomimicry. The last chapter is on bioinspired computing.

Engineered Biomimicry contains a plethora of topics critical to an evolution of the engineering paradigm. Its editors have created a coherent style throughout the book that is easily read despite the diverse range of authors. This coherence makes it possible for the reader to form intellectual connections even across several chapters with distinct content. Each individual chapter has been thoroughly and carefully referenced, giving assurance that the subject matter is of general relevance. This book is a productive investment of time for anyone concerned with solving problems with the help of nature. ×

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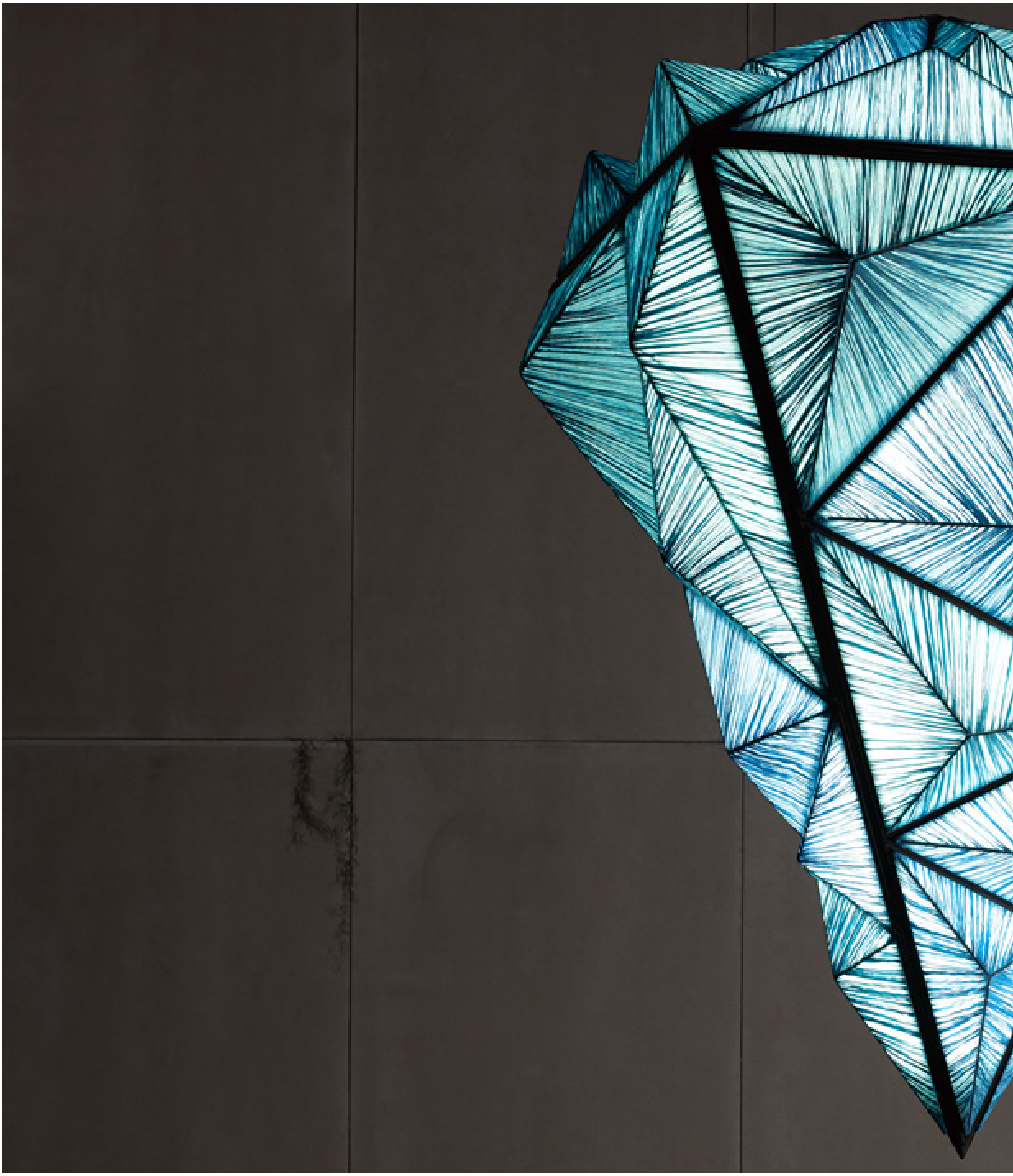
Hoverfly

Photo: Jack Skipworth, 2012 | Flickr cc



Two Blues

Image courtesy of Albi Serfaty

Product design
Aqua Creations
Lighting and Furniture Atelier

Albi Serfaty is a photographer, designer and the founder of Aqua Creations

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

It's hard to define the boundaries of what is nature and therefore what is or isn't natural: for most of us nature is what you experience with your Timberland boots on, anything that was neither made nor altered by man. Some questions come up here; for example – are our man-made or rather man-planted forests natural? Are the plants I keep at home a part of nature?

And what about my thoughts, are they "natural"? If nature is such an all-embracing thing I would probably say that the untouched, the pure, "raw" nature is what interests me (my photography of clouds as seen from airplanes, to name one example). That's the kind of raw nature that evokes my emotions and impels me to take those photographs. In my designs I try to transfer those emotions to the viewer-user, so to speak, hoping that the piece I have made will get a life of its own.

Albi Serfaty

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

I am attracted to things that are beautiful to perfection, no matter if they are man made or natural, no matter if they are abstract or what you'd call real: clouds, mountains, people, music, art, literature, love, ideas, thoughts... I look and wait until I see something. Then I stay there and try to memorize that moment as the source for my work. Sometimes I'll come back to the same place with a camera and sometimes I'll sketch or write something that will remind me of that moment. There is a story about Albert Camus in his forties, returning to the beloved city he was born in after an absence of twenty years. He wants to see if he can re-feel the same emotions after the passage of so many years and to his absolute surprise he can.

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

At the moment I'm working on two projects. One is called "Live & Let Dye": I print photographs I have taken with Epson large format printer on Tusser silk, then I and the people I work with crush the silk in our traditional way and apply it on a lampshade. For me, it's a big joy because it combines two personal passions – photography and design into one work. The second project that I'm working on is called "Memento Mori". This is a series of tables made from stone and

