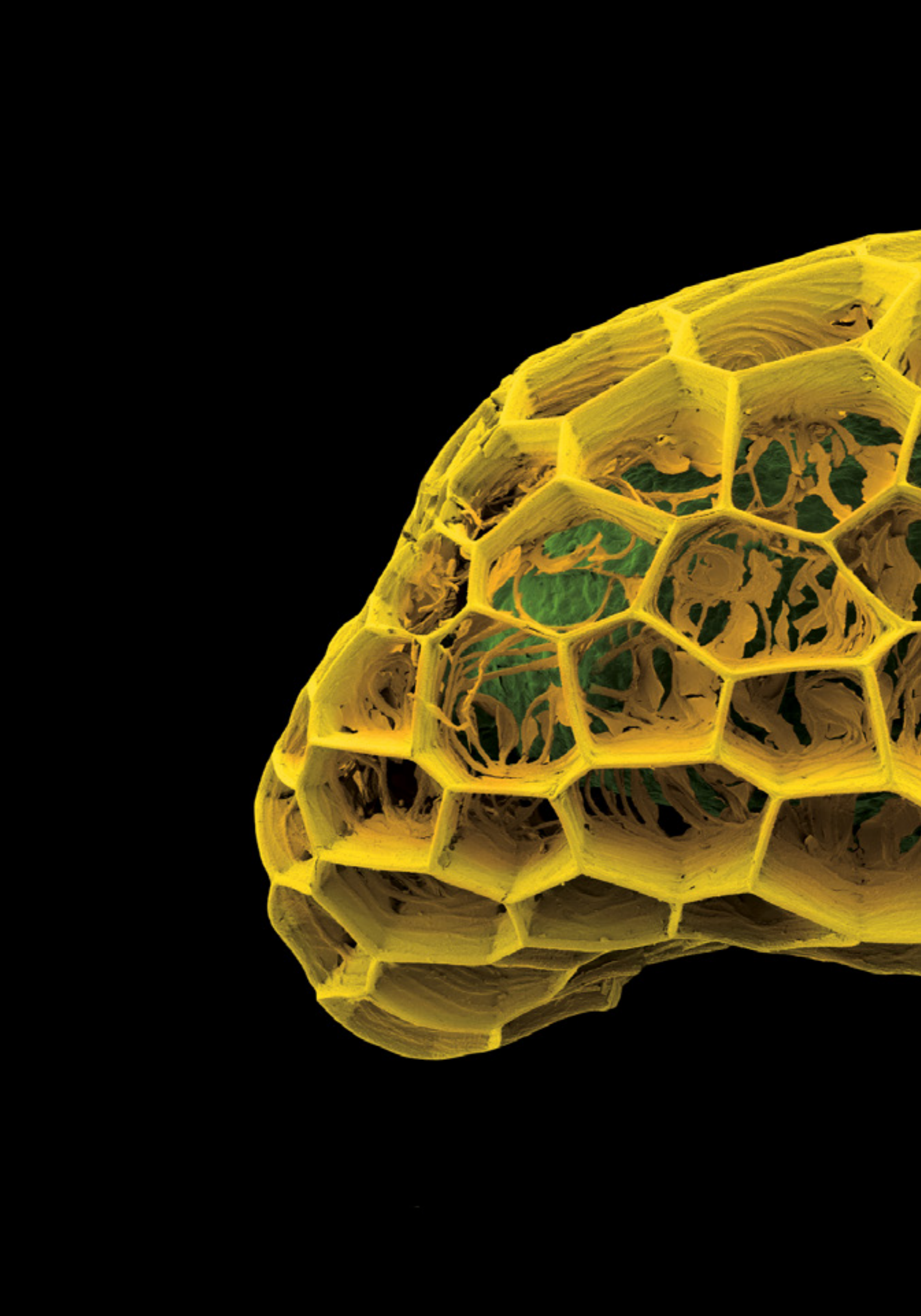
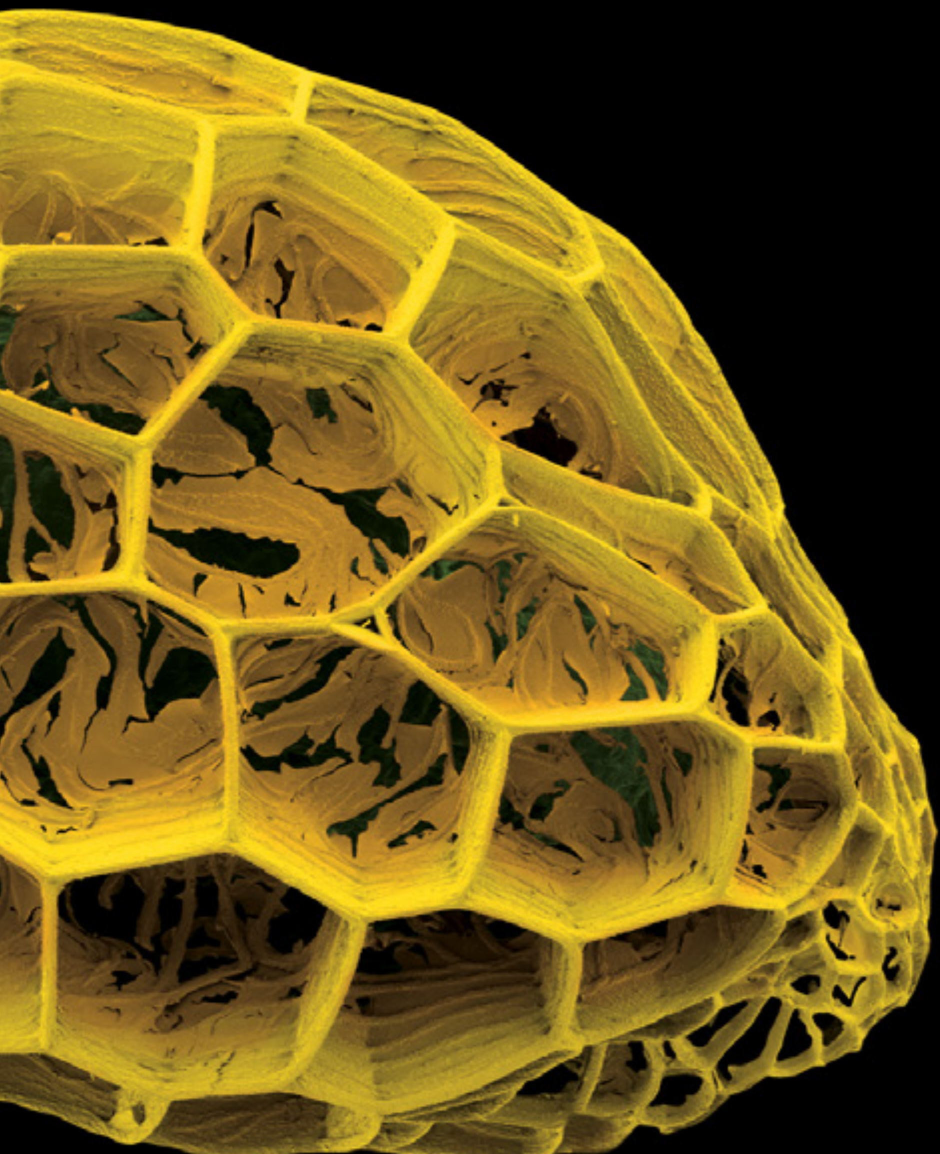

zq06
SUMMER 2013





About Zygote Quarterly

Editors

Marjan Eggermont

Tom McKeag

Norbert Hoeller

Contributing Editors

Raul de Villafranca

Adelheid Fischer

Kristen Hoeller

Offices

Calgary

San Francisco

Toronto

Mexico City

Phoenix

Contact

info@zqjournal.org

Cover art

Prunus spinosa, Blackthorn. Pollen grains, hand coloured micrograph | Rob Kesseler | 2010

pp. 2-3 & 108-109: *Castilleja flava*, Yellow paintbrush, seed. Composite hand coloured micrograph | From: *Seeds, time capsules of Life* by Rob Kesseler and Wolfgang Stuppy | Papadakis Publisher | 2006

Design

Marjan Eggermont

Colin McDonald

ISSN

1927-8314

“Wrinkled peach” fungus, species *Rhodotus palmatus* (Bull.) Maire. Strouds Run State Park, Athens, Ohio, USA.
Photo: Dan Molter, 2009 | CC-BY-SA

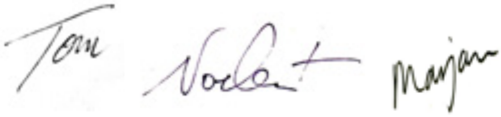
Editorial

Two of our articles in this issue concern the quality of the air we breathe, and how nature-inspired techniques might improve it. They are very different stories, and they illustrate the range of possibilities that bio-inspired design and human ingenuity afford.

On the one hand, a man who describes himself as a "serial inventor", who has ridden the ups and downs of the entrepreneurial market, has proposed an ambitious and untried scheme to clean up some of the worst outdoor air pollution in the history of the planet. The scale of his plan is outsized; its dimensions marked in hectares and kilometers, and the technology proposed has yet to be built, let alone tried, at the scale deemed necessary. If it works, it will quickly and radically change an entire local weather system for the better. If it does not, it may cause equally radical problems.

On the other hand, a state organization is sponsoring an initiative that has connected academic benchtop scientists and private manufacturers in order to improve a device that cleans indoor air within a single building. Any efficiency improvements to the device will be necessarily incremental, but within the micro and nanoscale being investigated, the bio-techniques discovered may be no less radical or disruptive.

Two very different stories, and yet, should all of these players come into the same room, they would have much in common to talk about. That is something to be celebrated, whatever the outcomes of their respective projects. The field of bio-inspired design needs both kinds of endeavor. ×



Tom McKeag, Norbert Hoeller, and Marjan Eggermont

"Indigo Lactarius", species *Lactarius indigo* (Schwein.) Fr. Strouds Run State Park, Athens, Ohio, USA.
Photo: Dan Colter, 2009 | CC-BY-SA

In this issue

We launch a new regular column in our pages this issue; Heidi Fischer will pen “The Science of Seeing” every quarter, and investigate one of her passions, the quest to understand nature. Heidi is an experienced and talented writer who also works in the education realm of bio-inspired design as the Manager of the Innovation Space at Arizona State University.

Two people who have pursued that quest are featured in our interview section. Brent Constantz has patented several high-impact technologies based on nature. Anamarije Frankić has developed an innovative program called LivingLabs that connects learners with the natural environment.

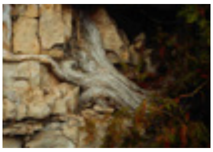
Our Portfolio section is devoted to the work of Rob Kesseler, author, ceramicist, professor and recent NESTA Fellow at Kew Gardens. Professor Kesseler’s colored SEM images of pollen, seeds and fruit are indeed delicious and fascinating grist for anyone interested in efficient form.

In the Tools, department, Tom McKeag presents a rational approach to organizing a design problem using categories derived from the study of biology. He explains his Bio-Design Cube and offers some suggestions for how to use it.

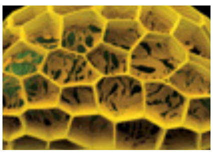
Two of our articles spotlight two very different proposed solution paths to mitigating air pollution. Jay Harman’s big idea on how to clear the skies over Beijing contrasts sharply with the indoor air pollution research being sponsored by the New York State Energy Research and Development Authority (NYSERDA) program.

Finally, we extend a warm welcome as a member of one of our families joins our magazine family. Kristen Hoeller, Norbert’s daughter, joins us as Copy Editor. The clean text you see before you is due to her meticulous efforts. ×

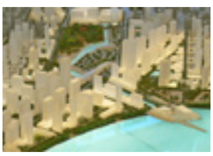
Spiral Hegira
Tom McKeag 10



The Science of Seeing: Hiding in Full View
Adelheid Fischer 30



Portfolio:
Rob Kesseler 42



Growing the Business of Bio-inspired Design in the Empire State
Tom McKeag 68

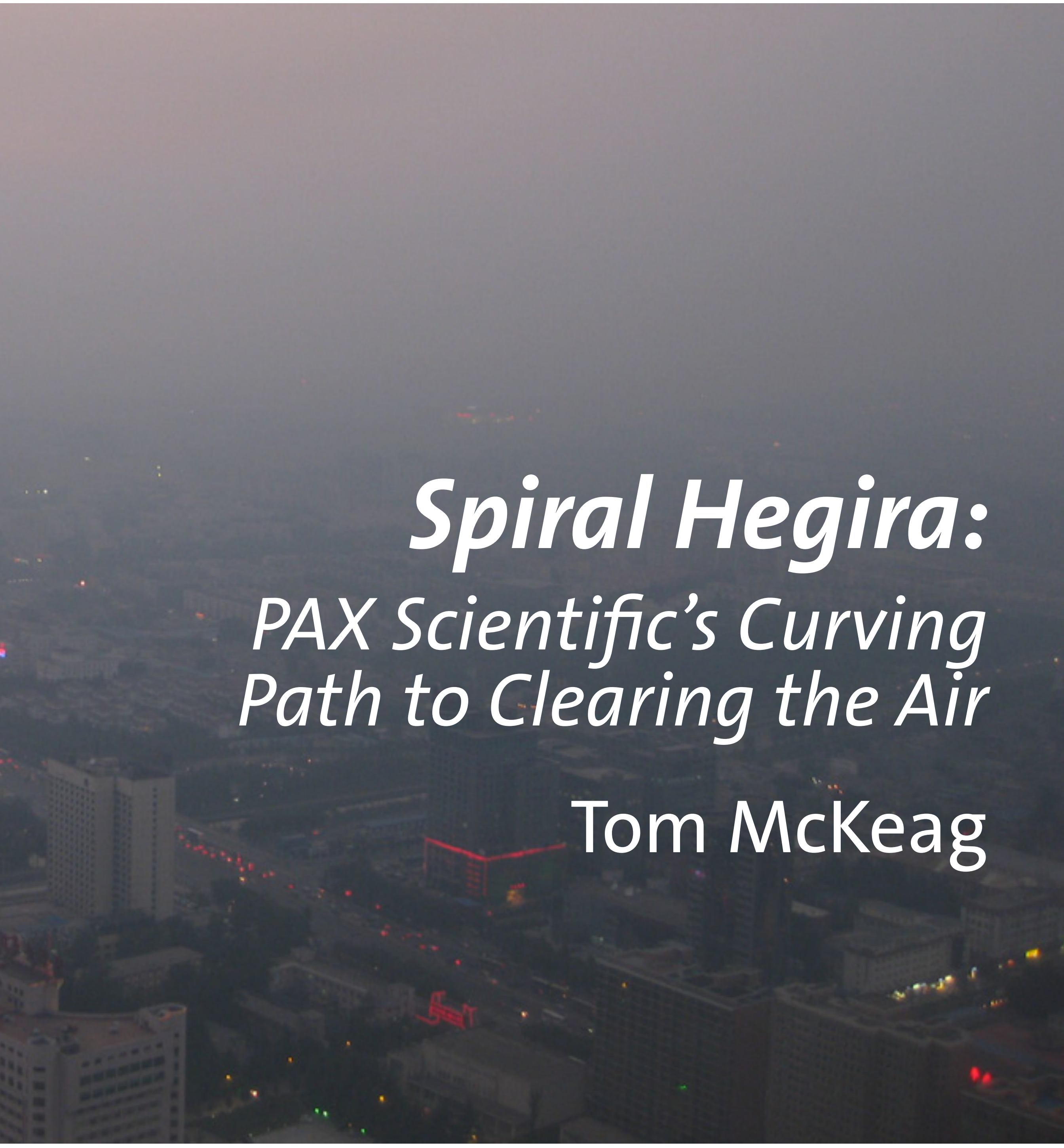
People: Interview with
Brent Constantz 82

People: Interview with
Anamarije Frankić 90

Tools: Framing Your Problem with the Bio-Design Cube
Tom McKeag 100

Smog, View from CCTV, Beijing / CN

Photo: william veerbeek, 2010 | Flickr cc



Spiral Hegira:
PAX Scientific's Curving Path to Clearing the Air

Tom McKeag

Spiral Hegira

A Universal Recipe

PAX Scientific CEO and Founder, Jay Harman has a recipe for cleaning our air that is based on the fundamental properties of fluids. Now he has to convince the rest of the world that the universal model he claims to have found can be used to alleviate smog in one of the world's grittiest cities.

The universal property that Mr. Harman has become obsessed with is the spiral, or, more precisely and three-dimensionally, the vortex. Vortices (or vortexes) are complex physical phenomena within the turbulent flow of fluids that appear at all scales in our tangible world, from nebulae to DNA. Air, water and even fire can assume this shape, and many of the solid forms in living organisms will reflect their once plastic state in this twisting form.

A two-dimensional "slice" of the spiral found typically in nature, the spira mirabilis described by Bernoulli, is a logarithmic or equiangular spiral, unlike the Archimedean or cylindrical spiral found in a watch spring. It is called equiangular because the angle in which a radius vector intersects the curve at any point is constant.

If one were to draw these two spirals as center points from which one traced curves radiating around these centers, then the logarithmic spiral would trace bigger and bigger curves around the center point as it moved outward. Vectors drawn from its center would intersect the curve at different angles. If one pulled our two spirals out into three dimensions, the logarithmic spiral would describe a cone, while the Archimedean spiral would describe a cylinder.

The importance of the logarithmic geometry to living forms has long been noted, for it is the only curve to possess the following property: radial growth and intrinsic growth in the direction of the curve bear a constant ratio to each other. D'Archy W. Thompson, in observing the nautilus in his classic 1917 text, *On Growth and Form*, wrote:

> "In the growth of a shell we can conceive no simpler law than this, namely, that it shall widen and lengthen in the same unvarying proportions: and this simplest of laws is that which Nature tends to follow. The shell, like the creature within it, grows in size but does not change its shape; and the existence of this constant relativity of growth, or constant similarity of form, is of the essence, and may be made the basis of a definition, of the equiangular spiral."

It is not that such vortices have escaped notice in our world; quite the contrary.

Nautilus Cutaway Logarithmic Spiral

Photo: Chris 73 | Wikimedia Commons

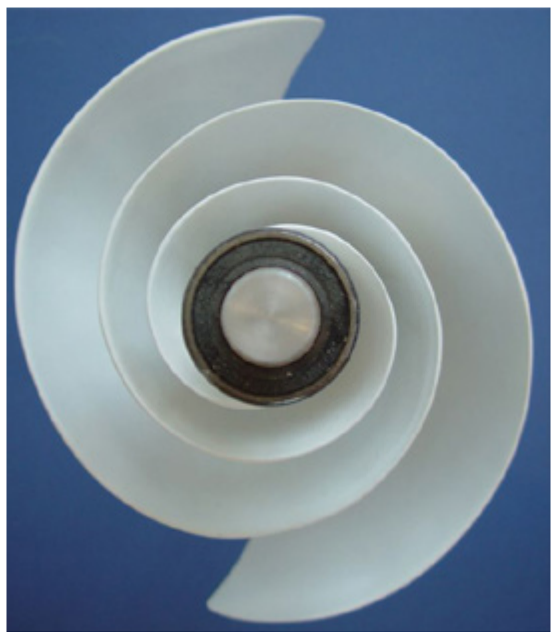
Descartes, for example, had described mathematically the equiangular spiral in 1638. It is just that Mr. Harman would like the world to realize that in three dimensions, this common phenomenon has mechanical properties, like pressure, electrical charge, temperature and velocity, and that these properties can be put to work. Since 1990 he has been presenting devices that capitalize on the mechanical efficiencies of vortices. His greater goal is to lessen our impact on the environment: "I am on a mission to halve the world's energy use and greenhouse gas emissions through biomimicry and the elimination of waste."

The Company

PAX Scientific (PAX) is a common stock, research and development and licensing company that controls four subsidiaries formed around applications identified originally by the parent company: PAX Water, PAX Fan, PAX Pure, and PAX Mixer. Refrigeration, turbines, fans, mixers and pumps have all been products that PAX has developed; all based on the geometry of a vortex. The company is based in Northern California and has over 40 employees spread throughout the system. Almost half work for PAX Water where they build and sell mixers for municipal water storage.

The Lily impeller is perhaps their best-known product. Named after the Calla Lily that it resembles, the device was designed by Harman by freezing and reverse-engineering a naturally occurring vortex (imagine freezing the whirlpool in your bathtub) and crafting a solid object based on its streamlines. The company claims that the six-inch device can mix a 10 million gallon storage tank using the same energy footprint as three 100-watt light bulbs. The impeller initiates a vertical spiral water column from which a ring vortex current develops within the water with very little further energy input. PAX Water Mixers using the Lily impeller are installed in over 600 municipal water tanks throughout the US.

His success with the Lily impeller as a water mixer and his belief in the eminent scalability of ring vortices has prompted him to initiate the Atmospheric Mixer Project. If he can translate the company's expertise in moving fluids to a different scale and application, it will bring the company unto a new international stage where problem solving is desperately needed.

