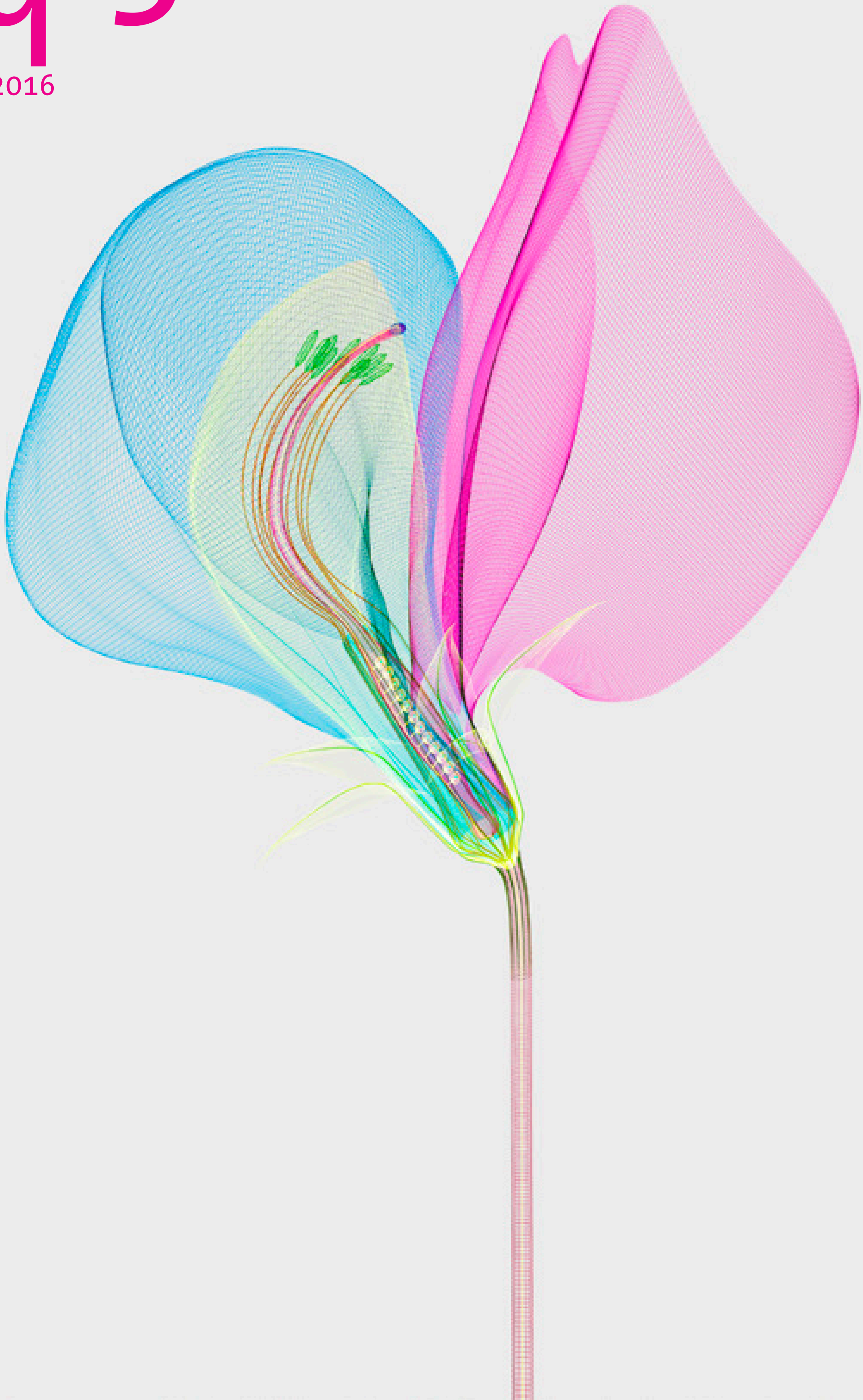
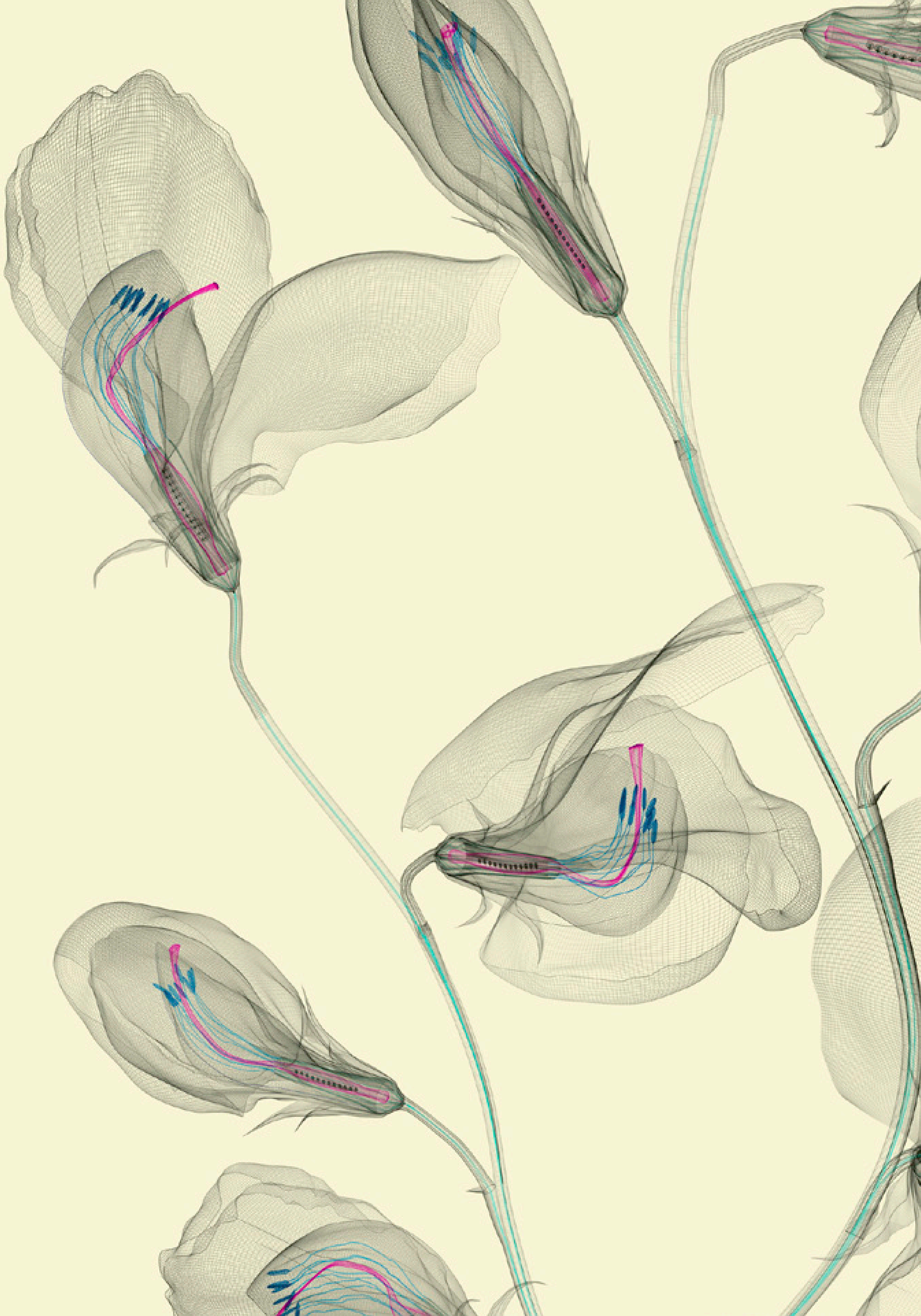
zq15

vol 1 | 2016





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Cover: Sweet pea-i-wc | Artist: Macoto Murayama | Courtesy of Frantic Gallery

pp. 2 - 3 & pp. 110-111: *Lathyrus odoratus L.* - ecology view - ow (detail) | Artist: Macoto Murayama | Courtesy of Frantic Gallery

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ISSN

1927-8314

Lathyrus odoratus and *Gypsophila elegans* | Photo: Juni from Kyoto, Japan, 2005 | Wikimedia Commons

Curiosity and Discipline

We dedicate this issue to the late biomechanics pioneer Steven Vogel, prolific author and inspirational teacher who had mentored an entire generation of successful academic scions. Starting with a brief summary of his life and philosophy, we reprint here two articles Steve had written for *ZQ*. Curiosity and the discipline to follow it were core features of Steve's life, and indeed seem to be the foundations of science and discovery.

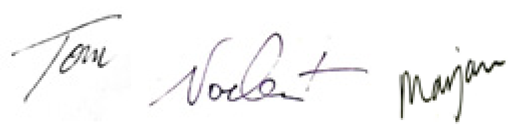
In both articles Steve leads us to think about ideas that we would have missed otherwise, either through inattention to the everyday wonders of the world or our less rigorous minds. Why discard technological "failures", for instance, when they can be such a rich trove of inspiration, and why assume *anything* about a tree, simply because it is a commonplace sight. Getting us to see the world through his discriminating lens was what Vogel was so good at and he touched thousands through his writing.

This mixture of curiosity and discipline is also evident in the interviews featured in this issue. Dr. Robin Rogers, noted green chemist, tells us about the challenges of deepening the impact and knowledge base of green chemistry through applied research in Canada and beyond. Dr. Kalina Raskin, network manager at CEEBIOS (Centre Européen d'Excellence en Biomimétisme de Senlis) in France describes the current issues in the dissemination of biomimetic information and building of a multi-sector hub for bio-inspired collaboration in Europe.

Heidi Fischer pens another wonderful tale of exploration, this time in the cataclysmic barrens of Mt. St. Helens. Here researchers are discovering surprising facts about how the natural world rebuilds its complex web after complete devastation.

Finally, our featured artist Macoto Murayama delights and inspires with his fresh take on botanical prints: juxtaposing the precision of CAD wire-frame drawings with the organic shapes of flowers and the retro feel of antique prints. In the process, he reveals, through curiosity and discipline, the inner geometries and structure of overlooked everyday forms. We are sure Steve Vogel would approve.

Happy reading!



Tom McKeag, Norbert Hoeller and Marjan Eggermont

Insect Flight

Photo: Steve Roetz, 2008 | Wikimedia Commons

Boundless Curiosity: A Tribute to Steven Vogel

Tom McKeag

vol 1 | 2016 **Tribute** Steven Vogel **Author:** Tom McKeag

Boundless Curiosity

Dr. Steven Vogel passed away on November 24, 2015, after suffering from cancer. He was the James B. Duke Professor Emeritus in the Department of Biology at Duke University, the author of ten books, including two classic textbooks, and of over 100 scholarly papers. Through his popular writing he helped define the field of biomechanics and was one of the first to explain clearly how mechanical constraints affect biological shape and behavior.

One fall evening in 2011, Steve Vogel mentioned to me that the field of bio-inspired design ought to have an informal publication or community hub where practitioners from all disciplines could exchange ideas. He thought that this could lead to all sorts of fruitful collaborations and insights and serve as a forum, especially for those working in the somewhat myopic field of benchtop science.

Steve was visiting with me after guest lecturing in a graduate course I was running at Berkeley, "How Would Nature Do That", and I found in those couple of days that the man in front of the classroom was no different than the well-known author or house guest: generous, self-effacing, and most of all, endlessly curious about the world around him. He was continually cogitating about how that world worked, and it was a challenge for me to keep up with his relentless drive to examine it or the deep reference knowledge he had with which to do so.

In a few months we had launched *Zygote Quarterly*, and Steve was kind enough to write an article for our first issue (reprinted on page 18). The topic was a fun toss-off for this prolific and adept writer: good ideas that had never found success. It was a fitting one for a man whose stock in trade was ideas. He believed in the value of ideas for their own sake, and by extension, the value of pure science with the rigor and discovery that it brings. "Science is the triumph of the human imagination disciplined to explain the world around us."

As for his position in the field of bio-inspired design, he had recently found himself sought out by a whole new generation of not scientists, but laypersons excited by the ideas in his very readable books and keen to apply some of his biological insights to practical problems. He was open to discussing his ideas with anyone, and showed no disdain for the less informed, as I can attest.

This is not to say that he did not maintain his standards of scientific rigor, and indeed found what he described as the "theological overtones" of some biomimicry zealots to be mildly troubling. He recognized the difficulties of direct translation between the two "technologies" of Nature and Man that he had so adroitly outlined in *Cats' Paws and Catapults* and found many popular claims to be unsubstantiated and "oversold". Still, the very act of comparison was immensely

Close-up of a flying ladybug | Photo: Luca5, 2008 | Flickr cc

useful in his opinion, indeed as important as any bio-inspired outcome. Talking with Adrian Smith of "The Age of Discovery Podcast", in September 30, 2014, he explained it this way:

> "...there is another way to look at it (comparing the two technologies), and that is, if the solutions you find in the two technologies are always the same, then maybe this is a constrained system. If they are different, then the system is unconstrained, and therefore there is a third option which is possible."

Speculating about what that third option might be was what made Steve Vogel tick.

Within his scientific work in biomechanics, comparisons were immensely important, particularly the biological concept of convergence. Convergence can be defined as the tendency of unrelated animals and plants to evolve superficially similar characteristics under similar environmental conditions. "Convergence is Nature's way of telling you what matters. Comparative biologists look to find shared non-derived characteristics, or problems that a good number of organisms have solved."

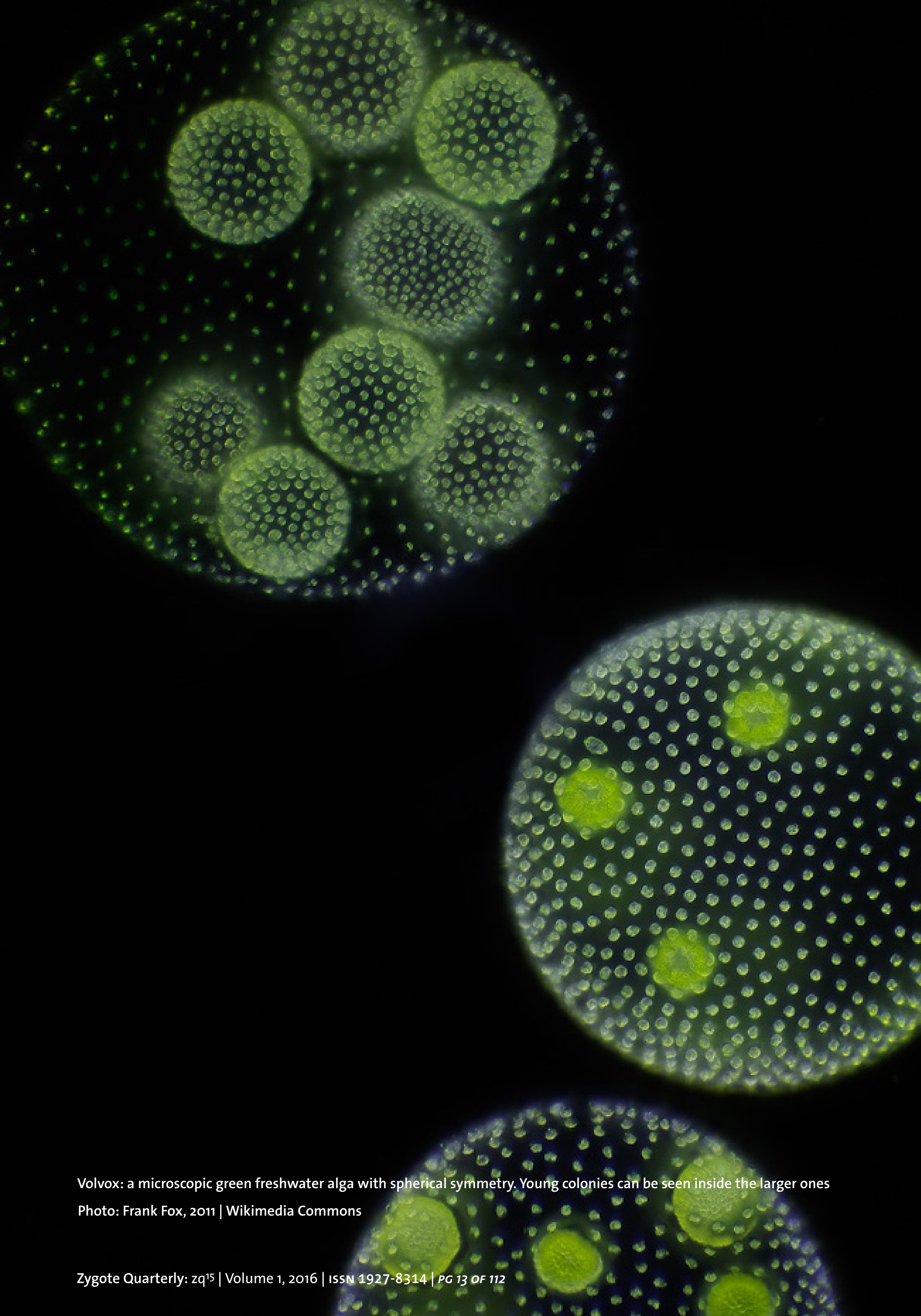
Sparked to an interest in biology by a high school teacher, Vogel studied at Tufts University and then Harvard where he gained first a masters and then a doctorate in Biology. He arrived at Duke in 1966 as an assistant professor and stayed for 40 years, first in Zoology and then Biology. During several summers he served as visiting faculty at the Marine Biological Laboratory, Woods Hole, Massachusetts, the Friday Harbor Laboratory of the University of Washington, and the Tjarno Laboratory in Sweden. He had particularly fond memories of Friday Harbor.

His main legacy, beyond the decades of inspirational teaching, lay in his writing of popular books, a fact that amused him, since it took him a while to realize that the writing was making more of a difference to the world than any experiments that he was conducting. It was the hands-on experiments, however, which provided the sustenance for his curiosity and the tangible examples that lent such credibility to his expressed ideas.

He initially had studied the biomechanics of insect flight, then switched to studying low velocity stresses on leaves, followed by studies of marine organisms such as limpets and algae, ballistic fungus, squid, sponges and mammals. One of his better known studies was of the induced ventilation in prairie dog burrows, an initial observation that he made sure to attribute to his graduate student.

Of his books, his most impactful was probably the textbook, *Comparative Biomechanics*, now in a second printing and widely used. Most popular was *Cats' Paws and Catapults*, *Vital Circuits* about circulatory systems, *Prime Mover*, about muscle, and *Life in Moving Fluids*, also a textbook. *The Life of a Leaf* was his last book, capping a productive career of science writing that had not begun until he was 40.

Often eschewing the continual chasing of research money, Vogel valued the independence of Yankee ingenuity and thrift that allowed him to pursue his own curiosity by hacking together his own low-cost lab tools. He would wax effusive about a trip to the local hardware store, and on more than one occasion had recited to me what appeared to be a mantra: "The more you do, the more you *can* do."



Volvox: a microscopic green freshwater alga with spherical symmetry. Young colonies can be seen inside the larger ones
Photo: Frank Fox, 2011 | Wikimedia Commons

Prarie Dog meeting | Photo: Tupulak, 2015 | Flickr cc

He also valued greatly the human impulse to learn. “We (scientists) are all autodidacts. A PhD basically certifies that you are an autodidact.” Indeed, his wide ranging studies came more from personal interest than formal training. “I never took a formal course in biomechanics or fluid mechanics, yet I wrote a book.”

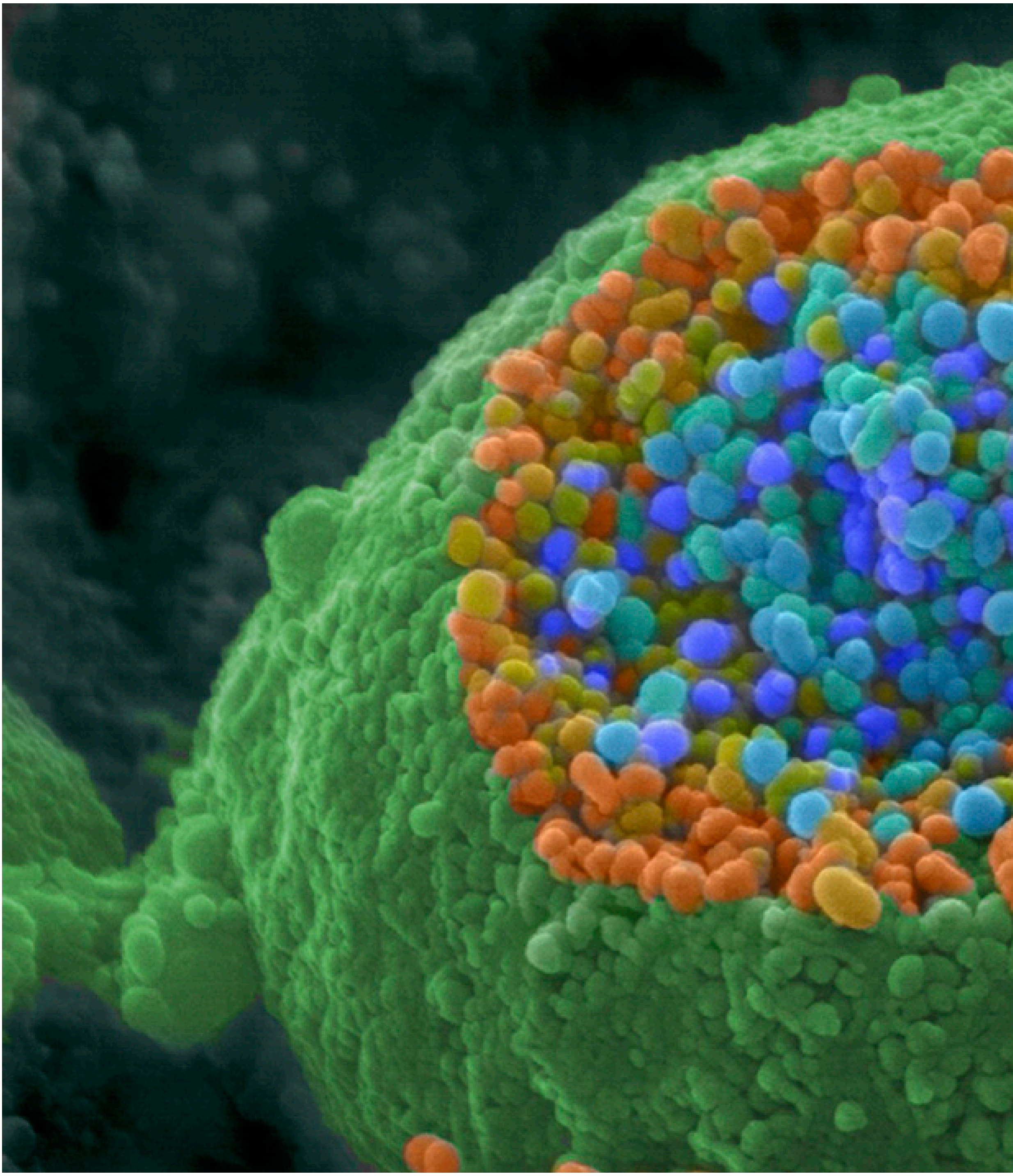
His circuitous explorations would fit with his philosophy about life being a somewhat random affair where one’s character was the only constant: “You follow your nose, keep your powder dry, and take advantage of opportunities - (that is) all you can do.” For Steve Vogel, and the rest of us, it was more than enough. ×

Most of the direct quotations in this article were taken from Adrian Smith’s audio series, Age of Discovery Podcast: interviews with biologists about being biologists, episode 9, http://www.aodpod.com/9-steven-vogel/

For a list of his published work:

http://fds.duke.edu/db/aas/Biology/svogel

Boleophthalmus boddarti: A mudskipper which is believed to share some features with extinct fishapods in terms of adaptations to terrestrial habitats
Photo: J Harrison, 2011 | Wikimedia Commons



Nerve Ending

Photo: National Institutes of Health (NIH), 2015 | Flickr cc

Article
When Success Fails
Steven Vogel

When Success Fails

Around 1770, Nicolas-Joseph Cugnot built a steam-powered, self-propelled vehicle intended as an artillery tractor. In the late 19th century, steam-powered, self-propelled vehicles saw extensive use on American farms both for traction and as movable power sources. In the early 20th century, steam-powered, self-propelled vehicles made an appearance on roads, most notably as the Stanley Steamer. A century later, coal-fueled power plants ordinarily use steam-powered external combustion engines to generate electricity. Yet, as far as I know, at this time one can purchase no roadworthy vehicle powered by an external combustion engine.

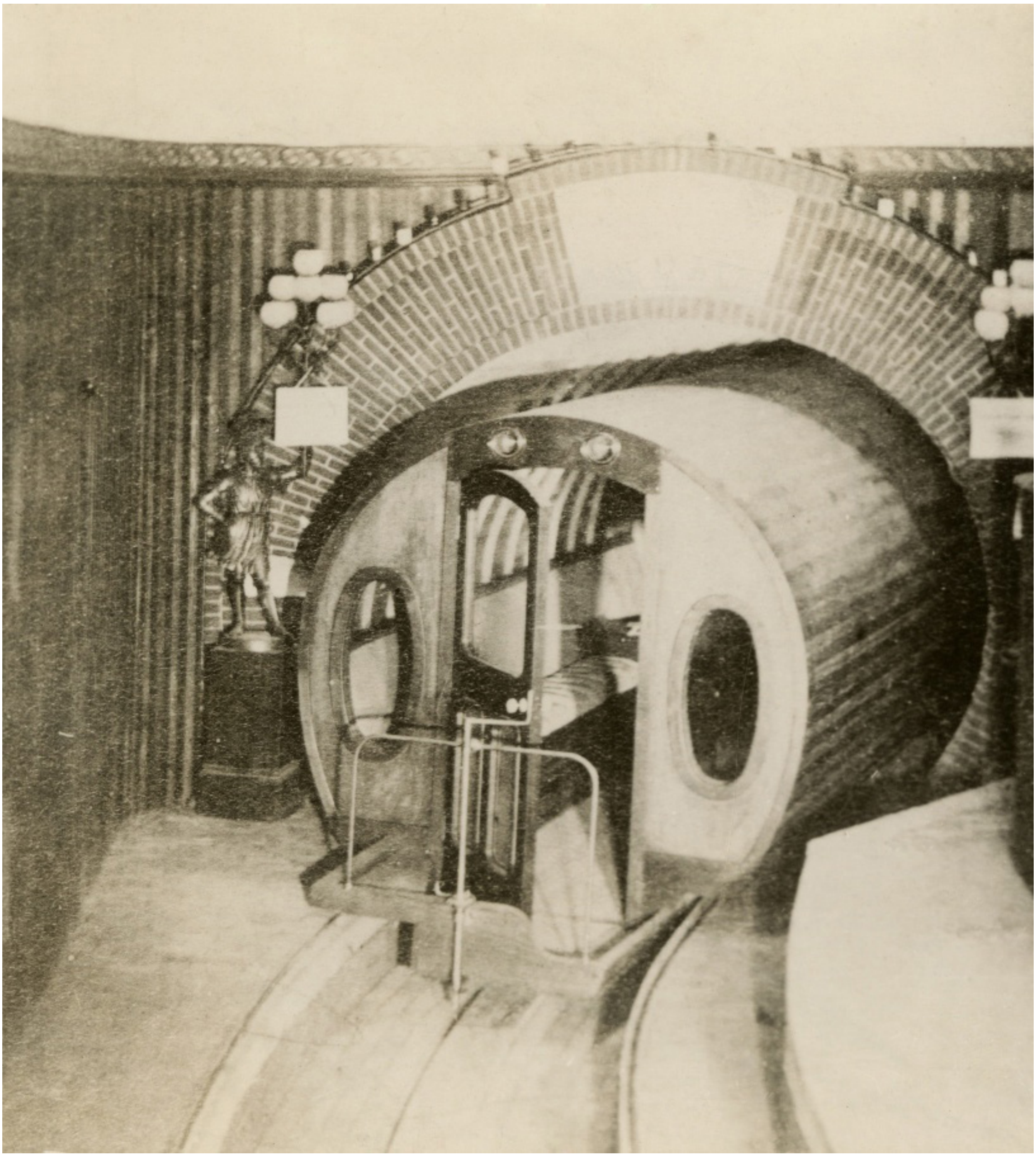
Two issues. First, is this a special case, a technology with either some intrinsic flaw or one kept from the marketplace by in insurmountable infrastructural hurdle? Second, might the case hold some lessons for current biomimetic innovation?

On the first issue, I would argue that the case represents only one of a surprisingly large number of instances of technical successes that proved to be commercial failures. Just as history is largely written by winners, not losers; just as life on earth shows evolution's successes, not failures; so histories of technology most often recount the stories of what has worked and become ubiquitous, not what has been discarded even if functionally successful. Consider and be impressed with the diversity of some technologically successful items that turned out to be impractical economic failures.