Simon Says

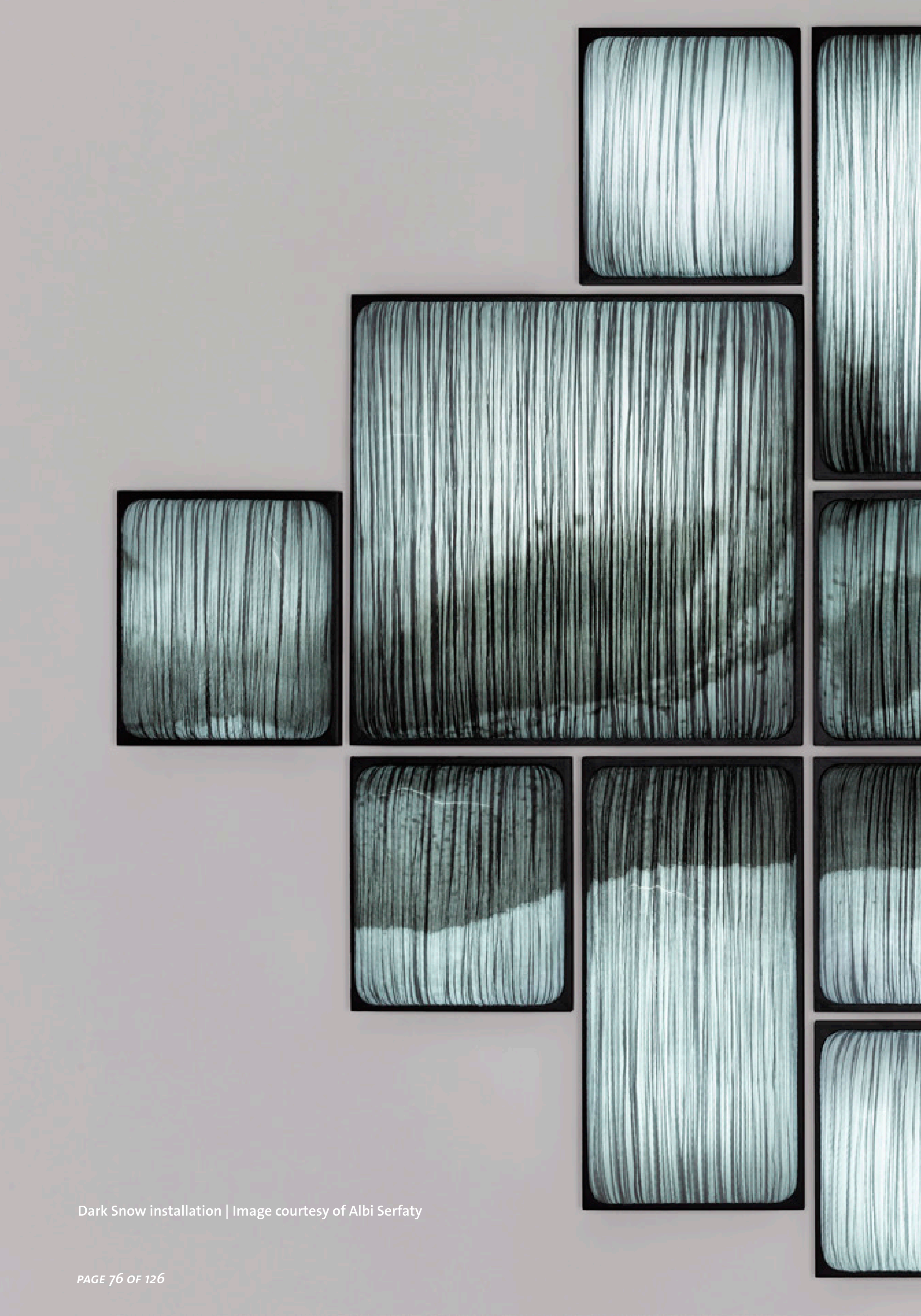
Image courtesy of Albi Serfaty

wood. I use raw gray stone from a quarry owned by a friend of mine in north Galilee. One of the many sides of the stone remains raw the rest is polished, then I scan the raw side of the stone and create a 3D file. In Aqua's Creations wood engraving machine we apply the previously scanned surface into the wooden side, which fits perfectly into the "negative" side of the stone. The result is a beautiful match between raw stone and digitally mechanically curved Mahogany wood. It's impossible to create two tables that are alike, each one is different – just as no two stones are ever alike in nature. ×