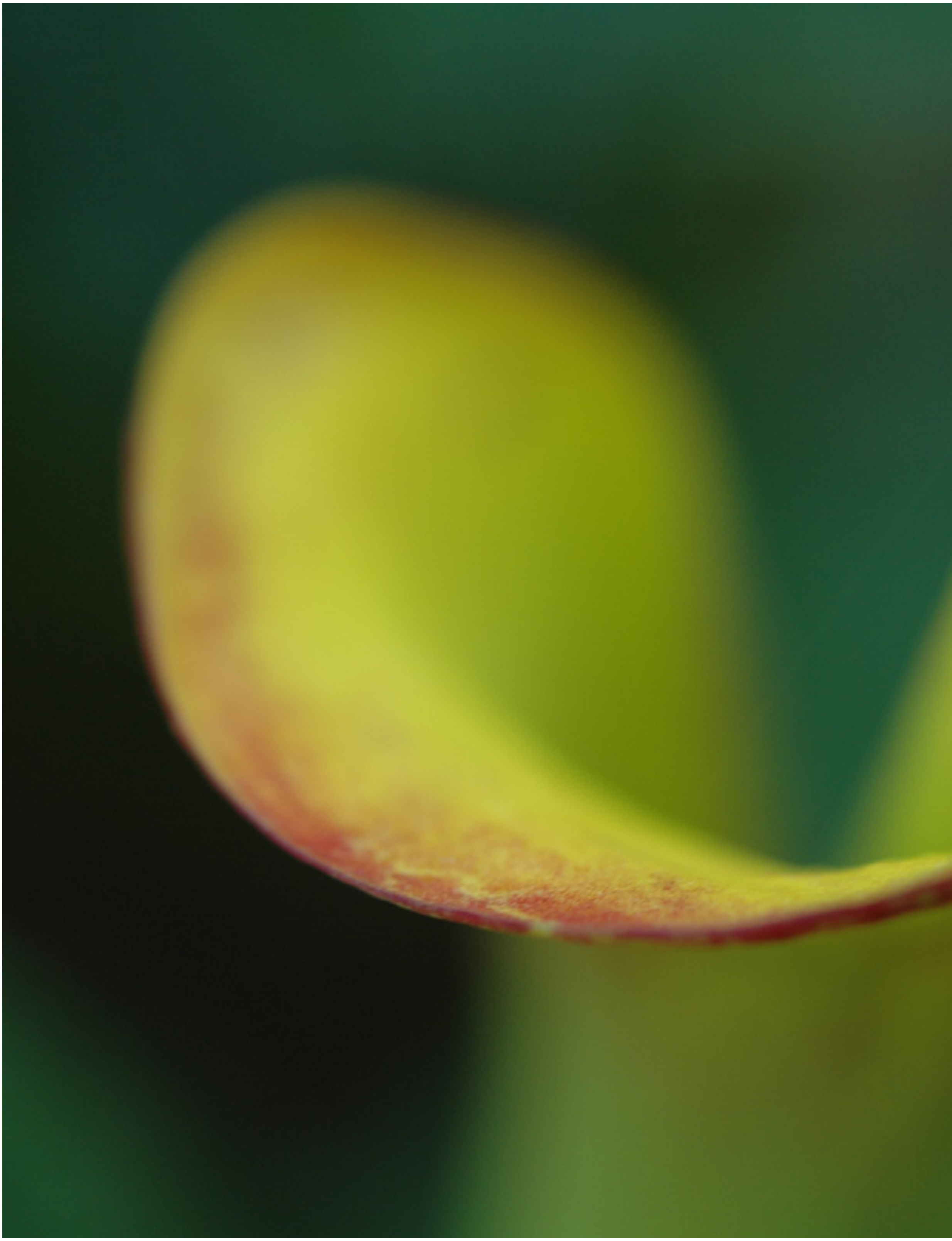


PAX Impeller

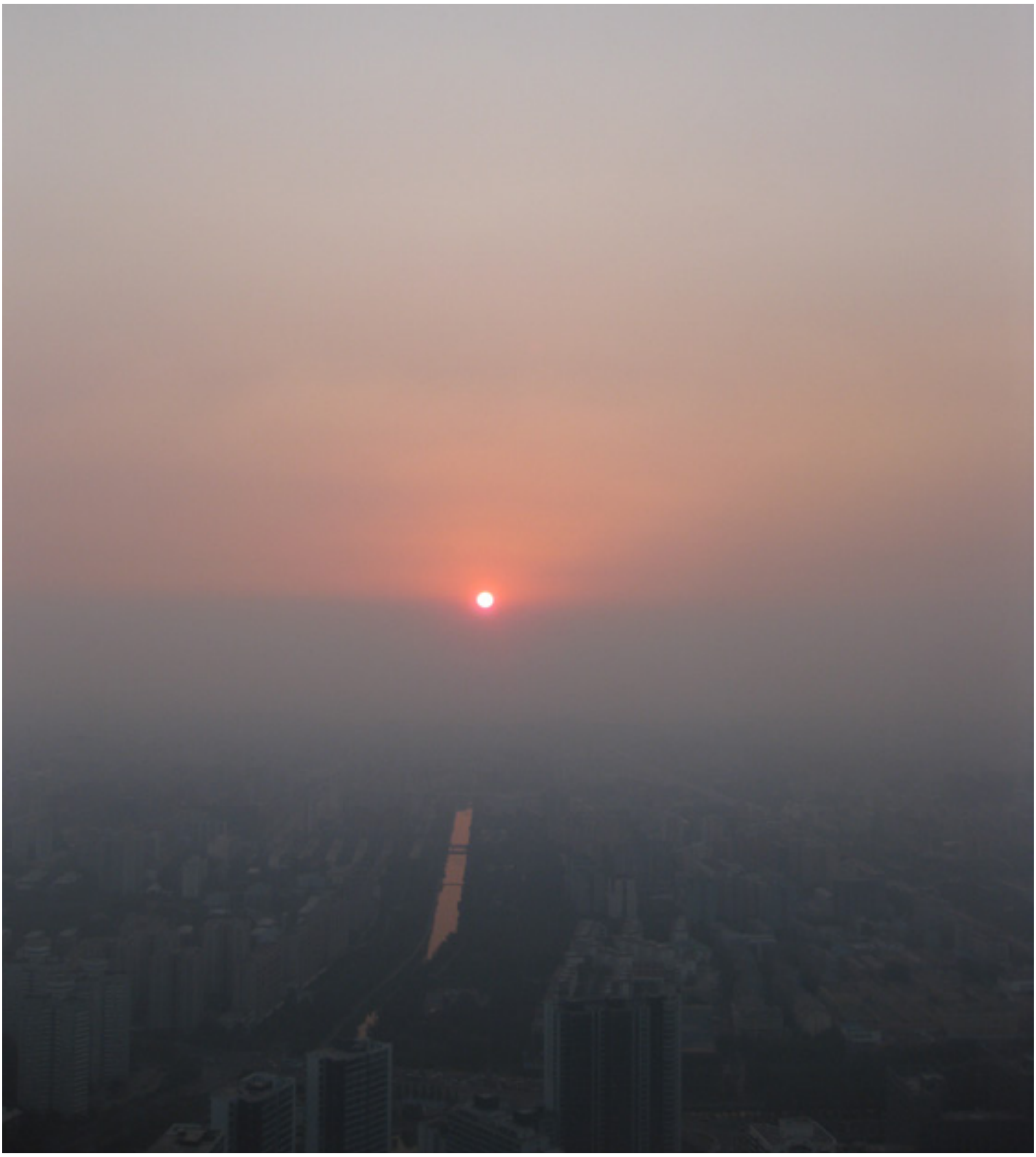
Photo courtesy of Jay Harman and PAX Scientific

Vortex

Photo: Jo Jakeman, 2008 | Flickr cc



Calla lily 011 | Photo: cygnus921, 2008 | Flickr cc



Smog, View from CCTV, Beijing / CN

Photo: william veerbeek, 2010 | Flickr cc

The Challenge

Megacity air pollution, and the resultant contribution to global climate change, is one of the biggest environmental challenges of the twenty-first century. In 2011, the World Health Organization estimated that there were 1.3 million premature deaths in cities worldwide because of outdoor air pollution. In the Lancet, the British medical journal, researchers estimated that 1.2 million premature deaths in China alone in 2010 were caused by “ambient particulate matter”.

This was the fourth-leading risk factor for deaths in China in 2010, behind dietary risks, high blood pressure and smoking. The China mortality figures comprised 40 % of the global total of premature deaths from pollution. Air pollution ranked seventh on the worldwide list of risk factors, contributing to 3.2 million deaths in 2010.

Worldwide projections are even more grim. In March, 2013, the Organization for Economic Cooperation and Development, based in Paris, warned that “urban air pollution is set to become the top environmental cause of mortality worldwide by 2050, ahead of dirty water and lack of sanitation.” It estimated that up to 3.6 million people could end up dying prematurely from air pollution each year, mostly in China and India.

Typical of the scenario are the cities of Los Angeles, Beijing and Mexico City, sprawling metropolitan areas of approximately 18, 20 and 21 million, respectively. These cities are built on flat plains ringed by mountains, and the dirty air they produce is trapped regularly by inversion layers contained within the topography. An atmospheric temperature inversion happens when a warmer mass of air covers cooler air near the surface of the earth. In Los Angeles, this often happens because warmer air from the Pacific Ocean rides over the cooler terrestrial air of the city. The result is that polluted air becomes trapped, unable to rise in a convective current since it is denser than the warmer air above.

Beijing in particular has become notorious for dangerous air, and one of the reasons is a shift in the local weather. The city recently had its highest levels of relative humidity and lowest surface wind speeds in a decade. Together this resulted in an even lower than average temperature inversion layer that trapped pollutants. Increased emissions within this period combined to create historic levels of pollution, known darkly to expatriates as the “airpocalypse”.

In the first quarter of 2013, two major air pollutants, nitrogen dioxide and PM 10, increased by almost 30% over the same period in 2012. PM 10 is particulate matter that is between 2.5 and 10 micrometers in diameter. Both of these pollutants spiked in January of the same year by 47%, according to a report by the Beijing Municipal Environmental Protection Bureau, as reported by the Beijing News.

The municipal government also recorded concentrations of particulate matter measuring 2.5 micrometers in diameter or smaller, called PM 2.5. The highest concentrations were recorded at nearly 1,000 micrograms per cubic meter, which was equivalent to some of the worse days of 1950's industrial London. One of the troubling features of this small particulate matter is its propensity to get into the lungs and embed itself in tissue. The content of PM 2.5 in Beijing is also a concern. It has a high level of arsenic, a carcinogenic byproduct of regional coal burning, according to a recent study by Greenpeace East Asia and the Public Health Faculty of Peking University.

So far, the City of Beijing has outlined emergency steps to curtail the source of the pollution, the burning of coal and fuel. Factories have been closed, non-essential government vehicles have been idled, some 180,000 older private vehicles ordered retired and certain open burning has been banned. In addition the large scale planting of trees on over 250 square miles has been planned.

Despite these actions to reduce pollution by 2% in the near term, the increase in motor vehicles will be allowed to continue, coal will remain the dominant energy form in the region, and the growth imperatives of the current industrial expansion will continue unchanged. Long-term projections by independent analysts of northern China air pollution remain dismal.

The Proposed Solution

PAX Scientific proposes to blow a hole in the inversion layer of Beijing, so that the trapped smog can escape and be dispersed by the winds above. The company has proposed to create an artificial cyclone to start a vertical convection current of air and its subsequent vortex rings to circulate pollution above the thermal inversion layer.

Vortex rings occur because of pressure differences between two masses of fluid. Smoke rings are a good example. When a smoker exhales air in a puff, the air exiting the mouth is pushed out with force, but the boundaries of the air mass are slowed by drag from the edges of the mouth. The center air moves faster than the boundary, and therefore, because of Bernoulli's Principle, has less pressure. The slower, higher-pressure boundary air loops back toward the lower pressure center area, thus forming the familiar doughnut or toroid shape. The force of the smoker's exhalation has given some momentum to this flying doughnut, so vortex rings can persist for some time before dissipating.

This sort of ring exists on a large atmospheric scale in convection currents that circulate air vertically. Cyclones often start with wind shear, either caused by the meeting of cool and warm air masses or the Coriolis effect. This causes horizontal rotation and then warm air is funneled up into the low pressure core of the growing storm. At the top the warm air condenses in the cold and travels back down to earth.

Hawker-Seafury smoke-rings [cropped]

Photo: CésarOP, 2012 | Wikimedia Commons

Hurricane Isabel

Photo: NASA Goddard Photo and Video, 2010 | Flickr cc

These vortices perpetuate the cyclone until the temperature and pressure differentials no longer exist.

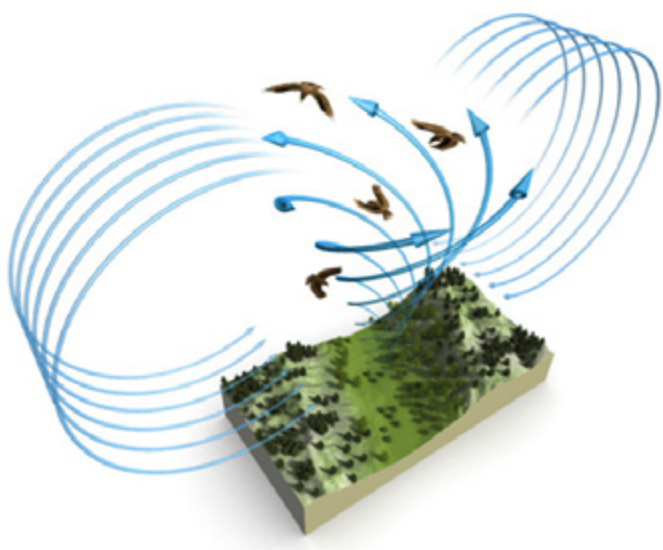
The plan is ambitious: set up a bank of powerful jet engines that will fire plumes of exhaust up 1500-2000 meters into the troposphere. Harman believes these plumes will result in the formation of ring vortices that will draw polluted air from a radius of 16 kilometers up into the core and send it aloft above the inversion layer where it can be carried away. Moreover, he believes this will result in a typical ring vortex pattern found in naturally occurring convective air currents, or so-called thermals, that can be maintained and enlarged to break up the smog layer.

The company is proposing to use pulse detonation engines (PDE), with nozzles configured in their proprietary geometry, to create the plumes. A typical PDE draws in air and fuel and ignites it to send an explosive burst of exhaust out a tube. The exiting of the hot gas draws new cool air into the combustion chamber through a one-way valve where it is sparked and the cycle repeats continuously.

PAX is hoping to build a test facility to operate a quarter-scale model of this technique within the next 12-18 months, but will need approximately $5 million to do it. The pilot plant will provide the effects needed to be measured and modeled for a full-scale operation.

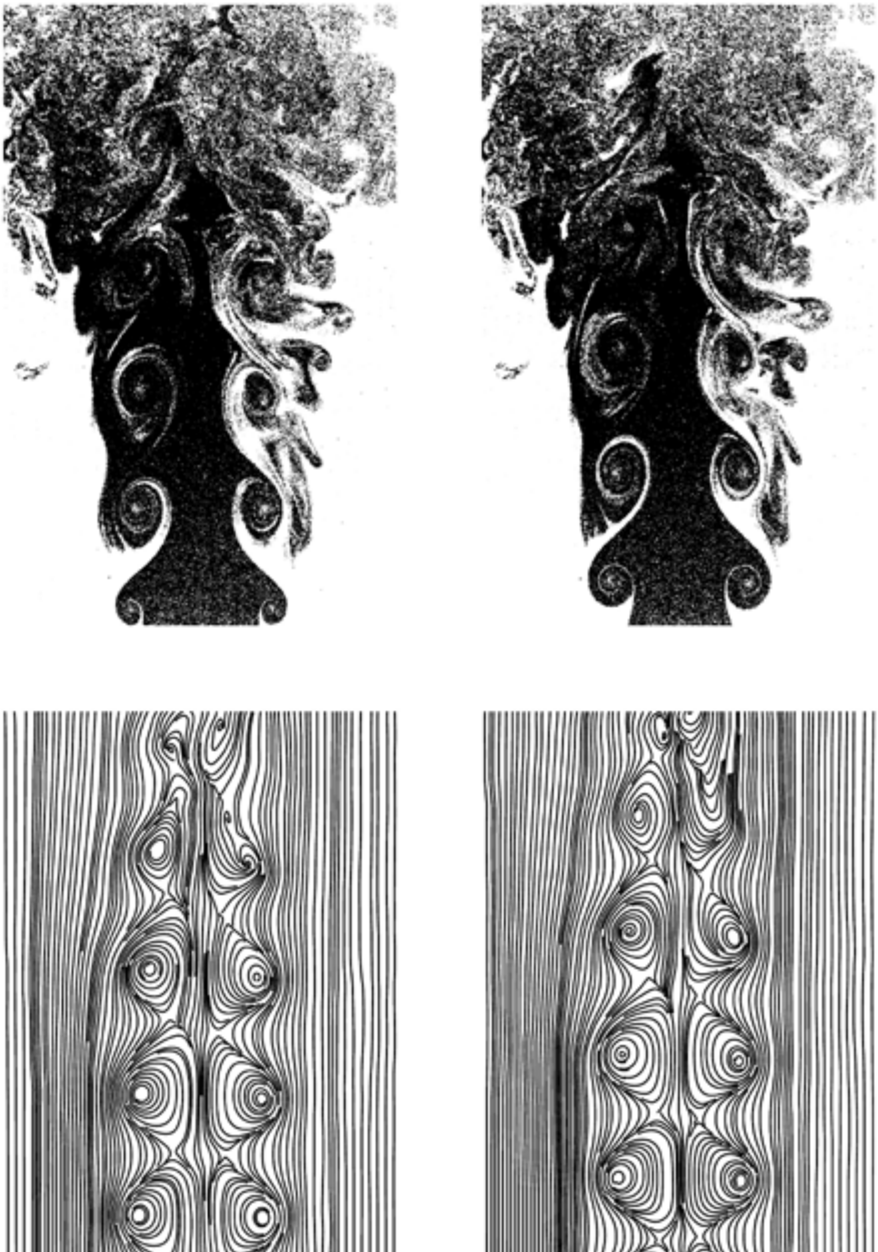
Admittedly, this proposal does not ameliorate the causes of the pollution, but could offer some short-term relief.

“This is not the best use of our technology, but a “quick fix” with great promise to improve the



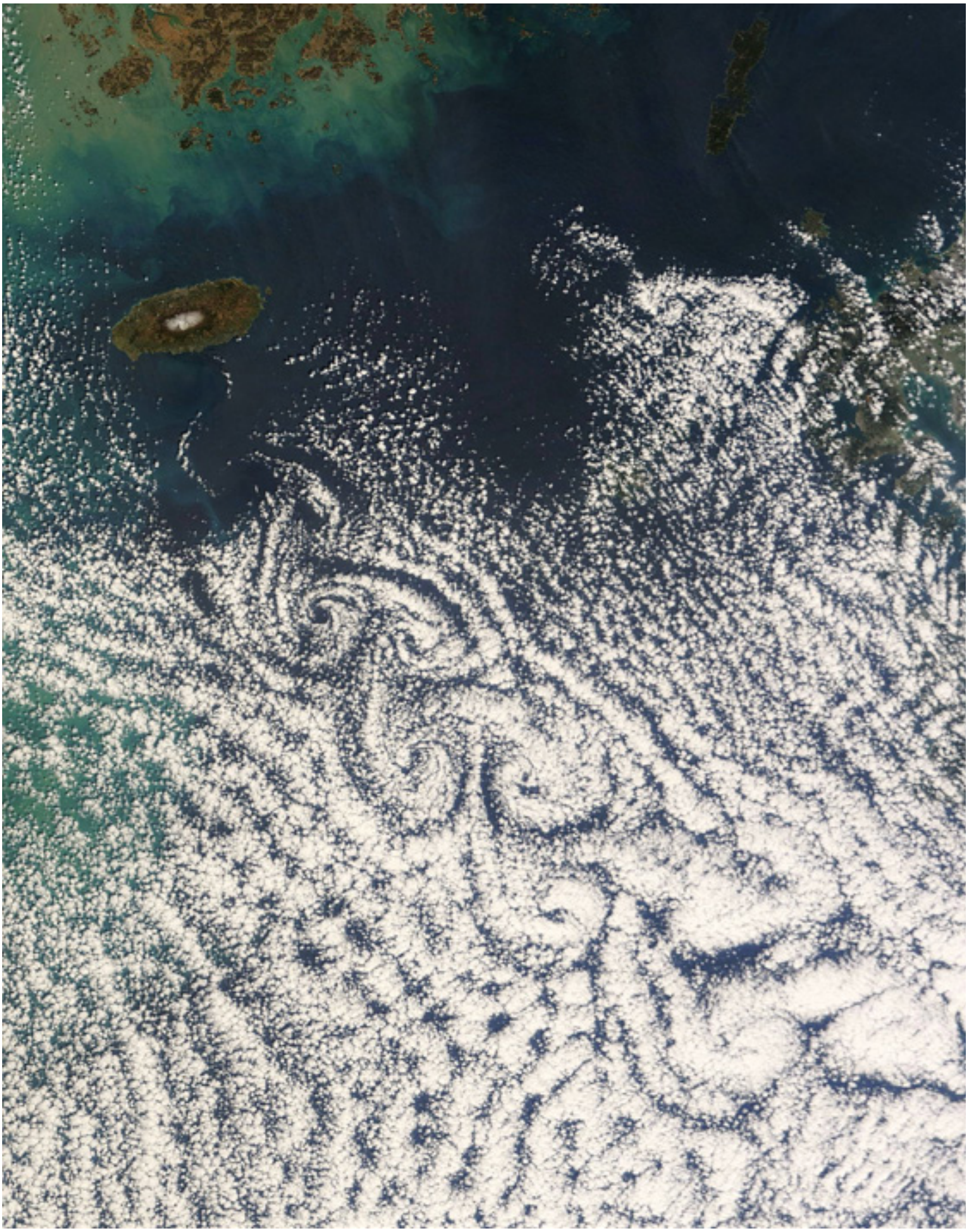
Ring Vortex Dynamic in Atmosphere

Image courtesy of Jay Harman and PAX Scientific



'Forced Jet'

Photo: Engineering at Cambridge, 2010 | Flickr cc



Von Karman Vortex street off Jeju Do

Photo: NASA, MODIS Rapid Response System, 2012 | Wikipedia Commons lives of millions, while freeing up the regional economy to clean up the ultimate sources of the pollution", said Jay Harman.

The Process

PAX engineers have spent nearly two years testing the feasibility of this approach, using the media of water and air at different scales. The company considers the pilot plant the next step toward full-scale operation of the technology.

The originally intended application for this process was not the dissipation of smog, however, but the making of rain. In the high humidity, high heat areas of the world, like the Arabian Gulf, it was thought possible to pump seawater inland and then spray it upward into the atmosphere. The created water vapor would, conceivably, travel in a ring vortex pattern and condense into rain as it accelerated, depressurized, and cooled. PAX continues to view this as a possible application for this technology.

So far, the PAX Scientific R&D sequence for the air pollution scheme has proceeded in four steps. First, the team studied Computational Fluid Dynamic (CFD) simulation test results for their current water and air mixers, in particular the Lily impeller. Next, the group performed experiments using an air chamber and dry ice. With these results they tested an array in a large water tank. Finally the group checked the air chamber results against more CFD simulation and physical tests in the water tank. They then collaborated with Dr. Thomas P. Gielda, Adjunct Professor of Aerospace Engineering at Iowa State University, to prepare a white paper for the purpose of attracting seed funding for a quarter-scale test of the proposed apparatus.

Each step has involved some inductive translation to the next, as water tank performance results of mixers informed tests of small-scale air movement, and so forth. What has made these translations possible is the Reynolds number, a dimensionless measure of velocity to viscosity that can, among other things, be used to predict the onset of turbulence (and therefore convection) in a fluid. The Reynolds number is the cornerstone of fluid mechanics and is the central scaling parameter used in this field.

Despite the utility of the Reynolds number, these translations do contain parameter assumptions that can only be corroborated in a larger-scale field test. By way of just one example of generic translational challenges not necessarily used in this study, the Rayleigh model, a measure of when a fluid becomes unstable and forms into convection cells, assumes an incompressible fluid and that viscosity does not change with temperature; both inappropriate when studying air.

In the water tank tests, the engineers tried two nozzle types powered by a pulse jet within a 3.65 meter diameter by 6.1 meter high vessel containing fresh and salt water to simulate the stratification found in an advection thermal inversion. Although the engineers achieved low Reynolds numbers, and could conceive of altering the parameters of the test (balancing velocity, nozzle size, height of plume), they claim to have achieved results that can be scaled to sending an exhaust plume 1500 meters into the air.

In the air chamber tests, an open-top 5 meter diameter by 1.5 meter vessel contained a

CO_2 cloud chamber created from dry ice. Air was drawn out of this cloud, compressed and pumped back into the cloud. The team was able to clear the cloud, but the Reynolds numbers were again low, so further simulations were done in the water tank, first using CFD software, and then the actual tank. This time five nozzle types were tested in water which was density-stratified by salt and a pulse jet compared with a continuously operating one. The group claims good results, being able to send a plume to the top of the tank in under a minute, the equivalent, according to their scale model, of 1500 meters at full scale in the air. They also claim to be able to achieve the necessary mixing using a pulse jet, at 5% of the power draw of a continuously operating one.

Future Prospects

The development of this application is still nascent, with many assumptions about scale, dynamic parameters, and feasibility still to be corroborated. It can be seen to be in the preliminary stage. The team at PAX, therefore, has prepared a set of recommendations to obtain a reliable proof of concept. These include the building of a quarter-scale PDE, and the conducting of larger scale modeling of its effects on an air column, perhaps within an abandoned quarry. This would yield a feasibility report, outlining performance criteria and results and the design parameters for a full-scale model.