During the summer of 1790, a steamboat created by John Fitch plied the water around Philadelphia and was reported to reach speeds of 12 kilometers per hour. Propulsion, in the rear, depended on a system of reciprocating paddles rather like the legs of paddling waterfowl. The system failed for essentially economic reasons, as did his particular paddlewheel version. About the same time, James Rumsey patented (but does not seem to have built) a jet boat, one that used two check valves and a chamber of variable volume, working much like a heart ventricle or a jetting fish. Water entered at the front, a steam-powered piston moved up and down in a chamber between the valves, and pulses of water squirted out the rear.

Stern-wheel steamboats had a brief run, from Robert Fulton's successful one in 1807, to about mid-century. They gave way to side-wheeled boats, with bigger and thus more efficient wheels as well as much better maneuverability. These last persisted where that maneuverability mattered, but both versions gave way to Robert Erickson's propeller-driven boats, the latter still more efficient even before the advent of properly cambered propellers.

We're familiar with cable cars, anachronistic railways in which fixed engines power movable carriages. In 1847, Isambard Kingdom Brunel, one of the pioneers of railroad design and construction, built a particularly sophisticated version of such a fixed-engine railroad, avoiding the need to move heavy steam engines in addition to



WP Beach Pneumatic Transit: the first attempt to build an underground public transit system in New York City
Photo: New York Historical Society, 1873 | Wikimedia Commons

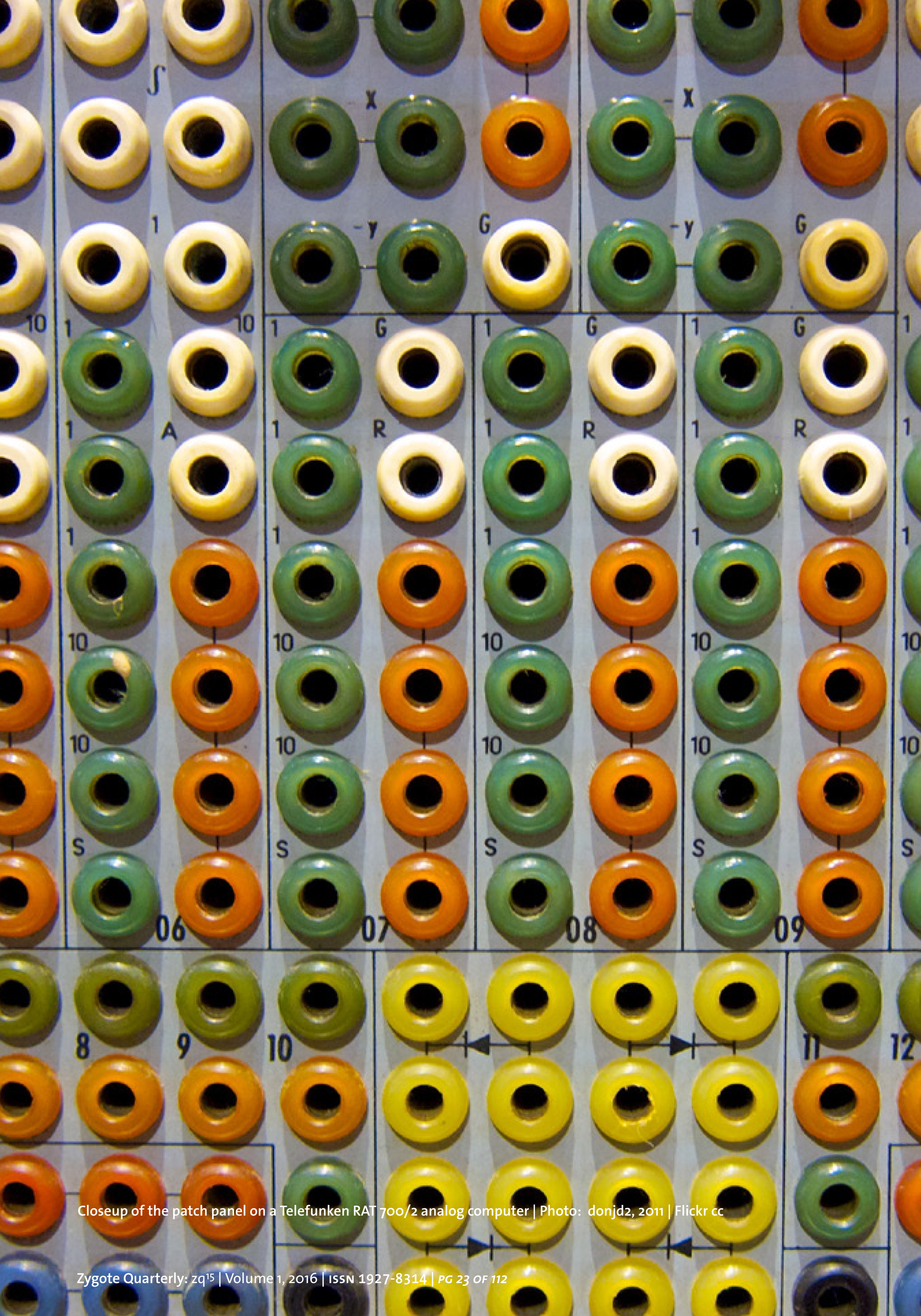
passengers and freight. Fixed pumping stations along his pneumatic railroad evacuated a pipe into which one or more pistons protruded; each piston had a lengthwise plate extending upward through paired leather fittings to the train car above. Speed and smoothness surpassed any contemporary system. But the pneumatic railroad was abandoned after less than a year—deterioration of the leather, the awkwardness of any switching system, and, finally, the promise of better locomotives put an end to what was never an economical scheme.

Around 1840, Charles Babbage designed what amounted to a sophisticated computer, one entirely based on, as was necessary at the time, mechanical components. Vastly superior to any previous calculating device, it might have revolutionized all kinds of computational tasks. But the machine would have been enormously expensive to build; indeed only small parts were ever assembled. And the design held little promise of any great economies of scale, even assuming a demand for more than a few.

For external combustion steam engines, vaporized water provides the working fluid not the fuel, which might be anything combustible—or any other provision of a hot source and cold sink. Other working fluids work also, and the commonest of these is air. Around 1816, Robert Stirling devised a proper heat engine that could use air instead of gaseous water. Yet a century later, steam locomotives still needed their water supply topped up from time to time. Not that the Stirling engine languishes in obscurity—it has long provided a heuristic tool for thermodynamic courses, and desk-top models are available for purchase.

Almost all quantifiable parameters of our world vary continuously, not stepwise. In the early days of computers, mainly the 1940s, analog machines commonly dealt directly with these continuously varying functions. One could even buy, in 1960, a make-it-yourself analog computer kit. Where are all the analog machines in our far more computer-afflicted world today? Who would have guessed that machines that chopped continuous variables before processing, digital computers, would have almost entirely supplanted them, that digital computers could simulate analog devices better than the analog devices themselves?

Present-day airplanes fly over a historical landscape littered with the wreckage of once-promising aerodynamic technologies. Never mind flapping-wing airplanes, for which the case rested mainly on our ignorance of how to go birds one better, how to scale up to devices bigger and faster. None of Count von Zeppelin's airships, with their rigid frames holding gas bags within, have been built since the 1930s. All later airships ("dirigibles") are non-rigid blimps, not rigid zeppelins, with the outer membrane providing both tensile support and container for the gas. Anton Flettner's revolutionary sailing ships took advantage of Magnus-effect lift when the wind blew on large, rotating, vertical cylinders on deck. Trial runs, including an Atlantic crossing, revealed no basic flaw; but about the same time, the early '20s, petroleum-powered ships replaced ones in which huge coal bunkers cut into payload, so auxiliary sail for long runs became unnecessary. In 1923, Juan de la Cierva invented a flying machine that, at least in appearance, anticipated helicopters. The horizontal rotor of these autogyros, though, was unpowered, driven indirectly



Closeup of the patch panel on a Telefunken RAT 700/2 analog computer | Photo: donjd2, 2011 | Flickr cc

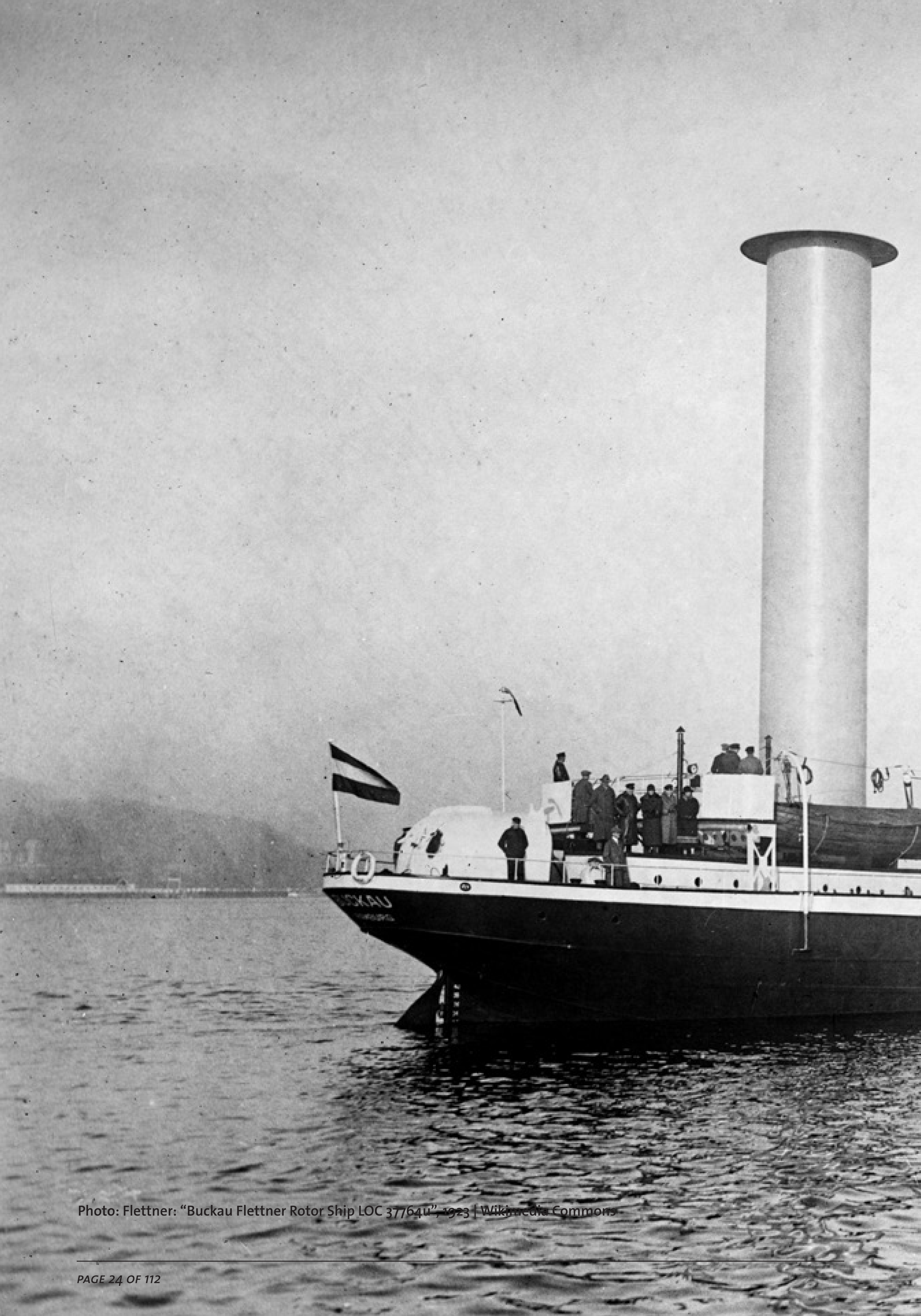


Photo: Flettner: “Buckau Flettner Rotor Ship LOC 37764u”, 1923 | Wikimedia Commons


FLETTNER-ROTOR

Duck feet | Photo: goodmami, 2005 | Flickr cc by the oncoming air as a conventional propeller in front or back drove the craft forward. Amateur aviators could buy and build autogyro kits for many years, but as far as I know, they have never enjoyed significant commercial use. And more recently there was the Concorde, the supersonic transport plane, a technological tour de force that never came close to paying its way.

One can continue, noting Buckminster Fuller's geodesic domes, reel-to-reel and 8-track home tape recorders, wind-up shaving razors that need neither plug nor rechargeable battery, pulse-jet and ram-jet aircraft engines, and so on. Successes all too often fail.

What relevance might all this history of might-have-beens hold for the aspiring biomimetic designer? One's first impulse is to examine each case for any biological analogs—which one can easily find. Fitch's paddling duck leg and Rumsey's squid-like pulse-jetting steamboat engines are obvious instances, although the first seems more likely to have real bioinspired roots than the latter. Flettner autorotation finds use by some autorotating seeds such as those of ash, tulip poplar, and ailanthus. But asserting that any ostensible biomimetic character contributed to failure of any of these stretches credulity. Moreover, one can point to the way nervous systems use something closer to a technologically successful digital than a failed analog system to encode information, even if neural signaling only distantly resembles digital encoding.

A more general message is the evidence of a sobering gulf between technological and commercial success. It suggests passing any idea through some preliminary filters before investing heavily in time or resources. Four filters might do for a start:

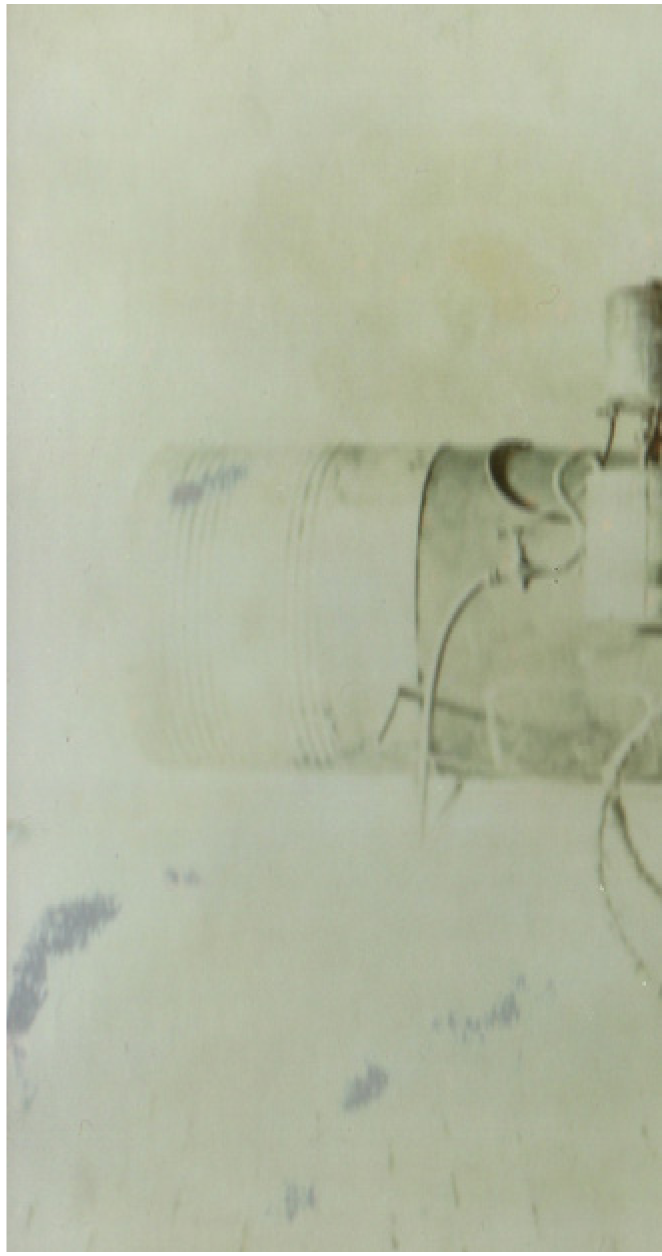
- Is the device likely to work on a scale that is useful for humans?
- Can a version of the device be constructed by means that are practical for human technology?
- Might the device possibly offer some advantage in an application over what we currently use, or might it offer some entirely new and attractive capability?
- Can nature's version be improved upon either in functional effectiveness or in ease of manufacture by some alteration in design such as using materials and components specific to human technology?

But here again, one has to tread a path between disabling skepticism and the enthusiasm of the perpetrator. In particular, the filters ask for what cannot be anything but educated guesses. I suggest a general formula, although hastening to add that its application promises none of the precision of our usual algebraic expressions and thus adds only a little additional focus to one's guesswork in dealing with these filters.

In some course in physical science, you may have encountered an expression, PV/T, which defines a constant for a given quantity of any gas: pressure times volume divided by absolute temperature will not vary—or vary enough to matter. We might borrow the expression for present use, just redefining the variables. P will now represent the probability that a device will work—both technically and commercially, if you wish. Low P, a long shot; high P, a sure thing. V is now the value of success—prestige, publication, tenure, or coin-of-the-realm—if the device works successfully. And T measures the time, effort, or resources needed to bring the notion to realization or to where it can be offloaded onto some other outfit. The combination, PV/T, then provides an index to the relative worthwhileness of a possible project.

Perhaps a semi-serious example might flesh out this abstraction. We've all heard of solar heaters. What about a sky cooler, something that gets radiatively chilled in the manner of a leaf on a plant on a clear, windless night (and which leaves contrive to avoid) or an overheating camel when night falls (quite a good thing, by contrast)? I figure that one might use an upward facing plate of high emissivity in the far IR, air passageways beneath it leading to a downward flowing antichimney, and that, in turn leading to a storage medium beneath some living space. Aluminum plate, a bit of perforated metal strip, a Styrofoam box, cardboard for the antichimney, thermometers—nothing beyond the ordinary flotsam and jetsam of my lab, assembled in about an hour. Then a few dawn measurements in the backyard. Never mind how high P or V might be—T could hardly be lower. So I play with it on propitious nights; so far a few degrees of chamber chilling have been realized. Nothing too great, but permutations are easy enough...

It's that simple—or would be if we could fathom the unfathomable, surmount the insurmountable, and so forth. Still, someone might find that the formula at least provides some useful mental guidance. ×



Ramon Casanova and the pulsejet engine he constructed and patented in 1917
Photo: Jcrbmc, 1916 | Wikimedia Commons

キバナコスモスとクマバチのおしり

(*Cosmos sulphureus* and carpenter bee)

Photo: houroumono, 2013 | Flickr cc

People

Interviews with Robin Rogers and Kalina Raskin

Untitled (hoar frost)

Photo: JeffT4, 2012 | Flickr cc

Interview
Robin Rogers

Dr. Robin D. Rogers is currently Canada Excellence Research Chair in Green Chemistry and Green Chemicals at McGill University in Montreal, Canada. His research interests cover the use of ionic liquids and green chemistry for sustainable technology through innovation including:

- **Materials: advanced polymeric and composite materials from biorenewables,**
- **Separations: novel strategies for separation and purification of value added products from biomass,**
- **Energy: new lubricant technologies and selective separations,**
- **Medicine: elimination of waste while delivering improved pharmaceutical performance.**

Rogers is the Founding Editor-in-Chief of the American Chemical Society journal *Crystal Growth & Design*. He is also an editorial board member of *Separation Science & Technology, Solvent Extraction and Ion Exchange*, and *Chemistry Letters*, as well as a member of the international advisory boards for *Green Chemistry*, *Chemical Communications*, and *ChemSusChem*. In 2005 he was awarded the US Presidential Green Chemistry Challenge Award for work related to the use of ionic liquids in sustainable technology.

How did you get started in green chemistry?

After getting my PhD from the University of Alabama in 1982, I taught at Northern Illinois University for a number of years. I became interested in the potential for minimizing or eliminating hazardous substances and associated chemical processes. My goal was to reduce environmental impacts by designing for sustainability and avoiding 'end of pipe' solutions. I returned to the University of Alabama in 1996, founded the Center for Green Manufacturing in 1998, and served as its Director until 2014, focusing on advanced materials from biorenewables, novel separation and purification strategies, more efficient biomass conversion and the reduction of waste in pharmaceutical manufacturing.

What led you to join the faculty at McGill University?

Bruce Lennox has built up expertise in green chemistry and sustainability at McGill for over 10 years, attracting researchers like C. J. Li from Tulane University. I was offered the Canada Excellence Research Chair in Green Chemistry and Green Chemicals in 2014, which comes with $10 million federal government funding over seven years. McGill provides me an opportunity to work synergistically with a broad range of top experts in sustainability and make a difference in the field of green chemistry. I also want to raise the profile of Canada as a country rich in natural resources but as value-added products and expertise.

What do you consider as the major challenges facing green chemistry?

In spite of great interest from business, green chemistry lacks a solid technology base, knowledgeable scientists and engineers, and a strong body of credible case studies. Businesses tend to be risk-adverse and venture capitalists want a return on their investment. Even if a scientist has the necessary expertise and knowledge of the risks associated with the proposed project, building a compelling business case requires additional business and technical expertise.

Systemic or structural inertia is another challenge. Polylactic acid (PLA) from corn has been used to replace polyethylene terephthalate (PET) derived from fossil fuels. However, in making PLA, the natural biopolymers are chopped up into monomers that we know how to use. These monomers are suitable feedstocks for the chemical industry that then re-assembles them into polymers used in products such as PLA for water bottles. Putting aside whether we should be manufacturing water bottles, using nature's polymers directly threatens the business model of existing chemical companies. The lack of industry funding for research makes it difficult to bridge the gap from concept to final product, which raises concerns in the investment community.

Even the term *Green Chemistry* emphasizes reducing toxicity rather than transformational leaps. We are still trying to solve today's problems based on past experience and practice. We need to get out of our comfort zone and explore tomorrow's possibilities. Paul Anastas, one of

Agricultural sludge sample

Photo: Wellcome Images, 2015 | Flickr cc

the fathers of green chemistry, told the story of the grave concerns in the 1890s that the growth in the horse-based economy could not be sustained especially in cities (Morris, 2007). No solutions were evident at the time, yet by the 1920s, the internal combustion engine was rapidly replacing horse power, transforming urban life and rural economies.

What solutions to you see for these challenges?

One of my heroes is George Washington Carver of Alabama's Tuskegee University. Alabama was hit by major boll weevil infestations in the late 19th and early 20th centuries, threatening to cripple the cotton industry. Carver worked with farmers to introduce new crops like soybeans and peanuts that not only helped restore

Boll weevil (*Anthonomus grandis*)

Photo: Wellcome Images, 2015 | Flickr cc

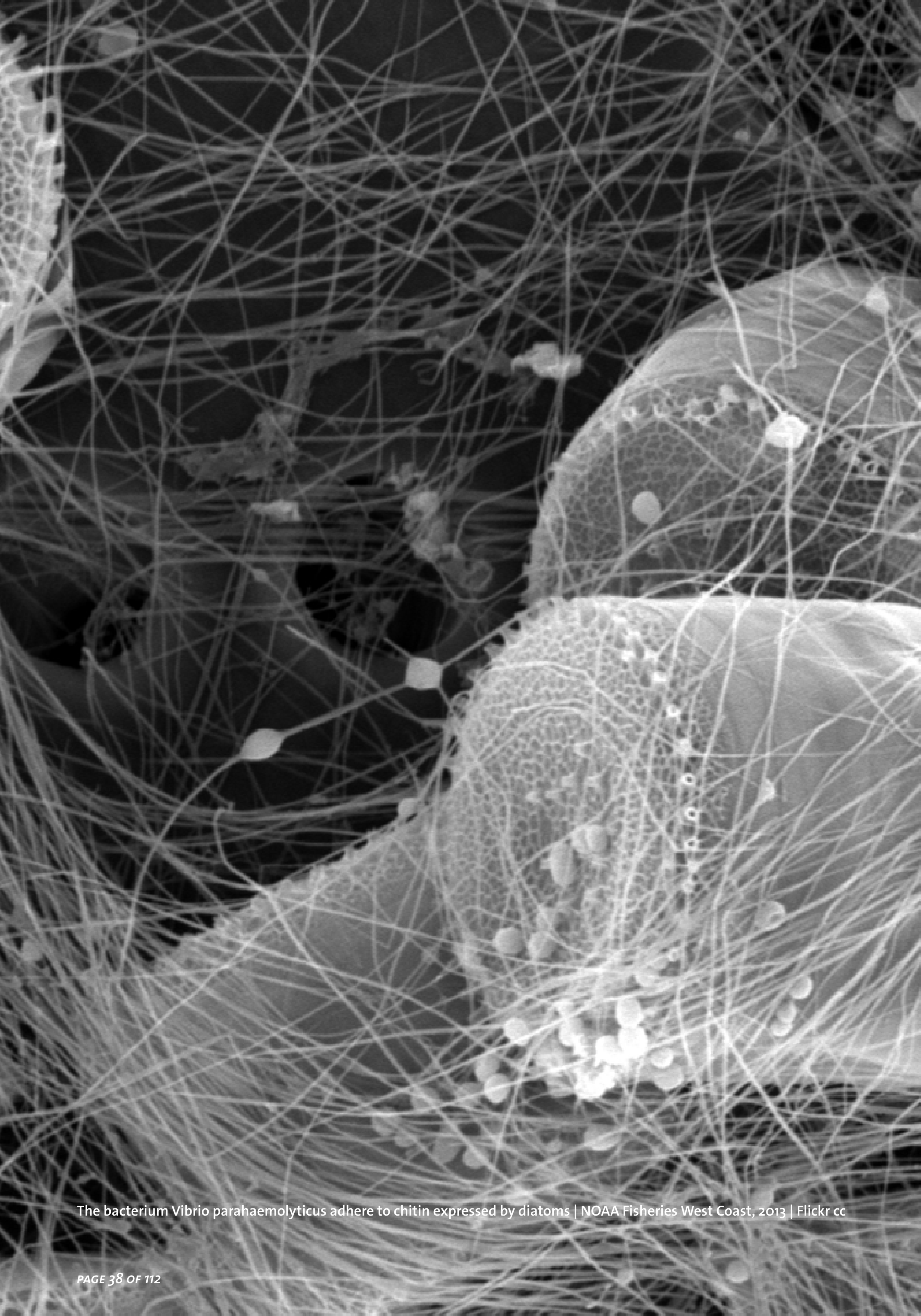
the soil but helped create a new economy that was not dependent on cotton. To help generate demand for these new crops, Carver developed and patented a stream of new products, including peanut butter.

I look for opportunities to build on small steps, starting with small academic grants to build lab prototypes, then entrepreneurship funding to allow initial scale up. This stage provides the data for credible based business cases that will convince the investment community to fund commercial-scale implementation. Taking small steps also allows time to properly evaluate the implications - even using natural resources may have unintended consequences or prove to be unsustainable as volumes scale up.

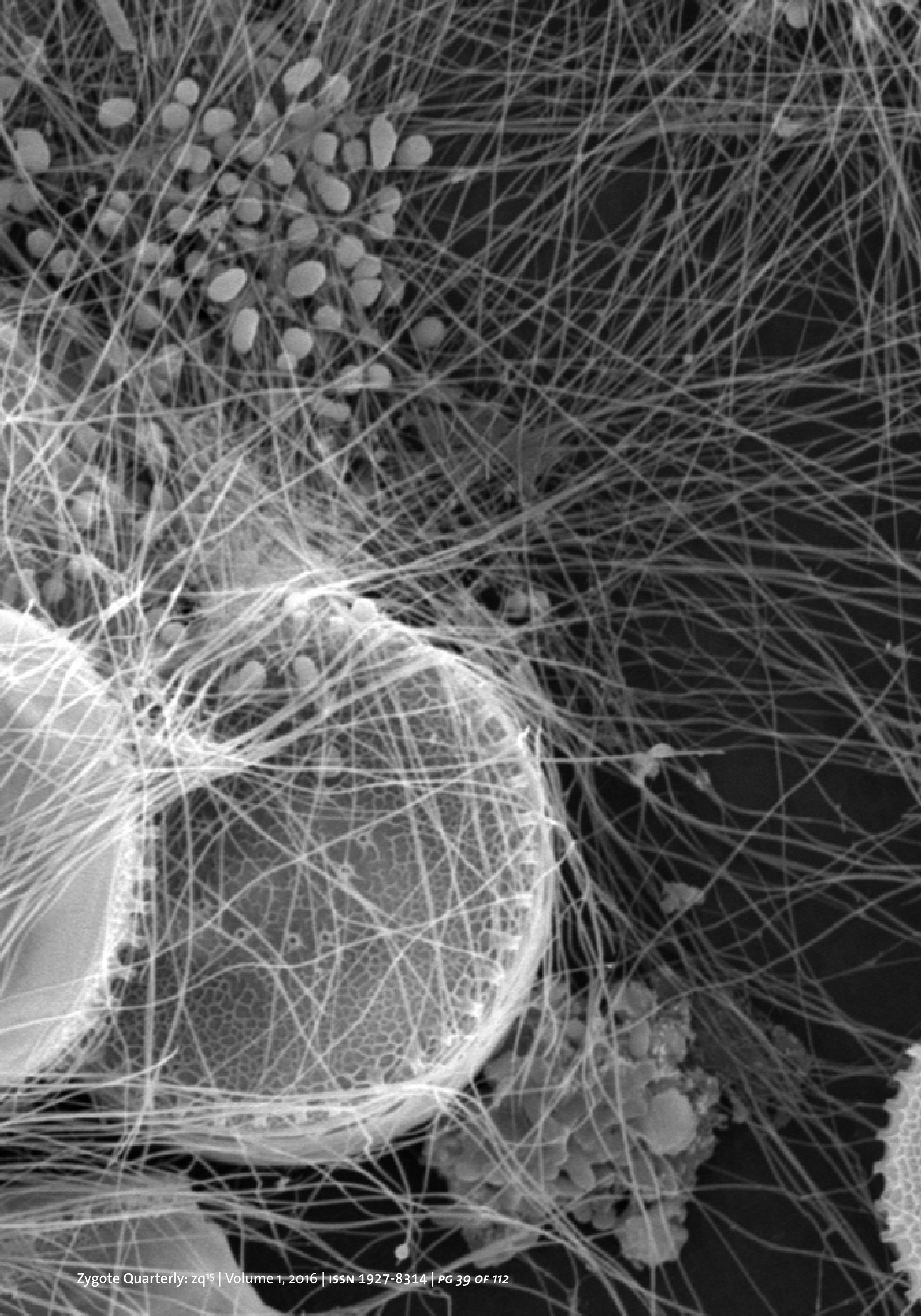
It is important to understand the system in which new ideas, products and processes are being introduced. What pain points will the new approach address? Is there a market for the product that will generate a revenue stream? Are there key suppliers who are essential for the success of the project but are threatened by it? What additional resources and expertise is required to deliver a 'whole product' and what motivates them to get involved?