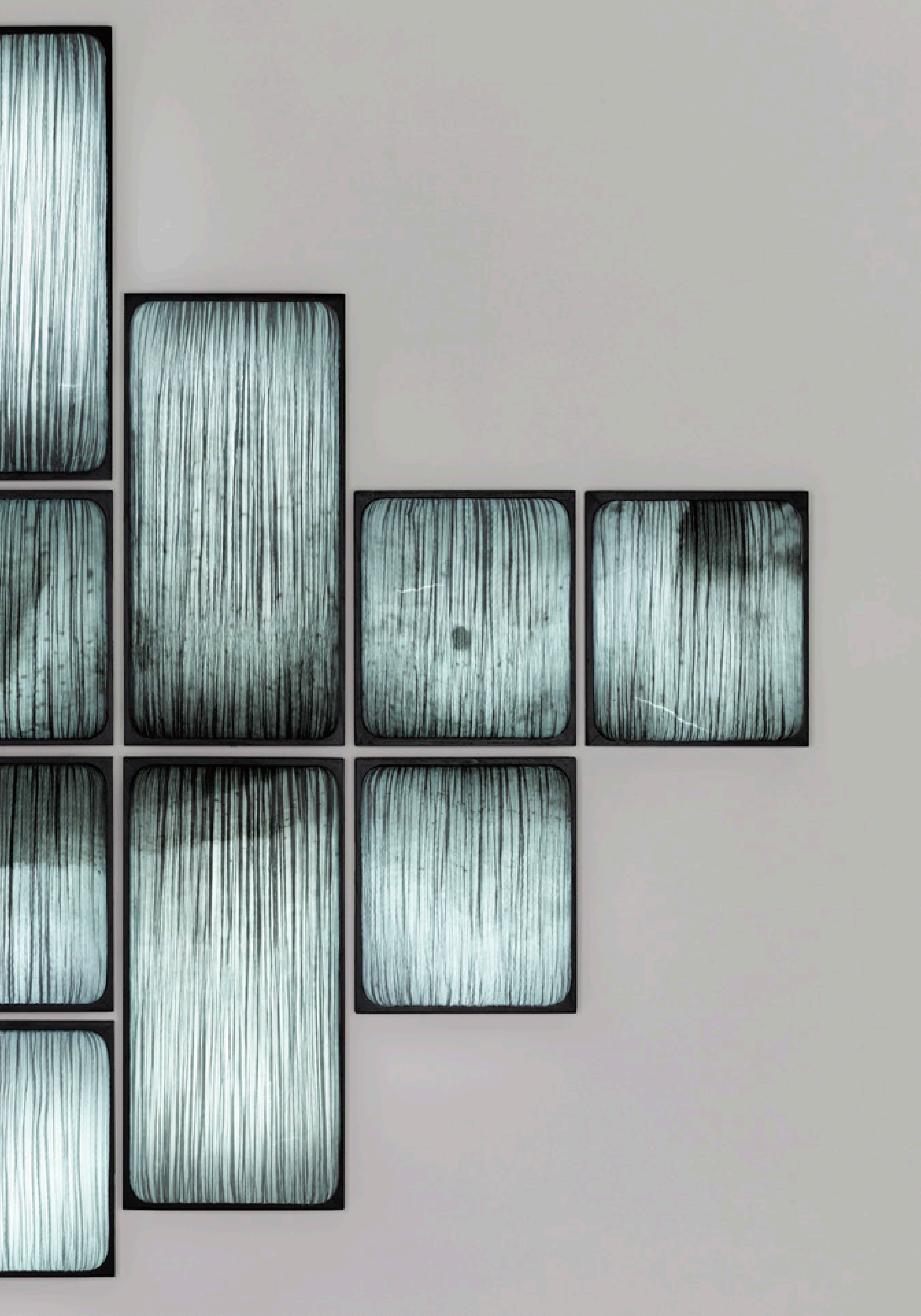
Simon Says

Image courtesy of Albi Serfaty

Dark Snow | Image courtesy of Albi Serfaty



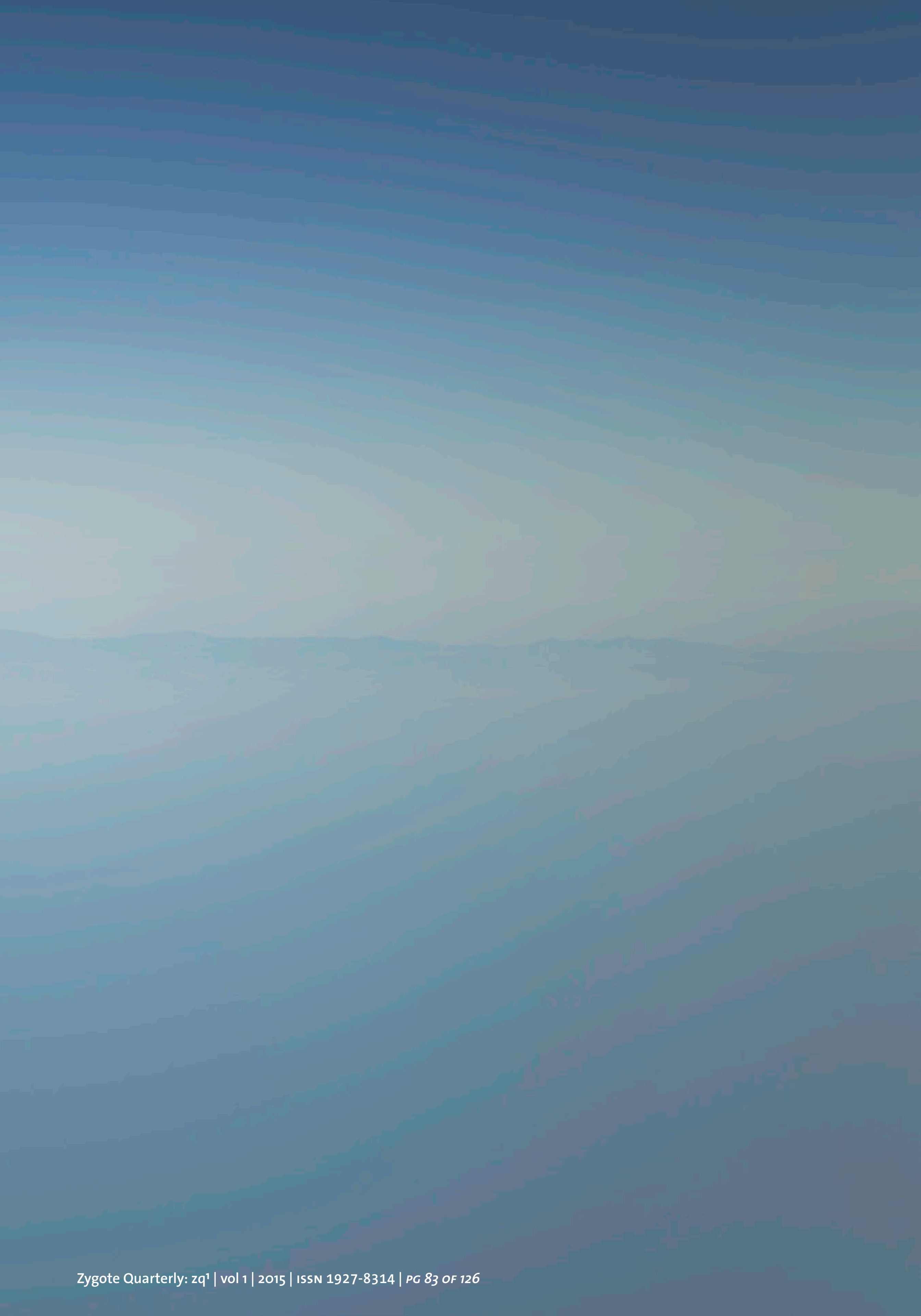
Dark Snow installation | Image courtesy of Albi Serfaty



tlvmilan | Image courtesy of Albi Serfaty

Two Blues | Image courtesy of Albi Serfaty

tlvmxp | Image courtesy of Albi Serfaty



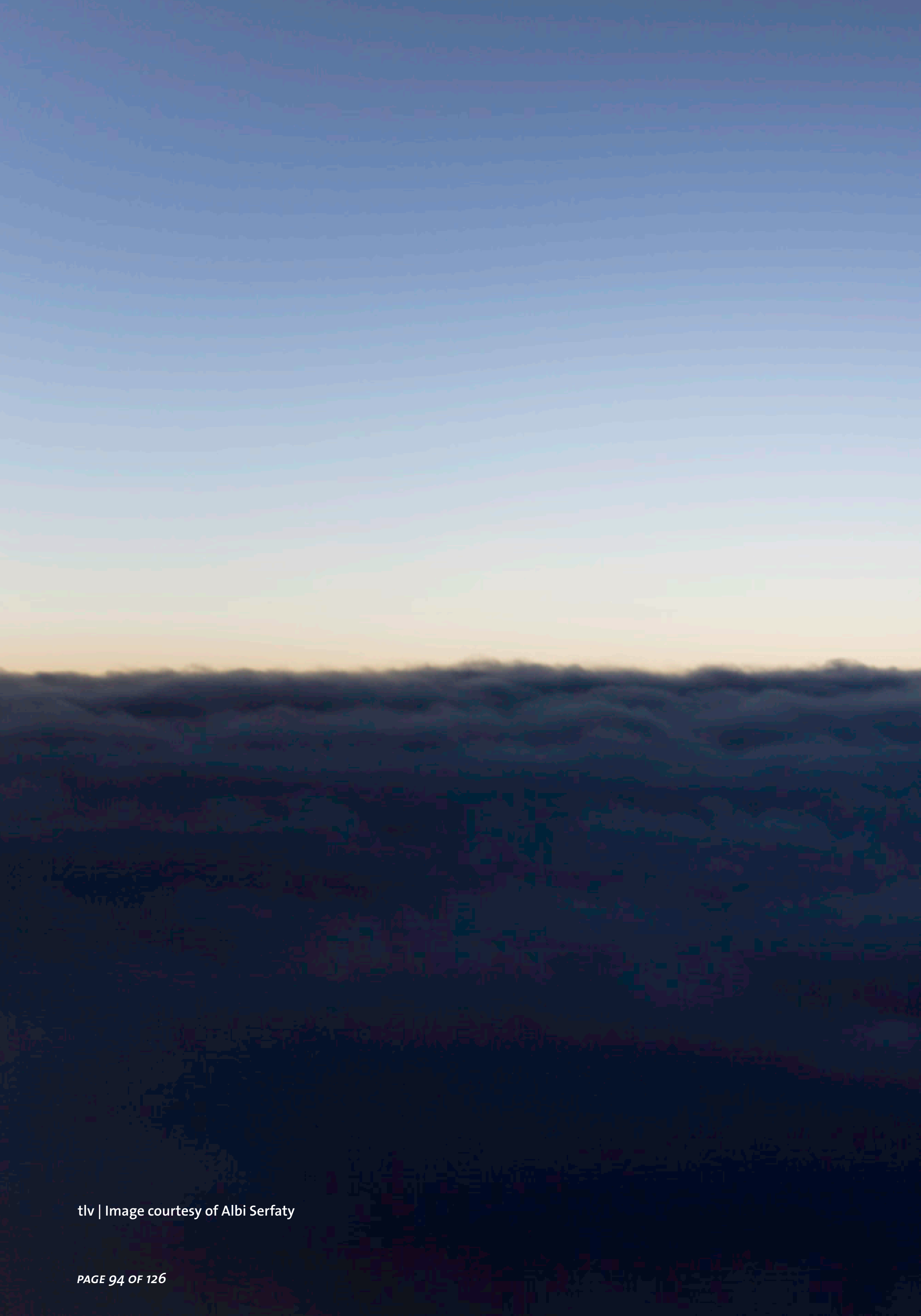
zooid Wall | Image courtesy of Albi Serfaty

tlvlondonedinburg | Image courtesy of Albi Serfaty

zooid Wall | Image courtesy of Albi Serfaty

A-50 | Image courtesy of Albi Serfaty

Yellow | Image courtesy of Albi Serfaty



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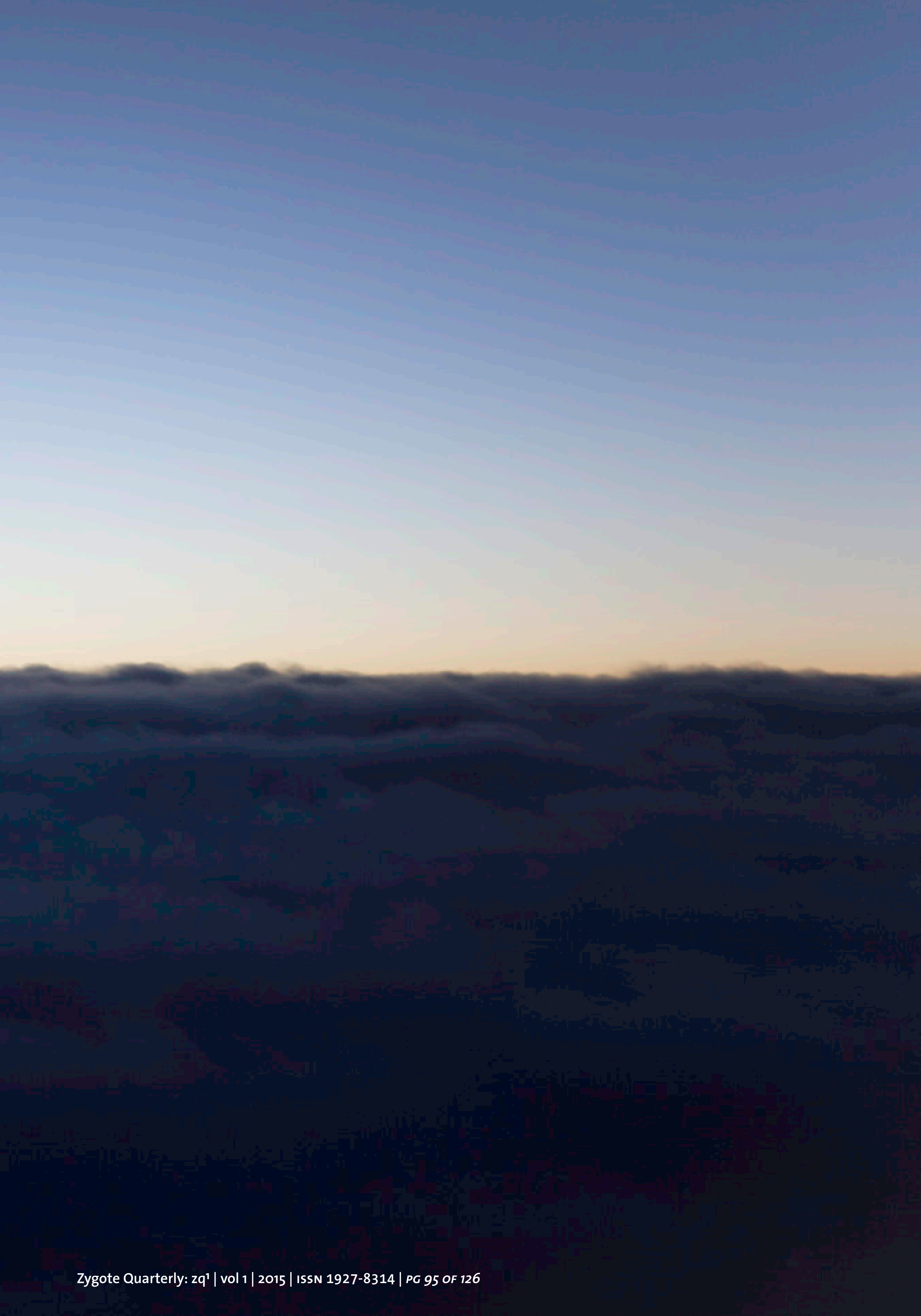