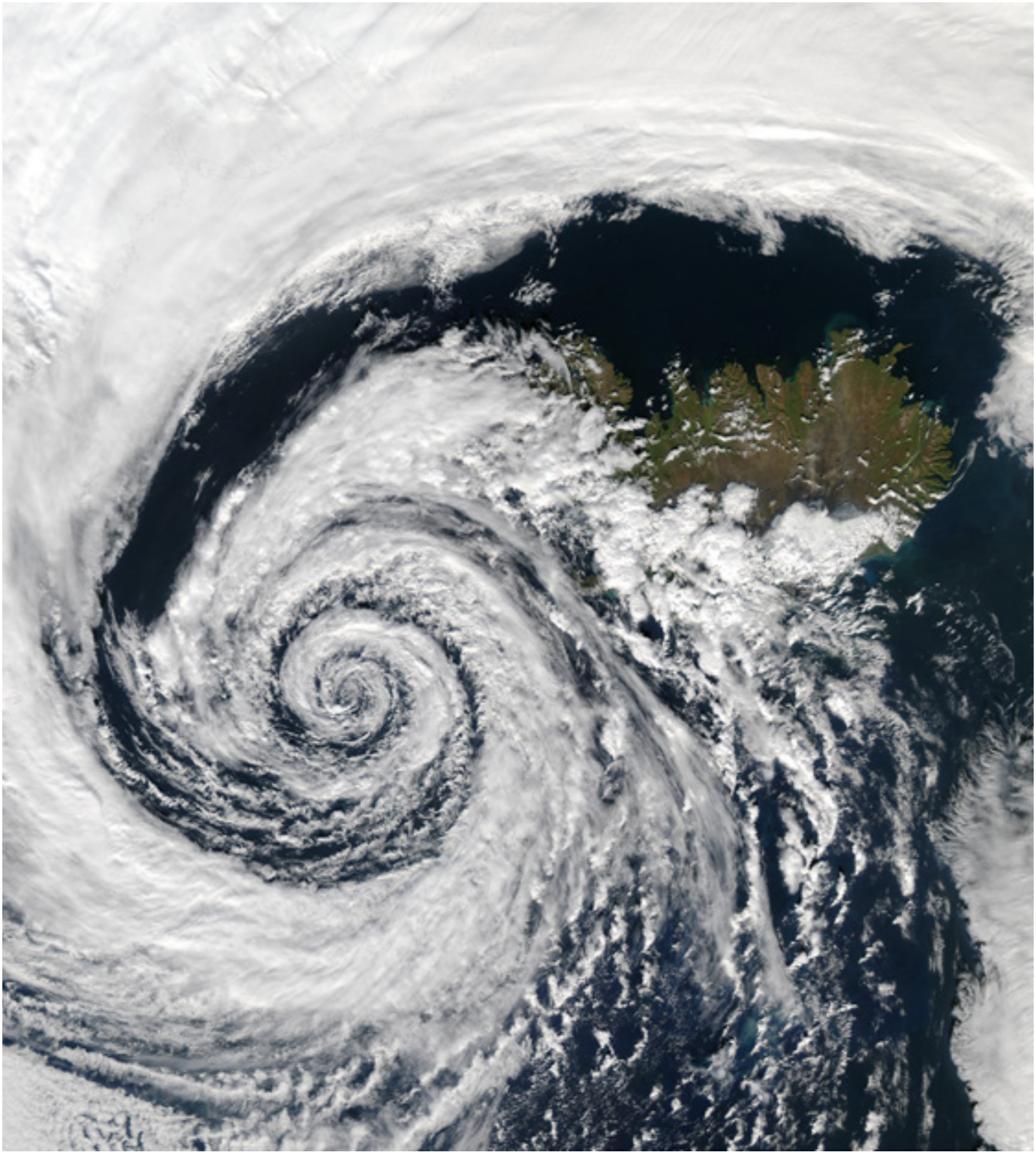
The number of uncertainties inherent in large-scale fluid dynamics does raise some questions about the effects of creating cyclones at the scale proposed. Mr. Harman does not share these concerns, believing that the heat engines of hurricanes and tornadoes, the destructive forms of cyclones, can be both diverted and prevented by diffusion of the underlying energy differentials that cause cyclic storms in the first place. As to his artificially created versions, he believes that setting his devices in a counter rotation to the natural hemispherical one, as seen in the Coriolis effect, would be an effective preventative. So too, according to him, would be placing two oppositely rotating arrays next to each other.

The company has presented its proposal to the municipal government of Beijing and are currently in discussion with Dr. Alex Westlake, Managing Director and Co-Founder of Clear World Energy, Beijing, about funding the pilot project. Clear World Energy is a sustainable technology investment company that has been operating in Beijing since 1994.

Regardless of the pace of this funding and development, Mr. Harman continues to look ahead and beyond, firm in his belief about the power of ring vortices. “The ultimate opportunity for this is really at the ozone layer scale. If we can fix that mess, using nature’s natural convective patterns, then we really have got something.” ×

See a recent supercell here:

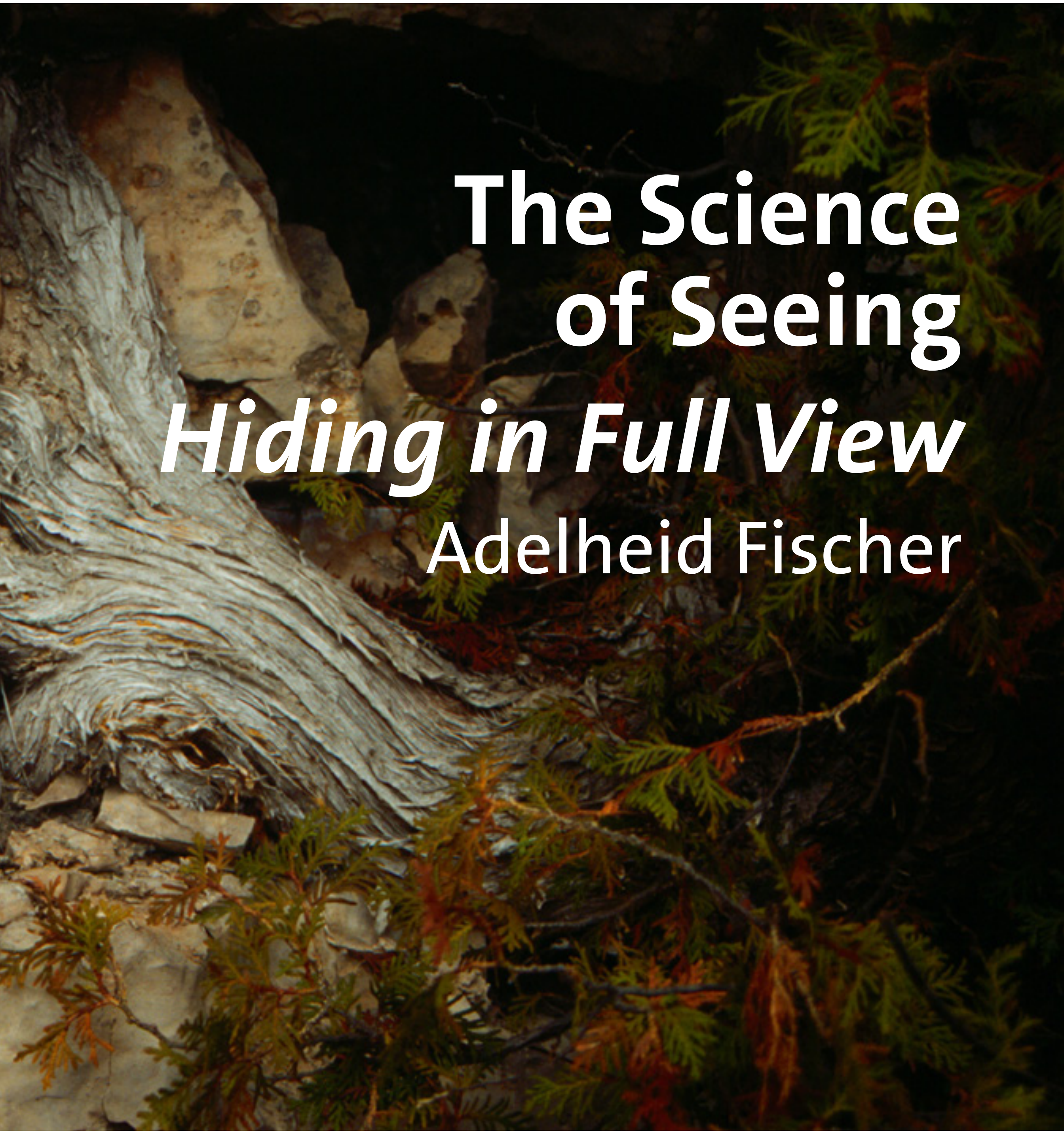
http://vimeo.com/67995158



Low pressure system over Iceland spins counter-clockwise due to balance between the Coriolis force and the pressure gradient force
Photo: NASA, 2003 | Wikipedia Commons

Cedar tree roots on the Niagara Escarpment

Photo courtesy of Douglas Larson, 2012



The Science of Seeing
Hiding in Full View

Adelheid Fischer

Hiding in Full View

You can observe a lot just by watching. - Yogi Berra, renowned baseball player and folk philosopher

The true journey of discovery consists not in seeking new landscapes but in having fresh eyes. - Marcel Proust

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

Therefore we welcome you to the second in a series of essays for a new column entitled "The Science of Seeing." The column focuses on a wide variety of subjects around the theme of seeing. This essay celebrates the Cliff Ecology Research Group, a cadre of Canadian scientists who did something simple and profound: they looked closely at the Niagara Escarpment, a place in their own back yards. Like all things made ordinary through force of habit, the escarpment attracted no attention until members of the group suited up in climbing gear and zoomed in for a closer look. In the process, they surprised themselves and stunned scientists around the world.

Several years ago, while researching the ecology of Great Lakes forests, I came across some research that stopped me in my tracks.

It all started with a Canadian rock climber named Steven Spring. In the 1980s Spring would spend hours dangling from ropes along the cliffs of the Niagara Escarpment, the limestone edge of an ancient seabed that slices across much of the Upper Great Lakes region. From time to time, the climber and avid naturalist would pause on his adventures to examine the cliff edge up close. From a distance, the 100-foot-tall façade appeared sheer and largely featureless. When viewed at arm's length, however, the rock wall broke into a complex puzzle of ledges, runways and alcoves that teemed with life: snails, snakes, centipedes and bobcats as well as rare plant species, some of which have held their ground in these vertical outposts since the last glaciation. What really captured Spring's attention, though—and his imagination—were the miniature white cedars that had sunk their gnarly, bird-claw roots deep into empty crevices or clutched at what appeared to be nothing more than bare rock. With little or no soils in which to root, how did these bonsai-like trees survive?

[Wild columbine on the] Niagara Escarpment
Photo: sbwoodside, 2007 | Flickr cc

Pinguicula vulgaris (Lentibulariaceae) | Tim Waters, 2012 | Flickr cc

In 1985 Spring began scouting for a project for his master's thesis. He wandered into the research lab of Dr. Douglas Larson, a botanist at the University of Guelph, Ontario. Larson, a lichenologist, had already attracted a cluster of students who were interested in the ecology of tough places. Spring's curiosity about the tiny trees had finally found a home. Larson's league of the like-minded coalesced into what became known as the Cliff Ecology Research Group. From the Niagara Escarpment, the group's research spread out to far-flung locations throughout the eastern U.S. and Europe. Before long, the news from Larson's lab began making science headlines.

It turns out that just about everywhere they went, the Cliff Ecology Research Group discovered ecological goldmines that were hiding in plain sight. Segments of the Niagara Escarpment, for example, could be seen from downtown Toronto, then a city of some two million people, and yet no one had even so much as bothered to take a census of their extraordinary inhabitants. "Vertical cliff ecosystems were completely overlooked by ecologists because they appeared to be hostile, lifeless and seemingly impossible to sample. Indeed they do not even show up on the most detailed aerial photographs," wrote Larson and his colleagues, Peter Kelly and Ute Matthes-Sears, in Encyclopaedia Britannica's 1995 *Science Yearbook*. Even world-famous cliffs like Gibraltar and Dover, they observed, which long had been the stuff of postcards and insurance logos, "have attracted no scientific inquiry."

For every ounce of investigative effort in places like the Niagara Escarpment, the researchers seemed to reap a tenfold reward. Initial surveys, for example, yielded an impressive tally of invertebrate species. An unexpected bonus was the extraordinary species diversity of the cliff's snail populations. The scientists also discovered startling clues to the region's paleo history which suggested that the cliff ecosystem once had—and continues to maintain—greater affinities with the tundra than with the temperate, sugar maple-dominated forest that surrounds it today. Among the tantalizing remnants of times gone by were the bones of an extinct species of pika. Not all the glacial holdovers were fossils, however. Of the 25 or so living species of herbaceous plants that the researchers documented, five were found to be members of species that occur more commonly in the Arctic. These were the descendants of plant communities that once had hunkered under the frigid katabatic winds of the Wisconsin ice sheet and still persisted in place on the steep cliff walls.

The biggest surprise of all came in some of the escarpment's small packages—the cliff's elfin trees. Temperature readings showed that they endured extremes of 110 degrees in summer to minus 20 degrees in winter. Many had grown bent and crabbed under the inexorable pull of gravity. Some of them seemed to defy gravity altogether by corkscrewing horizontally out of the rock. How did they survive?

A closer examination revealed a suite of extraordinary adaptations. For starters, the roots of the cliff-edge trees were covered in mycorrhizal fungi. These organisms are adept at exploiting the "solution hollows" in the rock surface, tiny dimples that capture soil and moisture, to scavenge precious resources like phosphorus, nitrogen and water. The root fungi share this harvest

Abbarbicato | Niagara Escarpment

Photo: palmasco, 2008 | Flickr cc

with their host trees in exchange for the carbohydrates they produce through photosynthesis. Thanks to mice and other animals, fungal spores are seeded widely in feces throughout the cliff ecosystem.

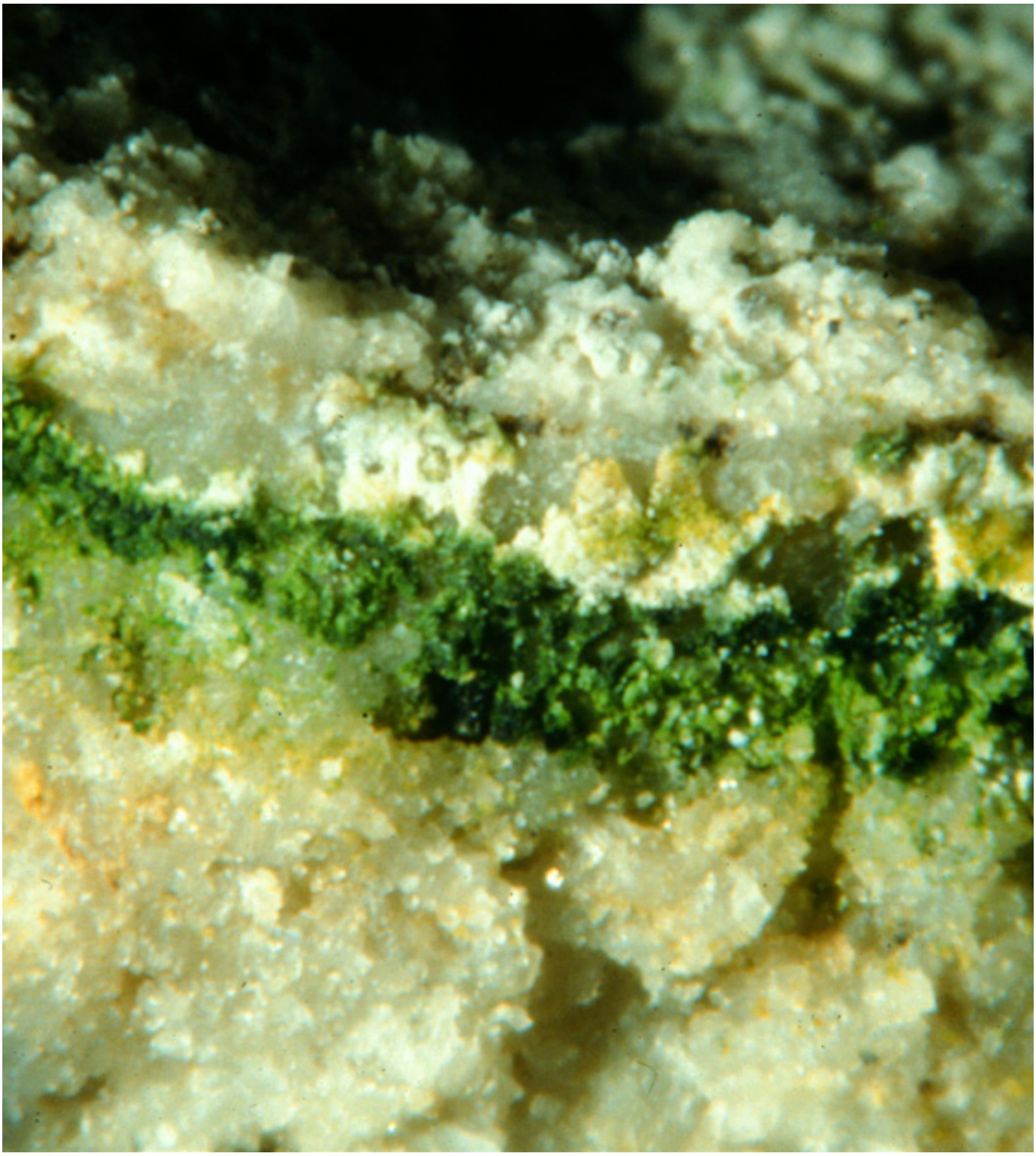
This nutrient-swapping arrangement between trees and mycorrhizae occurs commonly in other kinds of plant communities so it was not entirely groundbreaking news. Another kind of ecological partnership did grab headlines, however. The researchers suspected that the tiny trees might have been able to take advantage of a far more unusual source of nutrients: those produced by organisms that live inside the rock itself.

From Antarctica to the deserts of the Middle East and American Southwest, scientists have published sporadic reports of communities of algae, lichen and fungi that live within solid rock. They're known as cryptoendolithic ("hidden inside rock") organisms. Researchers speculate that the harsh conditions of their environments drove them "indoors" to find shelter from the elements. Among the most important are the algae, especially those known as cyanobacteria, which are able to transmute atmospheric nitrogen into a form that plants can utilize. No one had documented the existence of these cryptoendoliths in southern Ontario until the cliff-ecology researchers whacked a few chunks of rock from the cliff face and discovered, just beneath the surface, a thriving community of organisms arrayed in narrow, green band. How the nutrients that are produced by these secretive societies make their way into the cliff environment remains something of a mystery but "they are very likely contributing significant amounts of nitrogen compounds to the cliff ecosystems and are probably indirectly fertilizing the trees at a rate just high enough to keep them and the whole ecosystem alive," Larson and his colleagues write.

The most intriguing news of all, however, came after Larson's colleague, Peter Kelly, conducted dendrological tests on the miniature cedars. It was no easy task. To date trees, scientists commonly carry out a harmless procedure in which they core a plug from a tree trunk and count its rings. But the morphology of cliff-edge trees complicates this straightforward task. That's because 90 percent of them have roots and trunks that ripple over the rock face and attach in multiple places, forming splayed, asymmetrical growth patterns much like the disorderly locks on the head of Medusa.

These roots are extremely vulnerable in the cliff environment. During its lifetime, a tree will endure traumatic root loss about ten times as roots are dislodged or exposed by disturbances such as falling rocks or ice buildup. Whether on an unstable cliff face or in a quiescent swamp, cedars have, nonetheless, developed clever strategies for coping with the vagaries of this world. The roots operate independently of one another, each funneling water and nutrients to its own part of the tree stem. "It's a clever system," Larson observes. "If a rock gives way and detaches a root, only the portion of the trunk that was connected to that specific root will die." As such, he says, each individual tree "is actually behaving as a population of independent parts rather than as an integrated being."

The cedars' ingenious modes of gathering resources and safeguarding their distributed de-



Cryptoendolithic algae, fungi and lichens

Photo courtesy of Douglas Larson, 2012

livery channels have served these trees well. Overlooked by loggers and spared by wildfires, the trees have attained ripe old ages. Surveys by Larson and his colleagues showed that trees ranging between 300 and 800 years of age are common on the escarpment. Some are well over 1,000 years old. One dead tree that was discovered at the base of the cliff near Toronto was nearly 1,900 years old before it toppled to the ground! Common to all of them was their small stature. Even the oldest trees measured only about 10 feet high and less than 12 inches in diameter.

This was the most unexpected and wonderful discovery of all: in full view of factories and farm fields, surrounded by city streets and second- and third-growth woodlots was an old growth forest. "The exposed cliffs of the NE—the cliffs thought by some people to be 'barren' or 'lifeless'—actually supported the oldest and most undisturbed forest ecosystem in eastern North America," wrote Larson and his colleagues.

The potential for this kind of paradigm-busting discovery abounds, the scientists conclude. "What is most significant," they write, "is that by studying a place and by asking questions that have been ignored or avoided by others, researchers can make discoveries that are both globally important and exciting. Similar opportunities exist everywhere in the scientific landscape." ×

Thuja occidentalis (White Cedar) | Niagara Escarpment

Photo: modowd, 2006 | Flickr cc

Quercus alba, White oak, catkins and pollen. Hand coloured composite micrograph.

Rob Kesseler | 2010

Portfolio
Rob Kesseler

Author:
Rob Kesseler

Rob Kesseler (http://www.robkesseler.co.uk) is a visual artist and Professor of Ceramic Art & Design at Central Saint Martins, University of the Arts, London. A Fellow of the Linnean Society and Royal Society of Arts, he was a recent NESTA Fellow at Kew and Research Fellow at the Gulbenkian Science Institute, Portugal. During the past thirteen years he has collaborated with botanical scientists and molecular biologists in an exploration of the plant world at a microscopic level. His books are published by Papadakis, London.

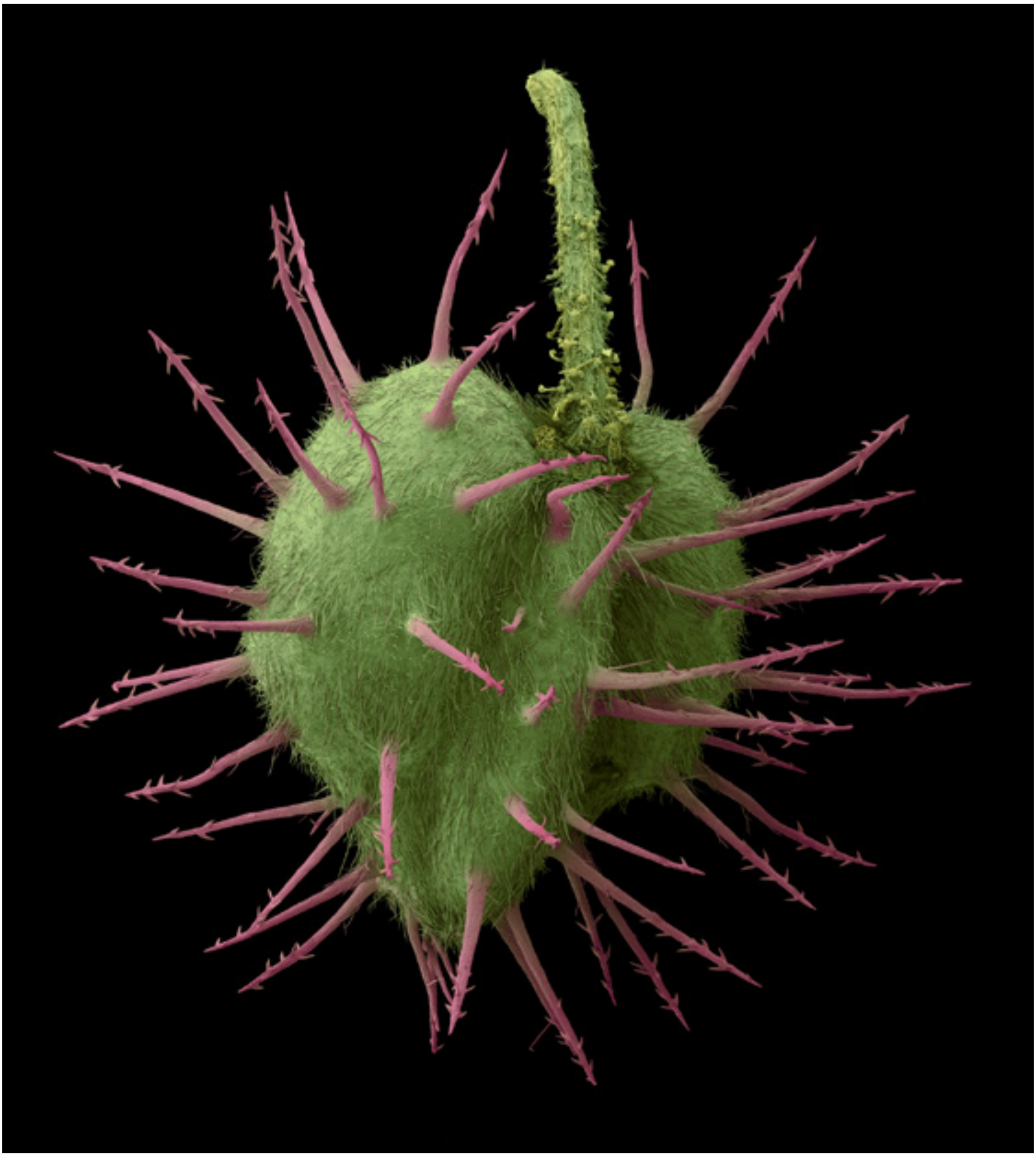
Could you tell us about your background and how you got to where you are today?