Soy sauce crystals

Photo: Wellcome Images, 2015 | Flickr cc



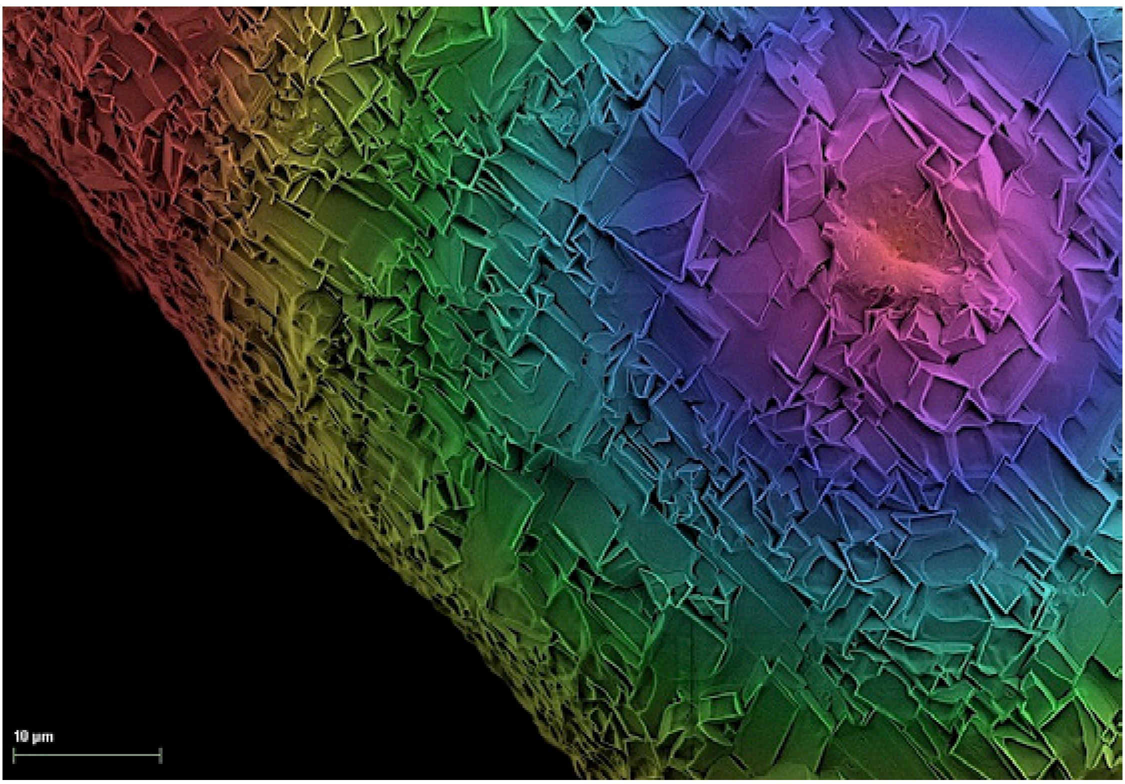
The bacterium Vibrio parahaemolyticus adhere to chitin expressed by diatoms | NOAA Fisheries West Coast, 2013 | Flickr cc



In some respects, the Canadian forestry industry has fallen on hard times, similar to what happened in Alabama. I have been trying to get the forestry companies to collaborate on a joint lab that would isolate every possible chemical and polymer from trees and develop a range of high value products. The goal is to help move the forestry industry from seeing themselves as suppliers of wood products to becoming innovation businesses delivering novel and valuable solutions to the marketplace, ideally in a sustainable fashion.

What are you working on now?

The Alabama shrimp fishery around Bayou La Batre was severely affected by the Deepwater Horizon oil spill. Recovery has been slow partly because shrimpers are paying about $100K per month to send shrimp shells to landfills. The shells of shrimp and other crustaceans are made of chitin, a polymer that can be turned into high value bio-compatible medical products including sutures and medical bandages. We started with an NSF grant that supported lab bench extraction of chitin in quantities of about 3 ml. The next stage was a Small Business innovation



Electrospun chitosan fiber strand with excess crosslinker

Photo: msaustero, 2010 | Flickr cc

and Research (https://www.sbir.gov/) grant of $1.5M over two years that allowed us to scale up to 20 liters of extraction, develop a metal-ion absorbate (Rogers, 2013), engage engineers and economists, and generate the data required for a full-scale business plan for a commercial chitin extraction plant.

Until recently, chitin has been converted into a lower molecular weight polymer through a pulping process and then further treated to create chitosan, a soluble compound. The goal is to build a new 'chitin economy' that uses chitin in its natural state, allowing us to benefit from its unique chemistry and structure while reducing the complexity and cost of manufacturing a comparable synthetic material. In addition, chitin can be combined with other materials to form composites, such as a chitin-calcium alginate fiber developed for wound dressings (Shamshina et al., 2014) or chitin-silk composites (https://zqjournal.org/editions/zq14.html p. 8). In addition to fibers, these composites can also be formed into beads and films by tuning the manufacturing process.

What key messages do you have for bio-inspired design?

Look for pain points that can be turned into viable business opportunities. There is nothing wrong with trying to change the world, but it is essential to generate a revenue stream.

Engage business advisors and financial advisors early, not only to tap their expertise but to help them fully understand the opportunity and better assess the risks.

Encourage entrepreneurs. While an established company may expect tens of millions in yearly profits before considering a project, graduate students will jump at the chance of $1M a year.

Develop a stream of products – few individual products create a viable revenue stream that covers both the capital and operating costs.

Move from a focus on chemicals and components to continuous sustainable innovation and added value.

If anyone is going to do it, it is going to be you. My personal challenge is to find renewable materials that can be turned into viable products: one product, one student, and one dollar at a time. ×

Additional Readings

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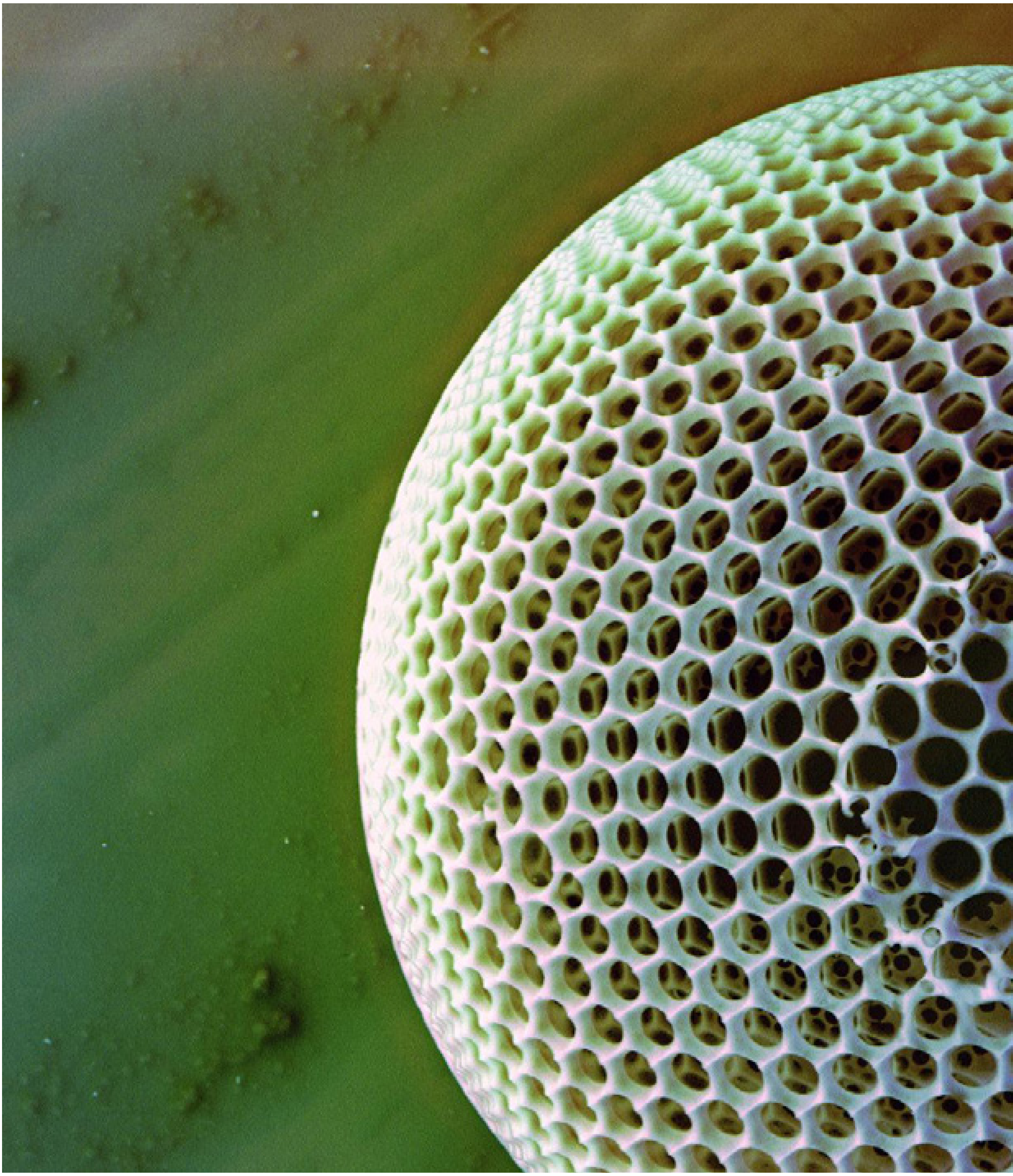


Coloured electron microscopy of a diatom

Photo: ZEISS Microscopy, 2015 | Flickr cc

Interview

Kalina Raskin

Dr. Kalina Raskin earned a Masters in Engineering, Physics, Chemistry and Biology from ESPCI Paris Tech, and a PhD in Neurosciences from the Université Pierre et Marie Curie. She is currently in charge of development at CEEBIOS (Centre Européen d'Excellence en Biomimétisme de Senlis) where she manages the national network, explores trans-national research projects, actively disseminates biomimetic information to innovators, and helps implement tools for enterprises. She is also editorial consultant for various French technical journals, participates in the ISO/TC 266 standardization work on biomimetics, and contributed as an expert on the roadmap for nature based solutions at the European Commission.

What are the challenges faced by biomimetics in France?

In Germany, BIOKON (http://www.biokon.de/en/) and the Kompetenznetz Biomimetik (http://www.kompetenznetz-biomimetik.de/) have been active for years as a result of experts in the field dedicating their time and expertise to building national networks. Until recently, France lacked such networks. Although there were French biomimetic projects, knowledge was not being shared. Without strong government, academic or industry leadership, building credibility is challenging.

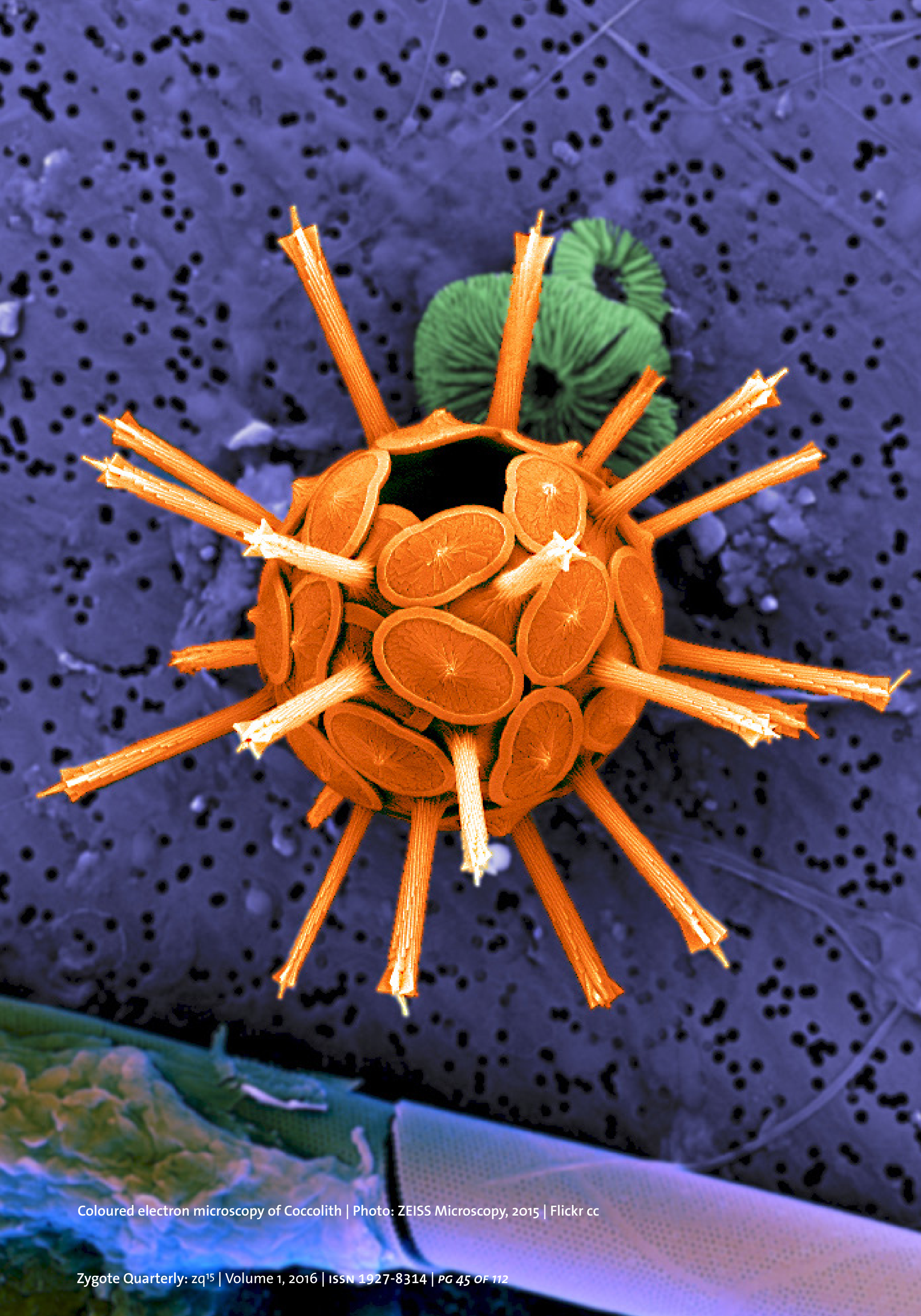
How did CEEBIOS get started?

In 2012, the City of Senlis (http://www.ville-senlis.fr/), 40 km north of Paris, population around 16,000) launched a project to build a campus and technology park dedicated to biomimetics on a 10 hectare (25 acre) site formerly used for training by the French army. This was initiated to encourage local economic development and place the city at the junction between the big northern region and the Paris Region area, where industry and academic research are effervescent.

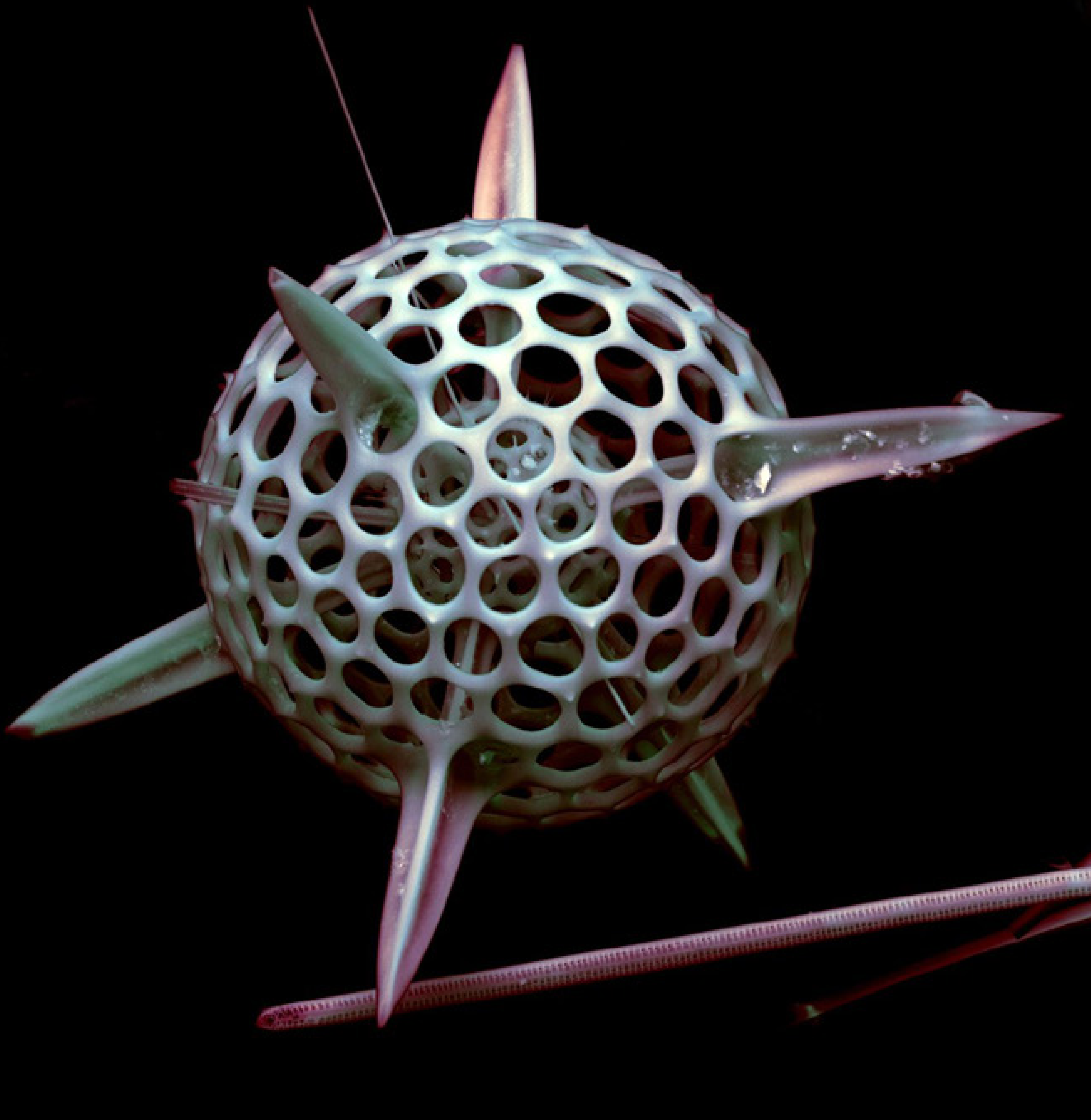
The Centre Européen d'Excellence en Biomimétisme de Senlis (CEEBIOS, https://ceebios.com) was intended to fertilize the soil for biomimetic innovation, acting as a catalyst by increasing collaboration between academic institutions, start-ups, SMEs and industry groups, initiating efforts on education and suggesting new innovative projects.

What has been your approach?

Although support from the City of Senlis raised the profile of CEEBIOS, we still needed to demonstrate our credibility with academic institutions and enterprises, as it was neither a governmental nor industrial initiative. From the beginning we were clear that excellence and expertise lay outside of CEEBIOS in academic labs and businesses. In addition to raising essential awareness of the topic, our goal is to bring together the community, listen to their needs, collect and highlight their efforts and accomplishments, coordinate efforts to raise funds, and lobby on their behalf. This was also and is still the purpose of the German networks such as BIOKON or Kompetenznetz Biomimetik that have been very effective in terms of academic research, education curricula and also transfer to industry.



Coloured electron microscopy of Coccolith | Photo: ZEISS Microscopy, 2015 | Flickr cc



Coloured electron microscopy of diatoms | Photo: ZEISS Microscopy, 2015 | Flickr cc

What initiatives have you undertaken?

We started awareness sessions in late 2013. We quickly realized that we did not have a clear picture of the key players in France. Initially we started to map the landscape of the academic labs using existing but incomplete "pioneer" reports as well as internet and database searches. Interviewing researchers led us to other labs that were working in the field of biomimetics but had not identified themselves as such. To date, we have information on about 100 labs. We are developing a survey to gather additional information that will be made available via a portal.

It proved harder to map the landscape of French businesses involved in biomimetics. France has multiple state agencies at the department level that assist start-ups and SMEs. We started in the Paris region with an agency funded through a European program on Responsible Innovation. We reviewed and classified over 700 projects funded by the agency. We plan to repeat the process in other regions with agencies that understand the local innovation ecosystem such as innovation clusters and incubators. Now that CEEBIOS has gained credibility, French companies are spontaneously reaching out to us and our map of the business landscape is growing organically.

We are building working groups and consortiums around areas of common interest. We have been most successful focusing on 'uses' where multiple sectors and fields can contribute. For example, a working group around bio-inspired habitat has been able to attract academics from multiple sectors (energy, materials and structures) and practitioners (architects, designers, building construction, real estate) that can collaborate in a non-competitive space. We are also launching R&D projects in areas such as materials and databases.

How are you funded?

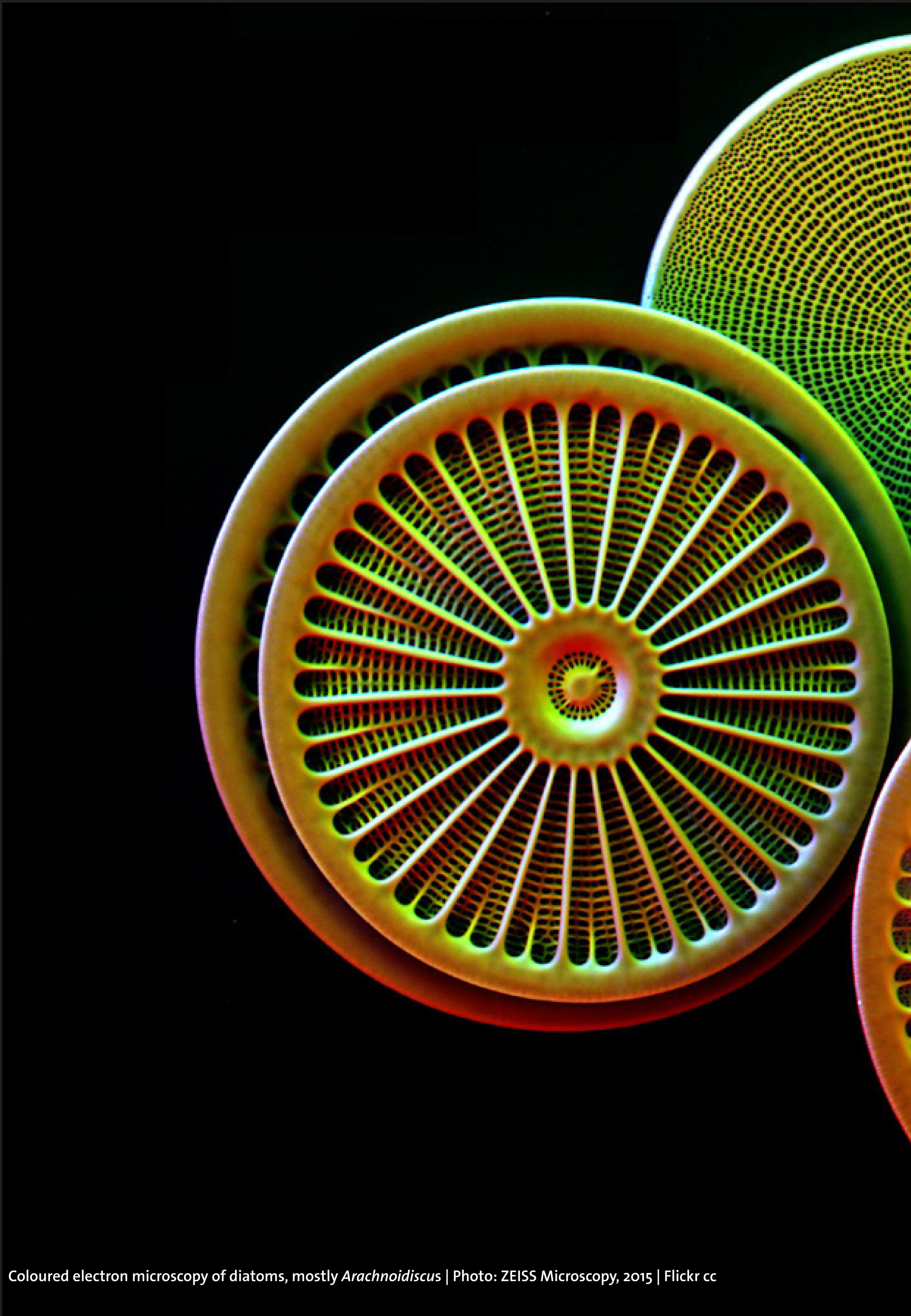
Although we currently have six corporations that are members of CEEBIOS and expect to double that number in 2016, companies will only invest significant funds in concrete projects that deliver tangible corporate benefits. In 2016, we expect to receive roughly equal funding from government agencies, memberships and CEEBIOS contract projects. We are exploring the possibility of applying for charitable organization status to tap funding from foundations, both private and corporate.

Have you experienced issues with information sharing due to Intellectual Property concerns?

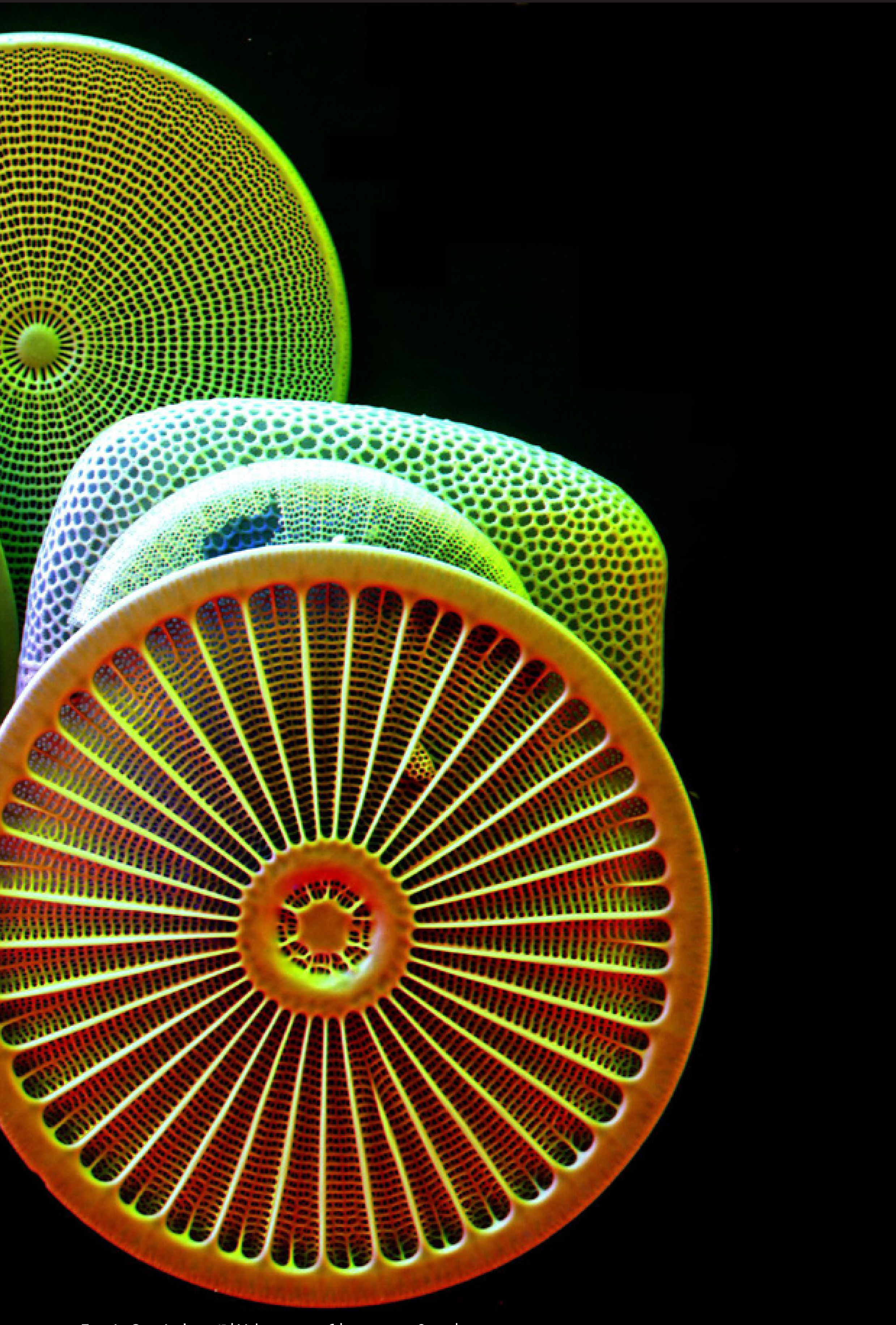
Corporate Intellectual Property currently has not been an issue. In any partnership/consortium, negotiation on IP is negotiated up front. In any proposal for public funding, a Memorandum of Understanding is required to ensure proper use of public funding.