Morel

Photo: ressaure, 2011 | Flickr cc

People

Interviews with

Blaine Brownell, Marc Swackhamer, and Michael Ellison

VarVac Wall 2

Photo courtesy of Marc Swackhamer

People
Interview with
Blaine Brownell and Marc Swackhamer

Blaine Brownell is an architect and former Fulbright scholar with a focus on emergent materials and applications. He is a principal of the design and research practice Transstudio and an associate professor and the director of graduate studies at the University of Minnesota's School of Architecture. Brownell authored the *Transmaterial* series as well as the books *Matter in the Floating World* and *Material Strategies* with Princeton Architectural Press, and writes the Mind & Matter column for *Architect* magazine. He has been published in over forty design, business, and science journals, and has lectured widely in the Americas, Europe, and Asia. Blaine's upcoming book with co-author Marc Swackhamer is entitled *Hypernatural: Architecture's New Relationship with Nature*, to be published in March 2015.

Marc Swackhamer received his B. Arch from the University of Cincinnati in 1995 and his M. Arch from Rice University in 1997. His research explores the relationship between performance and ornament as specifically developed through digital production and fabrication techniques. He maintains a partnership, under the name HouMinn Practice with Professor Blair Satterfield from the University of British Columbia. HouMinn's recent work reconsiders fabrication tools themselves to challenge in-place techniques of construction and material production. HouMinn won a 2014 Architect magazine R+D Award and a 2014 Core77 Design Award for this work. In addition to core design studios and lecture courses, Professor Swackhamer teaches on the topic of "hypernatural" design. Student work from this effort won a 2007 AIA COTE (Committee on the Environment) national education award and in 2013 a student team from a graduate studio was a finalist in the "Biomimicry Student Design Challenge," sponsored by the Biomimicry 3.8 Institute. He is currently co-authoring a book with Professor Blaine Brownell as mentioned. Professor Swackhamer is an Associate Professor and the current Head of the School of Architecture.

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

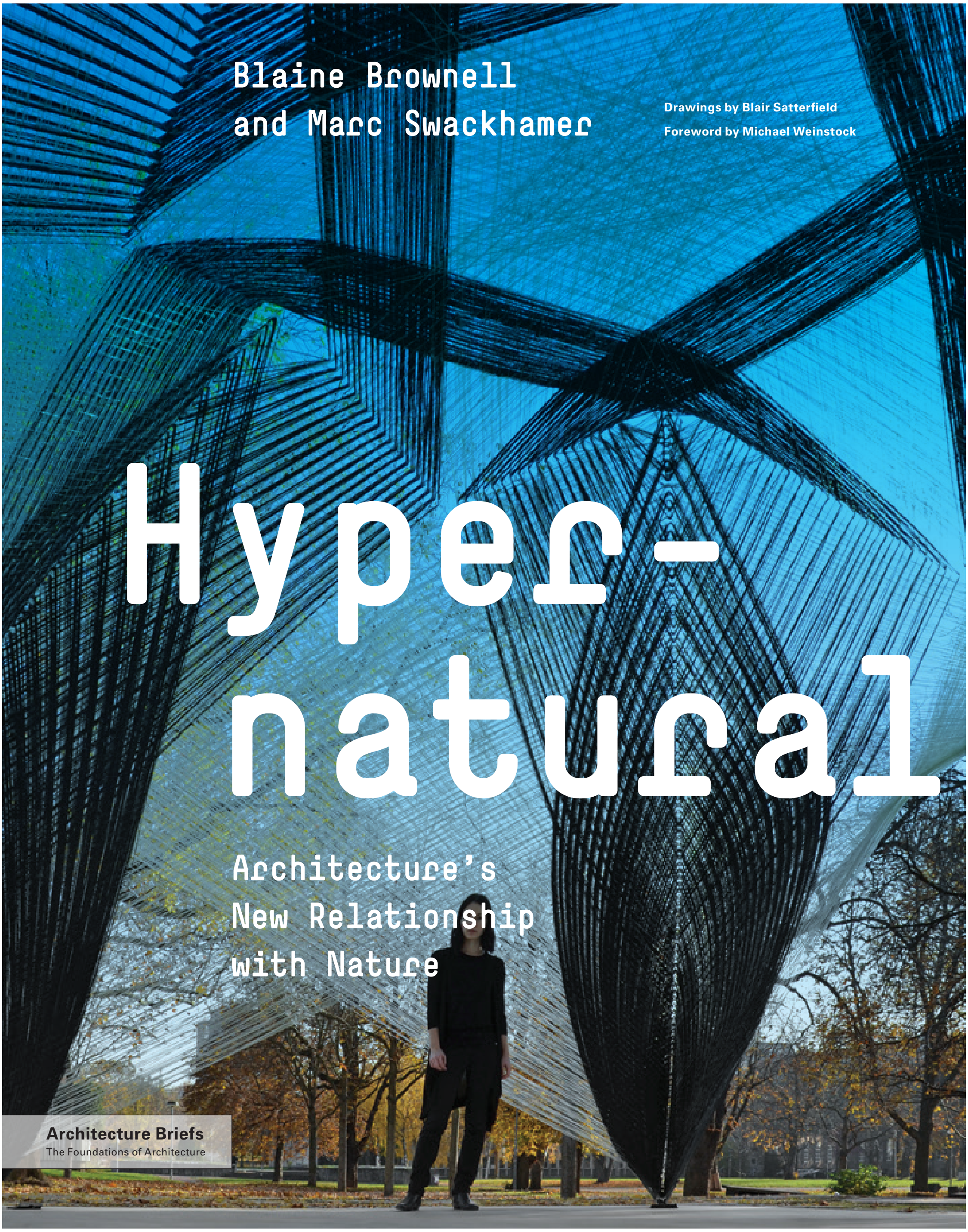
Blaine: The biomimicry/biodesign movement has gained a tremendous amount of momentum in the last decade. Major advances are now underway in a broad spectrum of the arts and sciences that are based directly on the workings of natural organisms, processes, and phenomena. The outcomes of this movement could be nothing short of revolutionary.

Marc: In spite of the potential, the current biomimicry/bio-inspired design profession, in my view, is caught in a state of uncertainty at the moment. I think it hasn't caught hold the way it can, remaining at the periphery of most design disciplines. A new language, encompassing a broader array of approaches to working synthetically with natural systems is now needed.

What do you see as the biggest challenges?