As a child, biology and art were my favourite subjects and at the age of ten my father gave me a beautiful Victorian brass microscope which opened up a natural world beyond the limitations of my own eyes. Ever since I have continued to work as a visual artist working across a range of media in that interesting territory where fine art, design, craft, photography and science overlap. From the beginning the natural world and plants in particular have always been at the centre of my work, in its many symbolic, metaphoric and cultural guises. About thirteen years ago I was at the end of a cycle and looking to move in a new direction. Thinking back to my old microscope I recalled the wonderful patterns and structures of tiny insects and fragments of plants and it occurred to me that there was a whole world there waiting to be exploited. In 1999 I approached Kew Gardens in search of a collaborator and was fortunate to connect with Madeline Harley, a palynologist responsible for research into pollen. She introduced me to the wonders of the Scanning Electron Microscope (SEM) and I have been producing my own images ever since.

What kind of techniques do you use for your work? Do you use any software?

I use a variety of microscopes to examine organic material. A SEM is a scanning electron microscope and it differs from a light microscope in that it does not use light rays. The specimen is first prepared by coating with a micro-fine layer of gold before being bombarded by a beam of electron particles and focused through powerful magnets onto a screen. The resulting images have phenomenal resolution at high magnification, anything up to X 10,000. But I often work with larger specimens at low magnification taking up to fifty shots subsequently pieced together in the post-production phase.

I then introduce colour using Photoshop. The question of colour is often a topic that arouses discussion – 'is this the real colour?' or is it 'false colour'? Well clearly this is not the colour of the real specimen, but neither do I consider it false, a term applied by scientists to colour that is added automatically with little scope for author intervention. My use of colour is a subjective and expressive interpretation that starts with reference to the original plant or flower, is modified to reveal structural and functional characteristics and finally is resolved through what I might describe as chromatic intuition. The end result is one where my relationship with each specimen, from collection through drawing and photographing are distilled into a powerful and mesmeric iconic image. As each plant uses col-



Krameria erecta, Little leaf rattany, fruit. Composite hand coloured micrograph.

From: *Fruit, edible, inedible, incredible* by Wolfgang Stuppy and Rob Kesseler | Papadakis Publisher | 2007 our to attract an audience of insect collaborators, so I use colour to attract a human audience for cultural and artistic purposes.

I also use a conventional light microscope. In a recent collaboration with the Gulbenkian Science Institute in Portugal, micro-fine sections cut from the stems of local wildflowers were stained with organic dyes, creating a luminous stained glass effect. Working at a higher magnification than would normally be used by the scientist, images were often composed of up to 500 separate frames carefully merged to form an image of up to four meters in diameter.

How has your thinking changed since you first started?

From the start I have always made it a point to do all my own lab work, to understand the processes and as much as possible communicate with the scientists on equal terms. But when I first started producing images I was cautious of modifying the images too much for fear of being accused of distorting reality. However over time it became clear that I am not a scientist, my motives are different and although we may use the same processes and materials we both modify and manipulate it to our own ends, to reveal truths as we see them.

How does photography influence the way you see science?

Photography is just another tool, another lens through which to explore and capture the world, but it has become a very sophisticated tool that has almost become universally accessible. When

Jardim Porcelânico, Porcelain plates with cellular decals, digital print on canvas
Rob Kesseler, made with support from The Gulbenkian Science Institute and Vista Alegre Atlantis | 2011

cameras were first attached to microscopes in the mid 19th century this caused a century long hiatus in the relationship between artists and scientists. The role of visualization was put in the hands of the scientist; equipment became more expensive, hidden away in laboratories and out of reach of the non-specialist. In effect the technology became an inadvertent gatekeeper. Now however the value of collaboration across disciplines is again recognized and facilitated by common digital platforms and technologies.

Could you tell us more about the Millennium Seed Bank?

The Millennium Seed Bank is part of the Royal Botanic Gardens, Kew and based at Wakehurst Place in Sussex. It is the largest ex-situ plant conservation site in the world, with a focus on plant life faced with the threat of extinction and those likely to be of the most use in the future. Working with a network of partners across 50 countries it has successfully banked 10% of the world's plant species. Targeting plants and regions most at risk from climate change and human impact it aims to collect 25% by 2020.

We are interested in your experience collaborating with botanists at Kew: what were the challenges, breakthroughs and lessons learned from your interdisciplinary activities?

Despite biology being one of my favorite subjects at school I did in fact flunk all my science exams. Consequently learning the basics of the many scientific processes and languages was and continues to be a challenge. But there was also common ground, a passion for the subject, a love of nature, a strong visual awareness and also etymological links – pollen is described as having sculpted and ornamental features. Ironically one of the initial challenges was persuading people that there could be an audience for the results. It took a long time to find a publisher, but with Alexandra Papadakis we found someone willing to share our enthusiasm and having sold well over 100,000 copies in seven languages our belief was confirmed.

Of all the forms that you have observed and talked about, what are the two best functional applications that you can think of?

Well, pollen is really a remarkable organism. That something so minute could exist in such a diverse array of forms and structures is in itself awesome, but its functional existence as the male sperm of the flower that will grow and fertilize the ovaries seems almost incredible.

In seeds, the hooks and spurs that catch on our clothes or the fur of passing animals to assist in the dispersal of the next generation is well documented. That it exists in so many forms and scale is just another thing to marvel at.

We see you are a member of the Linnean Society. Could you tell us more about the society and its activities?

The Linnean Society of London is the world's oldest active biological society. Founded in 1788, the Society takes its name from the Swedish naturalist Carl Linnaeus (1707–1778) whose botanical, zoological and library collections have been in its keeping since 1829. It provides a forum for natural history playing a key role in the documentation of the world's flora and fauna. Its members are drawn from a wide spectrum of biological sciences with particular emphasis on evolution, taxonomy, biodiversity and sustainability.

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

It is a tri-partite relationship with nature. I need to experience it directly, regularly. I am curious to understand it through my work with scientists and finally I am driven by the urge to translate and distil these experiences into a wide range of artworks that hopefully engage and enthuse audiences to share my passion and look more closely at the world with their own eyes.

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

I have just started a new collaboration, Gromorph, with the plant biologist Enrico Coen from the John Innes Centre for plant science and microbiology. Enrico and his team have developed a computational mathematical programme for exploring how flowers grow. Working from diagrammatic interpolations and 3D printed models derived from the programme, I am exploring the morphological parallels between plant growth and the formation of glass and ceramic vessels as described in D'Arcy Wentworth Thompson's 1917 book, *On Growth and Form* as the basis for the creation of a series of vessels in ceramics and glass.

Gromorph, exploring polarities # 6 (top) and #7.
Mouth-blown glass.
Rob Kesseler, made with assistance from James Maskrey,
National Glass Centre, Sunderland | 2013

At Central Saint Martins College of Arts and Design in London where I am professor of Ceramic Art & Design I have made moulds from the 3D models to create bone china versions of the hypothetical plant forms. At the National Glass Centre, Sunderland, working with glassmaker James Maskrey, we have been applying the analogous structural properties inherent in the mathematical plant models within the context of hot glass blowing to create a collection of prototype vessels.

What are your favorite 3 websites, and why?

Wolfgang Stuppy's blog for the Millennium Seed Bank, Kew. Always fascinating bits of information: http://www.kew.org/news/kew-blogs/millennium-seed-bank/index.htm

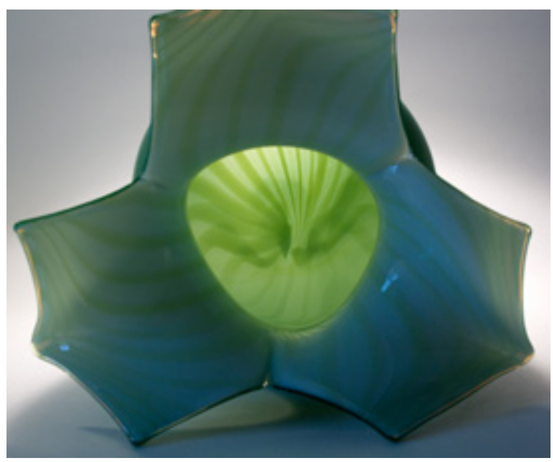
BBC Nature. Stunning mouth watering photography: http://www.bbc.co.uk/nature/

Exploring the invisible, a blog by a molecular biologist I have worked with. Something new every day: http://exploringtheinvisible.com/

What's your favorite motto or quotation?

The English artist Les Coleman who died recently was a good friend who published many small books of aphorisms illustrated with his drawings. Dipping into one of his books reveals a treasure of humorous perceptive quotes. Today I found this one in his book *Unthunk*:

"If you are not sure where you are going, it is possible you are on the right road" ×



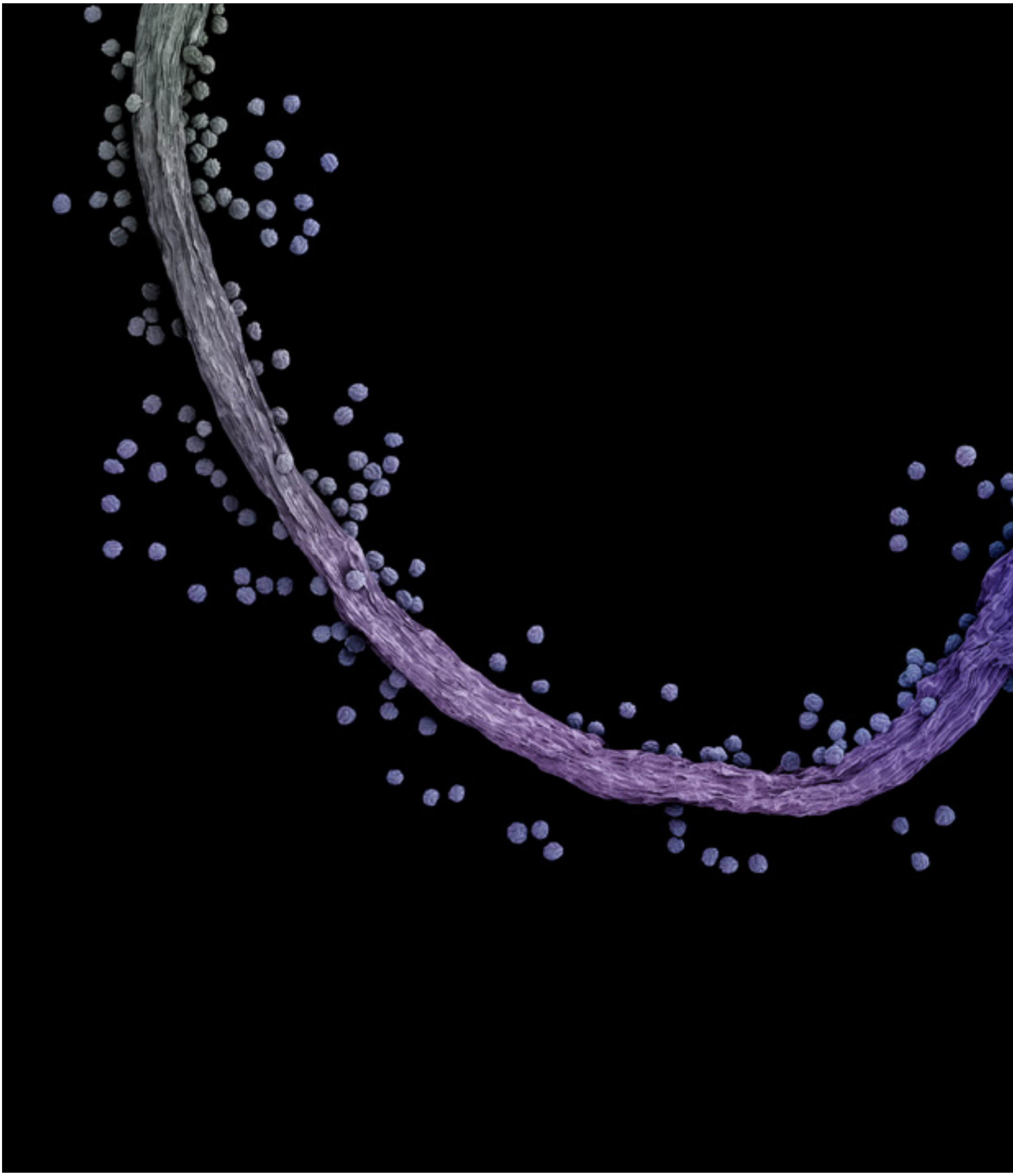
Gromorph, exploring polarities # 5 (top) and #7.

Mouth-blown glass.

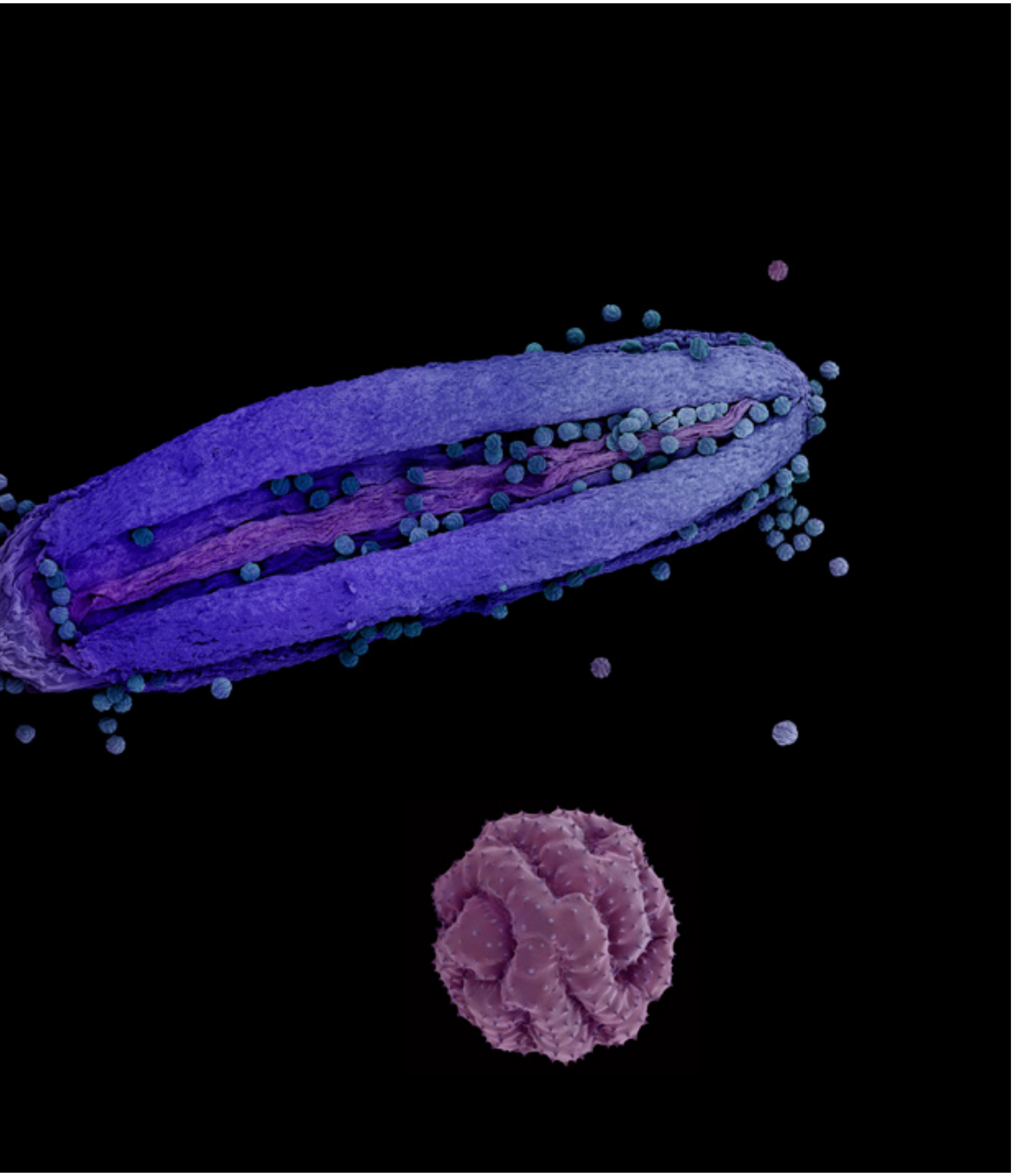
Rob Kesseler, made with assistance from James Maskrey,

National Glass Centre, Sunderland | 2013

Author:
Rob Kesseler



Anemone hortensis, Broad leaved anemone. Stamen with pollen grains, composite hand coloured micrograph. | Rob Kesseler | 2013



Salix, Willow, caught on the fibres of a car pollen filter. Hand coloured micrograph.

From: *Pollen, the hidden sexuality of flowers* by Rob Kesseler and Madeline Harley | Papadakis Publisher | 2009

Stellaria holostea, Greater stitchwort, pollen grain. Hand coloured micrograph

From: *Pollen, the hidden sexuality of flowers* by Rob Kesseler and Madeline Harley | Papadakis Publisher | 2009

Blackstonia perfoliata, Yellow-wort. Seed capsule, composite hand coloured micrograph.

Rob Kesseler | 2013

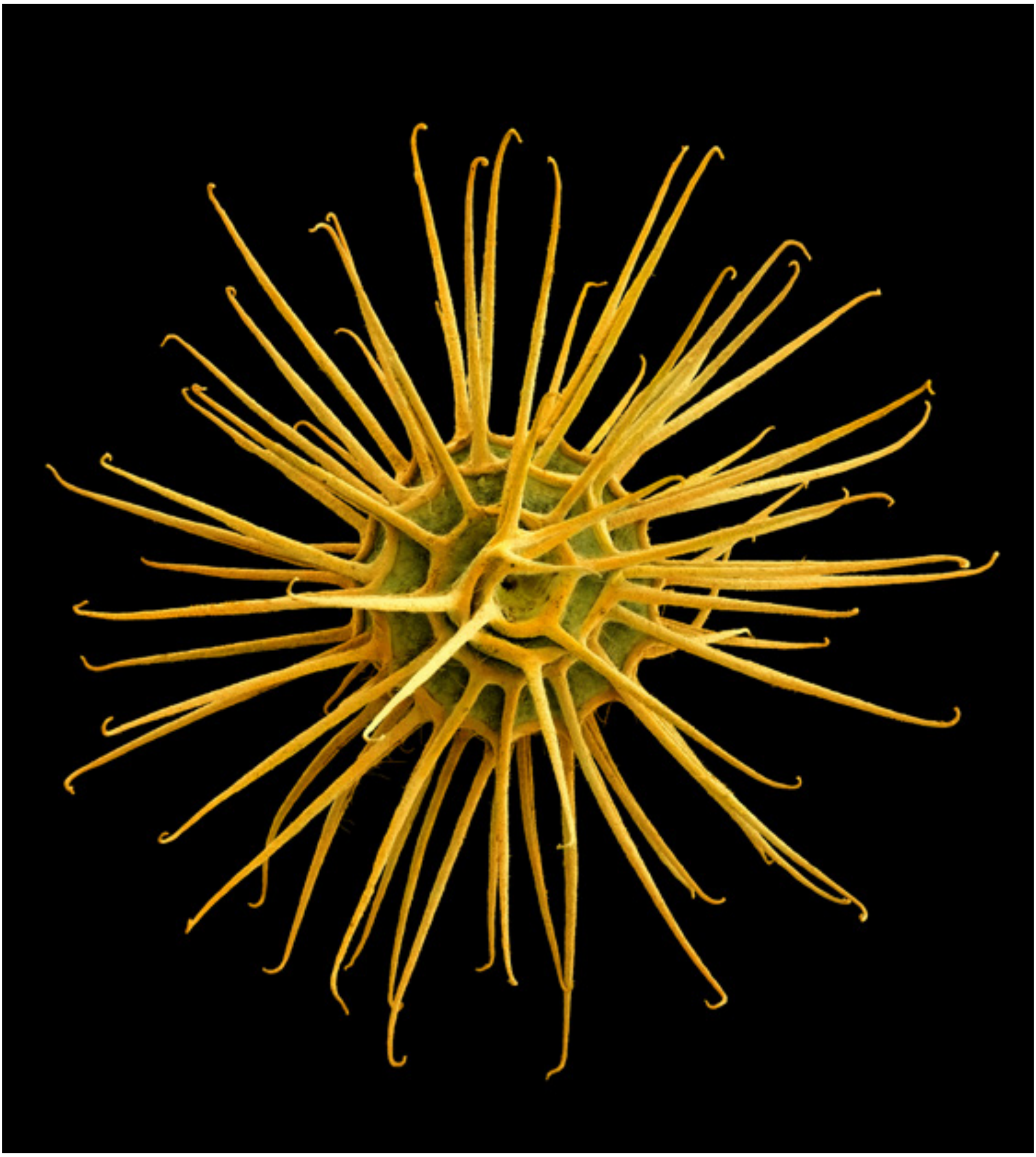
Capsella bursa-pastoris, Shepherds purse, fruit, seed, pollen grain. Composite hand coloured micrograph

Rob Kesseler | 2013

Author:
Rob Kesseler

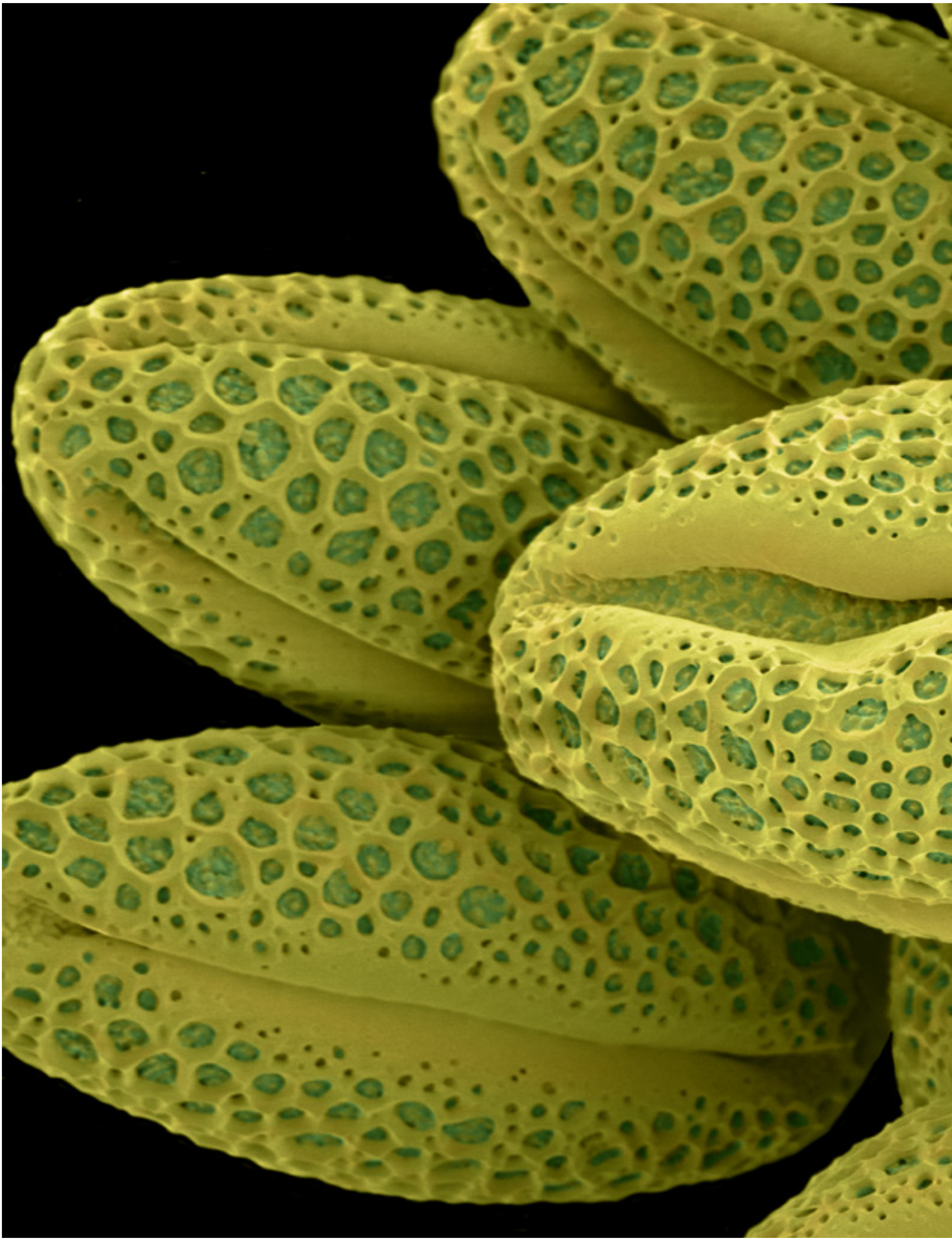
Calotis breviradiata, Short-rayed bur daisy, fruit. Composite hand coloured micrograph.