What are your plans for the future?

CEEBIOS needs to constantly look towards the future. Core biom* information is becoming increasingly available. Companies are building their own expertise and willing to dedicate resources to doing research in bio-inspired design. CEEBIOS benefits from having a physical pres-



Coloured electron microscopy of diatoms, mostly *Arachnoidiscus* | Photo: ZEISS Microscopy, 2015 | Flickr cc



ence and can continue to provide value through understanding the national and international networks.

CEEBIOS is investing in bio-inspiration tools in association with the Natural History Museum of Paris. We also plan to develop education and training sessions by pulling together material from experts in the field, ideally using online material that already exists. We are fortunate that France promotes and funds online education, including partnerships across academic institutions.

What are your key 'lessons learned'?

- Accept a 'back-office' role. Focus on improving the efficiency and effectiveness of the biomimetic innovation landscape.
- Highlight local/national initiatives rather than generic case studies.
- Emphasize pragmatic principles from sectors such as Green Chemistry, distributed/renewable energy and eco-design, rather than high level concepts.
- Rely mostly on projects with high scientific content.
- Hook into political hot buttons, such as conservation of biodiversity.
- Look for opportunities to accelerate the journey that clients are already on.

What is your favorite inter-disciplinary work of all time?

Exponential progress in medicine is probably an amazing illustration of the capacity to bridge the gap between disciplines.

Artificial photosynthesis is emerging as a key sector regarding bio-inspiration as a tool to answer societal needs.

What is the last book you enjoyed?

Comment tout peut s'effondrer (*How everything can collapse*), by Pablo Servigne and Raphael Stevens.

Whom do you admire? Why...

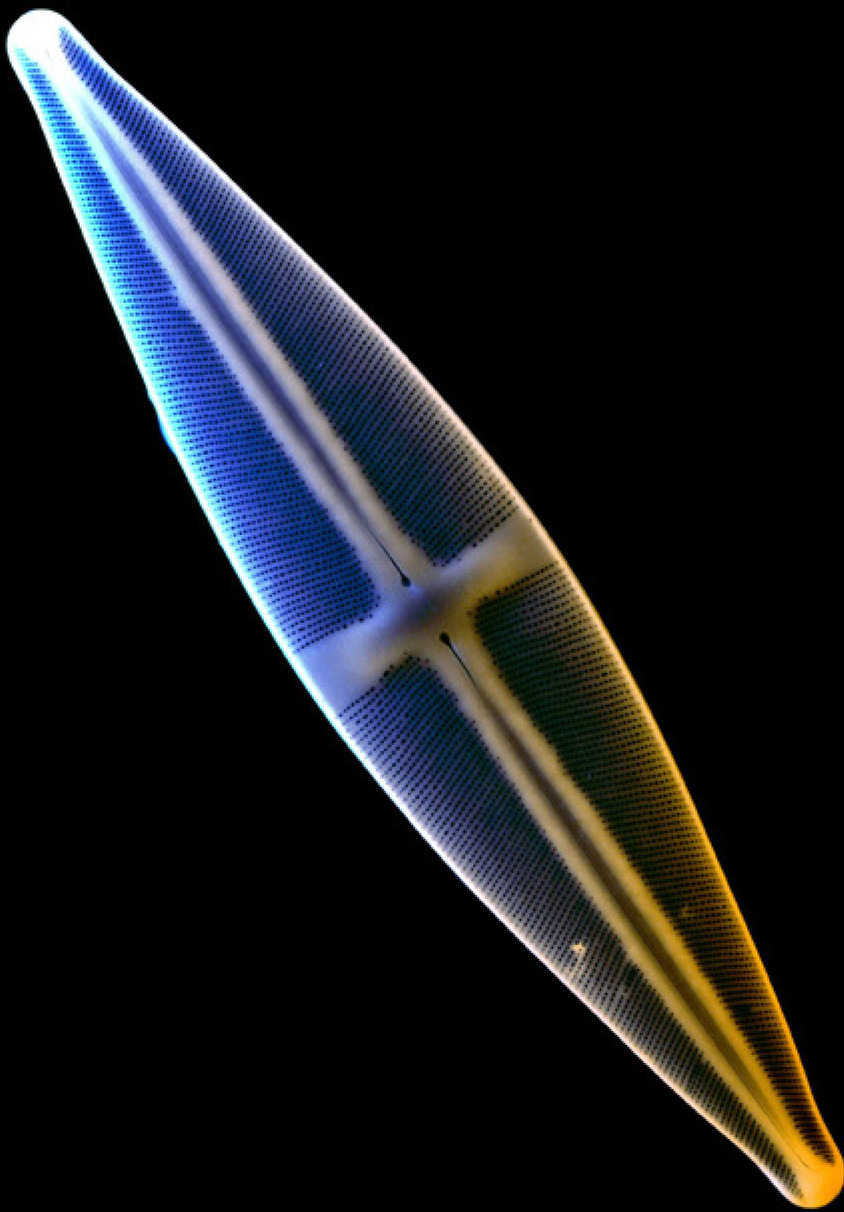
Jacques Livage, Chemistry Researcher at University Pierre et Marie Curie, Professor at College de France, and member of the French academy of science. He is internationally renowned for his work on diatoms and mimicking their process of glass production. He is a pioneer and the national father of soft chemistry. I admire him because of his humility, humanity and enthusiasm to share his monumental knowledge with the largest audience.

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

I would love to get involved in ecomimetic agriculture (http://www.appropedia.org/Ecomimicry). Back to earth! Food production is humanity's biggest concern for the next decades.

What is your idea of perfect happiness?

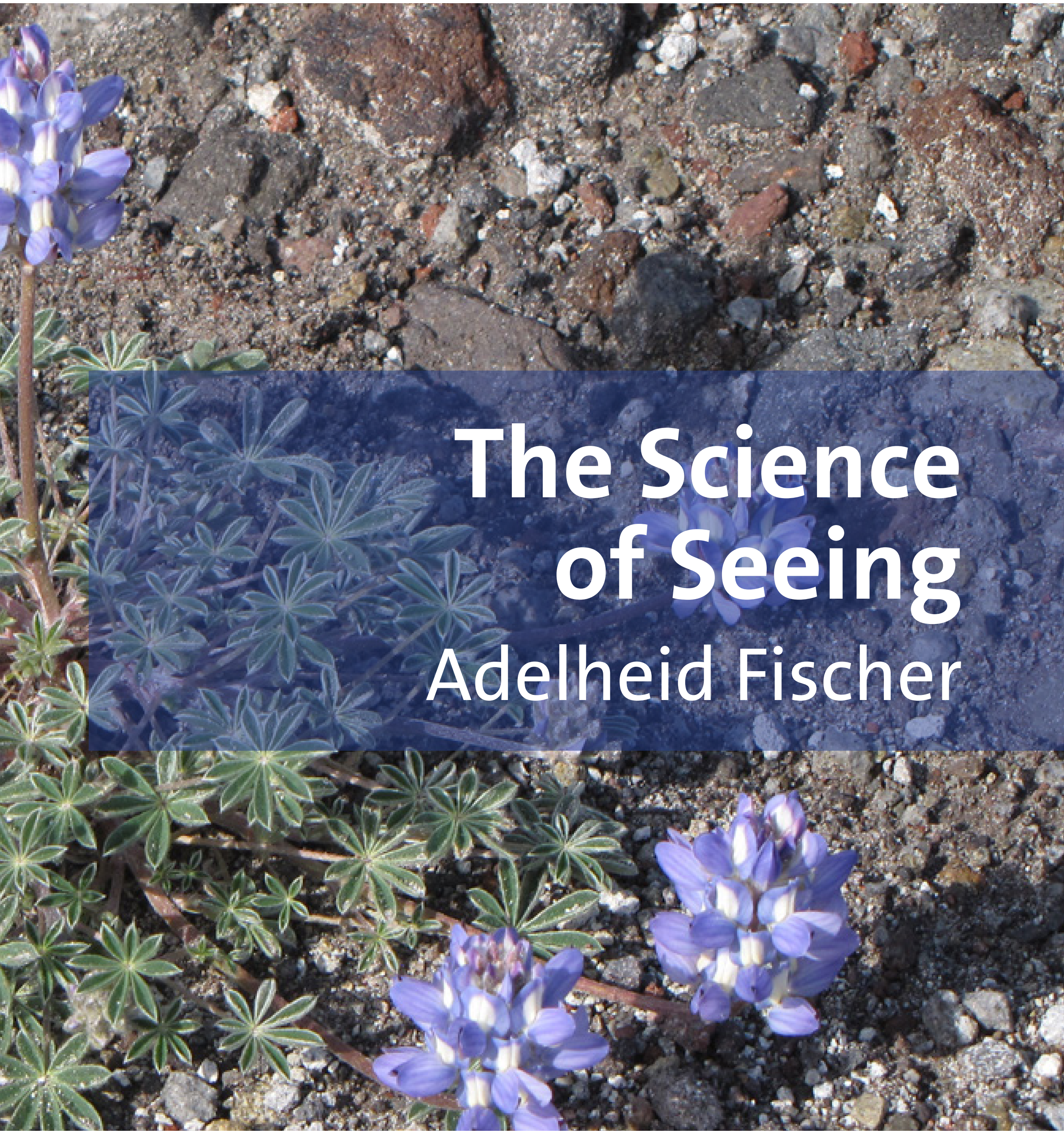
Being coherent in who I am and what I do: acting not for myself, but for the others, feeling at the right time, in the right place and authentic at whatever I do. ×



Coloured electron microscopy of a diatom | Photo: ZEISS Microscopy, 2015 | Flickr cc

Prairie lupine

Photo courtesy of Charlie Crisafulli



The Science of Seeing

Adelheid Fischer

Collaborating with Chance: The Aeronauts of Mount St. Helens

How do you calculate upon the unforeseen? It seems to be the art of recognizing the role of the unforeseen, of keeping your balance amid surprises, of collaborating with chance, of recognizing that there are some essential mysteries in the world and thereby a limit to calculation, to plan, to control. To calculate upon the unforeseen is perhaps exactly the paradoxical operation that life most requires of us.

From A Field Guide to Getting Lost *by Rebecca Solnit*

It is early November, the day before the road to Windy Ridge is scheduled to be closed for the winter. I study the map. The route I will be traveling unspools for 37 miles from the Town of Randle, Washington, climbing some 3,000 feet in elevation through the Cascade Range before dead-ending at Windy Ridge just northeast of Mount St. Helens. My late start means that I will reach the overlook by mid-afternoon. By then the misty rain will have turned to light snow. I look down at my Fiat rental car—a snub-nosed thimble of a vehicle that I had picked out from the Enterprise lot for its gas economy, not horsepower. It is the kind of toy automobile that you might drive into a circus ring for the sole purpose of disgorging an improbable number of fully outfitted clowns before an incredulous audience. En route from the airport in Seattle, however, the Fiat's get-up-and-go surprised me, and so I nicknamed it the Little Italian Stallion. I dismiss my misgivings about its tiny size, turn the key in the ignition and then pat the dashboard. “It's you and me, baby,” I say, as I put the car into gear and begin to thread the highway's tight switchbacks.

Even if I were forced to push the balking Stallion up slick mountain grades, I would not miss this journey for anything. I have been fascinated by Mount St. Helens ever since the 1980s when I walked into a friend's living room in Minneapolis and spied a print by landscape photographer Frank Gohlke on her wall. From across the room, the pewter-colored image resembled an abstract expressionist painting: a yin-and-yang composition that featured swirls of what looked like thickly worked paint on one side and a crazy quilt of brushstrokes on the other.

But this was no scene conjured from the imagination. Gohlke shot *Aerial view: shattered logs in south end of Spirit Lake. Four miles north of Mt. St. Helens* from a Cessna while circling the area in 1982, two years after the volcano's dramatic eruption.

The photograph depicted a massive new construction site that was bulldozed and reconfig-

Plumes of steam, gas, and ash often occurred at Mount St. Helens in the early 1980s. On clear days they could be seen from Portland, Oregon, 50 mi (80 km) to the south. The plume photographed here (1982) rose nearly 3,000 ft (910 m) above the volcano's rim. The view is from Harry's Ridge, 5 mi (8 km) north of the mountain.| Photo: Lyn Topinka, 1982 | Wikimedia Commons ured by nature when the largest landslide in recorded history roared down Mount St. Helens. The story goes something like this: In the two months leading up to the eruption of Mount St. Helens in May 1980, magma rose beneath the volcano, bumping up against a ceiling of brittle rock on its north face. The pressure eventually created an ominous bulge that grew by as much as five feet per day. Then at 8:32 a.m. on May 18, the bulge suddenly slumped like melting ice cream down the mountain's flank. A series of three landslides gutted the interior of the volcano. Great blocks of rock, trees and earth hurtled down the mountain into the Toutle River Valley which lay to the immediate north of the mountain. In a mere ten minutes, the debris hash stormed through 14 miles of rugged terrain, burying some places to depths of 640 feet.

A part of the avalanche smashed into the south end of Spirit Lake, a much-beloved getaway for generations of vacationers. It was like a sumo wrestler jumping into a bathtub of water, says Todd Cullings, assistant director of the Johnston Ridge Observatory at the Mount St. Helens National Volcanic Monument. The weight of the debris sent a wall of water to the far shore and up a slope that was 850 feet high. As the wave receded, it sucked everything in its path into the lake including forests that had kept watch over Spirit Lake for centuries. When it was all over, so much of the mountain had tumbled into the lake that its floor had been raised by more than 200 feet, causing its surface area to double in size. The pickup sticks in Gohlke's photo were the silvered remains of thousands of massive trees—some of them nearly seven feet in diameter—now floating on their sides and clogging the once deep, blue eye of the alpine lake.

But that was not the end of the story. The mountain would bust a seam and explode sideways, jetting a blast of fractured and pulverized rock and lava. The lateral blast cloud, like a searing, stone-filled wind, raced out of the mountain at velocities of up to 670 miles an hour. Hardest hit was the 30-square-mile Toutle River Valley. Once a verdant basin, it became known as the Pumice Plain after the eruption. Beyond this core, the blast flattened a fan-shaped area of 230 square miles of forests.

On the Pumice Plain, the blast cloud was followed by a series of 18 pyroclastic surges, mixtures of ash, gas and pumice that approached temperatures of 1,500 degrees F. Parts of the plain were so thoroughly cooked that they remained dangerously hot for three years after the eruption. As if for good measure, the volcano doused its handiwork with fragments of rock, lava and ash known as tephra. The north slope alone was buried under several feet of this material which, when moistened by the rain, took on the consistency of wet cement. After a flyover to survey the devastated landscape, then-President Jimmy Carter famously declared: "The moon looks like a golf course compared to this."

What kinds of forces could wreak such devastation? I wondered. I'm certainly not the only one who has found this question intriguing. According to the U.S. Forest Service (USFS), more than half a million tourists visit Mount St. Helens monument each year to stare into the maw of the broken volcano that shed so much earth in the 1980 eruption that it shaved off 1,300 feet from the summit, the equivalent of filling 15 buckets for every man, woman and child on the planet. Like me, they come here to satisfy a yen for what's known as the "apocalyptic sublime"—

Tree mats drifting on Spirit Lake, with Mount St. Helens' open crater in the background
Photo: Stephan Schulz, 2012 | Wikimedia Commons

Iron Creek Falls | Photo: jdhiker, 2013 | Flickr cc the desire we seem to have for sipping a disquieting cocktail of beauty, awe and terror while viewing vast landscapes that have been strafed by unfathomable violence.

What's unusual about Mount St. Helens, however, is that the fascination didn't just end with the power of nature's destructive forces. People began to ask: how does life make the transubstantiation from annihilation back into life? It was a beguiling-enough question that the U.S. Congress passed the Mount St. Helens National Volcanic Monument Act in 1982. The legislation created a 110,000-acre national monument for recreation, research and education, a whopping 106,255 acres of which were reserved to allow "geologic forces and ecological succession to continue substantially unimpeded." The law earmarked funding for fundamental field research in geology and ecology within this zone—a provision made all the more remarkable by the fact that it occurred during the science-averse Reagan administration. In the decades that followed, Mount St. Helens would earn the distinction as one of the most exhaustively studied volcanoes on earth.

"Approached attentively," Gohlke writes, "any place may persuade us to linger in an attempt to locate the source of its attraction." Like Gohlke, trapped in his Cessna by the gravitational pull of the mountain's apocalyptic sublime, I set out on my own complicated orbit around this beautiful and difficult place. I started my trek to Windy Ridge in the lowlands at Iron Creek, an old-growth forest of cedar, hemlock and Douglas fir. It was the kind of place that Hollywood might have chosen as the movie set for the retelling of Genesis. Sixty inches of rain fall here annually, 20 inches more than the national average. The precipitation feeds rivulets that tinkle through forest sponge. Both downed and living trees are covered in moss, as if the trunks and branches were wearing pajamas of plush fleece. Everywhere silence swallows sound, except in places like Iron Creek Falls where the stream shoots off a cliff into a crystalline capture pool. The pre-eruption forests around Spirit Lake must have looked something like this: big, big trees, shadows and dim light, moss, silence and the thread of water running through it all like a clear undercurrent of joy.

After gaining some elevation, I stop at Bear Meadow. It was here that camper Gary Rosenquist trained his camera lens on the volcano, manually advancing the film frame by frame at the precise moment when the north flank began to crumple, slipslide and blow up in a series of massive, roiling clouds. The explosion was heard in places as far away as British Columbia and northern California. A strange collusion between topography and the laws of physics, however, created a quiet zone radiating several tens of miles from the epicenter of Mount St. Helens. Not even the residents of Portland, Oregon, at a remove of 50 miles, heard the blast. It is eerie to stand here, knowing that Rosenquist and his fellow campers stood within the quiet zone as they snapped their photos that morning, narrowly missing the blast cloud's searing wind of rock and woody fragments by a mere one-third of a mile. His series of now-famous photographs have allowed geologists to reconstruct the unfolding of the eruption's events. Without them, the precise details of the story that day might have been lost in the clouds of ash and debris.

On this afternoon, mist obscures the peak of Mount St. Helens, whose perfect cone was shattered some 35 years ago. I imagine the mountain as I have seen it in photographs: the half-walls of the crater like a parenthesis embracing a central lava dome. I don't need to see the volcano, however, to gauge how close I am to it. Thirty-five years later the highway is still littered with casualties from the explosions. Tree trunks blackened with rain lie toppled at the side of the road. Others, the color of hoarfrost, are sprinkled across the hillsides, slowly decaying in the very places where they were felled. Bristled clumps of silver fir sprout in patches on the bald ground. From afar, the slopes resemble the coat of a dog with a nasty case of mange.

By the time I get to the Windy Ridge overlook, the temperature has dropped and the clouds are lowering. I hurry up a steep hill, my boots crunching on the putty-colored pumice, nylon poncho snapping in the wind and sleet. I look down on Spirit Lake playing hide and seek in the mist. The scene clears for a few moments and reveals the logjam of trees filling one of its big bays. The lakeshore once sheltered cabins, scout camps and tourist lodges. Having grown up on a small lake in Wisconsin, I know the smells and sounds of places like Spirit Lake: water dripping from a canoe paddle, the pounding of children's footsteps on boat docks, the kaboosh of their cannonballs in the lake, the shrilling of frogs on April nights, how the spring air startles with its sweetness as it fills a musty cabin that has been closed tight for the winter, the way words and laughter are snatched by the wind as neighbors converse on a lakeshore at night. The overlook suddenly feels strangely quiet.

On the way back to the car, I stop at a sign prohibiting off-trail wandering by visitors that was posted next to the remains of a charred tree lying prone and half buried in pumice. It reads: Reveg in Progress. Here and there, leafy clumps of low-growing plants emerge from earth that looks more like gravel than loamy, nurturing soil.

I suddenly realize that this is it—this is precisely what I came here to see: a ruffle of leaves in the sear, these frills of chlorophyll still pliable in the patter of November sleet. I hold a leaf in my fingers and close my eyes, half expecting that I might actually feel a pulse in this life that was audacious enough to put down roots in a place racked by the wind and shivered by cold.

The plant's persistence here is due, in part, to skills honed over evolutionary time. Like a Swiss army knife, every organism possesses an ingenious set of tools that are designed to meet multiple challenges. Adapting to change, however, requires more than a diverse portfolio of survival strategies. It's also about winning the luck of the draw in a game that sometimes might render such skills useless. The scientists who have studied the unfolding of life here in the aftermath of radical change point to a whole host of quixotic factors that determined what would prevail and what would succumb: the fact that the eruption occurred in the early morning rather than late afternoon or early spring rather than in the flush of summer, the fluctuations of rainfall in subsequent months or years; the fact that the volcano blew sideways to the north and largely spared its southern flanks.

Persistence, Mount St. Helens style, is about showing up, paying attention, adapting as best you can to the shifting world around you knowing all the while that life is an unspoken conspiracy of random forces, a risky and sometimes unnerving collaboration with chance that can sideswipe even the most attentive and skillful inhabitant.

Nearly every two weeks from 1981 to 1985, arachnologist Rod Crawford and his colleagues would leave Seattle and head south in the direction of Mount St. Helens. There was the obligatory stop for a burger at the Huff and Puff Drive-In in Randle. Then, he says, they would set out on the road to Windy Ridge, taking bets on whether or not "the outhouse at Windy Point had been blown over again," he recalls.

Two days before my trip to Mount St. Helens, I meet him in his office in the basement of the Thomas Burke Memorial Museum on the University of Washington campus in Seattle. We draw close around a lamp on a desk that is crammed with a computer and stacks of files. Behind us in the shadows are metal cabinets that store decades of taxonomic research. Crawford hardly needs to consult any of it since he easily retrieves information from the ready catalogue of his own memory.

He shows me a faded color photograph of himself in the early days of Mount St. Helens research. He is posing on the Pumice Plain, an expanse of drab rubble framed by the shell of the crater. If Crawford were wearing a space suit instead of T-shirt and khaki shorts, I would have guessed that he was standing on the moon.

It is here, on what looks like a far outpost of life, that Crawford and his University of Washington colleagues, among them the late John Edwards and his graduate student Patrick Sugg, pondered one of the most fundamental questions in ecology: What happens after all the living residents of a place have been extinguished, "cooked, buried, blown away or scoured clear," as they were on the Pumice Plain? In other words, What comes next after all is dispatched to hell in a handbasket?

Scientists use the classic theory of primary succession to help answer this question. The Mount St. Helens eruption would provide them with an ideal outdoor laboratory for testing its underlying assumptions. After all, "it's not every day that a volcano conveniently sterilizes 80 square kilometers of habitat," Crawford observes.

Primary succession posits that plants are responsible for triggering the reset button in bare mineral substrates such as sediments that had been newly exposed by scouring floods, a retreating glacier or, like the Toutle River Valley, buried and baked by a volcanic eruption. Among the first to take root are pioneer plants capable of tolerating the often-extreme conditions of a post-disturbance landscape—including intense solar radiation, drying winds or wide fluctuations in temperature. These hardy newcomers help build soil, for example, by trapping blowing particles of sediment or increase the availability of moisture and nutrients through their decaying remains. By ameliorating the raw conditions, they provide a toehold for other, more finicky plant species that gradually elbow them out of their habitat. Over time, even these intermediate plant communities are replaced by what is known as a climax community, i.e., a mature system with a relatively stable network of relationships that is able to persist until disturbance trips the cycle of succession all over again.

Mount St. Helens might easily have been cited as another textbook example of how plants initiate primary succession. In June 1982, a young ecologist named Charlie Crisafulli had been flying low to the ground in a helicopter, crisscrossing the Pumice Plain in search of any signs of life. “It was complete and utter barrenness,” he recalls in a 2010 *Nova* documentary on Mount St. Helens. Suddenly, smack dab in the center of the Pumice Plain, Crisafulli spotted a splash of intense blue color sprouting from the gray rubble. It was a prairie lupine. He speculates that a seedpod had somehow been washed down from the higher elevations, where lupines customarily grow, and had taken root in the volcanic ash. These colorful, showy plants had a special advantage in the nutrient-poor conditions of the post-eruption landscape: they come equipped with their own fertilizer factory. Like other legumes, lupines host bacteria on their roots that can transform the abundant nitrogen in the air into a form that the plant can use. In exchange, the plant provides the bacteria with sugars from photosynthesis. Crisafulli promptly staked out a research plot around the lone volunteer and revisited the site year after year. Within a decade, this one individual lupine had spawned 169,000 descendants. Moreover, they helped to jumpstart the conditions that allowed numerous other plants and animals to colonize the plain and to build thriving communities of more diverse species. Lupines, for example, provided food for northern pocket gophers. In the process of tunneling their burrows, the animals kicked rich soils onto the mineral surface. These gopher mounds served as islands of hospitality that invited additional plants and animal to gain a toehold on the Pumice Plain.

The research by Edwards and his colleagues, however, would provide a surprising twist to this story by demonstrating that animals, not plants, were the triggers of primary succession on the Pumice Plain. During ground operations in the very first days after the eruption, search-and-rescue helicopter pilots reported seeing numerous insects on the Pumice Plain. These organisms could not have survived the massive disturbances on the Pumice Plain, nor could they have made the journey on foot since the nearest intact refugia was at least 11 miles away. Edwards and his colleagues reasoned that any arthropods that appeared on the plain in the early years had to have dropped out of the sky.

The appearance of what Edwards called the “parachute troops” wasn’t altogether surprising. Scientists have long known that arthropods can travel far distances. Take spiders, for example. On Oct. 31, 1832, Charles Darwin aboard the *H.M.S Beagle* observed how spiders drifting on silk filaments, what he called “Aeronaut spiders,” had accumulated on the ship’s ropes. In his diary he remarked, “how inexplicable is the cause which induces these small insects...to undertake their aerial excursions,” particularly since they were sailing at least 60 miles off the coast of Argentina, far beyond the possibility of landing in any suitable habitat.

Back in 1904, the author of a *New York Times* column entitled “Things Novel, Quaint and Curious” recounts a similar observation by George H. Dodge, an American steamship captain. In winter 1881-82 Dodge was piloting a vessel more

Lupinus lepidus | Photo: Calypso Orchid, 2015 | Flickr cc than 200 miles off the eastern coast of South America when a wind from the direction of the continent blew a large squadron of eight-legged "Aeronauts" into the rigging.

Arachnologist Crawford points out that Darwin and Dodge were describing a behavior known as ballooning. A juvenile spider will climb to a high point—the top of a fence post or to the end of a tree limb, say—point its backside up into the air and then emit filaments of silk from spinneret organs located on the underside of its abdomen. The animal will adjust its position in the direction of the wind so that it can use its force to help unfurl the string. When enough silk is caught up in the breeze, the spider releases its hold and is carried aloft. Physicist Peter Gorham of the University of Hawaii recently published research suggesting that forces from the earth itself could give these threads an electrostatic charge that aids in keeping the spiderlings airborne and that they actually may seek out launch sites where charge densities are high.

Backlit Builder

Photo: Ingrid Taylar, 2013 | Flickr cc

On first glance, ballooning seems to be a hit-or-miss proposition. Many spiders will land in hostile terrain and die. Nonetheless, Crawford observes, there are advantages to undertaking the dicey journey. "Any organism that reproduces in considerable numbers has to disperse. If an orb weaver lays 900 eggs in one egg sac, the babies can't all live where mamma lived. They balloon to 'get away from it all,' " he says. Taking to the air in great numbers increases the odds that at least some spiderlings may find a home that allows them to survive and reproduce.

Crawford points out that there have been quite a few studies on the factors involved in take-off, but what happens after the arachnids become entrained in the wind is anyone's guess. "You can imagine the difficulties of such a study. You would have to find a spider that was about to balloon and attach some kind of telemetering device that wasn't too heavy to keep it from taking off," he says.