Blaine: Nature is obviously profoundly complex, and part of the fun of biomimicry involves the search for understanding. Specific natural functions like self-cleaning or repositionable adhesion have been studied and emulated; however, understanding how larger systems and interdependencies work is a much greater challenge.

Marc: The biggest challenge, from my perspective, is moving the field beyond its experimental phase. For the lessons we've gleaned from natural systems to have a more profound impact on


Blaine Brownell
and Marc Swackhamer
Drawings by Blair Satterfield
Foreword by Michael Weinstock
Hyper-
natural
Architecture's
New Relationship
with Nature
Architecture Briefs
The Foundations of Architecture

VarVac Wall 1 | Photo courtesy of Marc Swackhamer

some of the serious challenges our planet is facing, we need progress to be made in commercial practice, not just in academia or in the research lab.

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

Marc: Systemic, large scale thinking. Countless devices, technologies, materials, and chemical advances have grown out of bio-inspired design processes. But, in my mind, where nature has the largest potential to influence our built environments is in the realm of landscape and city design. If we can begin to think of our cities as living ecosystems, with their own metabolisms, where every component is dependent upon and connected to the other, we stand a better chance of producing cities that are adaptable and resilient.

Blaine: We should continue investigating the intersections between biomimicry and sustainability. Not all natural processes meet our definition of sustaining the built environment (e.g., viral epidemics), and not all sustainable design approaches are compatible with natural systems (e.g., petroleum-based insulation). However, methods that fit both definitions represent some of the most promising directions for design.

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

Blaine: My interest in biomimicry/bio-inspired design, as well as the natural sciences in general, developed out of a wonder with the profound beauty and mystery of the natural world. I realized that the most innovative material trends I was researching were closely related to these movements.

Marc: About eight years ago, Janine Benyus lectured at our School. Following that lecture, the Director of our Center for Sustainable Building Research, John Carmody and our Department Head, Renee Cheng, invited me to develop a studio based on the principles of biomimicry. While my views on the topic have evolved over time, I still think back fondly to that first graduate design studio. Janine and her partner in the Biomimicry Guild, Dayna Baumeister, graciously helped me develop my first syllabus. Since then, I have taught the class, in one version or another, about 6 or 7 times. Many of the principles established in that first course are still central to the way I approach the class today. I am forever indebted to John, Renee, Janine, and Dayna for pressing me to pursue this incredibly interesting topic.

What is your best definition of what we do?

Marc: We research, test, and design at the confluence of natural systems and technology.

Blaine: We study the natural world with a deep intensity, humility, and an open mind - and attempt to synthesize our discoveries within creative practice.

PET Wall

Photo courtesy of Blaine Brownell

By what criteria should we judge the work?

Blaine: We should judge the work by how well it adopts natural principles, how well it performs, and how well it relates holistically to deep ecologies.

Marc: Clarity, beauty, efficiency, resiliency, adaptability, and economy.

What are you working on right now?

Marc and Blaine: We are currently teaching a spring 2015 graduate architecture studio and have plans for a fall 2015 exhibition at the University of Minnesota's Goldstein Museum of Design, related to the March 2015 publication of our book *Hypernatural*.

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

Blaine: The ICD/ITKE Research Pavilion 2013-14, the design for which is based on research into the internal structure and performance of beetle shells.

Marc: I know Neri Oxman's Silk Pavilion has been widely published and anyone reading this is well aware of it. But, I think its notoriety is well-earned. It has opened bio-inspired discourse in new, profound ways. No longer are we talking exclusively about mimicking biology. We are now discussing partnering with natural systems themselves in the design and fabrication of our work. It raises important questions about authorship, control, and the role of the designer.

What is your favorite biomimetic work of all time?

Blaine: BacillaFilla, a concrete patch made of living microbes (technically, this is a work of bio-utilization, not biomimicry).

Marc: My example is one that has been around for thousands of years, but still amazes me, and I only recently learned of it through writing *Hypernatural*. These are the poetically elegant walk bridges grown from the roots of rubber plants in India called the Meghalaya Living Bridges. These amazing structures are produced by first extending hollowed-out betel nut tree trunks over river beds as guidance systems. The thin roots of rubber trees are coaxed through these armatures and subsequently take root on the opposite sides of the crevasses they are bridging. As the rubber trees mature, their roots thicken and intertwine to form robust structural trusses. While these bridges can take up to 15 years to grow, they can last for hundreds of years and can span up to 100 feet.

What is the last book you enjoyed?

Marc: I've been reading a lot of fiction lately. I really enjoyed *The Circle* by Dave Eggers. It's about the inevitable erosion of privacy that grows out of social media's continuous push for personal transparency. The technology predicted by the book has intriguing ties to biology, especially the differences between mono- and poly-cultural ecosystems and swarm theory.

Blaine: Junya Ishigami, *Another Scale of Architecture*.

Who do you admire? Why...

Marc: I admire my co-author on this book, Blaine Brownell. He is a tirelessly productive collaborator, a refreshingly big-picture thinker, and has encouraged me to consider the field of bio-inspired design in completely new and, I think, discourse-advancing ways.

Blaine: I certainly admire Marc as well. I couldn't imagine a better collaborator! I also admire Blair Satterfield, whose *Hypernatural* diagrams are some of the best drawings I have seen in the arts and sciences, as well as Michael Weinstock, whose insightful foreword for our book exemplifies his prescience and fundamental importance as a scholar and educator in this field.

What's your favorite motto or quotation?

Blaine: "The best way to predict your future is to create it." - Abraham Lincoln

Marc: "Experience is simply the name we give our mistakes." - Oscar Wilde

What is your idea of perfect happiness?

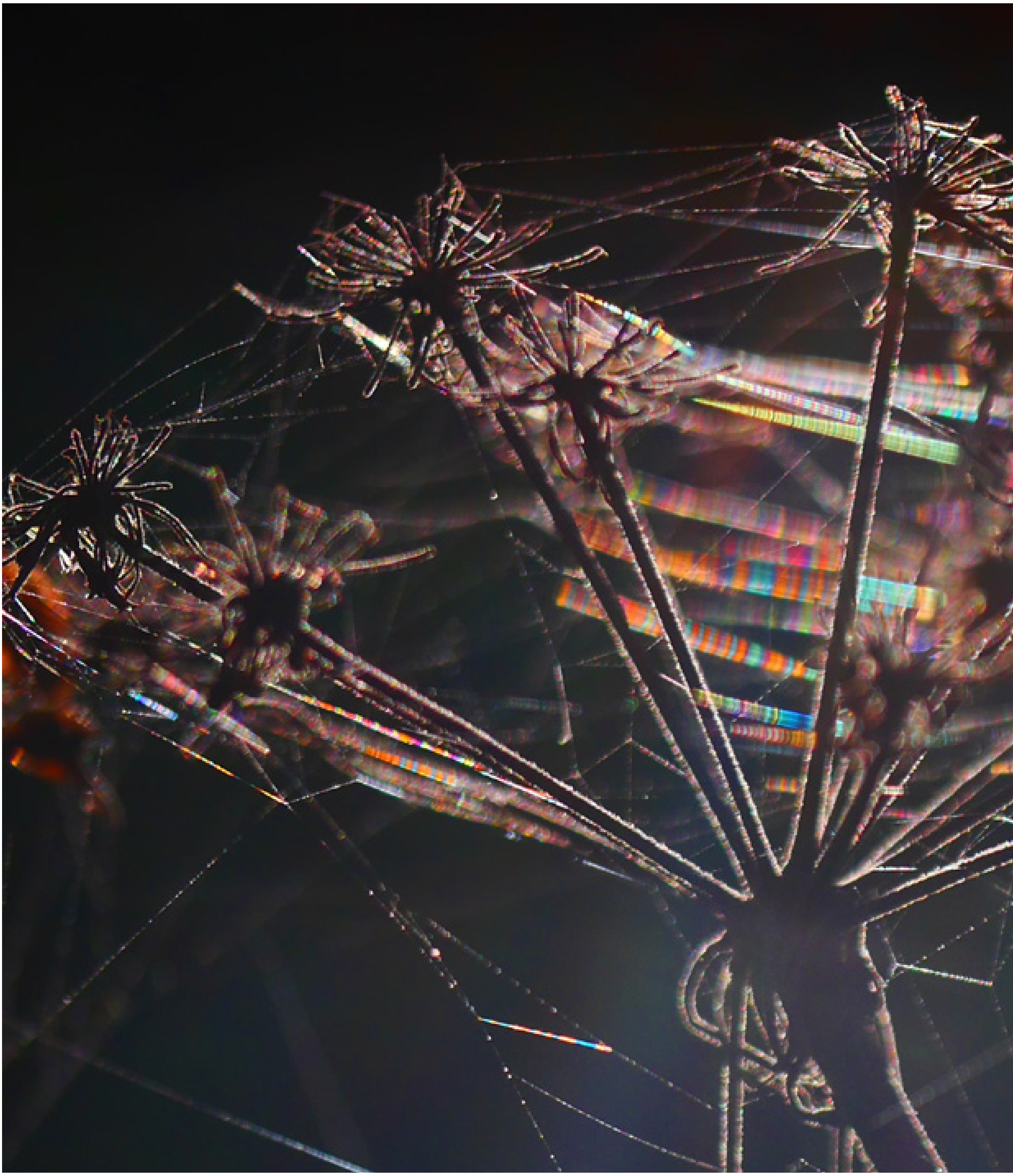
Marc: Rolling up my sleeves and tackling a difficult design problem through making and collaborating with a small, but diverse, group of interesting people.