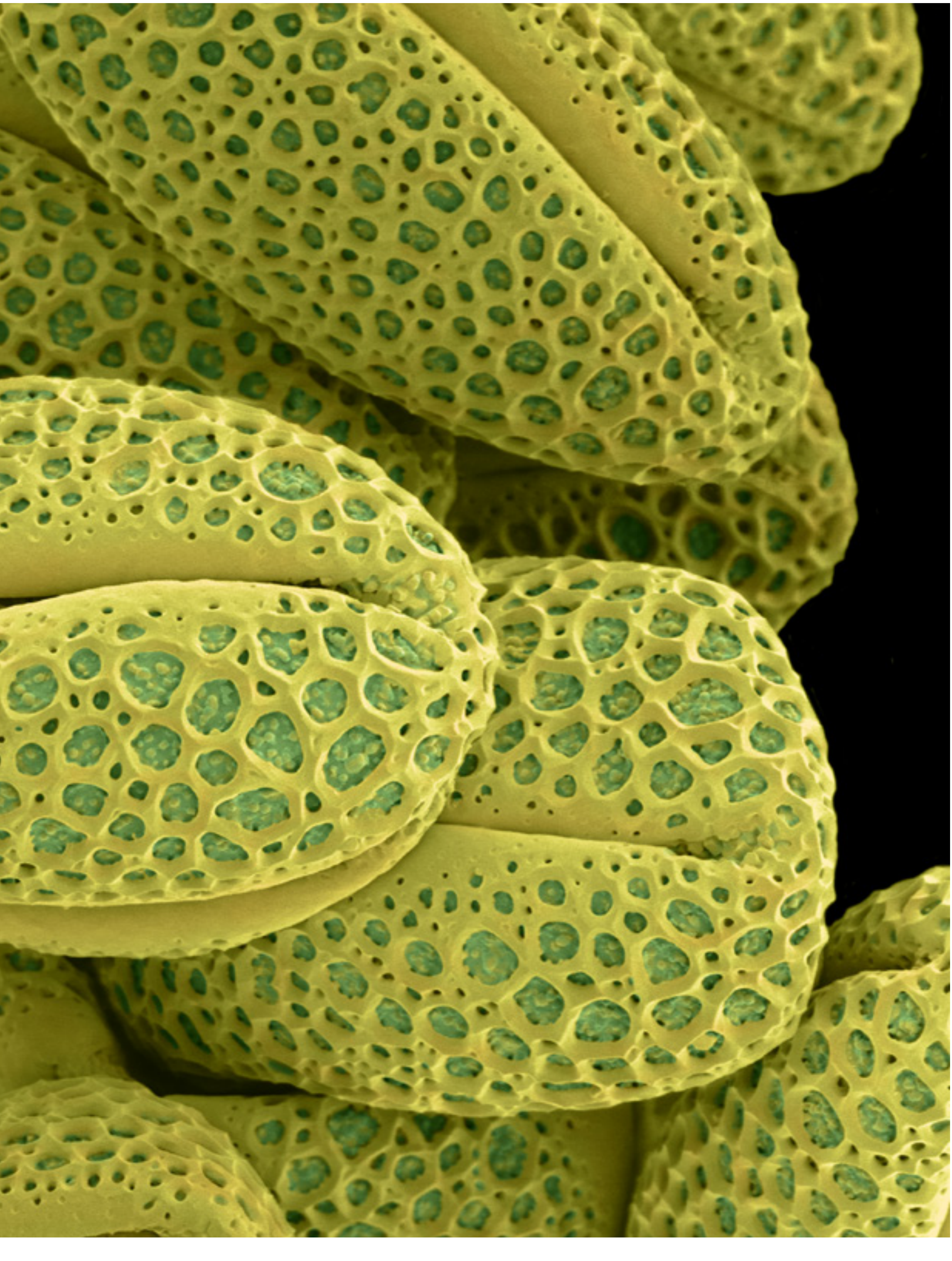
From: *Fruit, edible, inedible, incredible* by Wolfgang Stuppy and Rob Kesseler | Papadakis Publisher | 2007



Medicago minima, Small medick, seed. Composite hand coloured micrograph of seed.

Rob Kesseler | 2013





Previous page: *Salix caprea*, Goat willow, pollen grains.
Hand coloured micrograph
Rob Kesseler | 2010

This page: *Scabiosa cretica*, Scabious, fruit. Composite hand coloured micrograph of fruit.
Rob Kesseler | 2013

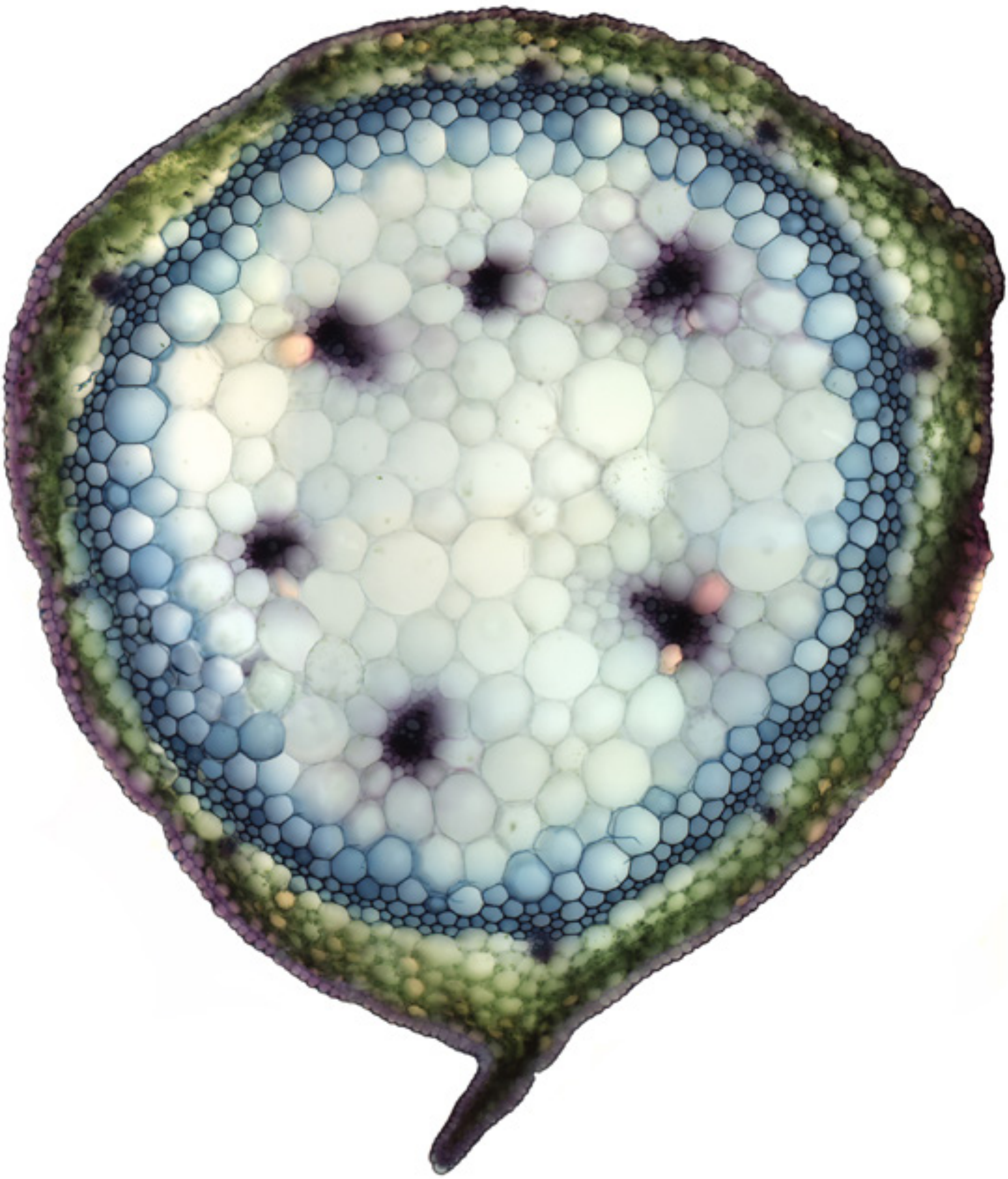
Cydonia oblonga, Quince, pollen grain. Hand coloured micrograph.

From: *Pollen, the hidden sexuality of flowers* by Rob Kesseler and Madeline Harley | Papadakis Publisher | 2009

Citrus aurantium, Bitter orange, pollen grain. Hand coloured micrograph

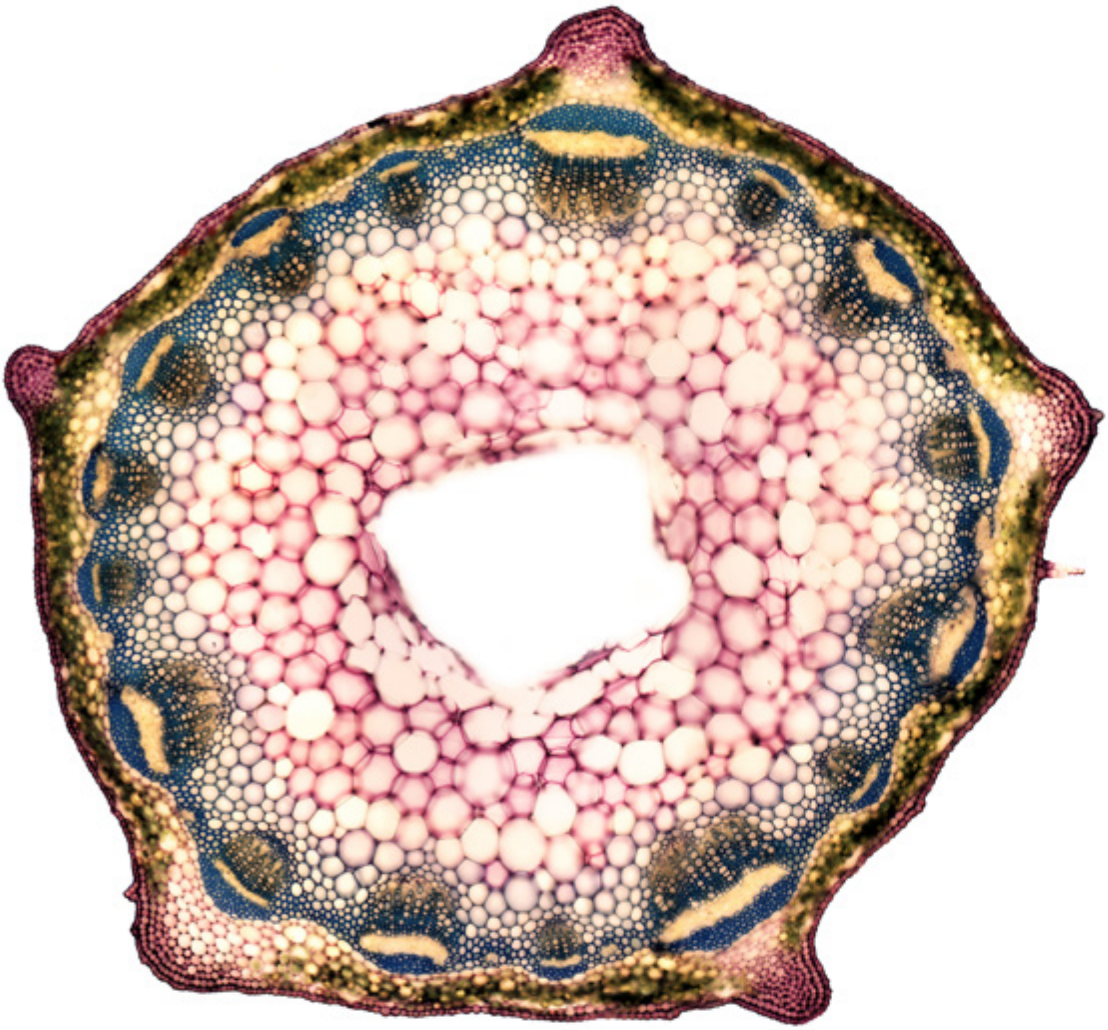
From: *Pollen, the hidden sexuality of flowers* by Rob Kesseler and Madeline Harley | Papadakis Publisher | 2009

Author:
Rob Kesseler



Allium neapolitanum, Naples garlic. Stained stem section. Composite light micrograph.

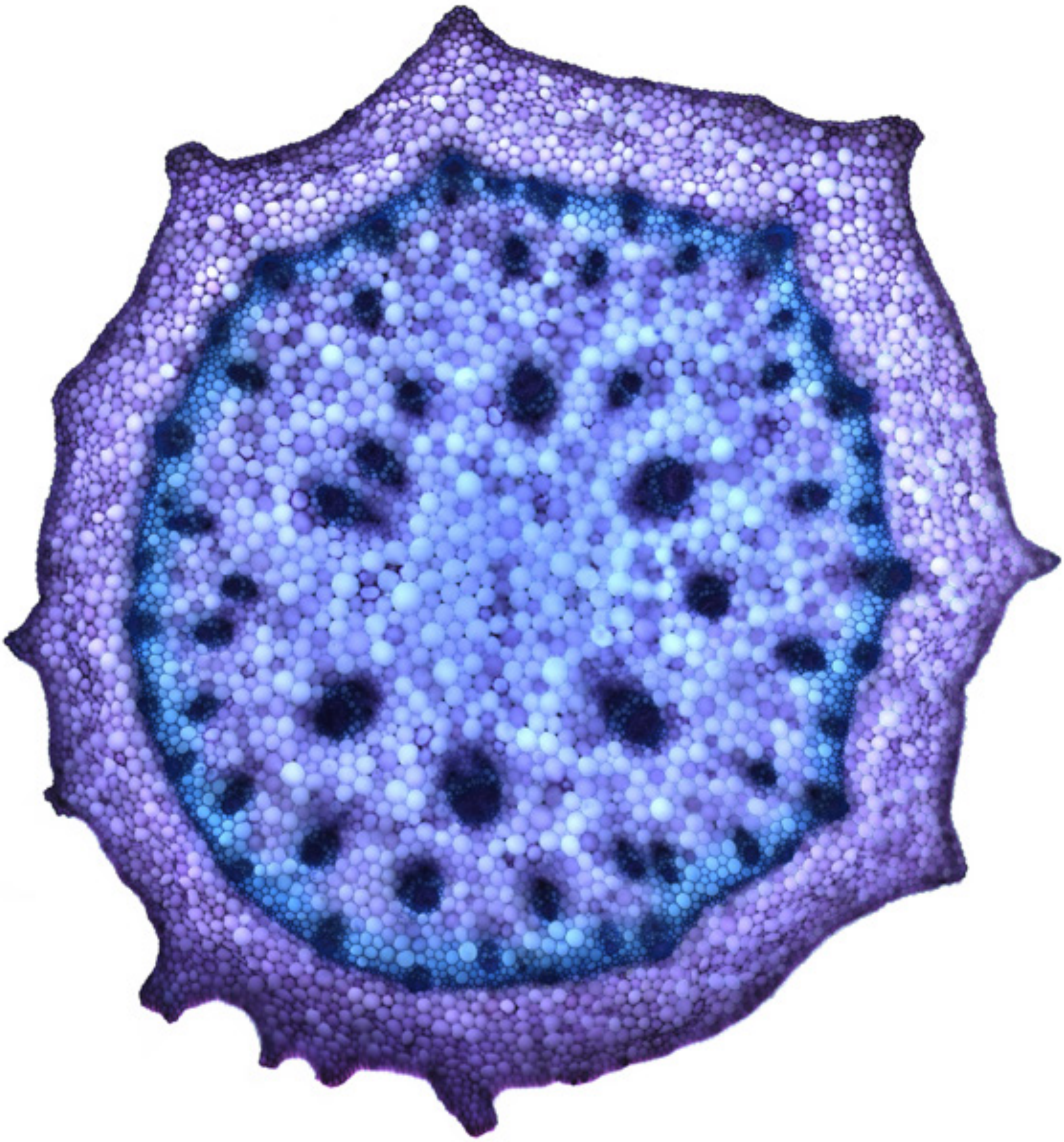
Rob Kesseler | 2010



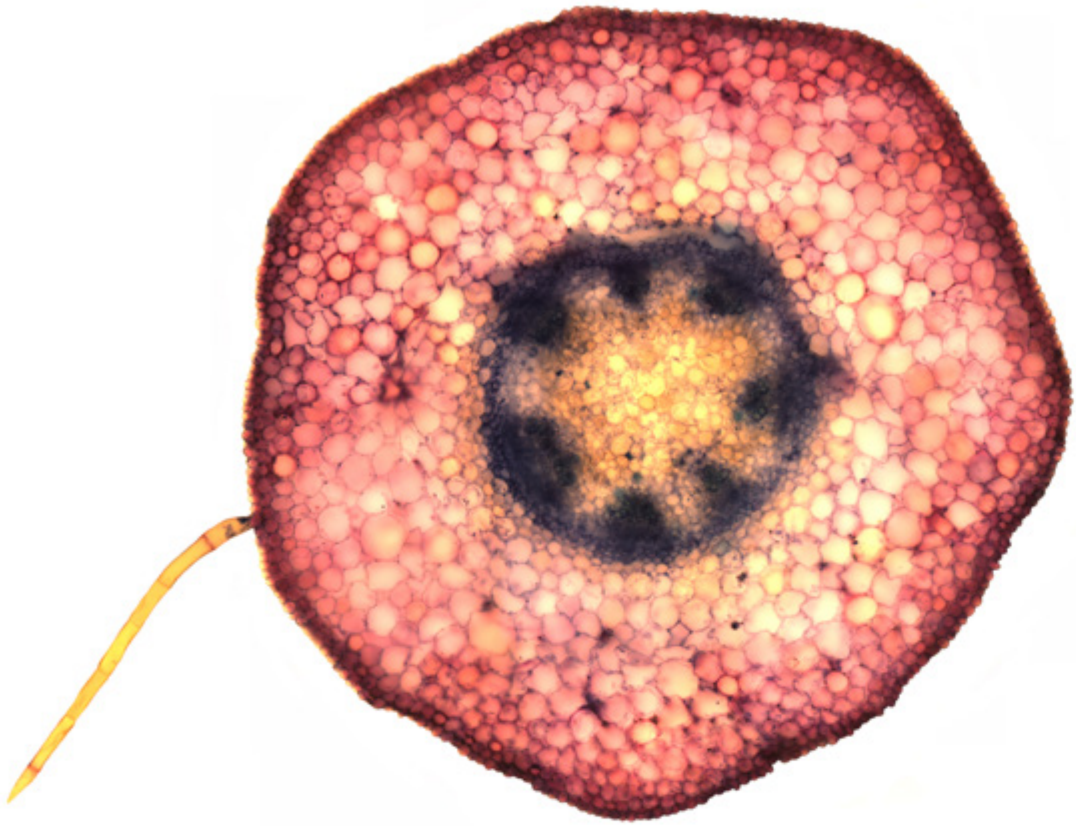
Calendula arvensis, Field marigold. Stained stem section. Composite light micrograph.

Rob Kesseler | 2010

Author:
Rob Kesseler



Cephalanthera longifolia, Narrow-leaved helleborine. Stained stem section. Composite light micrograph.
Rob Kesseler | 2010



See ‘*Field Work* Rob Kesseler’ here:

http://vimeo.com/59733758

If you are in London, England this summer please visit:
Meadow: a dynamic installation of drawings, photography, ceramics and glass by Rob Kesseler
Platform Gallery | Habitat, London | 5 July – 18 August, 2013

Primula vulgaris, Primula, Stained stem section. Composite light micrograph.
Rob Kesseler | 2010

Old timer structural worker

Photo: Lewis Hine, 1930 | Wikimedia Commons

Case Study

Growing the Business of Bio-Inspired Design in the Empire State

Tom McKeag

summer 2013

Case Study
Growing the Business of Bio-Inspired Design in the Empire State

Author:
Tom McKeag

Growing the Business of Bio-Inspired Design in the Empire State

A Region in Transition

Upstate New York has had a distinguished history as a center of innovative manufacturing. It was the incubator of Kodak, Corning Glass, General Electric and many other successful and pioneering companies from the Industrial Age. Times change, however, and, like its Rust Belt neighbors bordering the Great Lakes to the west, the area has had to make a difficult transition to the Information Age. Between 2000 and 2008, upstate New York had lost over 100,000 jobs and nearly 25% of its manufacturing base, according to the New York State Office of the Comptroller.

This has not been good news for a region where manufacturing accounts for 20% of the wages earned in the private sector. Fortunately, new jobs in information and communications, and electronics and computer manufacturing have increased the opportunities for the region's well-educated and skilled workforce. The increase in high-paying technical jobs has not happened simply because of the vagaries of the private market. The state and national governments have aided this process in a variety of both public and private partnerships.

In October, 2012, for example, the Economic Development Administration of the U.S. Commerce Department awarded over $3.5 million to expand technology research and development in the cities of Syracuse and Rochester. Syracuse University will be the home of the Thermal and Environmental Control Systems Cluster, and the University of Rochester will host the Regional Optics, Photonics and Imaging Accelerator. The purpose of the program is to develop regional innovation clusters throughout the United States to create, in the words of the Obama administration, "an economy built to last".

A Unique Partnership

The State of New York has also guided economic redevelopment. One unique partnership that has grown from this has been formed around the concept of bio-inspired design. The New York State Energy Research and Development Authority (NYSERDA) has embraced biomimicry as one avenue to innovation and committed itself to popularizing the concept among researchers, inventors and manufacturers.

The overall mission of NYSERDA is to help New York meet its energy goals: reducing energy consumption, promoting the use of renewable energy sources, and protecting the environment. To accomplish this NYSERDA has sought to develop a diversified energy supply portfolio, improve market mechanisms, and facilitate the introduction and adoption of advanced technologies.

Aerial Photo of upstate NY. Lake Ontario south coast.
Photo: Luciof, 2011 | Wikimedia Commons

Case Study
Growing the Business of Bio-Inspired Design in the Empire State

Author:
Tom McKeag

Documerica - Smog Layer Over Upstate New York, 2002

Photo: (NASA) pingnews.com, 2007 | Flickr cc

To promulgate bio-inspired design within the regional research and development field the organization has partnered with both public and private players in a unique blend of co-funding, education and matchmaking. Through the Energy Innovation and Business Development program NYSERDA provides a range of funding opportunities supporting R&D as well as collaboration with academics and scientists. A key part of the program is to match clean tech companies with academics conducting cutting edge research in natural systems and programs. Academics and scientists provide the knowledge base or engage in basic research, while the companies provide the challenges, an understanding of the parameters of commercial success and the manufacturing expertise to deliver the solution.

Funding can support proof of concept through actual manufacturing. The program's support is targeted to clean-energy technologies in six key areas: building products, additive manufacturing and biomaterials, solar power, smart grid and battery storage technologies, ceramics and thin films, and electronics and software.

One pivotal player is Terrapin Bright Green, a privately held sustainability consultancy based in New York City that specializes in promoting biomimicry. Terrapin was hired by NYSERDA in 2010, under a technical assistance contract, to help promote the bio-inspired approach, find biomimetic solutions to energy issues, and match academics with manufacturers for proposed NYSERDA biomimicry projects. Terrapin had been active before the start of the program, and indeed, together with the Biomimicry Guild of Helena, Montana, had organized a Biomimicry Roadmapping Workshop and a 2009 symposium on the topic at Rensselaer Polytechnic Institute (RPI) in Troy, New York.