Crawford and his colleagues suspected, however, that the ecological impact of aerial spiders and other arthropods was significant. "On a summer's day," write Edwards and Sugg, "at least half the insect biomass may be airborne, a fact well known to swallows and swifts but little appreciated by earthbound humans."

Indeed, as early as 1926, researchers from the U.S. Bureau of Entomology and Plant Quarantine tried to identify and quantify the organisms in the earth's aerial plankton. Outfitting planes with special sticky traps, they began to fly sorties over Louisiana to learn more about the migrations of crop pests such as gypsy moths and cotton bollworm moths. Their aerial reconnaissance, which lasted five years, yielded striking results. At any given time in the skies over one square mile of Louisiana countryside, at elevations ranging from 50 to 14,000 feet, the air column contained some 25 million to 36 million arthropods. Their catch included "ladybugs at 6,000 feet during the daytime, striped cucumber beetles at 3,000 feet during the night. They collected three scorpion flies at 5,000 feet, thirty-one fruit flies between 200 and 3,000, a fungus gnat at 7,000 and another at 10,000. They trapped anthrax-transmitting horsefly at 200 feet and another at 1,000. They caught wingless worker ants as high as 4,000 feet and sixteen species of parasitic ichneumon wasps at altitudes up to 5,000 feet. At 15,000 feet, 'probably the highest elevation at which any specimen has ever been taken above the surface of the earth,' they trapped a ballooning spider...." writes Hugh Raffles in his book *Insectopedia*.

These high-fliers do not circulate indefinitely, however. What then was the impact of all this winged biomass once it had dropped back down to earth? So few studies have examined this question largely because of one logistical difficulty: it is impossible to distinguish resident biota on the ground from new arrivals that fall out of the sky. "The eruption of Mount St. Helens gave us the perfect opportunity to test the hypothesis that, microorganisms aside, arthropods [rather than plants] would be the true pioneers of the barren pyroclastic surfaces and the initiators of biological succession," Edwards and Sugg wrote.

As soon as the scientists got the green light from the USFS in 1981, they set about investigating their hunches by installing traps around Mount St. Helens. As points of comparison, they also sampled arthropods in the blowdown zone and

Elk, Pumice Plain, September 2007 | Photo courtesy of Charlie Crisafulli

Goat Rocks, Mount St Helens | Photo: brewbooks, 2011 | Flickr cc on the south side of the mountain that was little impacted by the eruption. Their equipment was simple. At first, the researchers buried a series of plastic cups, setting their lips flush with the ground's surface. Each cup was partially filled with ethylene glycol that would trap and preserve the arthropods that wandered into them. When returning elk developed an unhealthy interest in slurping the cup's contents, Edwards designed another apparatus that was equally low-tech and effective—a wooden frame with fine screen on the bottom that trapped the aerial fallout while allowing rain to seep through. The frame was set into the ground and filled with golf balls to simulate the rough contours of the Pumice Plain's surface. "It turned out to be the magic data gatherer," Crawford says. The researchers visited the traps every two weeks during the field season for five years. On the Pumice Plain, they collected more than 100,000 arthropod specimens representing some 1,500 species. Insects made up nearly 80 percent of their catch, most of them flies and beetles. The remainder was largely made up of ballooning juvenile spiders.

Even the scientists were taken aback by quantity of arthropod fallout from the sky. "The surprising thing was the sheer magnitude of arrival that was going on," Crawford observes. "This had practically been unstudied before."

Most of the parachute troopers, however, were not adapted to survive the Pumice Plain's harsh conditions and quickly perished. Tephra abrades the waxy cuticles of arthropods, making them prone to lethal desiccation, a special hazard for organisms that have a high surface-to-volume ratio. Wide swings in temperature on the Pumice Plain, as well as inadequate cover from the sun and wind, were also problematic. Many could not find suitable food. Edwards called them the "derelicts of dispersal."

The doom of arthropod fallout, however, was not all gloom. Newly erupted volcanic sediments are so poor in essential nutrients, for example, that measurements of total organic carbon and nitrogen taken in 1980 near sampling sites on the Pumice Plain registered zero. Five years later, the amount of these nutrients in the pyroclastic-flow materials, while still low, had undergone a noticeable increase. The rain of material from the sky, a large fraction of which was composed of arthropods, was helping to gradually rebuild the fertile conditions for supporting new life. Moreover, it was doing so in subtle, almost covert, ways. Indeed, when the researchers examined the crevices of rubble on the Pumice Plain, they discovered small junkyards of arthropod remains, and wind-blown seeds germinating in what Edwards and Sugg called the "arthropod compost."

These derelicts of dispersal also provided food for the predators and scavengers that were able to survive and reproduce, the first of which were fellow airborne dispersers such as beetles and true bugs. The reliable rain of food allowed them to establish breeding populations on the Pumice Plain within three years of the eruption. By 1986, after a few isolated patches of vegetation had taken hold on the Pumice Plain, six species of spiders also had established breeding populations, some of which originated from a distance of 31 miles to the west.

The results of this research on Mount St. Helens led the researchers to conclude that the biomass that falls from the sky had been grossly underestimated and that arthropods can serve as the critical agents of primary succession in deeply disturbed landscapes. In the process, they rendered visible what was nearly invisible: diaphanous specks of life hitchhiking currents of air, parachuting to earth unbidden in a mysterious rain of particles that changed everything.

On my last day at the monument, I visit the Mount St. Helens Visitor Center. There in the gift shop I spot a cutout card with a colored drawing of Mount St. Helens in its heyday on the cover. It was a reference to the time not so long ago when the perfect symmetry of its lineaments earned it the nickname “Fujiyama of America”: long fingers of snow draped over its crown like icing, a stippling of conifers on its lower flanks and, in the foreground, a section of the shoreline of Spirit Lake complete with a cluster of cabins and a sandy swimming beach. It looked like an ordinary day in July.

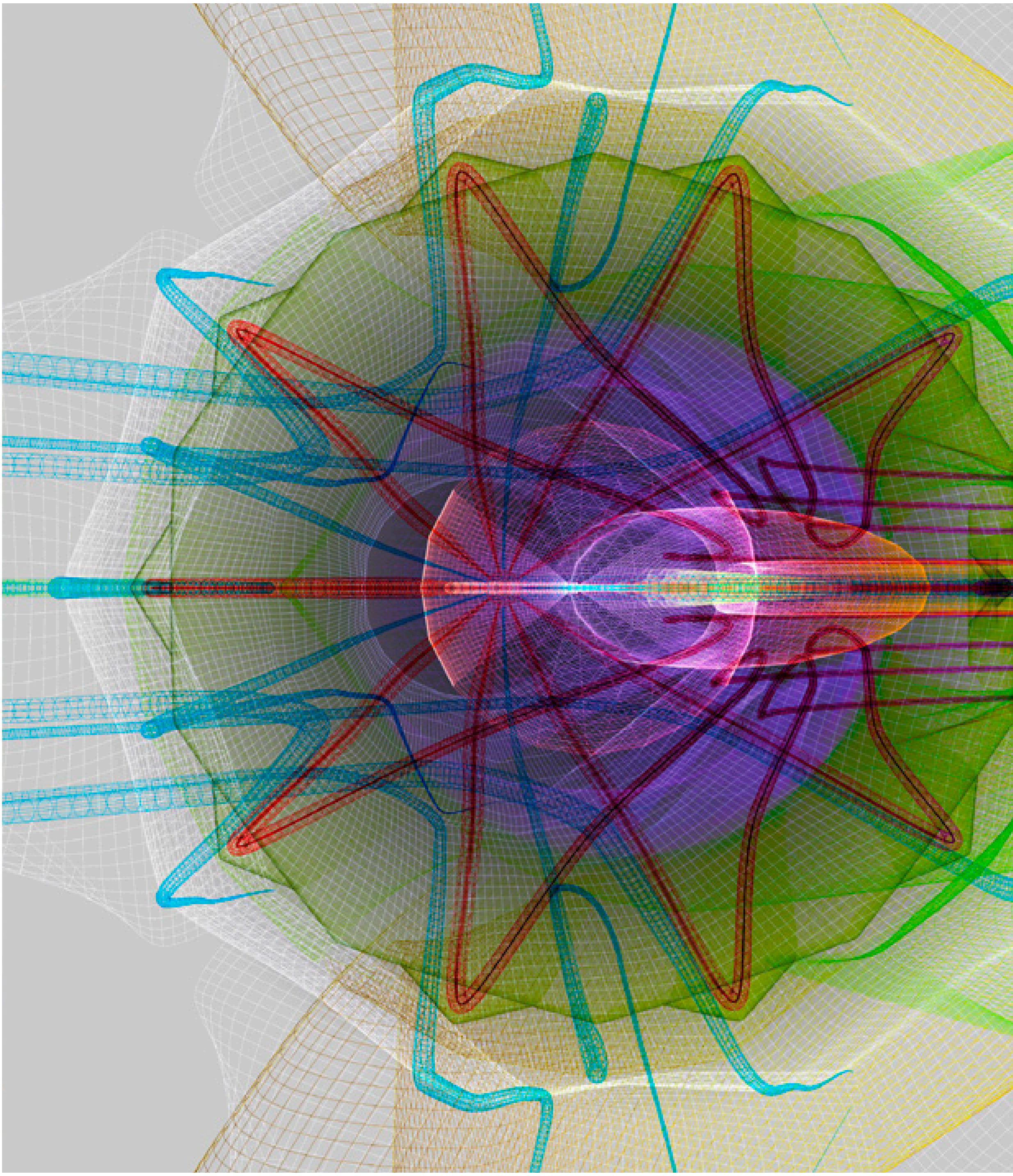
When I open the front flap of the card, however, I nearly gasp. There is a drawing of the post-eruption landscape, a Mr. Hyde lurking beneath the volcano’s Dr. Jekyll: the menacing grin of Mount St. Helen’s broken crater, its green slopes melted into a gray slurry, and Spirit Lake choked with ash and logs. It poses, through pictures, a simple question about the aftermath of catastrophic change: What now?

For nearly four decades, scientists have been answering this question on Mount St. Helens. The longevity of their patient, painstaking investigations is, in itself, an extraordinary achievement and an anomaly in the way science is typically conducted. In 1989, for example, the prestigious journal *Ecology* reported the results of a review of 749 papers that had been published over the prior decade. Only 1.7 percent of the total number of field studies was carried out over a period of at least five years. A similar study by biologist Patrick J. Weatherhead in 1986 reviewed 308 papers in major ecology, evolution and animal-behavior journals and found that the mean duration of these studies was 2.5 years, the average length of a research grant or the research phase of a graduate degree. These snapshots can skew the judgments we make about how nature really works. Mount St. Helens is a case in point. It took the eruption of a volcano in our midst and five years of diligent study to show us that there are oceans of animals in the air that can change the course of life on the ground.

Before the Stallion and I saddle up for what would be our final ride to Seattle, I take one last loop around a wetland on the center’s grounds. The sun has burned off the mist around the peak of Mount St. Helens, and I finally get a glimpse of the snow-covered volcano, solitary, almost standoffish, in the distance. Suddenly, I catch sight of an iridescent strand of silk floating in the air overhead, a flash of blue, then orange twisting this way and that like a live flame, then another strand and another. The air is filled with the fly lines of ballooning spiders. Had they tiptoed to the edge of some grass blades and patiently waited for a rare sunny day in a Pacific Northwest autumn to let loose their kite strings? Would they touch down in the reeds across the pond or become derelicts of dispersal in the rubble of the crater? Would some of the high-fliers make it to the Pacific coast, become entangled long enough in the riggings of a sailboat to cause the occupants to exclaim in wonder, as Darwin and others did before them?

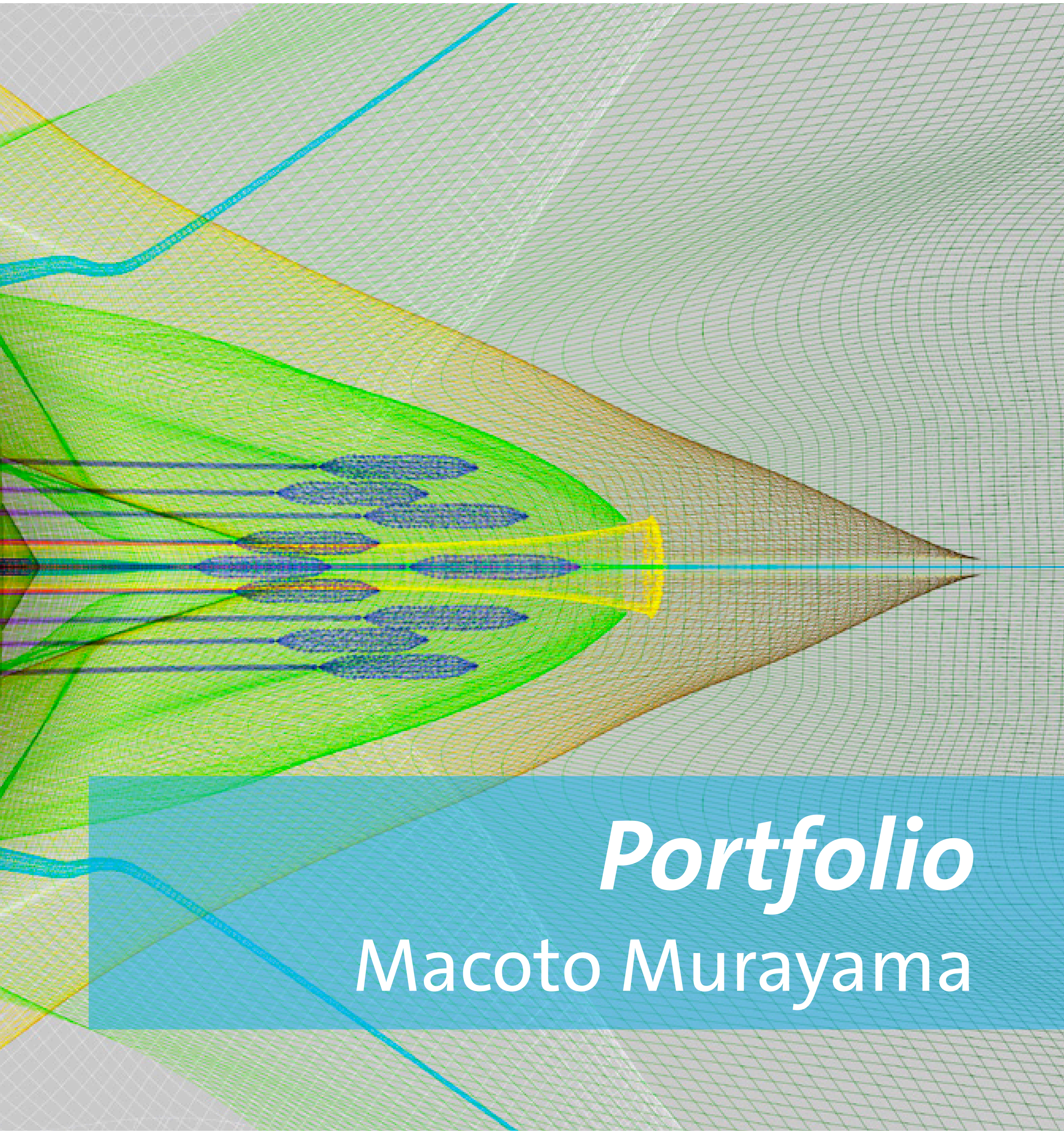
Where would their collaboration with chance take them? ×

Spider web at Lake Conner | Photo: jc.winkler, date unknown | Flickr cc



Sweet pea - iv - wc (detail)

Macoto Murayama | Courtesy of Frantic Gallery



Portfolio
Macoto Murayama

How did you first get interested in art, and illustration specifically?

I was studying architectural design in university. I was originally interested in architectural structures and engineering elements, but the university was mainly teaching design. There I learned how to build architectural diagrams and perspective using CAD (Computer Aided Design) and CG (Computer Graphics). At that moment I got more attracted to CG than to architecture and started to put more effort into it. Nevertheless, it was more CG animation (I was fond of Pixar) than art expression. After that the original form of my own work - Botech Art - was created and I understood the interest and depth of “creating expressions” and started to feel a strong interest toward arts.

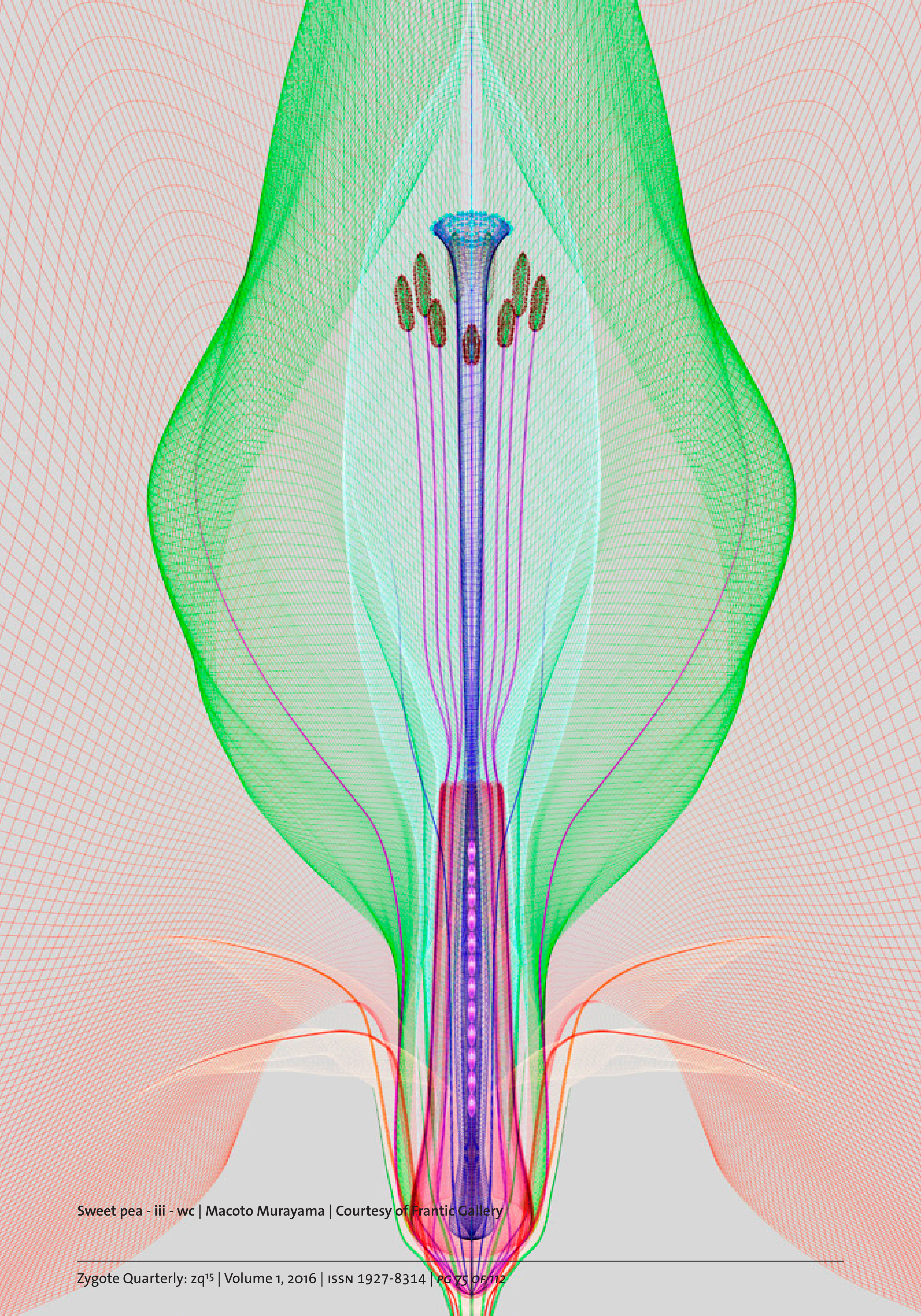
What drew you to scientific illustration? Do you do your work for any kind of scientific value, or is it purely for aesthetic appeal?

One of my teachers in the 4th year of university showed me scientific illustrations. I immediately understood what they are for. I was thinking, “That’s all, that’s why it is so beautiful.” Also, the explanatory descriptions were strangely fascinating. It is the same with architecture: architectural plans are just meticulous descriptions, but it provokes thinking at multiple levels. A common feature is that they both are explanatory figures: accumulations of information. An image of a thing presented with massive and various information is not just visually beautiful, it is also a revelation of the essence of a model. At the moment I present my work as artistic expression, but if I continue in the same direction the value of scientific document might appear in my works.

Why flowers?

In the beginning, I was just searching for a model I would like to create with CG. I had a bit of experience in doing architectural sketches so was thinking to try with something different. In that moment a plant, a flower appeared in my head. It is organic and is rather different from architecture and my creative desire took a new point of view. Besides, when I looked closer into a plant that I thought was organic, I found in its form and inner structure hidden mechanical and inorganic elements. It was very exciting work. I was previously interested in architecture and structural elements, so I was very surprised to discover that common features are hidden in plants. My perception of a flower was completely changed.

Also with the existence of botanical illustration, I was thinking “Why flower?” Botanical art is a type of natural history illustration, which is “scientifically” precise and possesses a value of “artistic” ornamentation. It is different from painting and fine art and possess original charm in uniting *science* and *art*. Observing it, I was thinking that it might be possible to return to my own artistic expression and create a natural history illustration that can overcome the horizons of botanical art.



Sweet pea - iii - wc | Macoto Murayama | Courtesy of Frantic Gallery

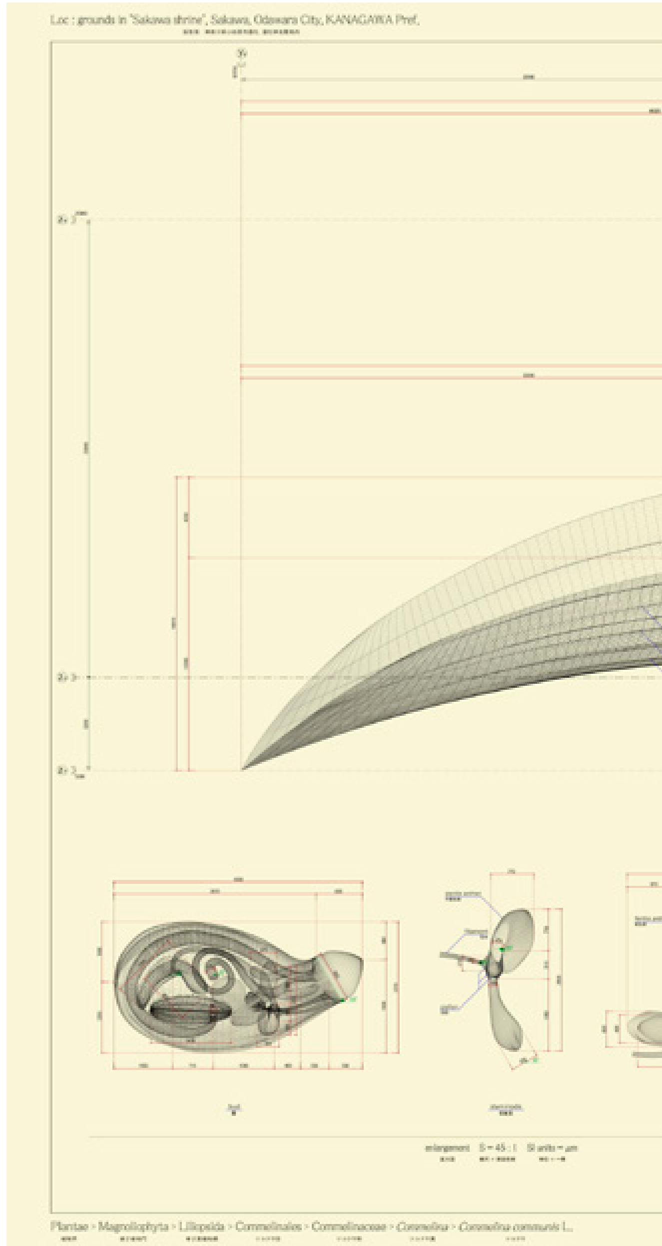
You have a BA in spatial design from Miyagi University, and your bio also lists the IAMAS. What degree did you get from IAMAS?

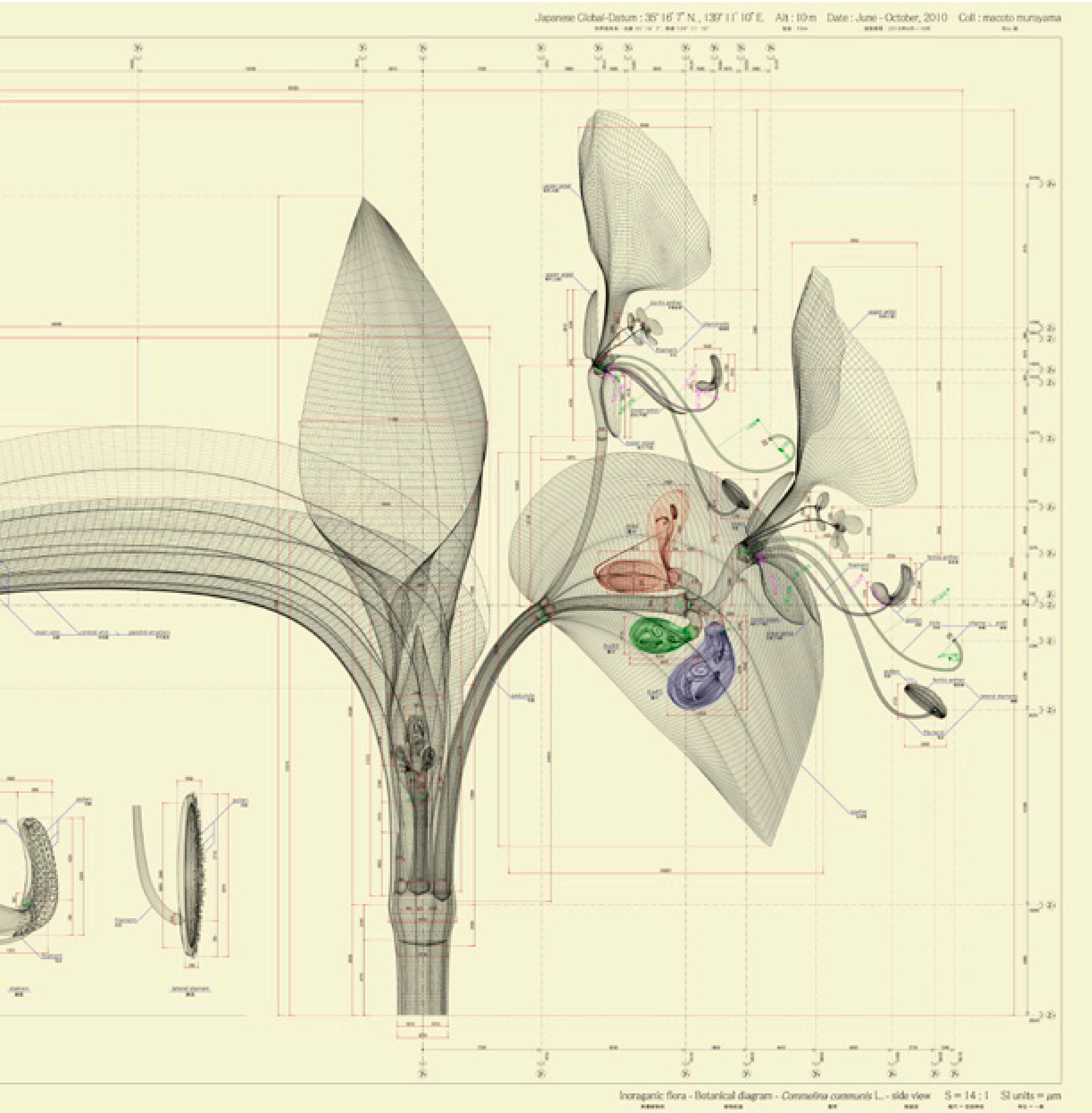
It is “Media Expression.” IAMAS is new educational engine that generates new expression/culture which synthesizes advanced technologies, information sciences and art expressions.

Your bio says you were a researcher at IAMAS from 2009-2010. What did you research? Are you working on your art fulltime now, or do you have another job, as well?