Blaine: My idea of perfect happiness is studying the world by traveling to thought-provoking destinations with family and friends.

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

Blaine: If not an architect/educator, I would be an itinerant photographer of architecture, landscapes, and cities.

Marc: Probably a craftsman, wood worker, or fabricator. I immensely enjoy working with my hands and always search for ways to do more of it. I think working with one's hands exercises a different part of one's brain than writing or talking. ×



Carousel

Photo: fOtOmoth, 2014 | Flickr cc

People
Interview with
Michael Ellison

Michael S. Ellison is an emeritus professor in the Department of Materials Science and Engineering at Clemson University, in Clemson, South Carolina, USA. He received undergraduate and graduate degrees in Physics and a Ph.D. in Polymer Fiber Physics (1982) from the Davis campus of the University of California. After remaining at UC Davis as a research scientist, he joined the Clemson University faculty in 1984. He advanced to full professor in 1998 and served as Interim School Director from August 2003 until January 2005. His research embraces both synthetic and natural polymer fibers, including spider silk as a biological material for inspiration in new fiber development. With colleagues in the School of Architecture at Clemson, he is developing unique architectural materials. He teaches courses in physical properties of fibers and in melt extrusion production of synthetic fibers. When not holding forth as a professor, he plays traditional Irish and American fiddle music.

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

Currently, we are wandering the landscape, exploring and being excited by what we find. An important aspect of this kind of research is to define pathways along our own journey and build bridges to the disciplines of other sojourners. In this way we can find our way back to where we were when we first started searching; the field of biomimetics is so entrancing that it is easy to lose our bearings. The biomimetics community has made several discoveries and established a robust foundation on which to build further advances.

What do you see as the biggest challenges?

The one surmountable challenge is to continue building a common language between the physical and chemical sciences and the biological sciences. Not just in terms of language, but also sharing amongst the practitioners the differing epistemology of these basic sciences. In my experiences when setting up the biomimetics group at Clemson, some of the most basic concepts in materials science took on different meanings to the biologists in the group. For example, “crystallization” in materials science means the systematic aggregation of elementary units into a point lattice. I found that to the biologists it could also mean the formation of protein dimers and trimers, a process I would refer to as polymerization (or the formation of

The fingers belong to Mrs. Janci (Ketner) Despain. She was a graduate student of mine when the spider silk research program was just getting underway. Along with Dr. Jackie Palmer, Janci was instrumental in setting up the tent for housing the spiders. The spider in the photograph is a female Golden Orb Weaver (*nephila clavipes*), one of the specimens from which we obtained the silk. Photo courtesy of Michael Ellison

Golden silk orb weaver spider

Photo: Clicksy, 2010 | Flickr cc

oligomers). Of course, the language used by the molecular biologists in describing genetics often sounded like something foreign to me. The many worlds that intersect in biomimetics often use the same language to mean subtly different things.

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

There are the materials, of course, that nature uses to maintain the infrastructure of the natural world. This arena is rife with possibility, not just at the molecular or supermolecular level, but at all scales. PBS in the US aired an excellent BBC presentation in September 2014, highlighting recent research into the relationship between beavers, with their remarkable hydrology comprehension, and re-establishing of wetlands. Equally important as the actual materials is the methods of production of these materials. The methods are, in present day parlance, sustainable. We would do well to concoct our own version of "sustainable" that will work for our needs.

What is your best definition of what we do?

Humans possess highly successful complex pattern recognition systems. What we do in biomimicry is to apply those pattern recognition systems to assess patterns in the parallels between our needs or wants and what we find in nature. For example, in the formation of fibers from melt spinning of polymers that undergo a liquid crystal (LC) phase transition, the conditions of that transition are critical. There is a LC phase transition in the spider duct during silk formation. Understanding the behaviors of the LC phase in both systems is paramount to improving the standard fiber formation process and creating a biomimetic process and product. Then we set about synthesizing ways to assimilate what we had learned.

By what criteria should we judge the work?

First, elegant simplicity and function. Then do the most good with the least harm possible. I use the term "least harm" because thermodynamics teaches that everything has an energy and entropy "cost." Thus, as designers, we must consider the impact of what we are doing on other residents of our planet.

What projects exemplify your approach?

I am essentially a materials physicist, so my approach has been to study the materials and their production methods. The program we started at Clemson University was initially focused on the molecular biology of spider dragline silk, the production methods and the associated material properties. We initially followed the pathway of many of the other people in this field, constructing the known nucleic acid sequences in the genetic material that produces the silk protein, producing clones in bacteria and collecting and analyzing the product. Several of our students took this training and went on to further the efforts of synthetic silk production. My lab was also studying the actual amino acid arrangement on the surface of wool fibers using methods based

Waiting

Photo: hyper7pro, 2010 | Flickr cc

Golden silk orb-weaver | Photo: jack 246, 2012 | Flickr cc

on functionalized-tip atomic force microscopy and surface-functionalized nanoparticles viewed by scanning electron microscopy. At the present time, we are having some success with using that approach to determine the amino acid arrangement on spider silk surfaces. The ultimate aim of this work is to enhance our understanding of the relationships between the protein sequence as one measure of the material's structure and the resultant properties.

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

I was listening to a talk on the issues surrounding the development of artificial arteries and the rejection problems. I figured that using recombinant DNA technologies to make a fiber based on the biology of a person would prevent the individual's body rejecting it. I was so very naïve then! As my molecular biologist friend, Bert Abbott, understatedly put it, "that would be really hard" so we tried something a trifle more simple: we began looking at the silks of spiders and their genetic underpinnings. Since my expertise was (and is) in the material science of fibers, I became very excited by the possibility of studying the natural silk processes and materials for inspiration, and ultimately develop a biomimetic fiber.

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

One was the BBC/PBS special on beavers I mentioned above. We could learn from their skill in hydrology, and that what appears to be a pest is not always the case. I really enjoyed the keynote talk on hagfish slime by Douglas Fudge at the Fall 2014 Fiber Society meeting at Drexel University. That is another material we should study.

What is your favorite biomimetic work of all time?

I do not have a favorite piece. I have always enjoyed the body of work by Fritz Volrath and that of Randy Lewis, including the subsequent work of their students, and my chats with Julian Vincent are inevitably richly rewarding and entertaining.

What is the last book you enjoyed?

I am still enjoying an English translation of *The Old Gringo* by Carlos Fuentes (Farrar, Straus and Giroux, NY, 1985).

Whom do you admire? Why...

Richard Feynman. His broad intellect and communication skills are renowned. J. S. Bach, whose music presages much of what we claim as modern improvisation in music. Picasso, whose art teaches us about space and time.

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

I believe that the path I followed, that of an academic, was the one for which I am most suited. I would not choose another.

Golden Silk Orb Weaver Sack

Photo: Clicksy, 2010 | Flickr cc

What is your idea of perfect happiness?

Positive interactions with students, being creative in research and then making music with my friends is a good example of a happy day. But perfect happiness is an elusive goal. Being a contributing member of a diverse and supportive community is important: diverse ecologies are stable and "no man is an island."