A Preliminary Case Study | The Problem

One example from this program is Air Innovations (AI), a mid-sized company located in Syracuse, NY, that develops and manufactures OEM (original equipment manufacturer) environmental control systems and other air conditioning products. One of their products, the "HEPAirX", is a room air purification product using high efficiency particulate air (HEPA) and/or carbon-based filtration for the removal of airborne particulates and volatile organic compounds (VOCs). The HEPAirX "dilutes, filters and reduces the indoor pollutants that are often cited as causes of asthma, respiratory irritations and allergic reactions", according to the company website.

Air Innovations was searching for a better filtering technique for their product, and thought nature-inspired innovation could provide an answer. They had two problems. First, the better that the filter worked, the more particulates that it collected. This resulted in reduced airflow and increased the energy needed to pass air through the filter: a built in contradiction and devolution of performance. Second, there was no way economically to tell when the filter had reached its "saturation" point when collecting the VOCs. For this reason, filters would be changed out, perhaps prematurely, on a schedule rather than a needs basis.

The Process

Terrapin held a general information workshop about bio-inspired building technologies which allowed Air Innovations to formulate potential biomimicry R&D project ideas that would improve their system. After a discussion of this needs list the consultant identified a research partner for the company at the College of Nanoscale Science and Engineering at the University of Albany (CNSE).

That research partner was Dr. Nathaniel Cady, Associate Professor of Nanobioscience and his laboratory team at CNSE. Dr. Cady had been part of the original NYSERDA biomimicry panel discussions, so was familiar with the program and its goals. His work has centered on several nano-scale research issues: the development of new types of biosensors for use in clinical diagnostics, and how cells interact with their environment at the nano-scale, specifically how they adhere to, move along, and penetrate different surfaces. Dr. Cady is keenly interested in knowing more about this nano-scale landscape and how it affects cell behavior. His work could provide needed insights into the bioengineering applications of prosthetics, medical device design and their biocompatibility as the boundaries between patient and machine become increasingly blurred.

Dr. Cady began exchanging ideas with Larry Wetzel, Engineer and Chairman of the Board of Air Innovations by phone and email. Mr. Wetzel, in addition to his many managerial duties, was the principal investigator on several HEPAiRx ventilating air purifier research studies and was involved actively in the product's commercial launch.

A face-to-face meeting, however, brought some surprises, according to Dr. Cady.

"Initially, we had a misperception about the energy fit. We had assumed that the room-sized air filtration unit given as an example would define the boundaries of the problem of energy saving. Consequently we had focused on passive solutions for removing contaminants.

When we met with AI, we realized that they wanted to consider their larger, building-sized systems and that therefore additional energy inputs to cleaning the air would be allowed in the solution set. As they pointed out, these additional inputs would be a drop in the bucket in the overall energy budget of these larger systems. It was then that we reintroduced some solutions that we had thought were off the table."

The two collaborators applied for funding from NYSERDA to conduct a feasibility study of bio-inspired methods for improving indoor air quality as well as reducing the energy needed to do it. They have since received a contract and funding for FY 2013, estimated the work to take six months and are halfway to completion. They have finished a formal problem statement and literature search, while they continue to work on the proof of concept phase involving the main laboratory work and the final summary report.

The problem statement comprised a discussion of indoor air quality, a correlation between this quality and human health, a review of the state of the art of current filtering solutions (including a detailed walk-through of those at AI) and a few examples of promising solutions

Whitaker Park - Martinsburg, New York

Photo: Dougtone, 2011 | Flickr cc

for a scale-up to larger systems. The report drew heavily from the indoor air quality research done at the Ernest Orlando Lawrence Berkeley National Laboratory (LBNL | http://www.lbl.gov/)

The early meetings also yielded a refinement of the focus of the study. While both particulates and VOCs were targeted in the initial problem statement, the team now decided to restrict work to the removal of VOCs from air. Air Innovations doesn't manufacture its own particulate filters, relying on subcontractors to supply them. Their intent, moreover, was not to redesign the system but to enhance the filtering capability of the system. CNSE therefore felt that investigating a redesign of this type of filter would not be as productive as solving the second part: VOCs.

Traditional methods of removing VOCs center on the use of activated charcoal to adsorb the pollutants. Activated carbon filters are quite effective at clearing the air of pollutants, and they can be regenerated through a combination of desorption and venting to the outside air. Their typical presence in an HVAC (heating ventilation air conditioning) system, however, present the problem initially identified: clogging. When they do become saturated, they reduce the airflow and increase the energy and cost needed to force air through the system. The CNSE team, which included Dr. Magnus Bergkvist and Dr. Andres Melendez, pointed out in their first report that one study had demonstrated a pressure drop of ~350 Pa across an activated charcoal filter at 100 cfm.

As an alternate to activated charcoal, the CNSE team started to ask in what ways nature changed toxins. One common way is through redox reactions (see sidebar). They have also looked at how nature absorbs toxins investigating both plants and bacteria. The researchers knew that some organisms make inorganic materials that could be useful but were also interested in how they template material for filtering, for example, to increase relative surface area.

Specifically, the team looked at how micro-organisms convert toxic substances to non-toxic. Enzymes are what accomplish these redox reactions, an exchange of electrons between reactants. They therefore have had to figure out what source and sink they could use for these electrons, in say, an oxidation process. Enzymes are

Indoor Air Quality

Indoor air quality (IAQ) is a significant area of research, being both a source of public health concern and an opportunity for innovation and cost-savings in the building industry. The increasing urbanization of the world's population, time spent indoors, and the proliferation of synthetic materials are three trends that have contributed to the gradual degradation of the air that a modern city-dweller breathes. Several recent studies of Californians found that adults spent an average of 87% of their time indoors. Most of the unhealthy indoor air comes from inside the building: off-gassing from adhesives, carpets, upholstery, pesticides, cleaning agents, and furniture, to name a few.

The prime culprit in this unhealthy chemical air pollution is a class of material known as volatile organic compounds, or VOCs. VOCs are broadly defined as chemical compounds based on carbon chains or rings with vapor pressures greater than 0.1 millimeters of mercury at room temperature. These compounds typically contain hydrogen and may contain oxygen, nitrogen and other elements. Carbon monoxide, carbon dioxide, carbonic acid, metallic carbides and carbonate salts are excluded. Methane also is often excluded from the definition.

They are caused typically by either emission from new building materials, like paints, carpets and furniture or the chemical or physical breakdown of older such materials. They have been correlated to childhood asthma, chronic bronchitis and chronic obstructive pulmonary disease. Of the hundreds of VOCs associated with poor indoor air quality, formaldehyde is a common component in urea-based resins that are found in adhesives, wood floor finishes, pressed-wood products, and carpeting. Exposure to levels of formaldehyde as low as 1000 μg m-3 have been shown to cause eye and lung irritation.

Traditional particulate filters are not able to clean the air of VOCs and an activated carbon filter is typically added to this type. Activated carbon filters take advantage of the propensity of VOCs to bond with the carbon, and after a period of time this carbon becomes saturated with the chemicals and free VOC molecules in the air no longer adhere to the filter. It must then be purged of the chemicals and re-installed.

The Indoor Environment Department at the Lawrence Berkeley National Laboratory (LBNL) conducts a broad program of research,

View south from Breakneck Ridge, Hudson Highlands
Photo: ScubaBear68, 2008 | Wikimedia Commons

what accomplish redox reactions, but how to get the enzyme to work reliably presented a challenge, followed by how to incorporate these solutions in a device like the one AI makes. One possible approach is to lay the organic enzymes onto a substrate. While they had looked at some bio-utilization schemes involving the use of whole plants, they had rejected this approach as requiring too much maintenance.

"One challenge that we have faced is the gas matrix problem, since most biological reactions occur in liquids, not air. Could we humidify the air to keep enzymes active in a gas matrix, or would that cause other problems? Could we do redox reactions without moisture? A broader question became how far should we take the biological approach?" said Dr. Cady.

Despite these ongoing challenges Dr. Cady is quietly sanguine about the work: " I would never have gotten into this area of research without the NYSERDA program and it has been a very worthwhile investigation that has allowed me to work with a company in applied science. The seed funding is a good way to test this interdisciplinary approach and find out if an idea is sound and has demonstrable impact."

Miriam Pye, Senior Project Manager at NYSERDA, believes that their gradual balancing of outreach to include the appropriate academics has paid off: "Initially we were reaching out primarily to industry for biomimetic solutions, but you need to find people who know about details. That's when we turned to academics. We needed that depth of understanding."

A Possible Model

This New York example may provide a model for innovative bio-inspired product development in other locales. NYSERDA has not tried to incubate a bio-inspired based company by "pushing" a technology unto the market, but rather has presented the advantages of the bio-inspired approach and provided funding to companies in need of solutions; the "demand pull" approach. Demand alone, however, may not be sufficient for successful innovation and technology change: the technology must be sufficiently

technology development and dissemination activities directed toward improving the health, comfort and energy efficiency of the indoor environment. One such area is the study of indoor air quality. Two nascent methods for removing VOCs investigated by LBNL have been the use of a woven carbon fiber, and the use of metal oxide nanomaterials. Both methods were reviewed by the team at CNSE in their initial report.

Redox reactions are an area of research now being pursued by the team at CNSE as a method for converting toxins in the air. The term is a conflation of "reduction" and "oxidation", and includes all chemical reactions in which atoms have their oxidation state changed. This can be either a simple redox process, such as the oxidation of carbon to yield carbon dioxide (CO_2) or the reduction of carbon by hydrogen to yield methane (CH_4), or a complex process such as the oxidation of glucose ($C_6H_{12}O_6$) in the human body through a series of complex electron transfer processes.

Redox reactions comprise the transfer of electrons between molecules and the processes of reduction and oxidation are two complementary halves of the same action. Oxidation is the loss of electrons or an increase in oxidation state by a molecule, atom, or ion. Reduction is the gain of electrons or a decrease in oxidation state by a molecule, atom, or ion. Hence one side of the action must lose at least one electron (a source/donor) and one side must gain (a sink/acceptor).

An example of this method applied to a building technology is the Pilkington Glass product, Activ glass, which uses a thin, transparent coating of titanium dioxide to oxidize any dirt or debris that may fall upon it. Titanium dioxide is a so-called photocatalytic, meaning that sunlight charges it electrically and its charged surface interacts with air and water vapor to create ions. It is these ions that break up the organic material. The result is a degree of self-cleaning, as the degraded organics are easily washed away in the sheet flow of water that will form on this type of surface.

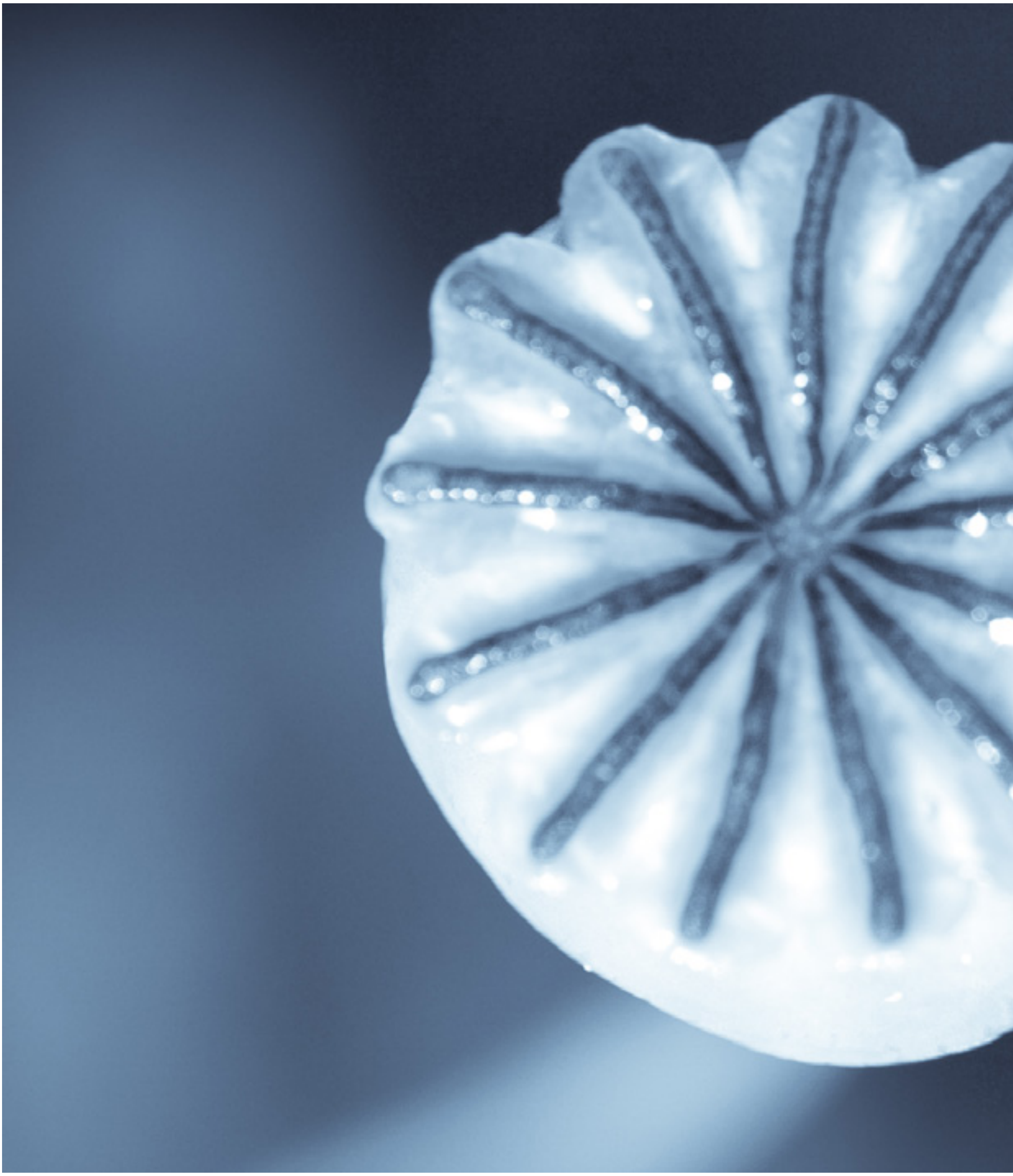
mature and compatible with existing delivery mechanisms. This is especially relevant: rather than targeting startups, the program emphasizes existing companies that have commercially viable products but require innovative solutions to solve limitations.

Key to this compatibility appears to be the matchmaking of research and manufacturing in a focused and funded application. This includes the sometimes messy and iterative process of interdisciplinary collaboration between those inspired by discovery and those constrained by commercial performance. It remains to be seen if this process will yield an important energy product improvement within the next few years.

So far, the collaboration between CNSE and AI has gone smoothly. Speaking of the Air Innovations collaboration, Dr. Cady said, "As for what I think they learned from us, I think they knew us only as experts in biology, and were surprised at the extent that our interdisciplinary team was knowledgeable in engineering and technology. Both groups were surprised at how much closer we were in mutual understanding and approach to the problem than was expected." He believes the biomimetic approach was most useful after the boundary conditions of the problem were set, and a broad, divergent search for new methods needed. He will consider using the process again as a broad check to avoid professional myopia in the optimization phase of their work.

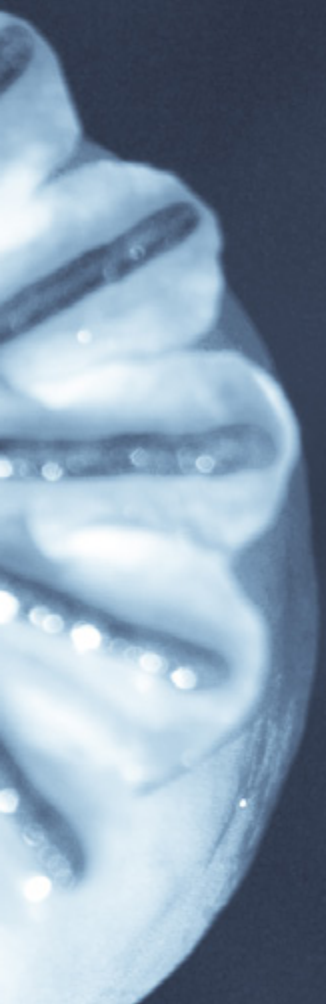
Although in its early stages, this program can only be seen as unique and pioneering. For the participants, there are different potential benefits: the academics are able to discover a new technology, the company is able to develop a better product, and the funder is able to improve the energy equation for the citizens that it serves. As Chris Garvin, Project Lead at Terrapin, put it:

"The Terrapin-NYSERDA Biomimicry project is the only state-funded innovation program focused on harnessing nature's genius to drive innovation in the U.S. It's a worthy model for other states to emulate." ×



Seed head

Photo: simpologist, 2007 | Flickr cc



People
Interviews with
Brent Constantz and Anamarije Frankić

Cirripathes sp. (Spiral Wire Coral)

Photo: Nick Hobgood, 2004 | Wikimedia Commons

Interview
Brent Constantz

Brent Constantz was trained in biological and geological sciences, and has special interests in biomineralization - mineral formation by organisms. Following his graduate and post-doctoral studies, he founded and led three medical device companies that improved the quality of care for conditions related to mineralization in the human body that are used today in most hospitals around the world. Over the last five years he has directed his attention to global climate change problems, exploring sequestration of carbon dioxide in carbonate minerals and fresh water production to relieve drought caused by climate change.

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

There is enormous potential to advance the broader appreciation of evolutionary designs. Engineers and other scientists could be inspired by broader understanding of evolution. I think people are starting to realize that 'biomimicry' and 'bio-inspired' design has been around for centuries. These are just newer terms that sound pretty sexy which we started using in the early 1980s, but fundamentally don't describe anything new.

What do you see as the biggest challenges?

Making sure people in the field have fundamental training in biology, natural sciences and engineering, especially evolutionary processes. Many individuals entering the field may not be fundamentally grounded in biology, physical sciences and engineering. The field requires rigorous training more akin to bioengineering programs, instead of what some would see as a branch of environmental studies.

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

Climate change presents the greatest impact for mankind. There are many applications in improving the built environment.

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

As an undergraduate, and in graduate school, we studied 'functional morphology' – an area of paleontology where we try to understand the function of structure in extinct organisms. We asked questions like "what was this for?"

What is your best definition of what we do?

Study the evolution of form.

By what criteria should we judge the work?

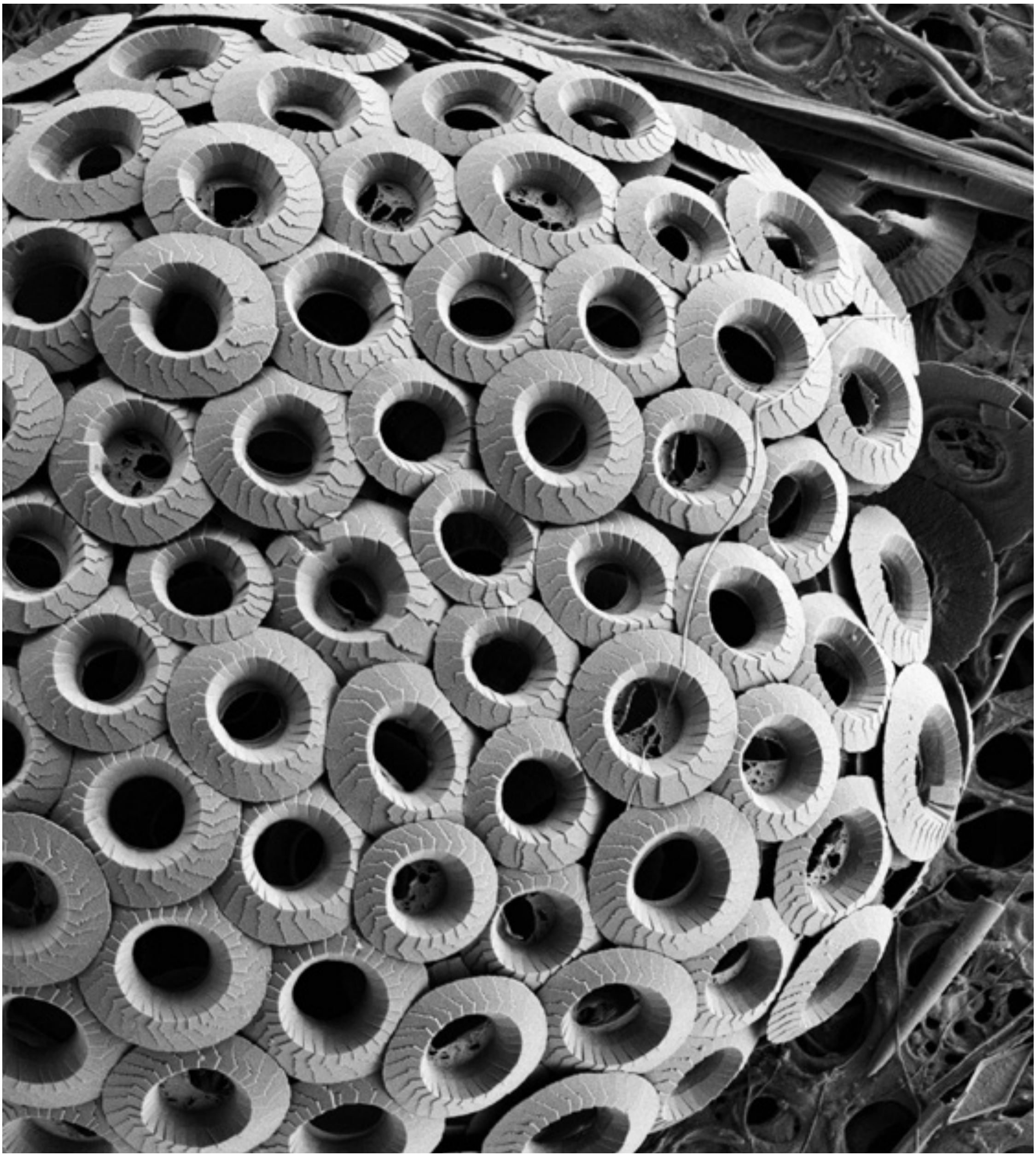
The extent to which we capture the function of biological form in our inspired designs

What are you working on right now?

Carbon dioxide capture by living organisms – especially mineralizing systems like reef building corals – with the intent of mimicking carbon dioxide sequestration in structure or beneficial reuse, especially in the built environment.