When I was a student, I was searching for further possible development of my work. Would I offer myself as a graphic designer or I will be working with art gallery, or I will continue to Ph.D. and make a research of a higher level. At that moment, during AATM2009 Exhibition I was approached by Frantic Gallery, with which I work now. What is art, how is it different from design? What is this being an artist? There were so many things I couldn’t understand. After I entered the art world, I think I might be able to answer these questions and to elevate my works to the higher dimension. This is what I am doing now. ×

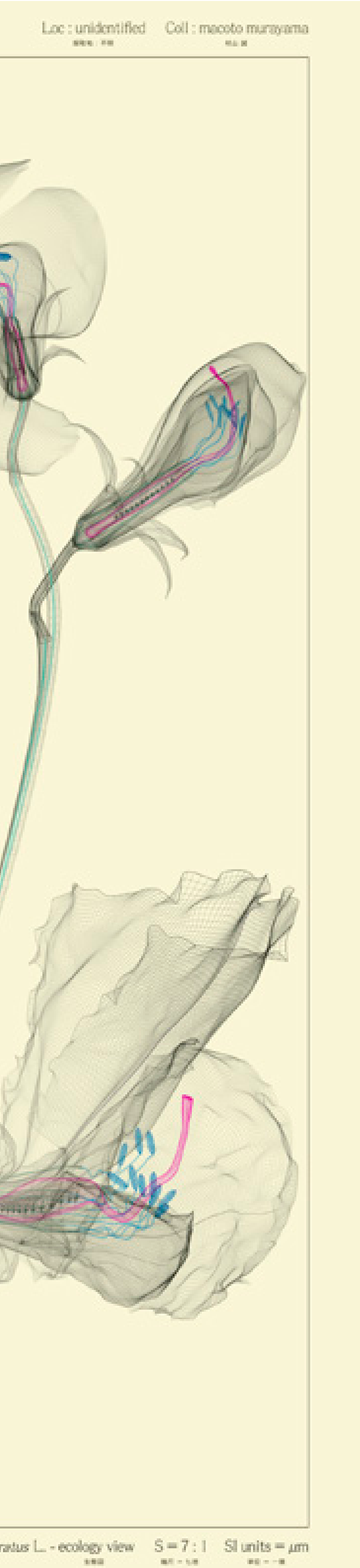
For more of Macoto Murayama’s work please visit http://frantic.jp/en/artist/artist-murayama.html





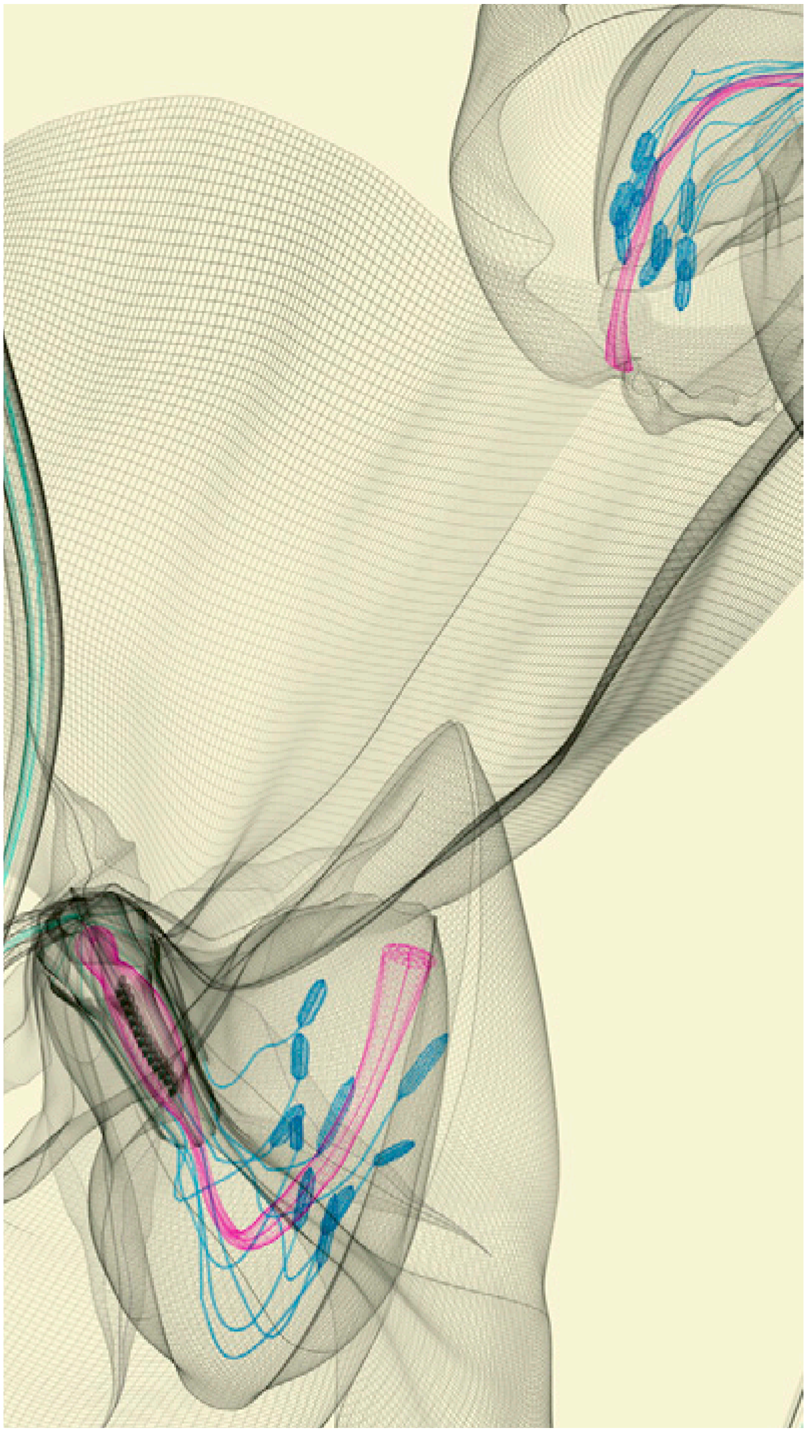
Commelina communis L. - side view - ow (and detail)
Macoto Murayama | Courtesy of Frantic Gallery

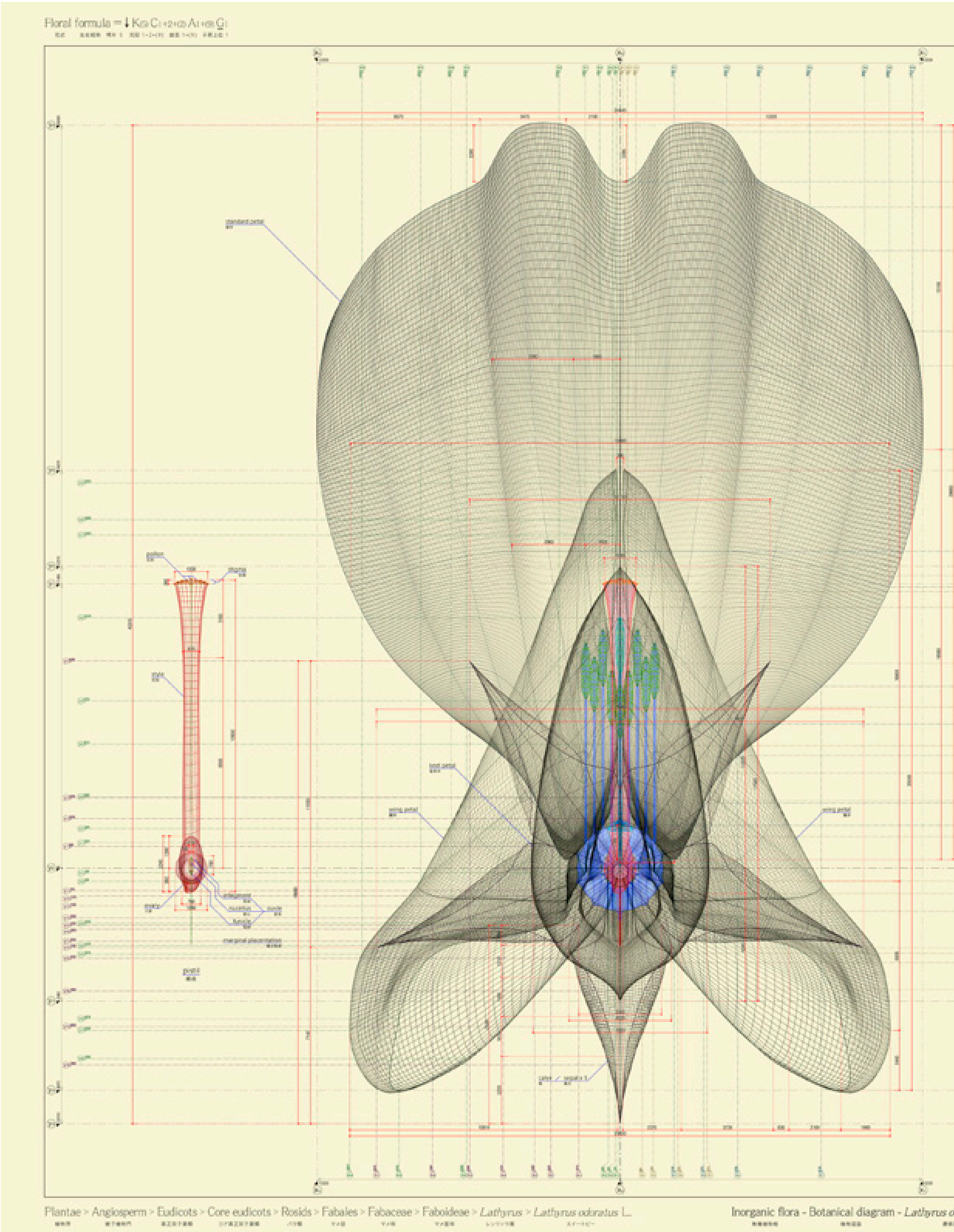
Floral formula = ↓ K(5) C1+2+(2) A1+(9) G1
Plantae > Angiosperm > Eudicots > Core eudicots > Rosids > Fabales > Fabaceae > Faboideae > *Lathyrus* > *Lathyrus odoratus* L.
Inorganic flora - Botanical diagram - *Lathyrus odo*



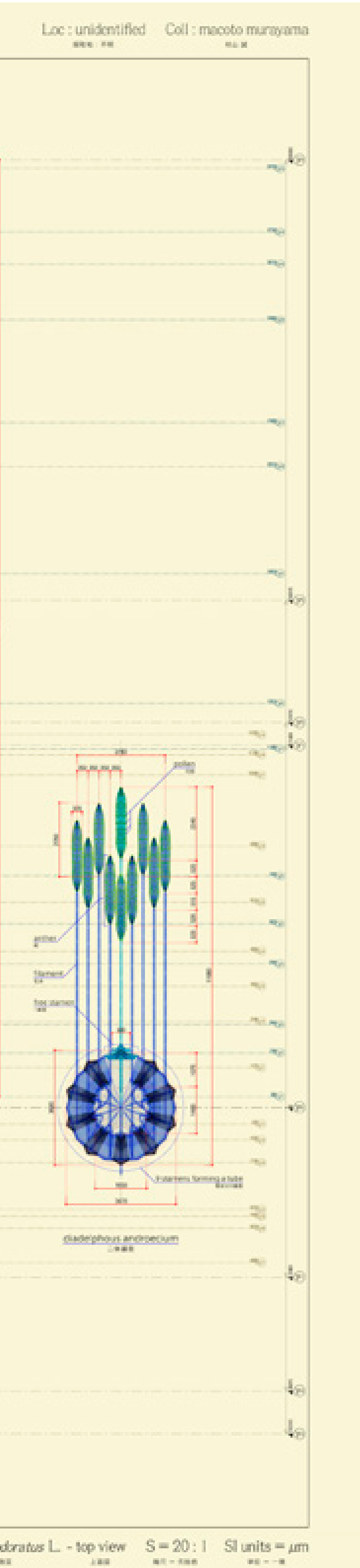
Lathyrus odoratus L. - ecology view - ow (and detail)

Macoto Murayama | Courtesy of Frantic Gallery



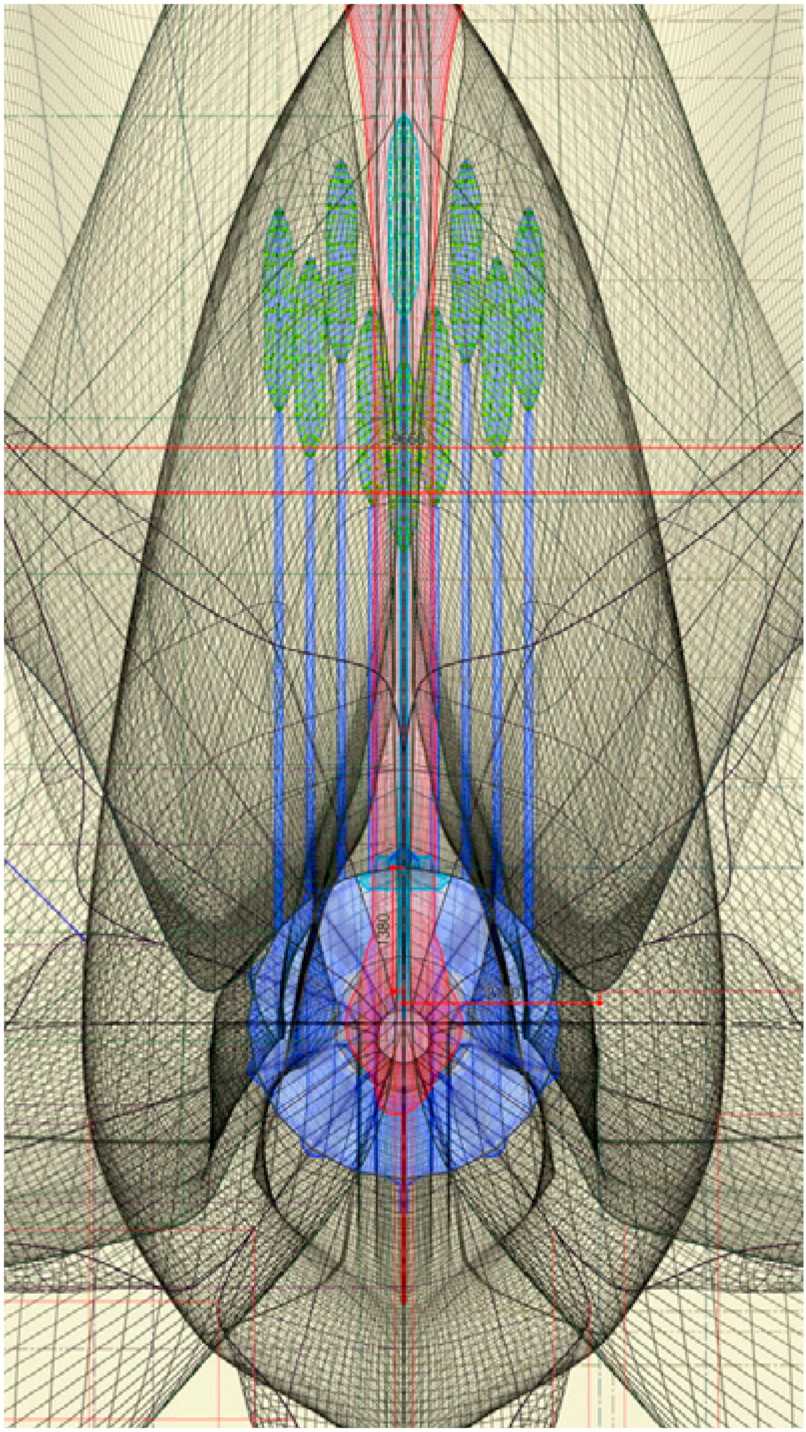


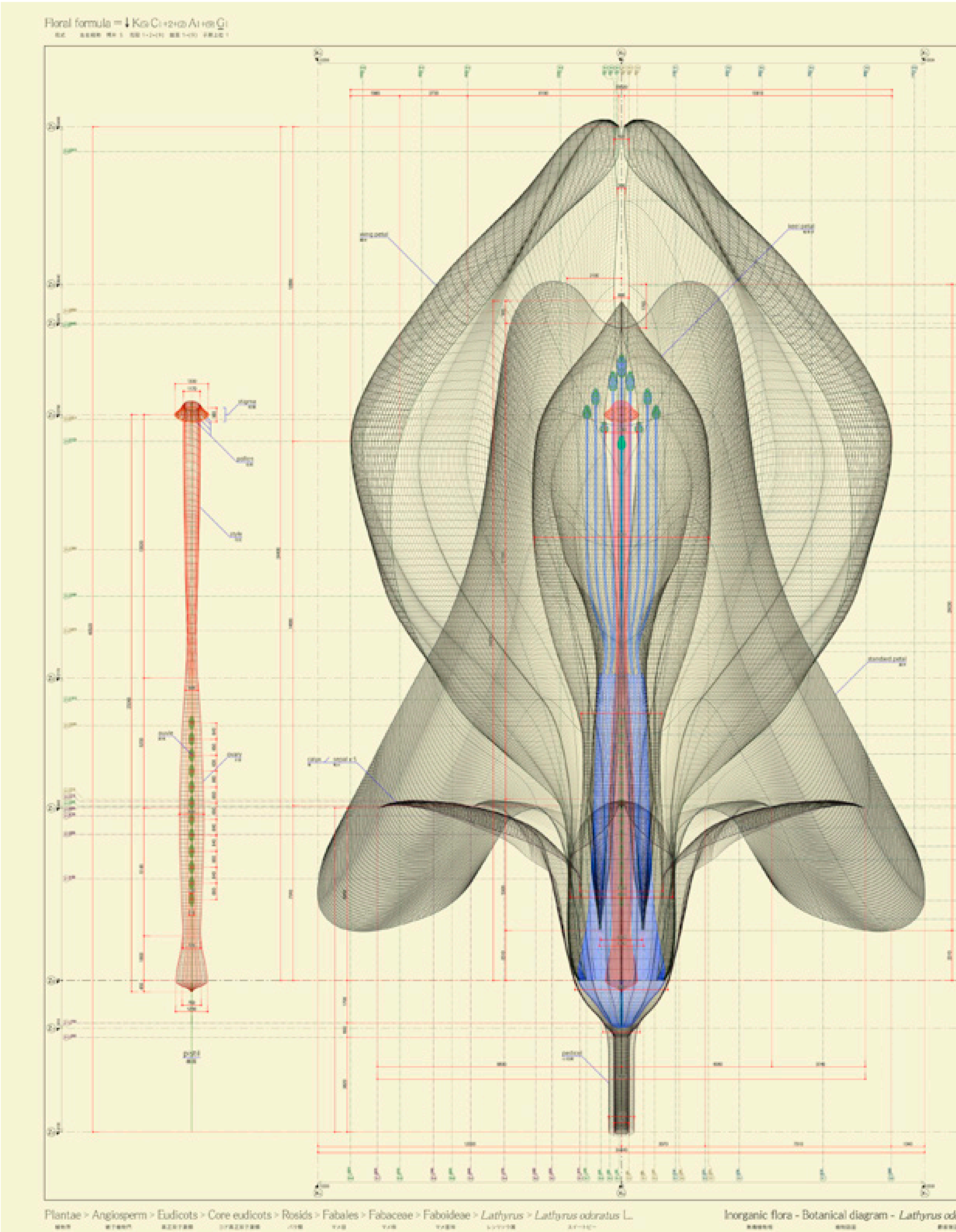
Floral formula = ↓ K(5) C1+2+(2) A1+(9) G1
standard petal
keel petal
wing petal
wing petal
pollen
stigma
style
ovary
pistil
Plantae > Angiosperm > Eudicots > Core eudicots > Rosids > Fabales > Fabaceae > Faboideae > *Lathyrus* > *Lathyrus odoratus* L.
Inorganic flora - Botanical diagram - *Lathyrus o*



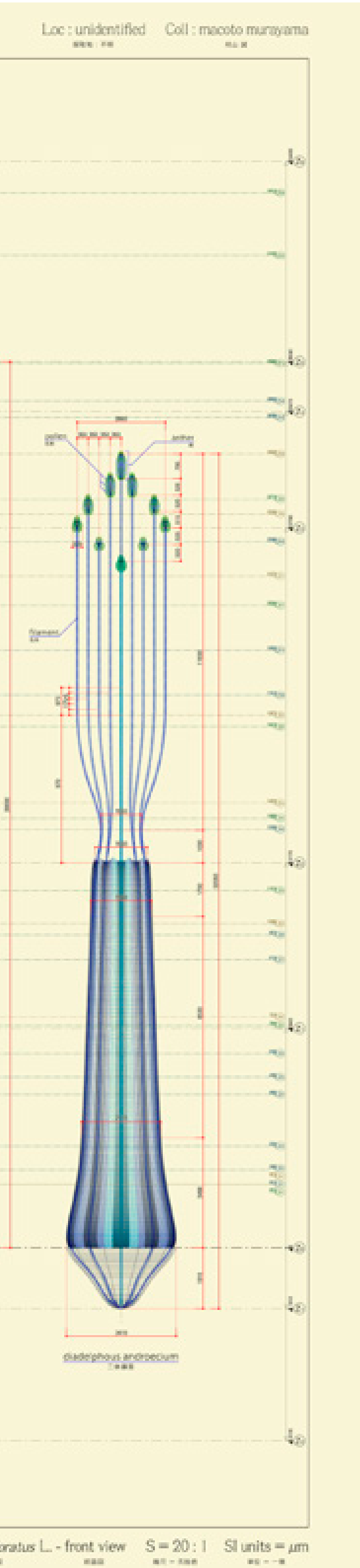
Lathyrus odoratus L. - top view - ow (and detail)

Macoto Murayama | Courtesy of Frantic Gallery



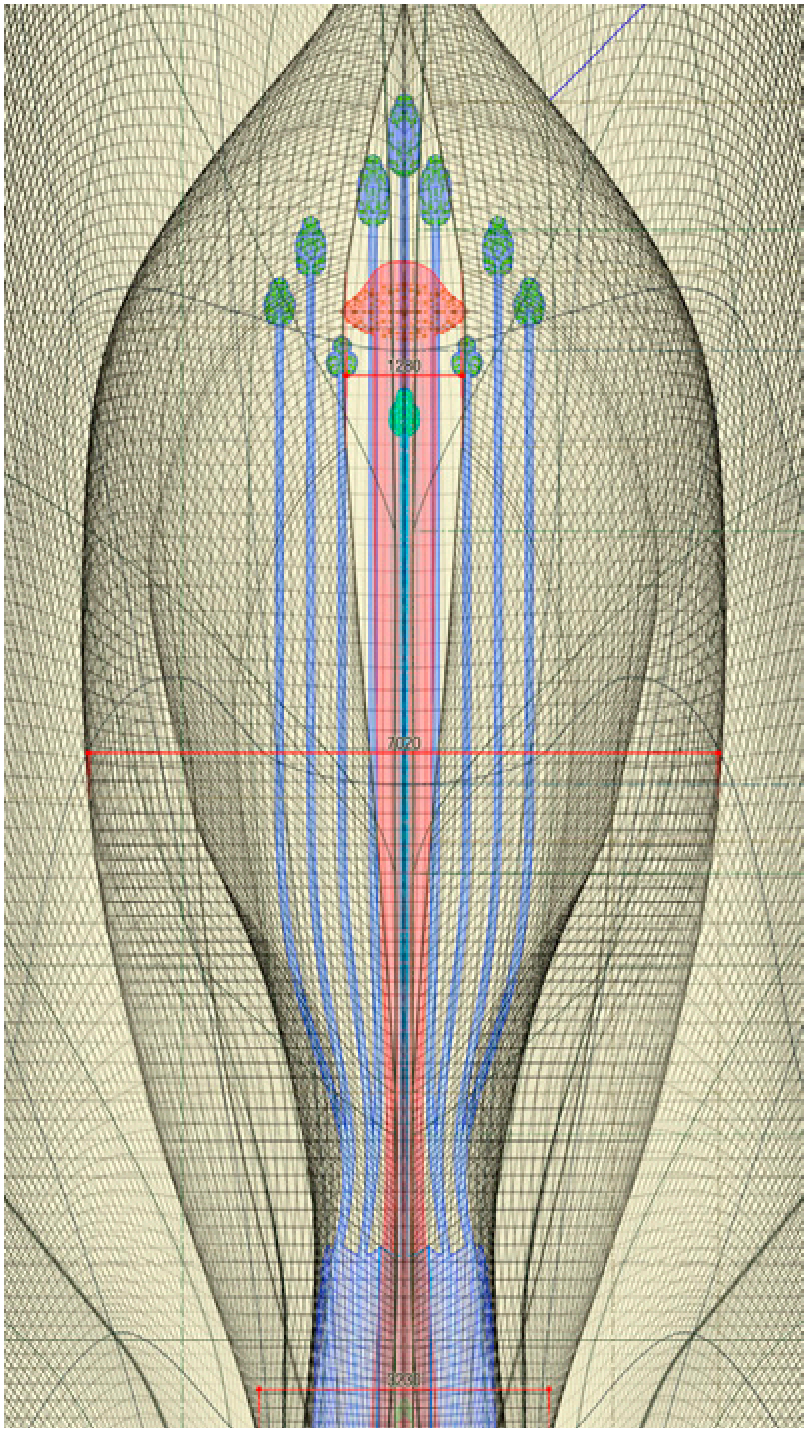


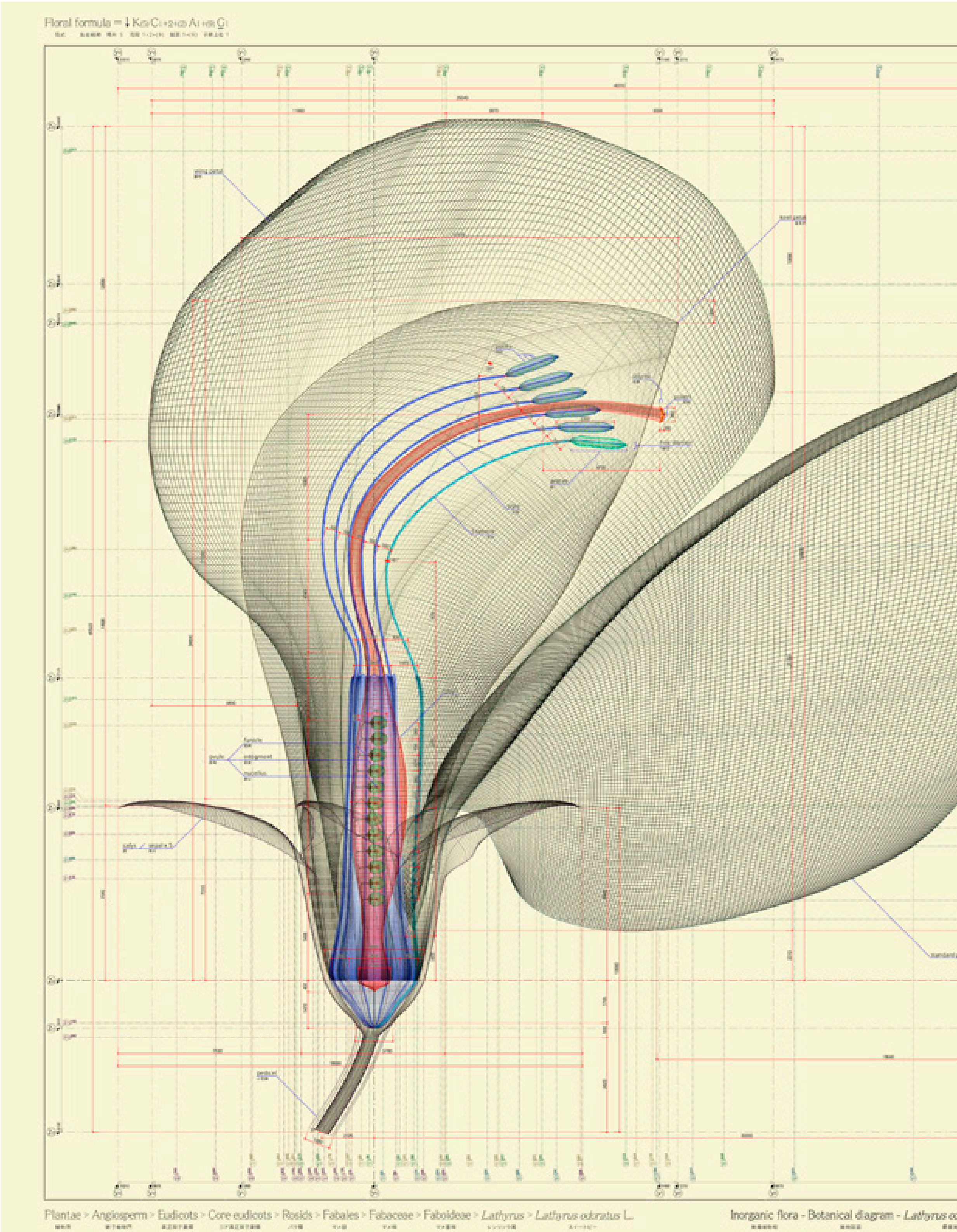
Floral formula = ↓ $K_{(5)}$ $C_{1+2+(2)}$ $A_{1+(9)}$ $\underline{G}_{1}$
wing petal
keel petal
standard petal
pedicel
Plantae > Angiosperm > Eudicots > Core eudicots > Rosids > Fabales > Fabaceae > Faboideae > *Lathyrus* > *Lathyrus odoratus* L.
Inorganic flora - Botanical diagram - *Lathyrus od*



Lathyrus odoratus L. - front view - ow (and detail)