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

A full-time fiddler. Now that I am retired, I am working toward that goal, while being a partner in a "natural" although not "organic" farm producing grass-fed beef and pork, and pasture chickens. ×

Golden silk orb weaver (*Nephila clavipes*)

Photo: kellyv2012 | Flickr cc

Nepenthes ampullaria Pitcher Plants

Photo: AnSchieber, 2012.jpg | Flickr cc

Infographic

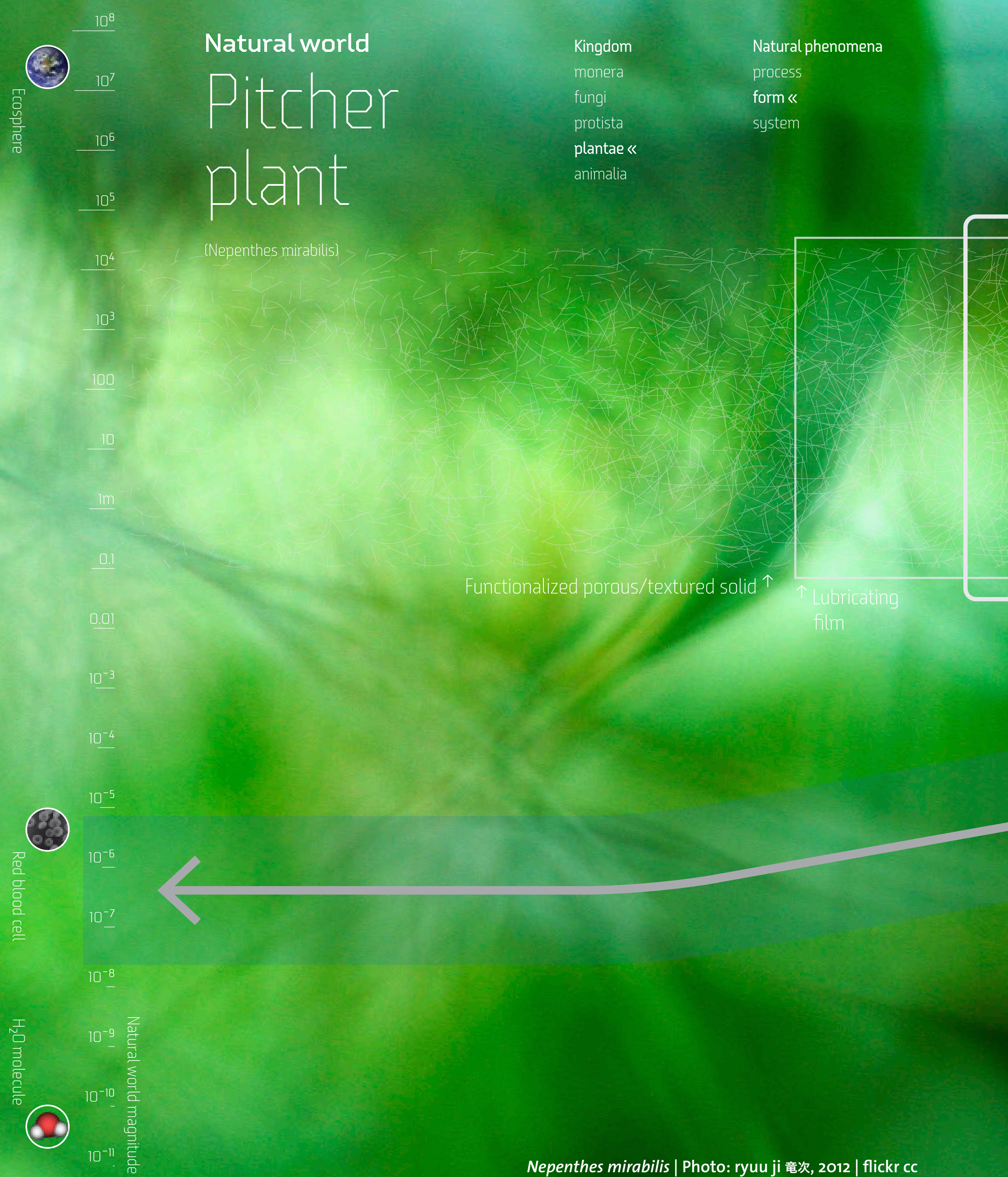
Return of the Swamp Thing

Raul de Villafranca
and Colin McDonald

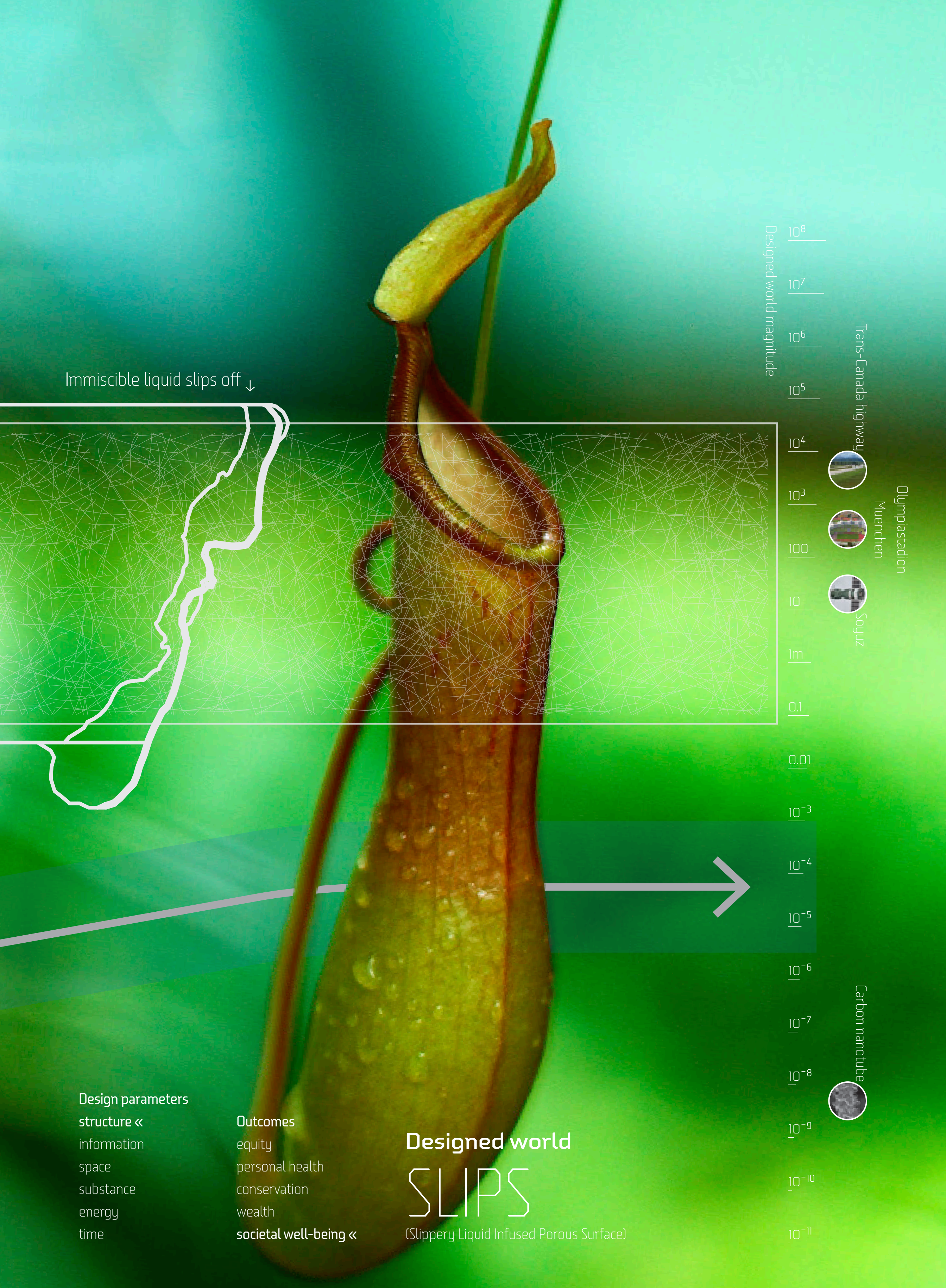
vol 1 | 2015

Infographic
Return of the Swamp Thing