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

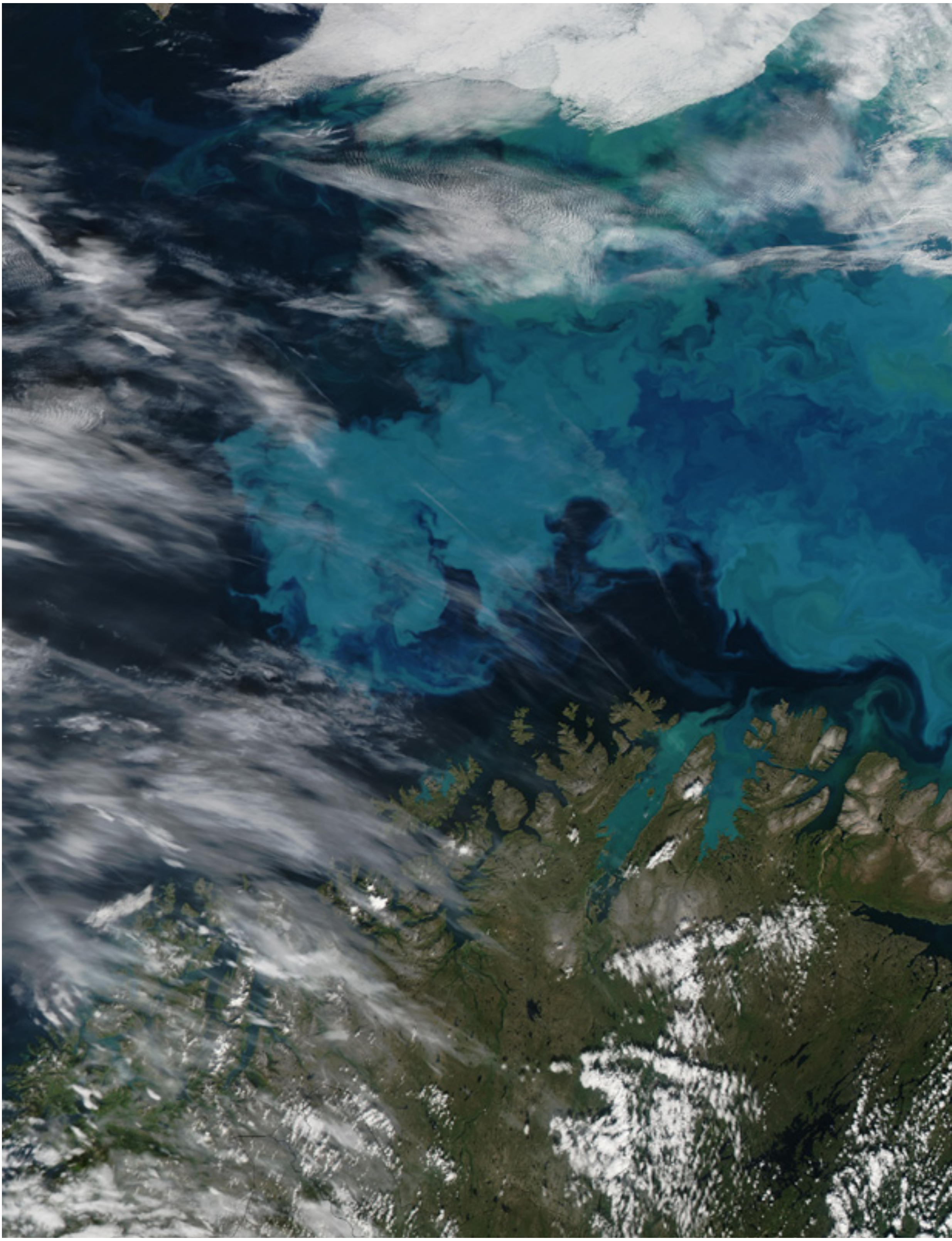
My new company, Blue Planet Ltd.



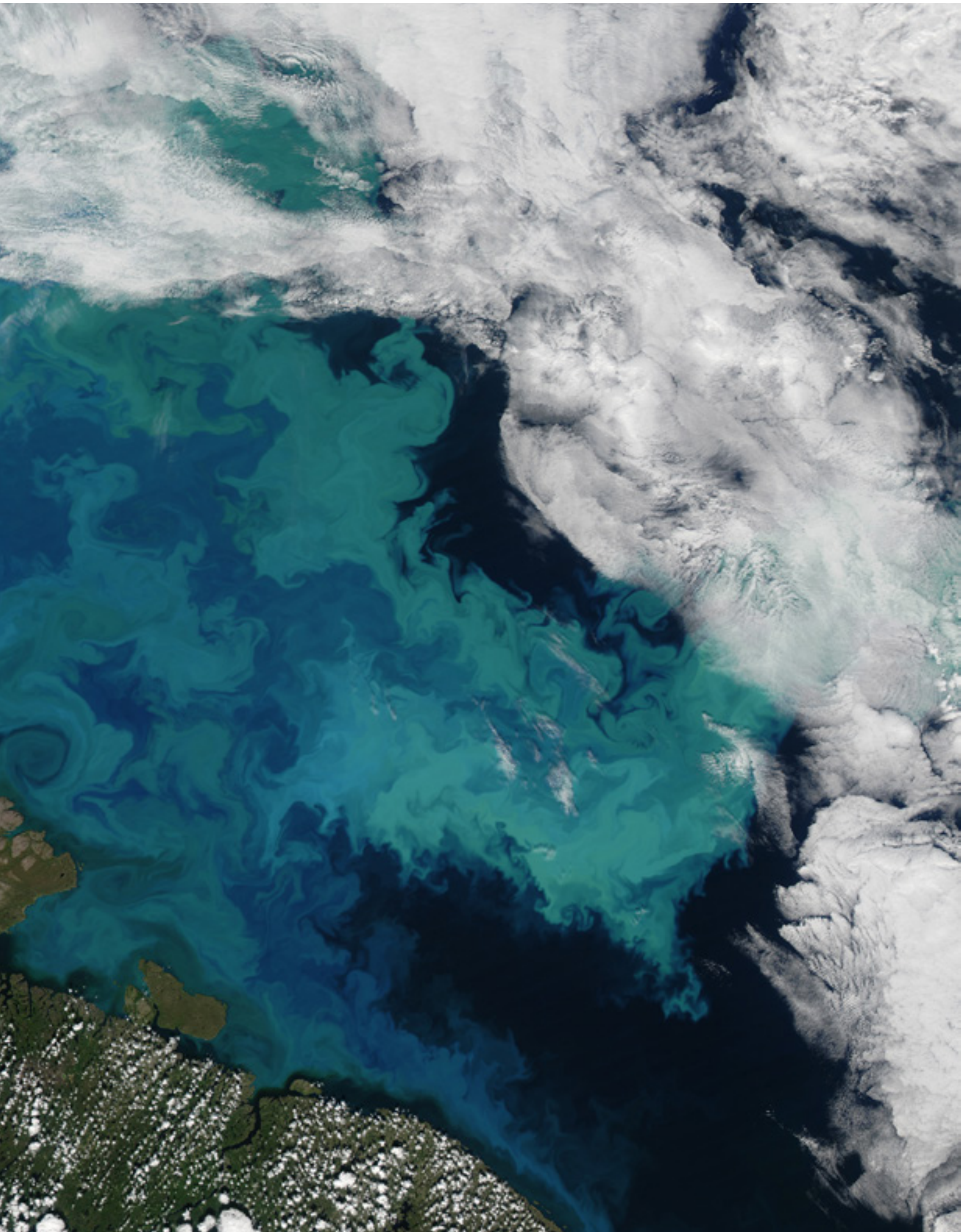
Umbilicosphaera sibogae conglomeration (A Coccolithophore) | unicellular, eukaryotic phytoplankton (algae)

The individual plates of calcium carbonate formed by coccolithophores are called coccoliths

Photo: Carl Zeiss Microscopy, 2012 | Flickr cc



Bloom in the Barents Sea | Jeff Schmaltz, NASA Earth Observatory, 2011 | Wikimedia Commons



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

I've founded five companies, all based on biomimetic design over the last 27 years. Two make synthetic bone for orthopedic surgery, one makes cardiovascular revasculatization devices, and two sequester carbon dioxide for beneficial reuse in the built environment.

What is your favorite biomimetic work of all time?

My bone cement use for treating osteoporotic fractures.

What is the last book you enjoyed?

Valley Boy, by Tom Perkins.

Who do you admire? Why...

Children – they have no biases.

What's your favorite motto or quotation?

"Courage is being scared to death, but saddling up anyway" – John Wayne

What is your idea of perfect happiness?

Not knowing you're happy, or worrying about it.

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

A musician. ×

Travertine - Calcium-carbonate-encrusted, Plitvice Lakes National Park.

Photo: Jason Rogers, 2009 | Wikimedia Commons

Shells Inner Harbor - Wellfleet, MA

Photo: Brian Birke, 2012 | Flickr cc

Interview
Anamarija Frankić

Anamarija Frankić, Director, Green Harbors Project, and a founder of LivingLabs™, faculty at UMass Boston, and adjunct professor at the Institute of Fisheries and Oceanography, Split, Croatia. She is a Biomimicry Education Fellow, and a Fulbright Fellow. Her educational background in biology, ecology, limnology and marine science, guided her interdisciplinary work in coastal and watershed ecosystem restoration and management, nationally and internationally. In 2008, Anamarija and her students established the Green Harbors Project to discover how urban harbors can become healthy, wealthy and sustainable, right here and now. She initiated and established LivingLabs to practically connect campuses and communities by 'learning and teaching by doing' concrete sustainable research projects and apply solutions with local community. Her present work is based on learning from nature's three coastal keystone habitats that can only be restored and managed when addressed together: salt marshes, shellfish beds (oyster reefs) and eelgrass beds. Her premise is that 'the environment sets the limits for sustainable development'. She is member of the advisory board AASHE (Association for the Advancement of Sustainability in Higher Education) and on the board of the American Association of the University Women (AAUW).

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

We are at the tipping point - the 'anthropocene' era when we need to massively embrace the bio-inspired designs and strategies in every aspect of our lives; we cannot miss this opportunity that was unfortunately provided the dire straits caused by our behavior in the last few hundred years.

What do you see as the biggest challenges?

How to change our industry, and wasteful behavior that has been instilled in us through education and everyday lifestyle that everyone else wants to imitate globally; how crazy is that? We have been leading ourselves into a disaster, the change is happening too slow, so biomimicry education needs to be available for free.

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

Those two questions are linked – challenges and solutions – we have answers to if not to all but to most of our issues – nature can teach us how to move forward – the major focus should be in education – however, the progress needs to capture every field – like in nature – everything is connected from nano to macro levels and it is not a species competition that has been the driving force for evolution – it is collaboration – so we need to focus how to better collaborate in different fields by using biomimicry and its life principles.

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

I was born with it like everyone else, we just lose the connection through various lifestyles. As a biologist and marine scientist, I also tried various ways in science and technology to search how to solve environmental problems. My education took me from biology, limnology, marine science, environmental management and policy, and the same year I finished my doctoral degree the biomimicry book came out. And that was it,

Oyster spats (baby oysters) on a clam shell, Wellfleet Harbor

Photo courtesy of A. Frankić

Oyster reef restoration site | Photo courtesy of A. Frankić, 2011

the cycle and search was almost done, as I started to practice what I believed in and what I knew the best.

What is your best definition of what we do?

We are learning, teaching and doing what nature has been doing for millions of years. It is hard to catch up and remind ourselves that we are part of the same nature and that we can learn much faster if we can just let go of the forms that we inherited and that have nothing to do with resiliency. We need to be adaptive in order to be healthy, wealthy and sustainable – and that is what nature thrives for every single moment. And that is what we are trying to do by doing biomimicry.

By what criteria should we judge the work?

I think that we have been doing a great job by evolving the biomimicry life principles. It is hard to fulfill all of them and have a holistic approach in everything humans do and produce, which is the main reason for compromises. So, criteria should be life principles (nature principles) that are also human principles – and that should be the main set of criteria to guide our work (judging is the word I don't really like to use, how about 'assess', or 'evaluate').

What are you working on right now?

It is a work in progress, almost organically grown, as I was learning form nature how to best help it heal. In coastal urban systems, where we accept them to be polluted and degraded, I have been working on restoration projects, through LivingLabs as part of the Green Harbors Project. My focus is on one amazing species oyster – that told me that it cannot function just by itself, it needs a reef, where many oysters build these amazing structures and homes for hundreds of other species. I learned that oyster reefs also like to have salt marshes nearby and they support each other sharing food and water; they support each other's resiliency by working together. There is another part of the coastal story – eelgrass beds (or subaquatic vegetation) that depend on both salt marsh and oyster reefs. Although we recognize that these habitats coexist in coastal areas, we tend to address them separately. To regenerate degraded coastal areas, we need to change how we see and do both science and management.

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

I think I answered this question, but as I came to Boston area (2006), I realized that even with the best possible restorations we don't have space to bring back lost habitats, so my interest shifted to how can we build human structures that can biomimic oyster reefs and salt marshes, and whole watersheds. How can human structures support human services and ecological services at the same time and space? I started designing with students 'green piers' and harborwalks, ripraps, etc., and that was when I proposed the LivingLabs program for teaching and learning by doing biomimicry; where we can showcase existing and new applied sciences and technology designs and solutions – it is time to get outside the academic labs and closets ☺.

Salt marsh

Photo courtesy of A. Frankić, 2011

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

Floating islands that inspired me to do green piers, so we can combine human and ecological services and functions.

What is your favorite biomimetic work of all time?

There are so many, but the ones that are capturing the wisdom of a green cell are the best – although not done yet but biomimicking the most effective way to use sun energy and produce food is something I wondered about even as a kid; my mom said that I wanted to have a green hair so I don't have to come home for supper – and continue to play outside and produce my own food like a green plants do☺.

Not bad for an eight year old; which is the main reason I've been teaching young kids as they do get it, while most of my colleagues still don't.

What is the last book you enjoyed?

There are so many, as I always read several books at once: *One square inch of silence* by Gordon Hempton, and *Always, Rachel* (letters of Rachel Carson, who has been and is my inspiration).

Who do you admire? Why...

Women, when you read biographies of Maria Sklodowska Curie, Marguerite Yoursenar and Rachel Carson, it just blows your mind how brave and strong they were at the times that there was no support for women in science and art. Women were invisible in those fields until today and they still made a difference, by following their passion and wisdom (Mrs. Curie had to pretend to be a man in order to study physics at Sorbonne, and she is the only human being that received two Nobel prices for two different science fields: physics and chemistry). It is unfortunate that today we still don't teach and learn about everyday women that made it possible for us (me) to do what I love the most.

What's your favorite motto or quotation?

> "We have a beautiful mother,
>
> Her green lap
>
> Immense
>
> Her brown embrace
>
> Eternal
>
> Her blue body
>
> Everything we know." (Alice Walker)

What is your idea of perfect happiness?

To be here and now in nature, preferably near the ocean and listen with love and appreciation, and dance ☺.

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

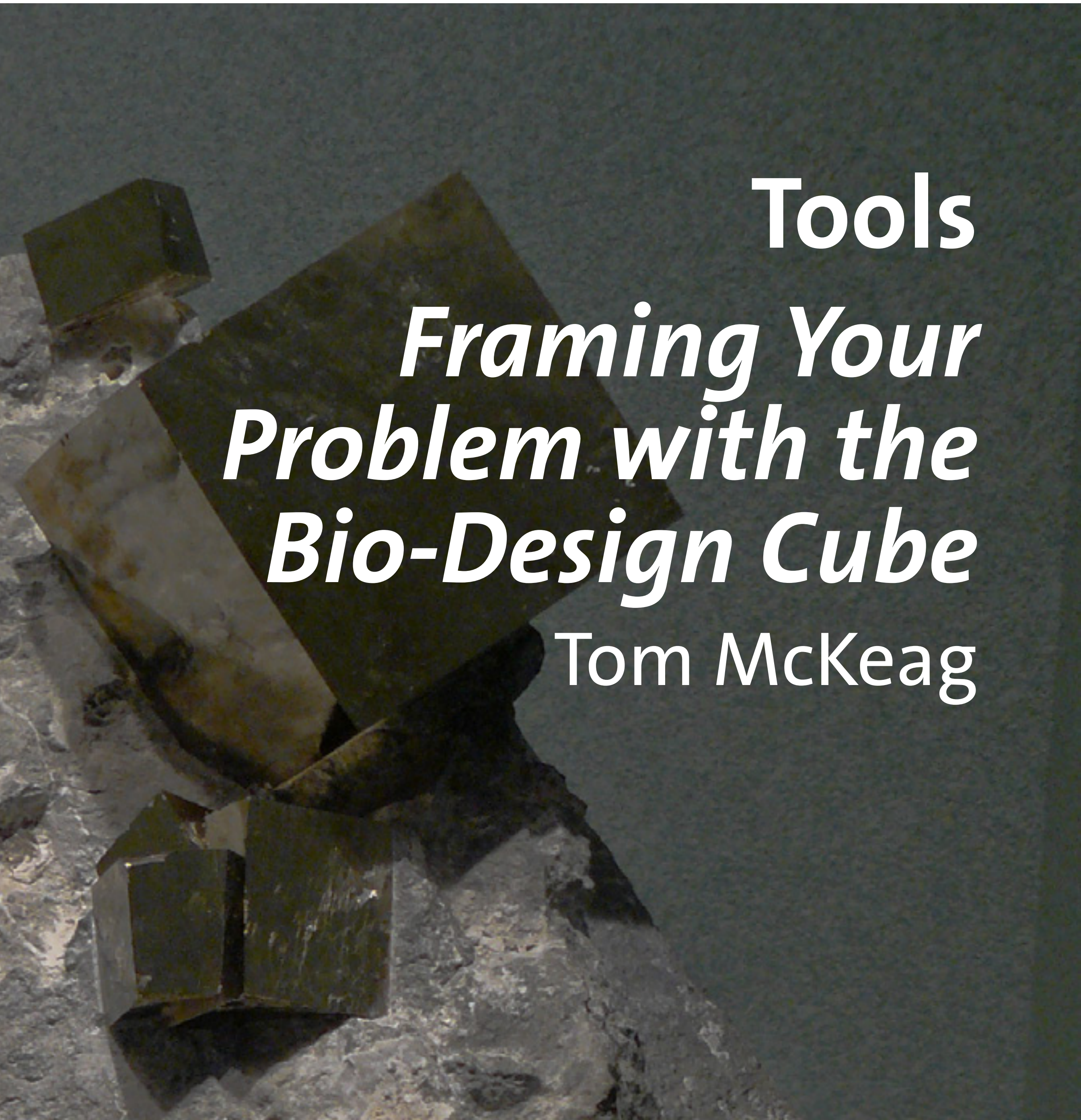
An artist – but I can still be that through biomimicry as it brings, arts and sciences together in harmony (STEAM). ×

Wellfleet Harbor

Photo: Яick Harris, 2012 | Flickr cc

Pyrite

Photo: Tchotchkes, 2009 | Flickr cc



Tools

Framing Your Problem with the Bio-Design Cube

Tom McKeag

Framing Your Problem with the Bio-Design Cube

One of the most important tasks for designers and problem-solvers is defining just what the problem is. Call it what you will, “boundary definition”, “design brief”, or “problem statement”, it is an essential task for all productive and creative work.

To accomplish this task one needs some rational pathway, however skeletal, in order to make judgements about which topics or issues to pursue and which to leave alone.

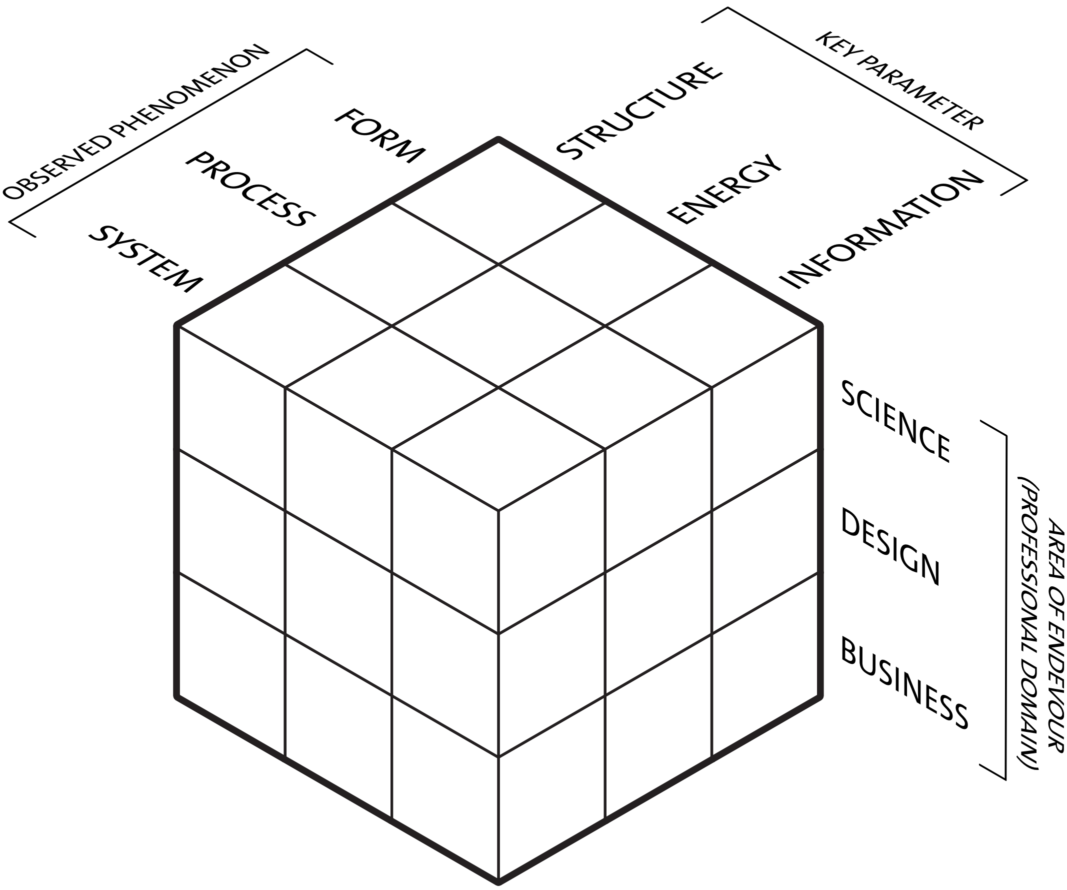
This framework ought to be complete, useful, instructive and provocative. In other words, it should map out a reasonable universe of possibilities to investigate, be directly helpful in starting a search, inform further study and provoke thought about the study itself.

The field of bio-inspired design is in particular need of such a framework. It can be characterized by emerging and fast-changing developments, scattered sources in specialized subjects, and seemingly limitless scope. This is not reassuring to a generalist designer looking for an easy protocol for inquiry. Often proposed integrations of biological inspiration and technological application look more like collisions. One of the reasons, in my opinion, is that the designer has gotten “lost in the weeds” of fascination with a particular organism or function, without a wider awareness of the dimensions of the phenomenon under investigation.

These dimensions do matter, and one would be wise to know of them early on. For example, translating the biomechanics of a mosquito to a larger technological application like a vehicle will soon run into the issue of drag, a very big deal to the tiny mosquito, and then later into the issues of gravity and inertia, important constraints to the vehicle, but not to the mosquito. Similarly, in moving from biological inspiration to technical application, it would be useful to know what characterizes the solution that seems so worthy of one’s attention: was it done with chemical reactions, or by an efficient shape, or by timely coordination of components?

~

Some simple categorization of the areas of investigation is a good first step. My solution is the Bio-Design Cube. Like all cubes, this one has three dimensions, and, therefore, three axes. Each axis represents a major characteristic divided into three parts. Since my intent is to provide a “search frame” for designers to organize their bio-design inquiry, I’ve kept the number of cells to a minimum, but the cube is expandable.



Bio-Design Cube

Image courtesy of Tom McKeag

First axis: “What is it?” The three phenomena of Form, Process and System seem to cover the possibilities in this universe, and indeed, these divisions are often used in biological investigation.

Second Axis: “What is its key parameter?” For this I have chosen Information, Energy and Structure as the factors that might drive a particular phenomenon. We will see later that there are other parameters that could be considered. We will also see how shifting emphasis from one to the other can have an impact on our built world.

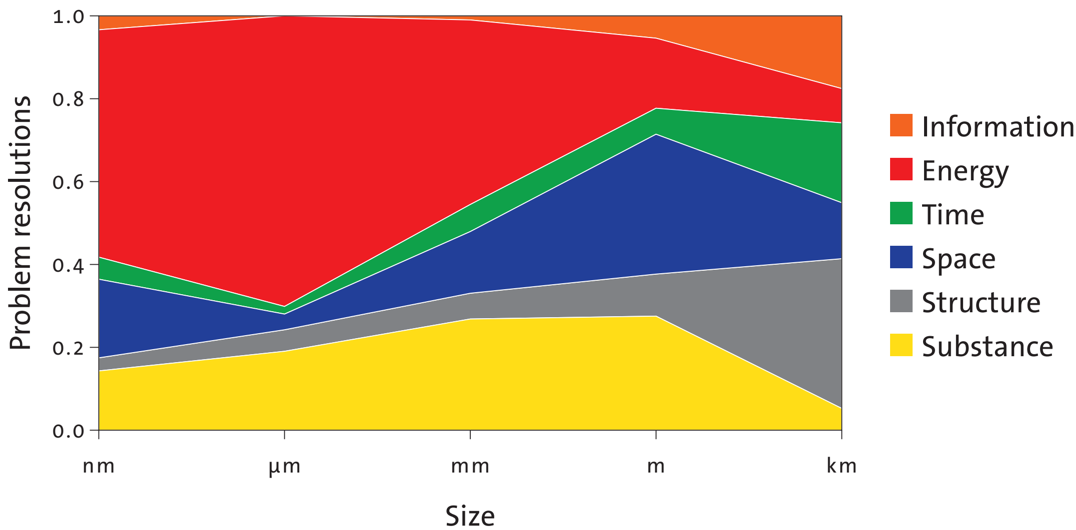
Third axis: “Where can it be applied?” The most general categories of human endeavor that I can think of are Discovery, Creation and Production, but I suppose that a more utilitarian version would list the professional domains of Science, Design and Business as the divisions of this axis (Business is used here as a general term that includes the “business” of government). My fellow editor and colleague Norbert Hoeller offers these three terms to unite mine: understanding, exploring, and making.