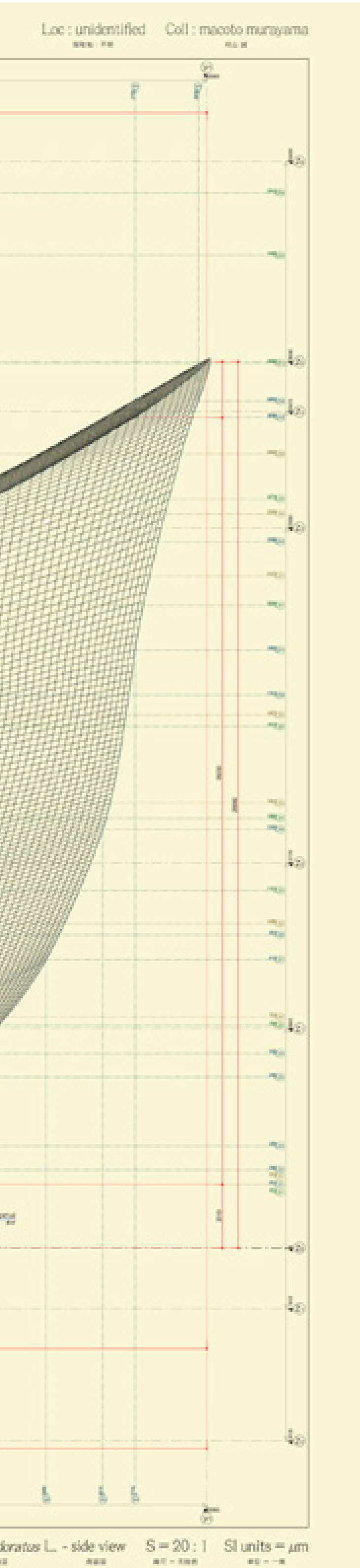
Macoto Murayama | Courtesy of Frantic Gallery

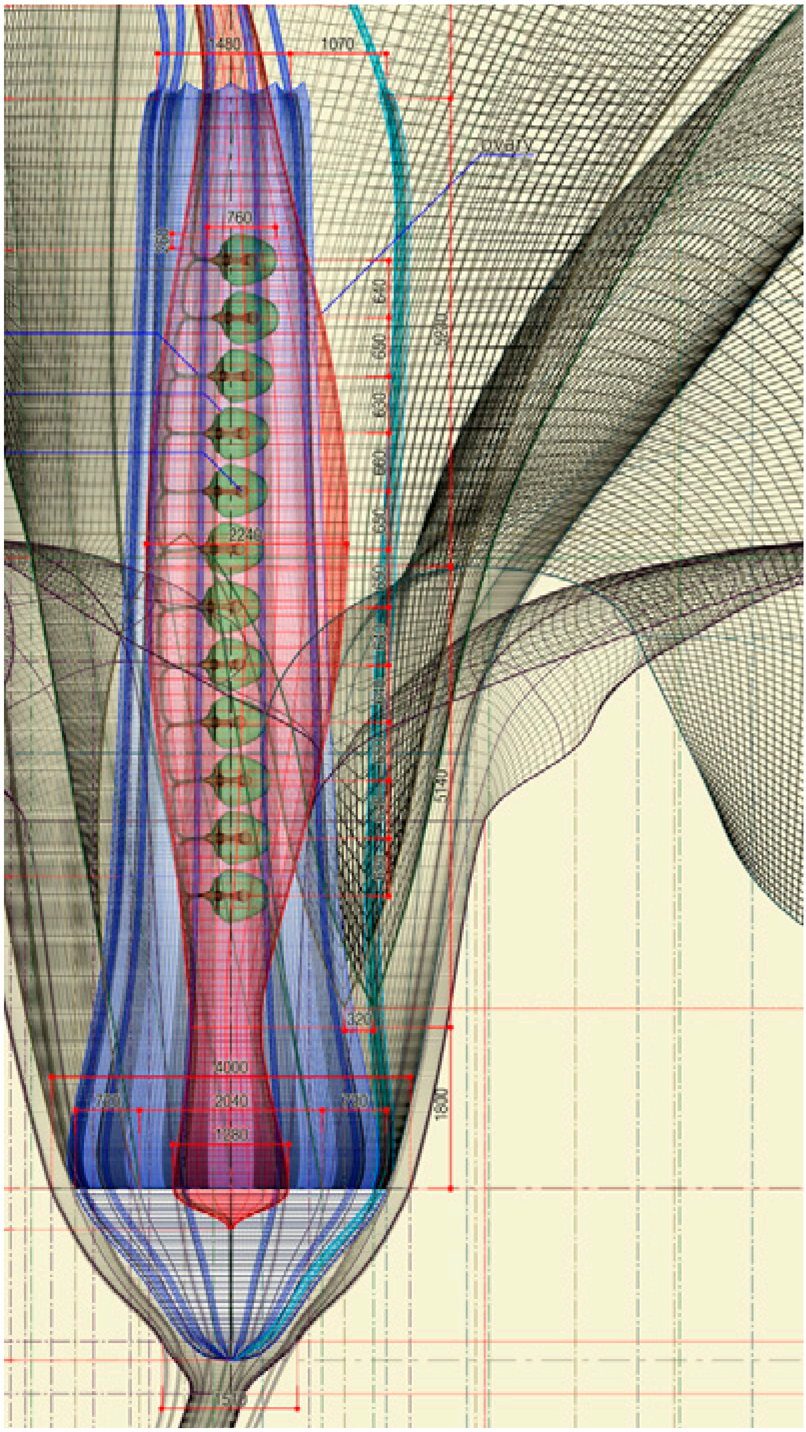


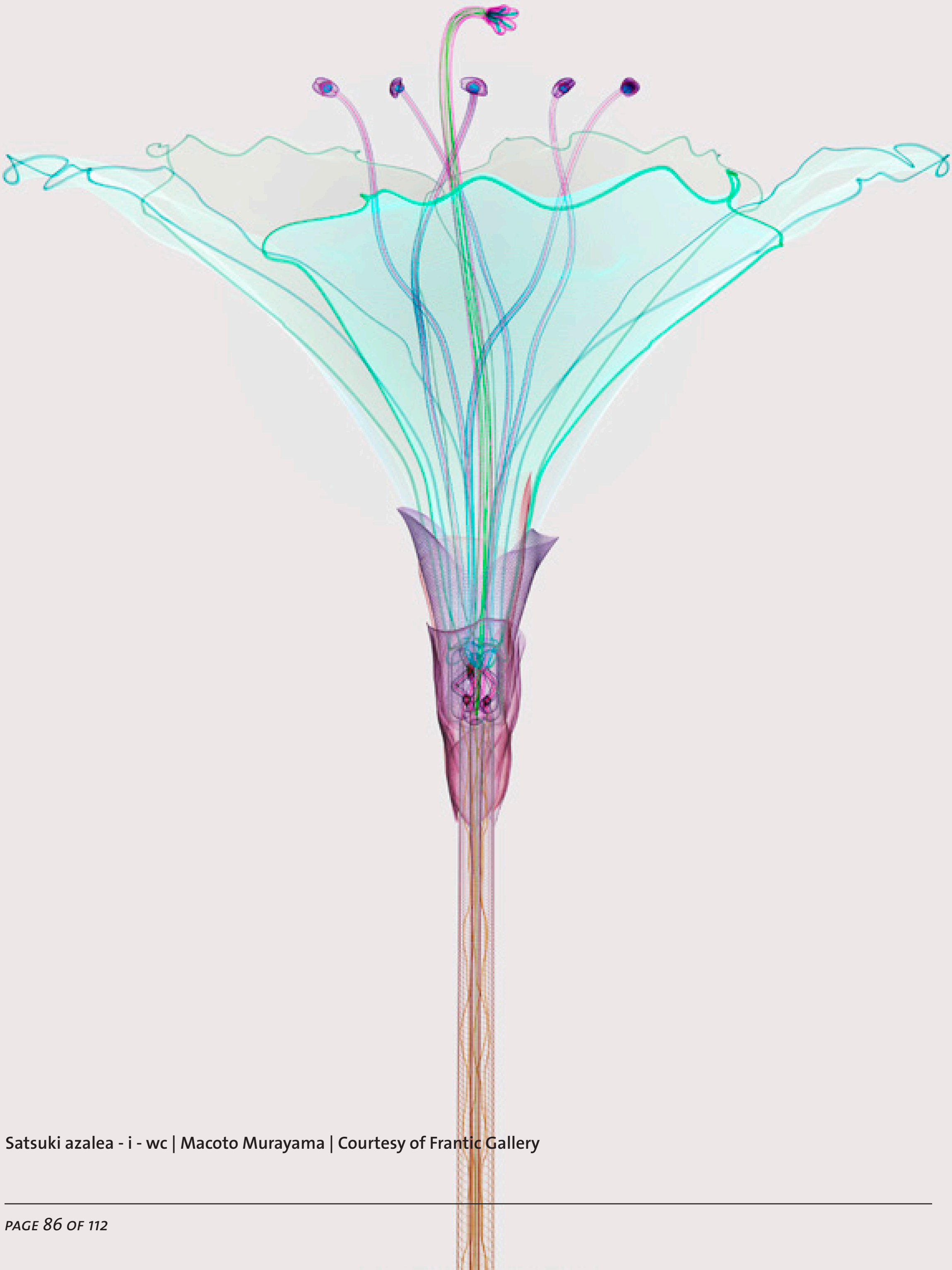


Floral formula = ↓ K(5) C1+2+(2) A1+(9) G1
Plantae > Angiosperm > Eudicots > Core eudicots > Rosids > Fabales > Fabaceae > Faboideae > Lathyrus > Lathyrus odoratus L.
Inorganic flora - Botanical diagram - Lathyrus o

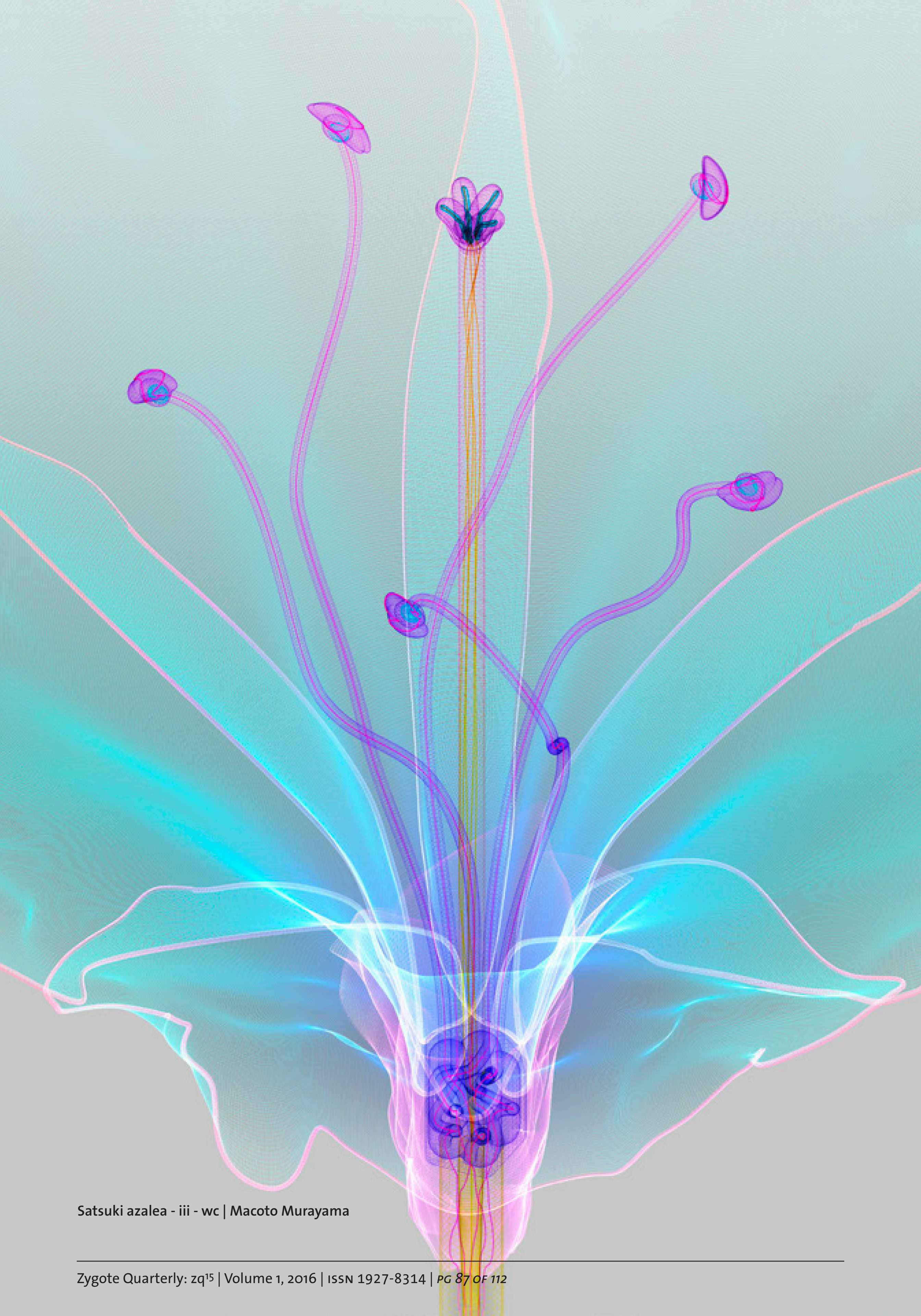
Lathyrus odoratus L. - side view - ow (and detail)
Macoto Murayama | Courtesy of Frantic Gallery



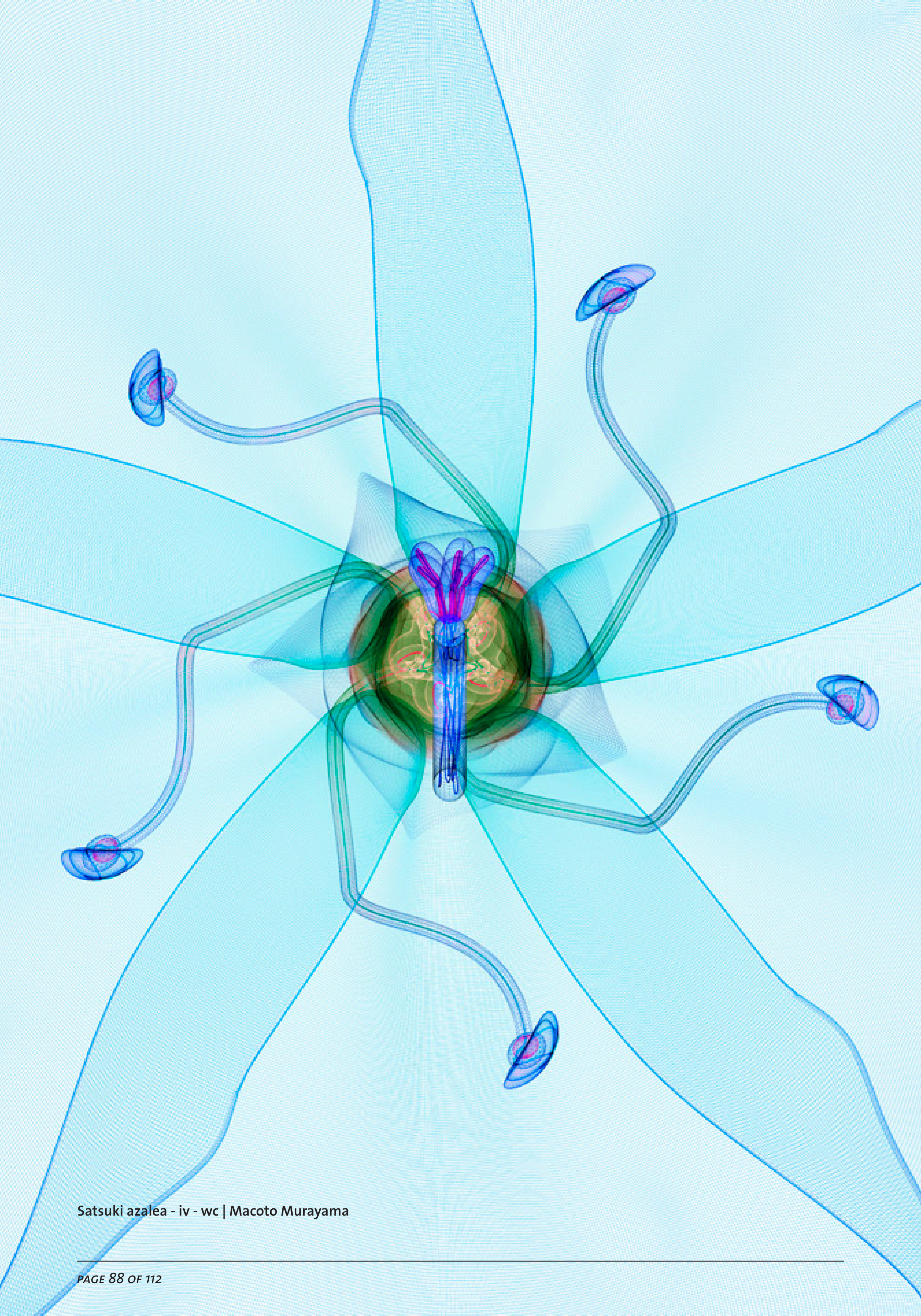




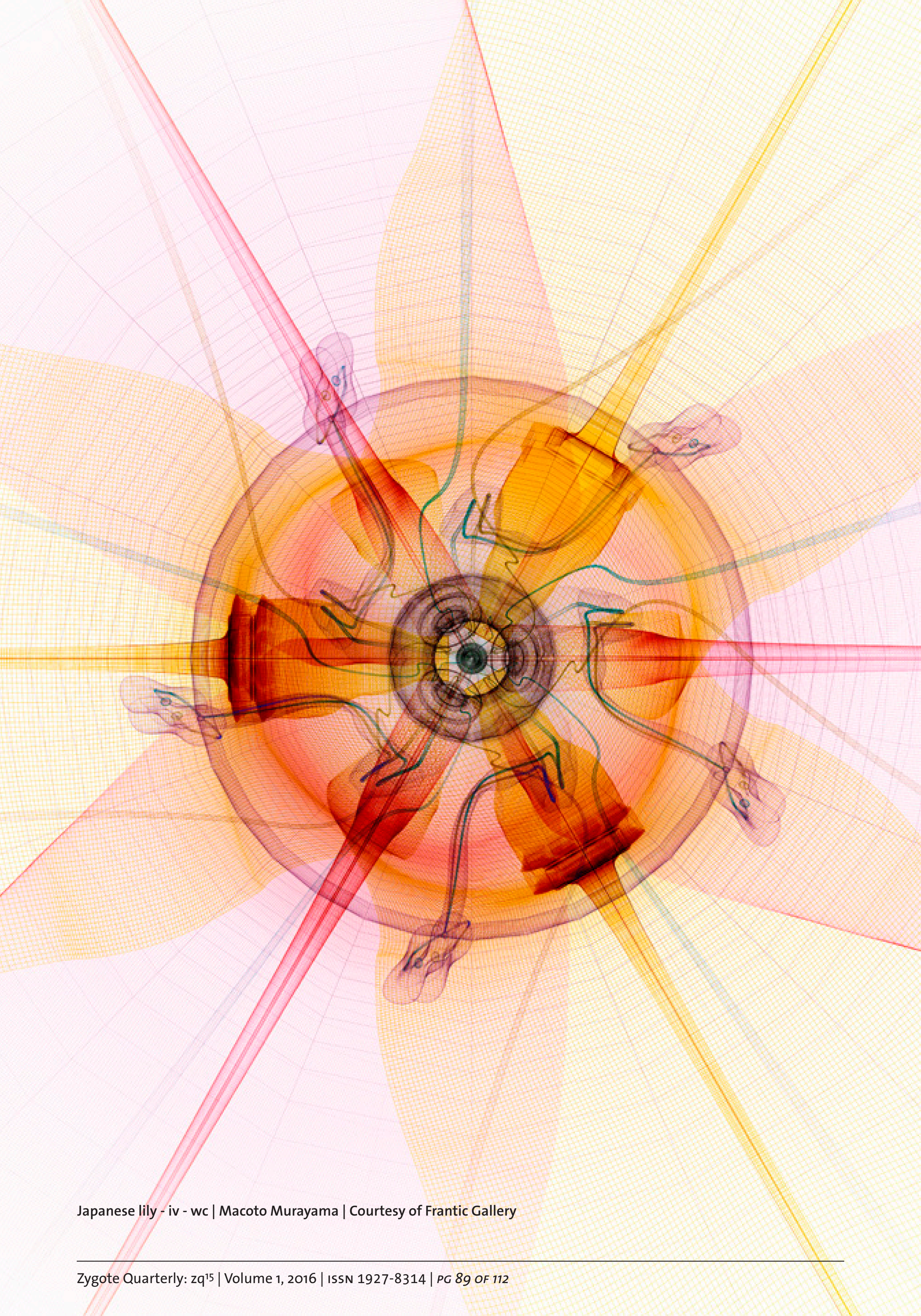
Satsuki azalea - i - wc | Macoto Murayama | Courtesy of Frantic Gallery



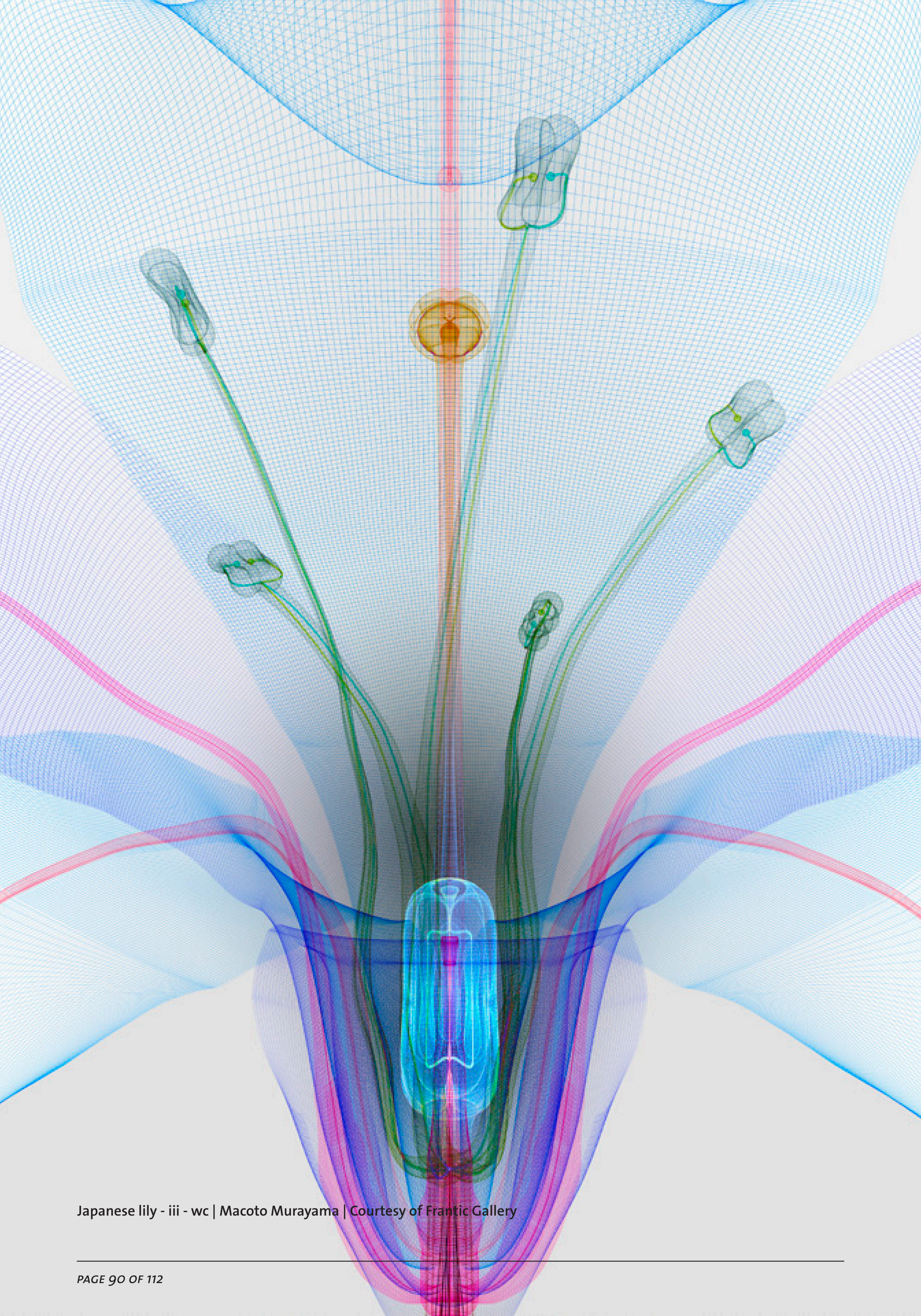
Satsuki azalea - iii - wc | Macoto Murayama



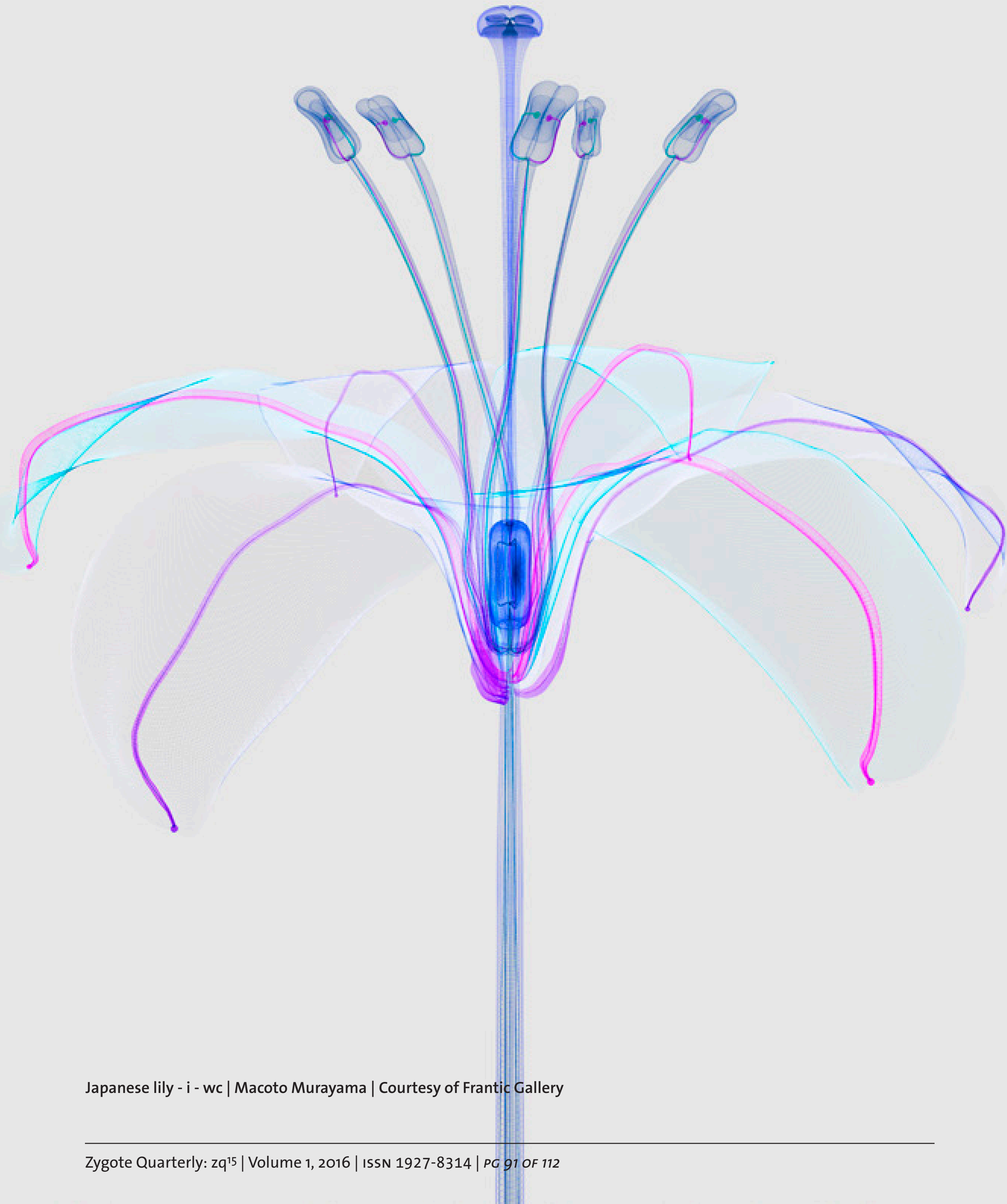
Satsuki azalea - iv - wc | Macoto Murayama