Authors:
Raul de Villafranca and Colin McDonald



Nepenthes mirabilis | Photo: ryuu ji 竜次, 2012 | flickr cc


Immiscible liquid slips off ↓
Designed world magnitude
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Soyuz
Carbon nanotube
Design parameters
structure «
information
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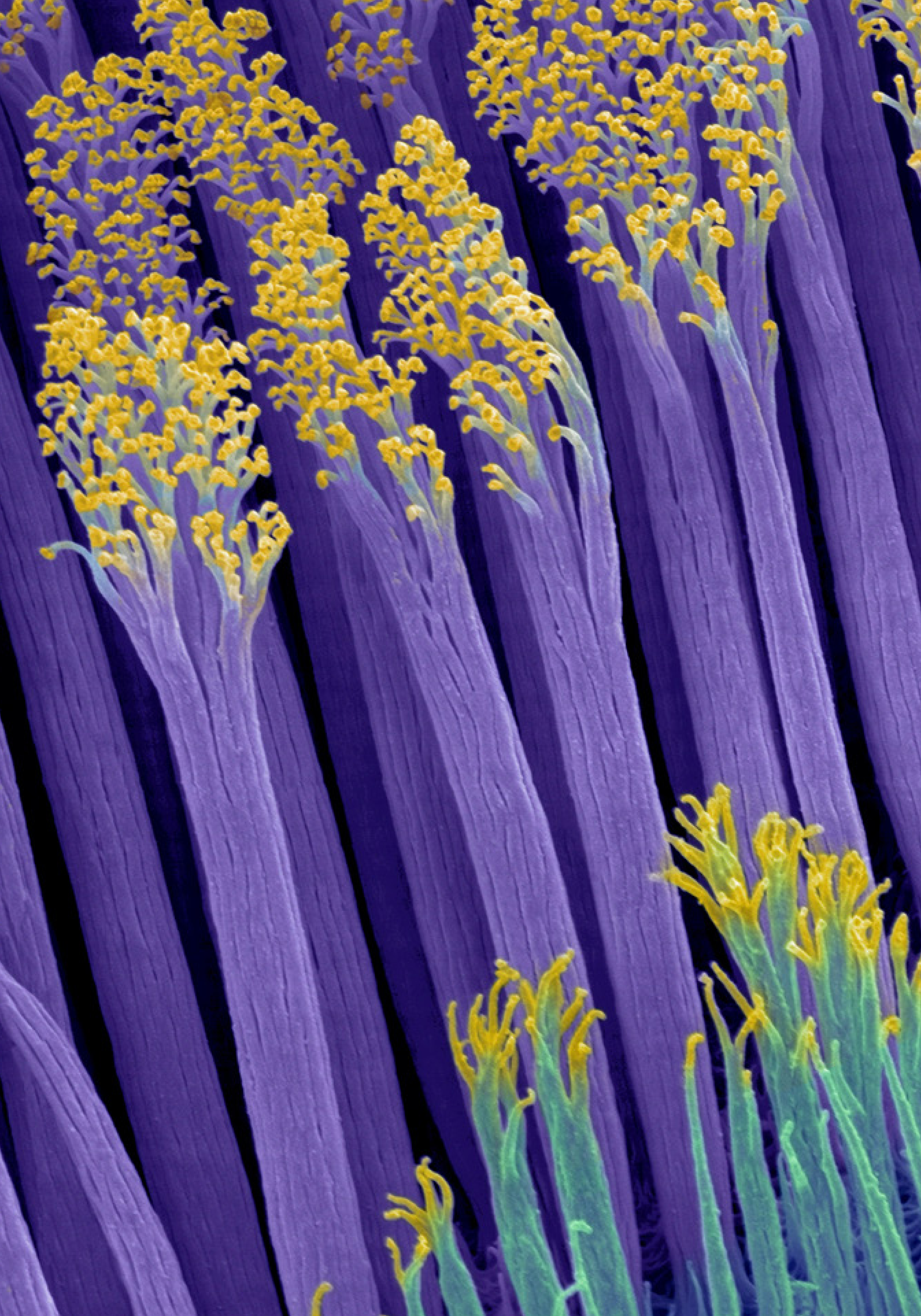
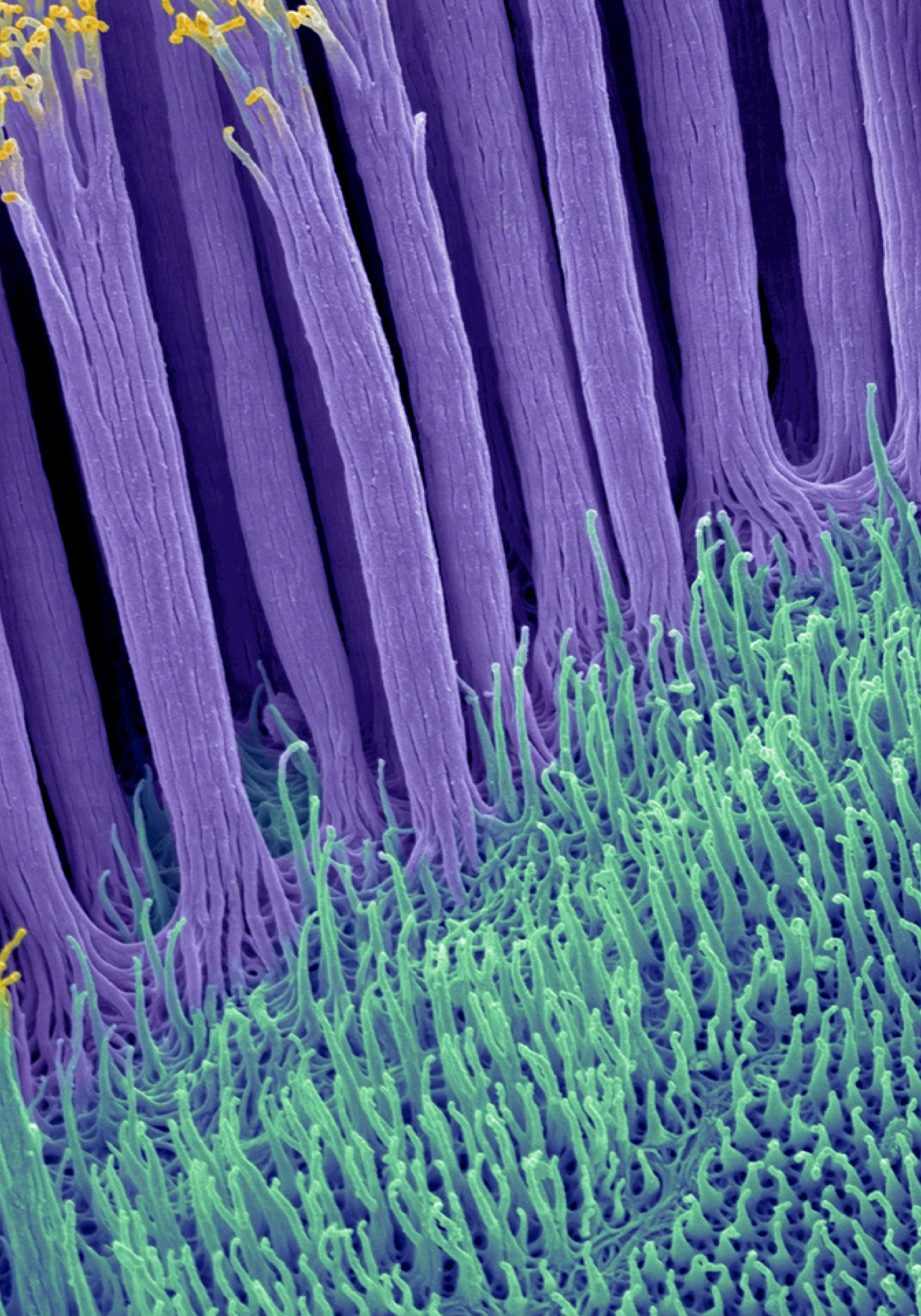
energy
time
Outcomes
equity
personal health
conservation
wealth
societal well-being «
Designed world
SLIPS
(Slippery Liquid Infused Porous Surface)





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