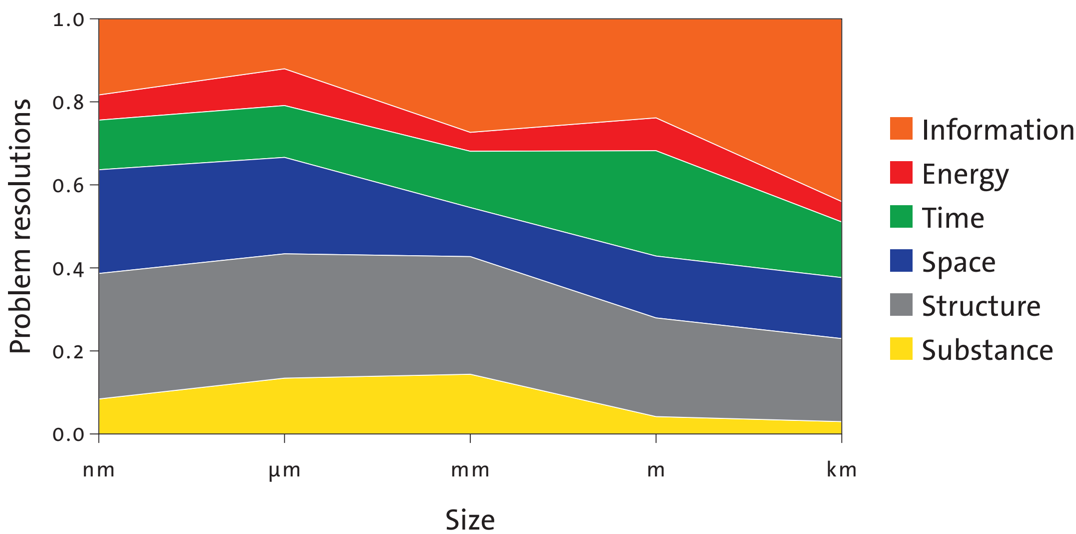
~

Theoretically, your solution should be contained in one of the 27 cells of the cube, each a combination of one of the three factors: phenomena, key parameters and areas of endeavor. As is typical in bio-inspired design, you can use the cube to approach your problem either from the problem end - “I need a process that is most determined by information that I can use in the business arena” - or from the biological mentor end - “This self-cleaning lotus leaf is most distinctly a form, the most salient parameter seems to be structure and I think I could best use it in a design application.” Naturally, many occurrences in our world do not fit neatly or exclusively into these cells. It may be evident to you also that there are multi-directional flows of information possible within the cube. Choosing one cell or axis as a starting point will determine a unique pathway in your design approach and there is a two-way flow of influence implied for all the walls of each cell, much like a natural membrane.

The relationships between the cells (and the relative emphasis given to each), therefore, become as important as the substantive content discovered in their space. In short, despite its reductionist appearance, this search frame can be extended into a more systemic tool. Extended or not, the cube is useful for visualizing how a change in emphasis in the key parameter can be a path to innovation. In *Natural Capitalism*, authors Paul Hawken, Amory Lovins and Hunter Lovins cite a number of cases in which a change of emphasis can lead to improvements. One is of an engineer who, questioning dogma, realized that enlarging the diameter of the pipes in his building and designing a more direct layout would reduce his need for more powerful pumps, saving energy, space and money. Translated to the cube, he de-emphasized the energy parameter (more powerful pumps), and emphasized structure (wiser layout of bigger pipes).

The parameters in axis two are taken from “Biomimetics: its practice and theory”, published in the 2006 *Journal of the Royal Society Interface*. Julian Vincent and his colleagues had taken a serious look at six parameters germane to problem solving: Information, energy, structure, time, space and substance. Their purpose was to compare the use of each in technological





Engineering TRIZ solutions arranged according to size/hierarchy. Vincent, J.F. et al *J.R. Soc. Interface* 2006; 3:471-482

Biological effects arranged according to size/hierarchy. Vincent, J.F. et al *J.R. Soc. Interface* 2006; 3:471-482

Pyrite from Ampliación a Victoria Mine, Navajún, La Rioja, Spain

Photo: JJ Harrison, 2009 | Wikimedia Commons versus biological problem-solving across a range of sizes. Their conclusions should be of interest to designers who aspire to create innovative solutions. Vincent points out "… in technology the manipulation of energy can account for up to 70% of the solution to technical problems, whereas in biology, energy never figures more than 5% of the time." The article concludes that the biological solutions tended to emphasize information and structure, were more hierarchical and systems-based and therefore more applicable to a wide range of sizes. Technological solutions, by contrast, tended to be more narrowly focused and less scalable and sometimes problematic at a different scale. In other words, according to Vincent, our dominant solution, energy, isn't nature's primary choice at all.

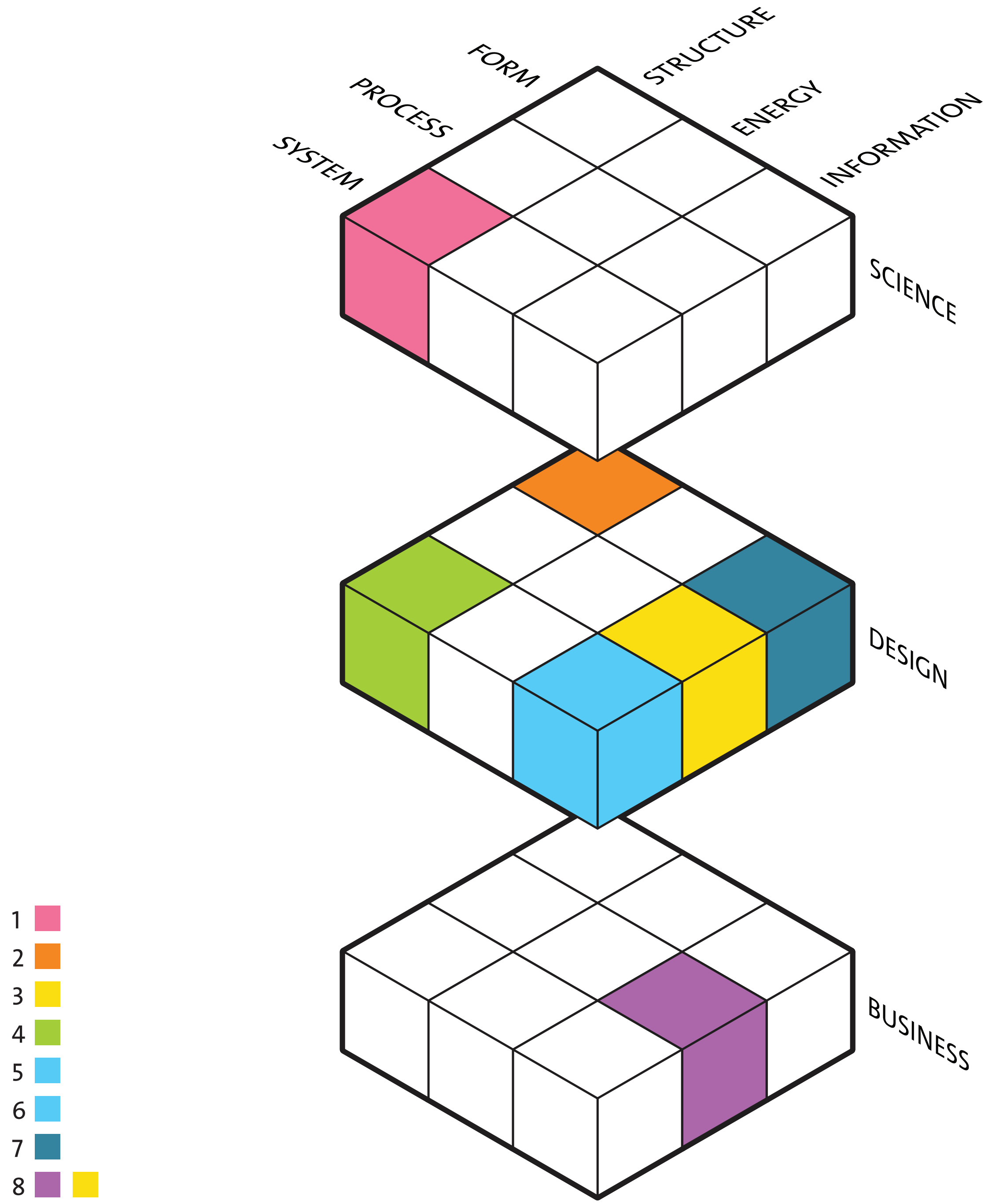
The Bio-Design Cube is most useful in the problem definition and conceptual design phases of a project, and can be particularly helpful when used as a "tickler list" early on to ensure enough divergence in ideation or later as a check for comprehensiveness in those results. In my experience with a couple hundred undergraduate and graduate design students, the distinguishing of these solution spaces from each other has appeared to be more useful for provoking innovative thought than for finding a specific biological mentor.

~

At the University of California, Berkeley, graduate students were presented with an overarching theme from biology, asked to compare two organisms of their choice from separate taxonomic kingdoms, and tasked to reverse engineer selected functional aspects of the organisms using the Bio-Design Cube as a framework. The theme or principle was "Unity within Diversity", popularized by Mahlon Hoagland, which includes such concepts as modularity, minimum components for maximum diversity, and random mixing as a solution strategy. Students were given a list of possible sources for the organism search, including the Asknature.org website and the Encyclopedia of Life, http://www.eol.org.

Although an academic exercise, the assignment did suggest lessons for the practicing professional. First, the use of the Bio-Design Cube to categorize an observed phenomenon as a form, process or system counteracted the common prejudice among designers to only consider form. Second, it forced the designers to consider how these other types of phenomena might be integrated into a functional solution; in particular, system relationships. Third, the comparison of key parameters ultimately led to a decision on what factor, structure, information or energy, was most influential, and further suggested which would provide the best leverage for an application. Finally, the ultimate application sphere or "area of endeavor" insured that critical considerations like user experience and client satisfaction were taken into account.

This exercise was used as a ramp-up to a design challenge that provides some examples of how the Cube had been used. The designers were asked to create a new version of an urban greenhouse based on biomimetic innovation. Quickly, the issue of controlling the three interrelated factors of light, temperature and moisture be-



Bio-Design Cube Example used in project report

Image courtesy of Tom McKeag

came apparent to the three-person teams. In particular the objective of being able to control light precisely was a common pursuit.

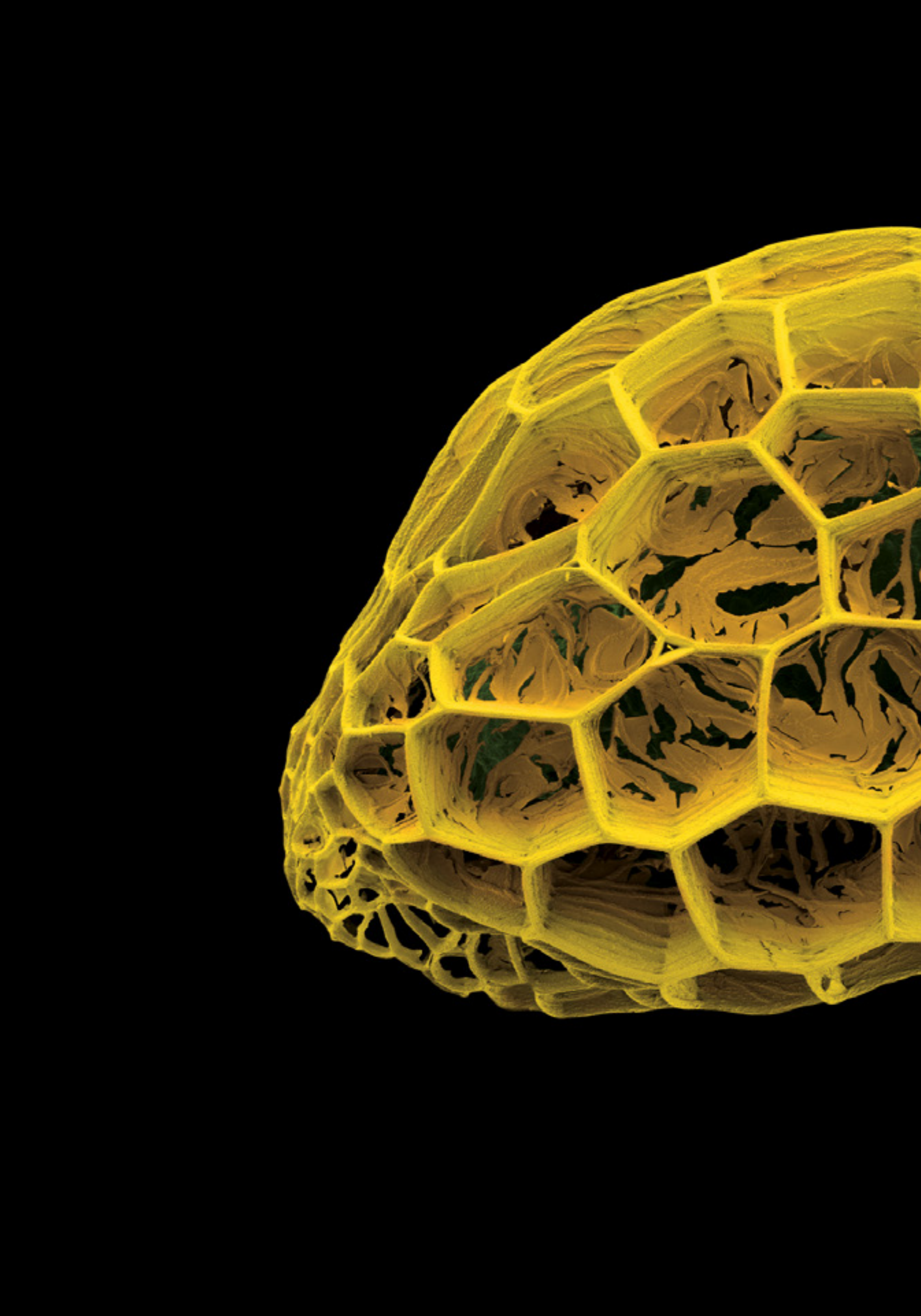
Early categorization of a phenomenon allowed the designers to plan for more focused research to aid their translation of natural means to technological ends. For example, one team had identified the desert plant Lithops, the lobster and the balloon fish as three inspirations for light control. Lithops grows largely underground but has developed transparent top cells and a light-capturing geometry that allows it to photosynthesize without being scorched by the sun. The lobster uses a unique system of multiple reflective tubes to gather scarce light and concentrate it to its retina. The balloon fish, by contrast, has a light-activated set of chromataphores around its eyes that fill with pigment to filter bright light. The team categorized both Lithops and the lobster solutions as the same although they dealt with opposite problems (too much light and too little light). They characterized their solutions to light capture as a “form” with a dominant parameter of “structure”, while the balloon fish solution was seen as a “process” with the same dominant parameter.

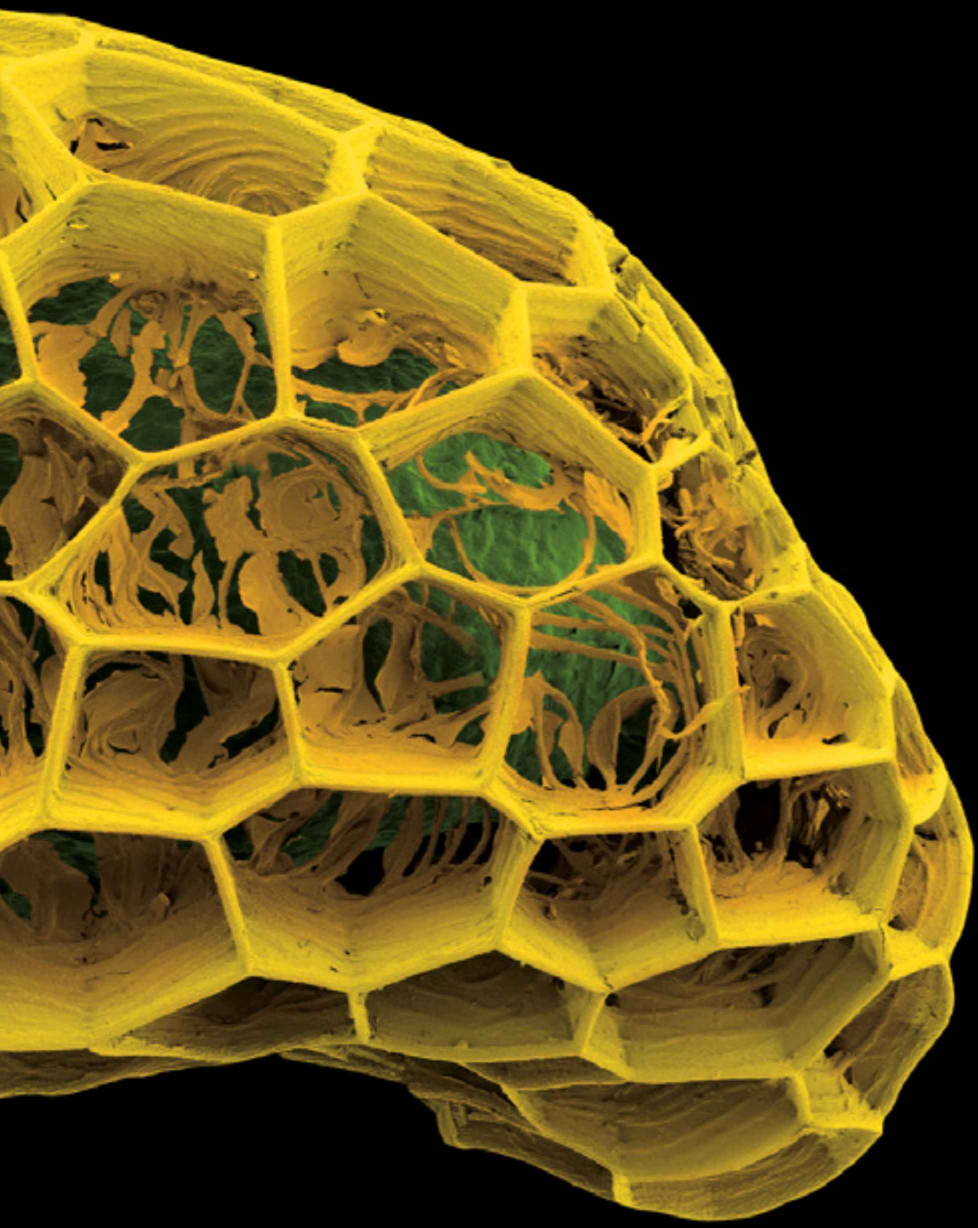
Merely making these simple choices led to a discussion of the categorical difference between the two mechanisms: the lobster solution was a completely passive structural device while the balloon fish’s was actuated by the energy of the environment and was tunable. This informed the team about what scale might be appropriate to work in and how much time might be spent in designing a macroscale reflective prototype and how much time might be spent in researching light-activated filter processes and smart materials.

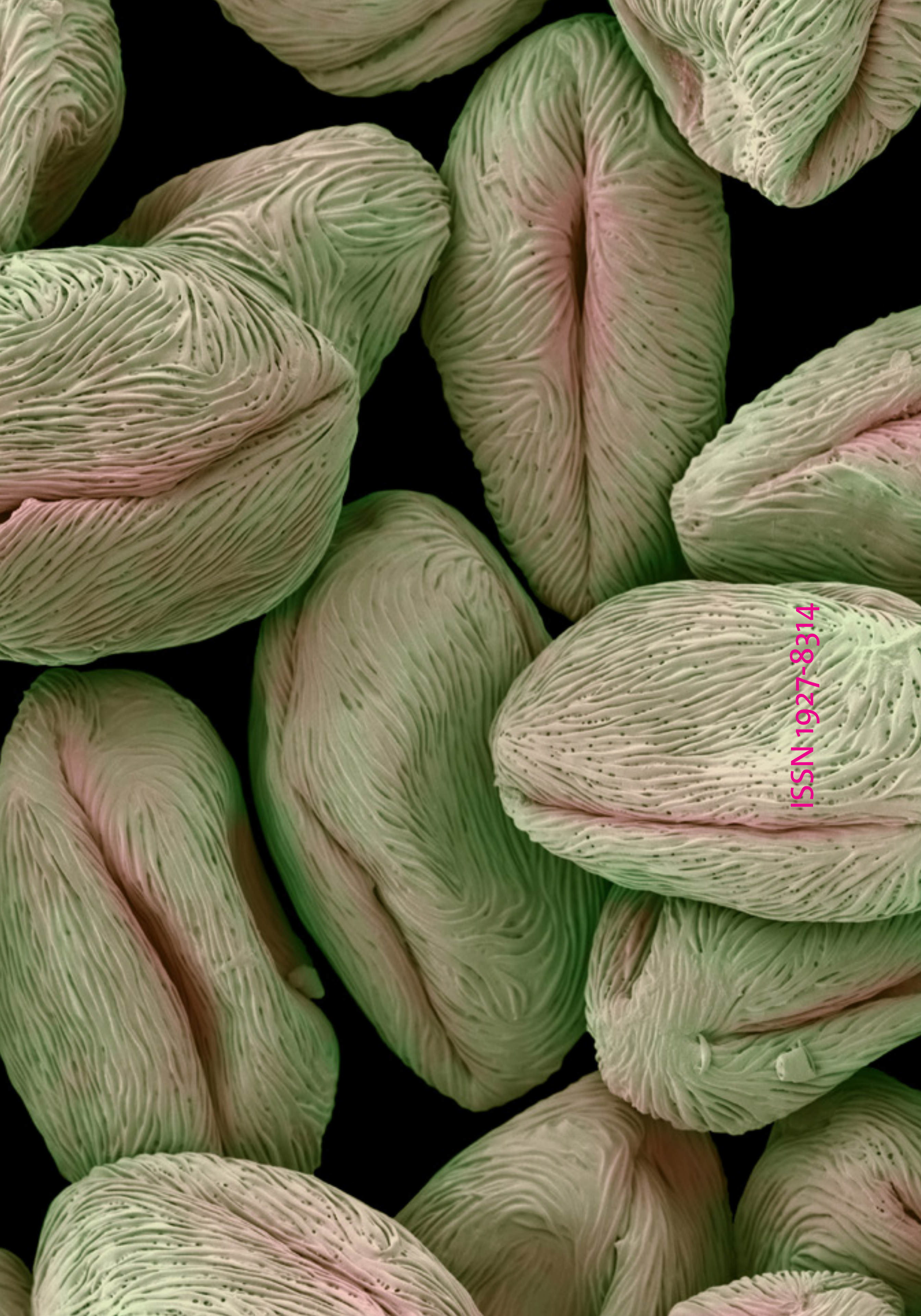
~

The use of the Cube was not without its challenges. Students reported some confusion about categorizing a function based on just one dominant parameter; understandable given the complex integration of nature’s solutions. Those who had used the Asknature website noted the translational issues of linking the limited information about function at that site with the parameter framework of the Bio-Design Cube. More research about how some of these tools can best be used will be very useful and I intend to incorporate some of these concepts in my upcoming 2013-2014 Fulbright research and teaching posting at the Centre for Product Design and Manufacturing at the Indian Institute of Science in Bangalore, India.

I would describe this tool as an orientation map, a launch point for a design sequence or a component that can be coupled to other tools. Results, certainly not standardized or quantified, have been mixed and not amenable to any identification of a trend. I would welcome any study of this tool, and imagine even a simple comparison to other early phase methods would yield data helpful to our profession. ×







ISSN 1927-8314