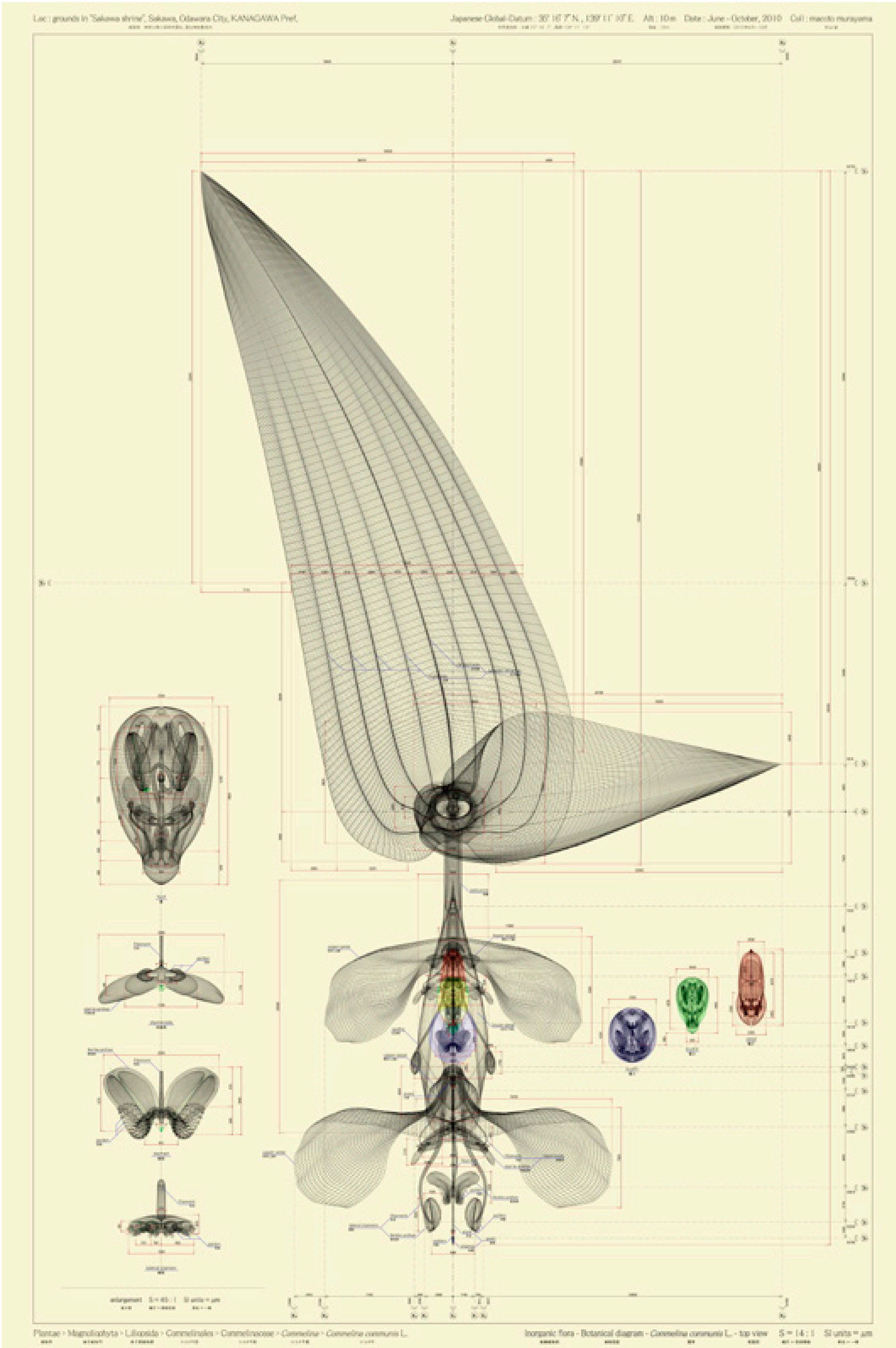
Japanese lily - iv - wc | Macoto Murayama | Courtesy of Frantic Gallery



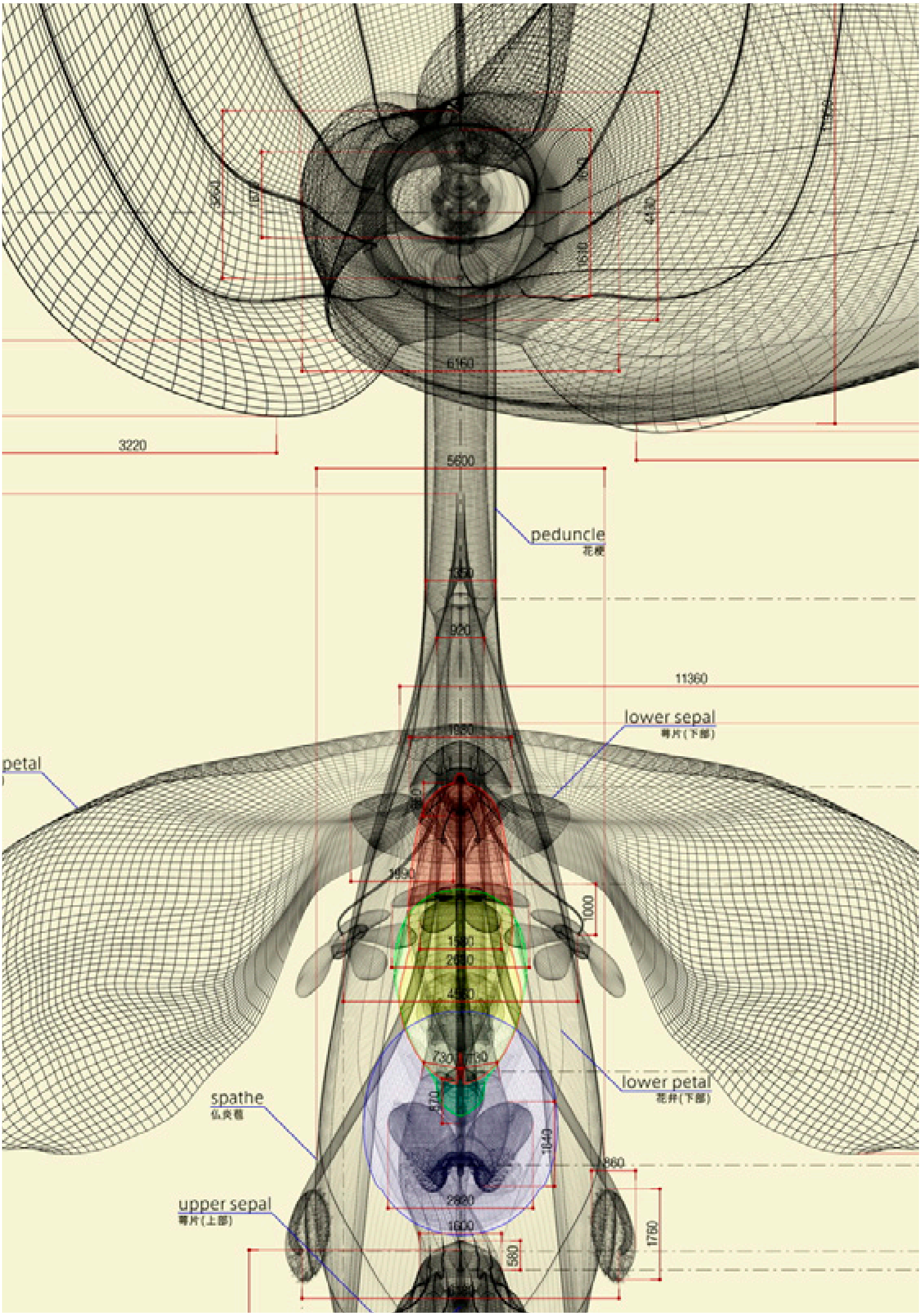
Japanese lily - iii - wc | Macoto Murayama | Courtesy of Frantic Gallery

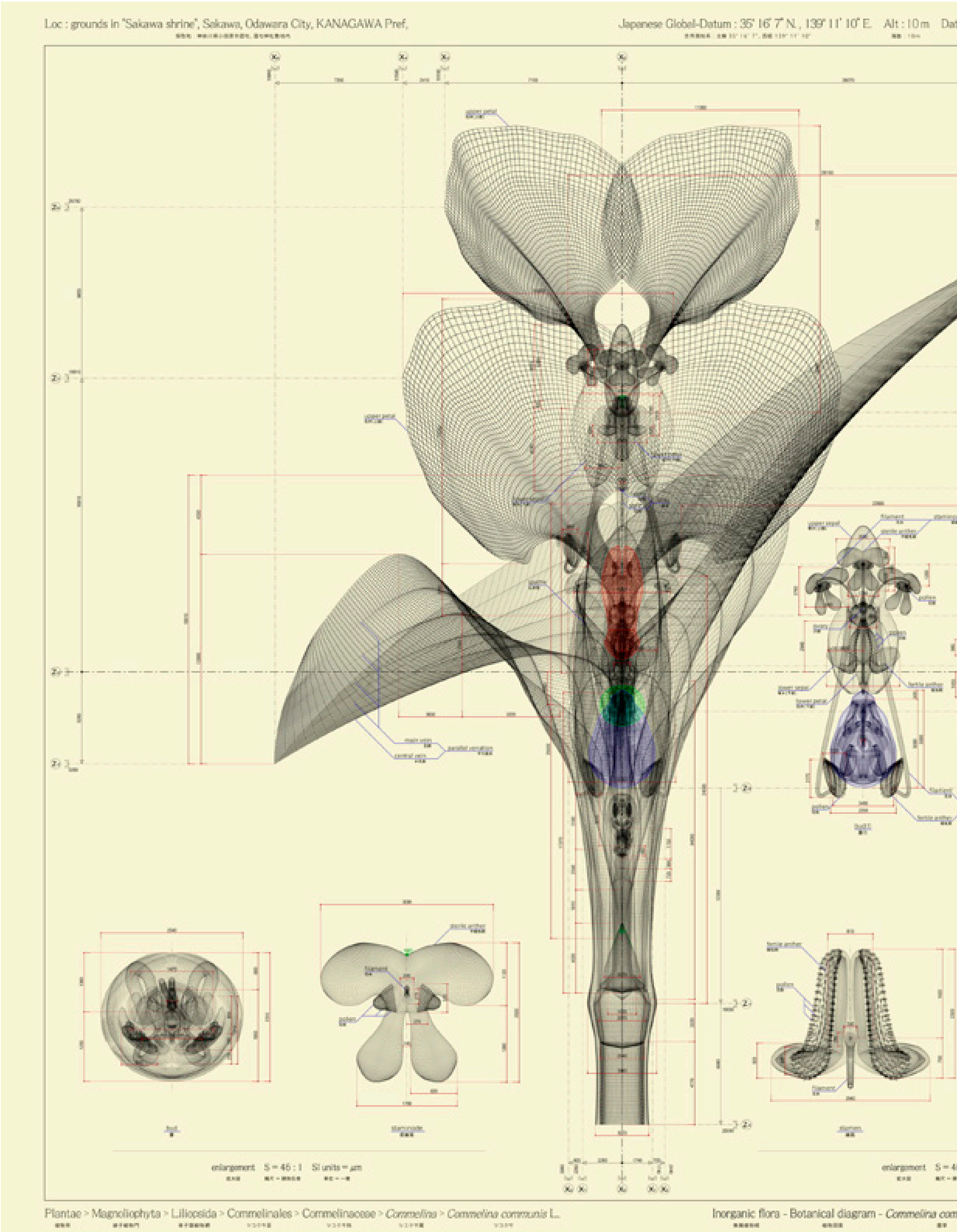


Japanese lily - i - wc | Macoto Murayama | Courtesy of Frantic Gallery

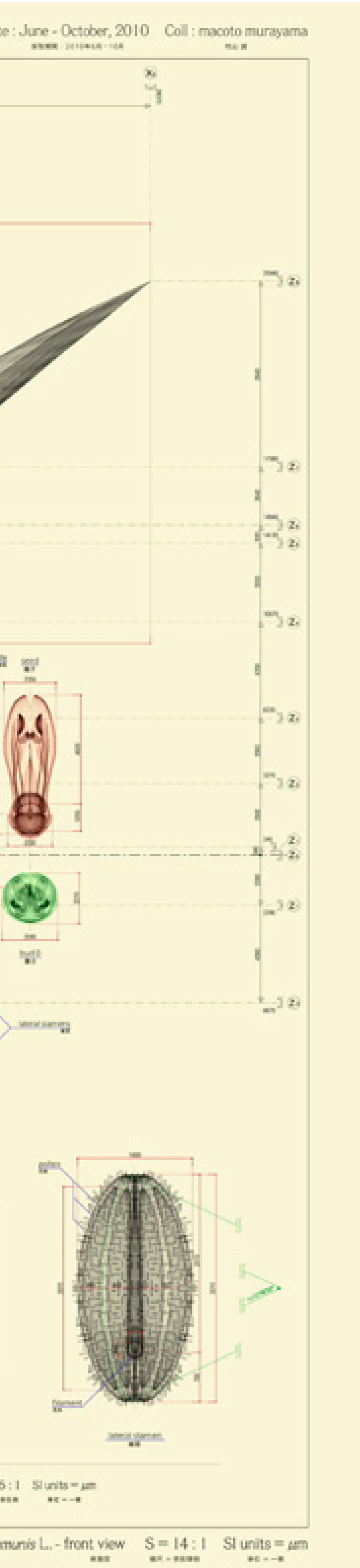


Commelina communis L. - top view - ow (and detail) | Macoto Murayama | Courtesy of Frantic Gallery


6160
3220
5600
peduncle
花梗
1350
920
11360
lower sepal
萼片(下部)
1980
petal
1090
1000
1500
2080
4500
730
730
lower petal
花弁(下部)
spathe
仏炎苞
670
1040
1860
upper sepal
萼片(上部)
2880
1600
580
1760

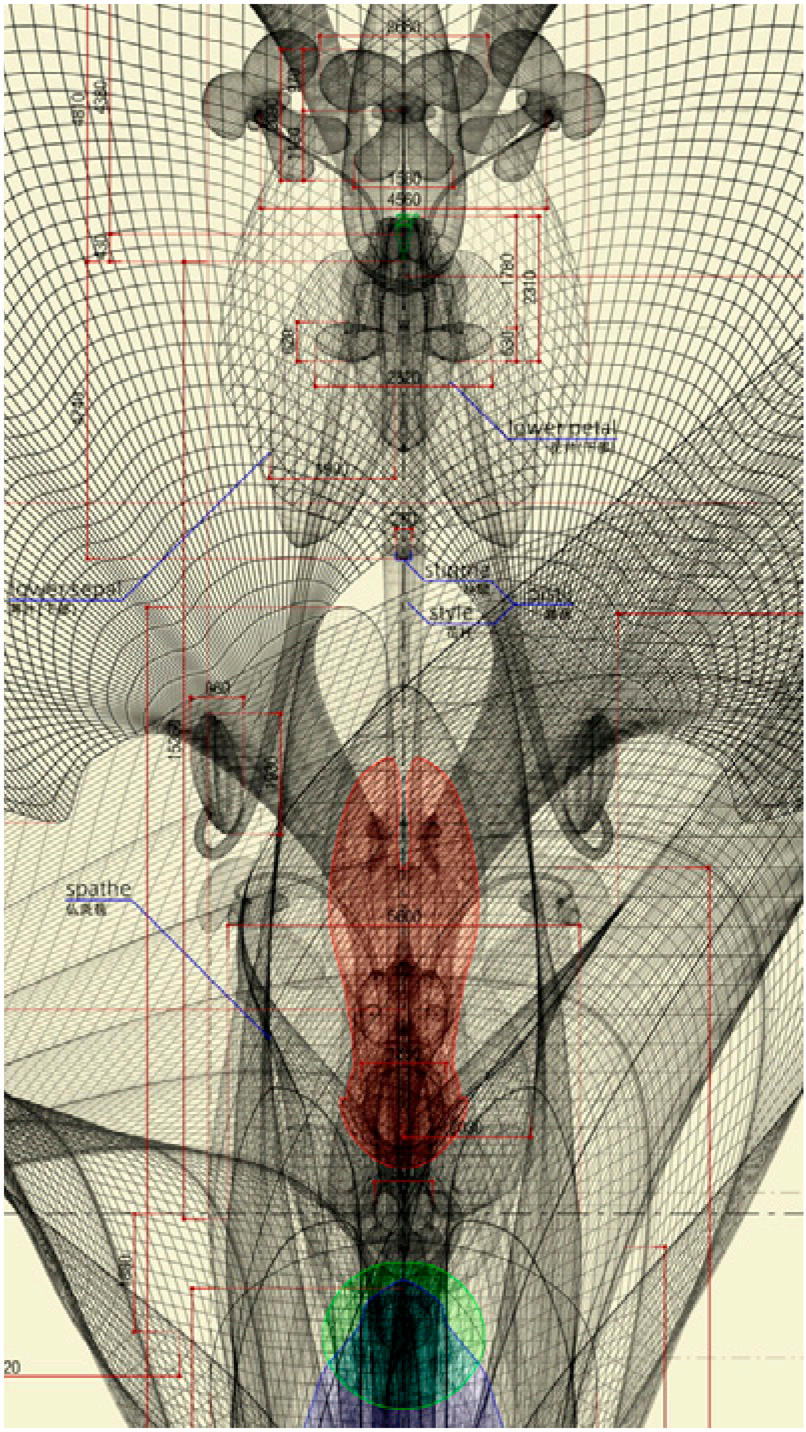


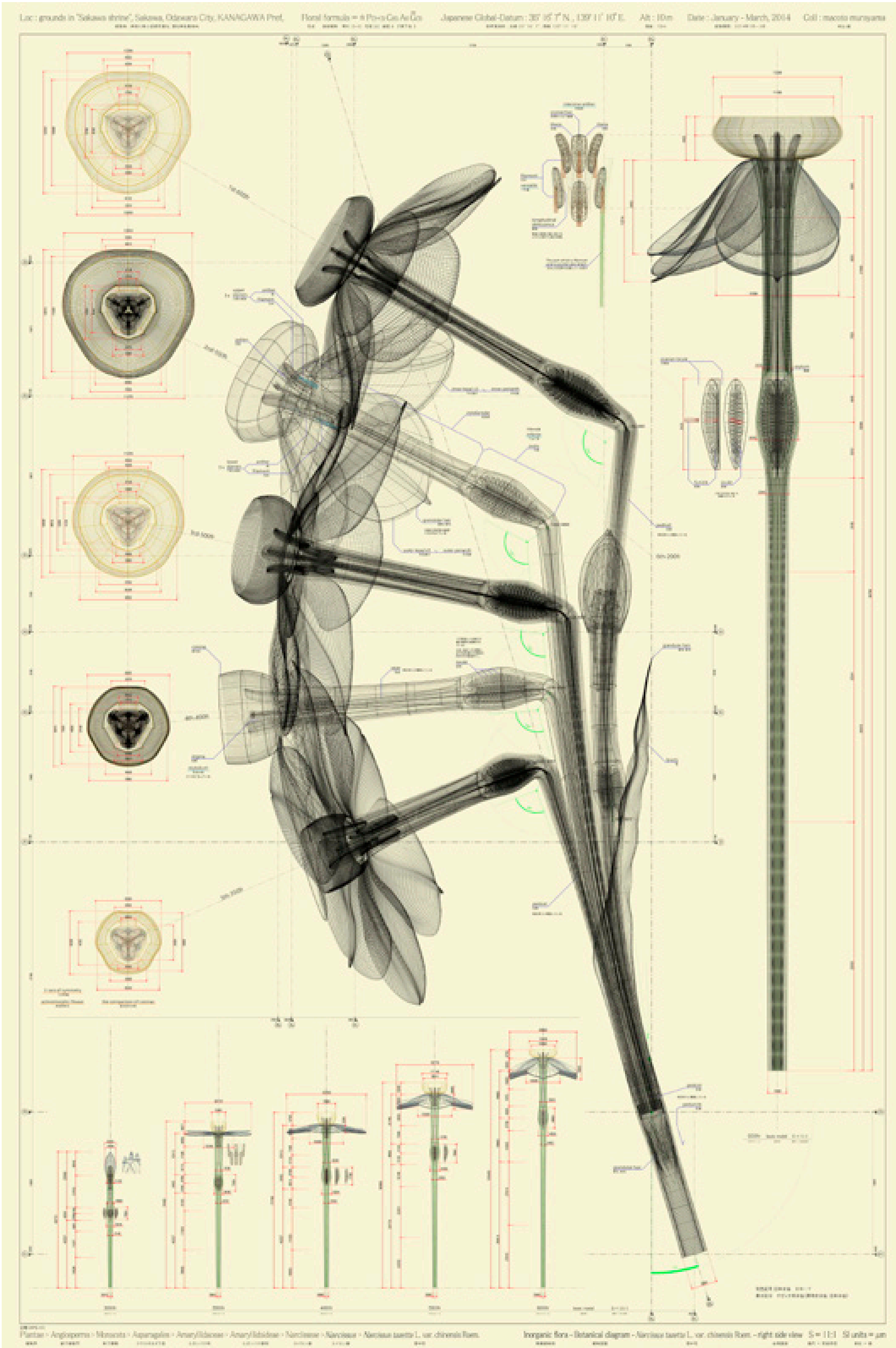
Loc : grounds in "Sakawa shrine", Sakawa, Odawara City, KANAGAWA Pref.
Japanese Global-Datum : 35° 16' 7" N., 139° 11' 10" E.
Alt : 10 m
enlargement S = 45 : 1 SI units = μm
Plantae > Magnoliophyta > Liliopsida > Commelinales > Commelinaceae > *Commelina* > *Commelina communis* L.
Inorganic flora - Botanical diagram -



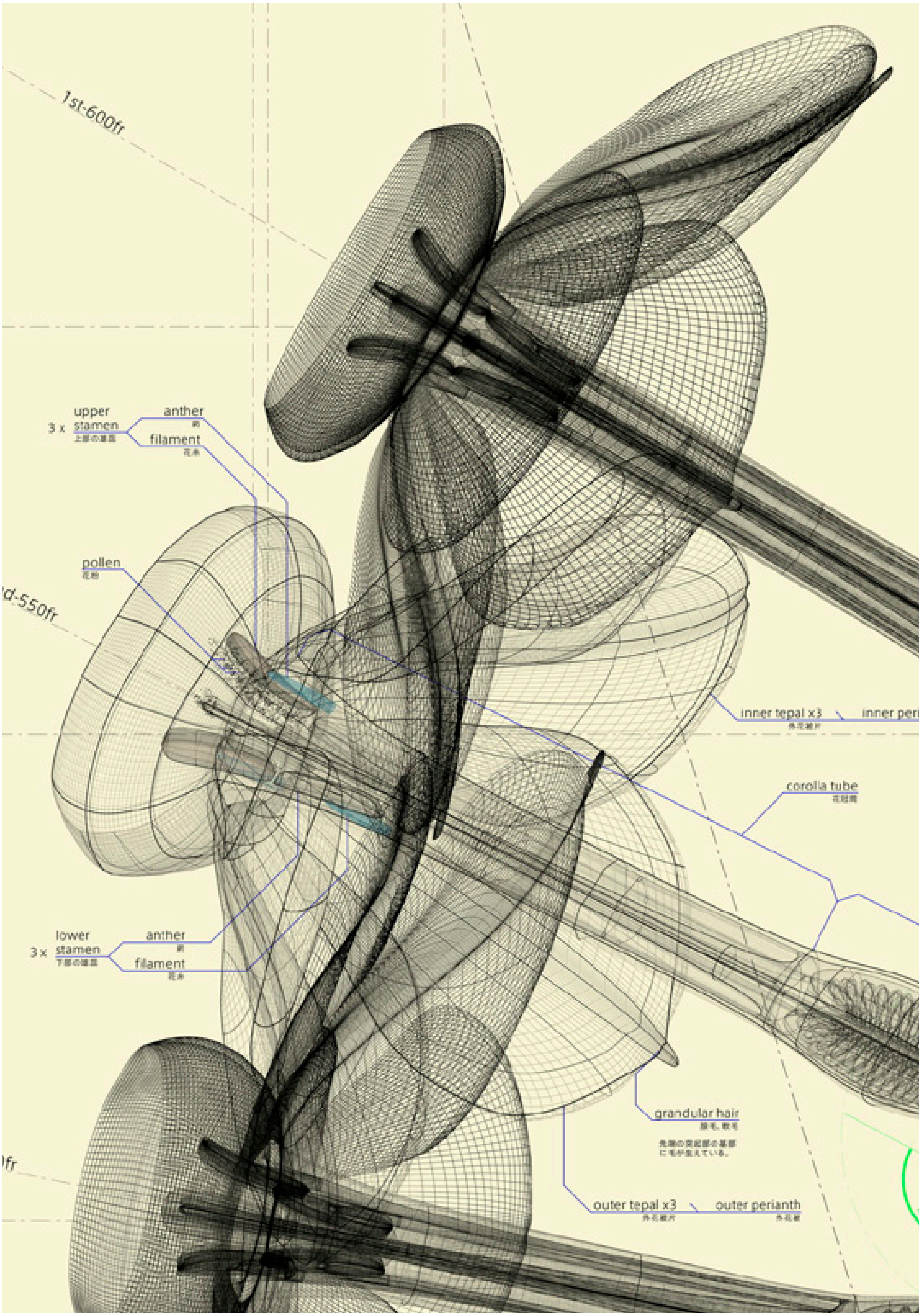
Commelina communis L. - front view - ow (and detail)

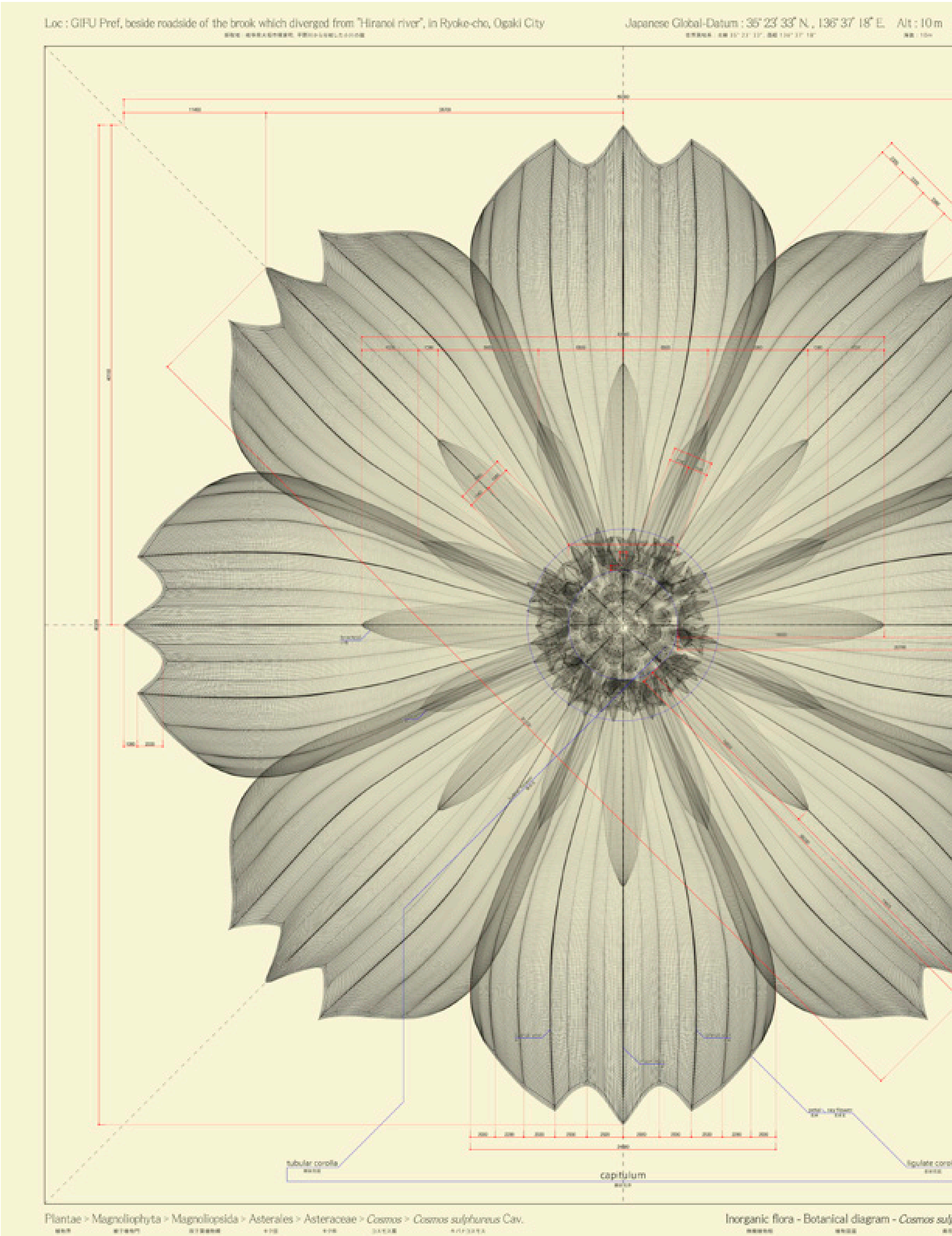
Macoto Murayama | Courtesy of Frantic Gallery

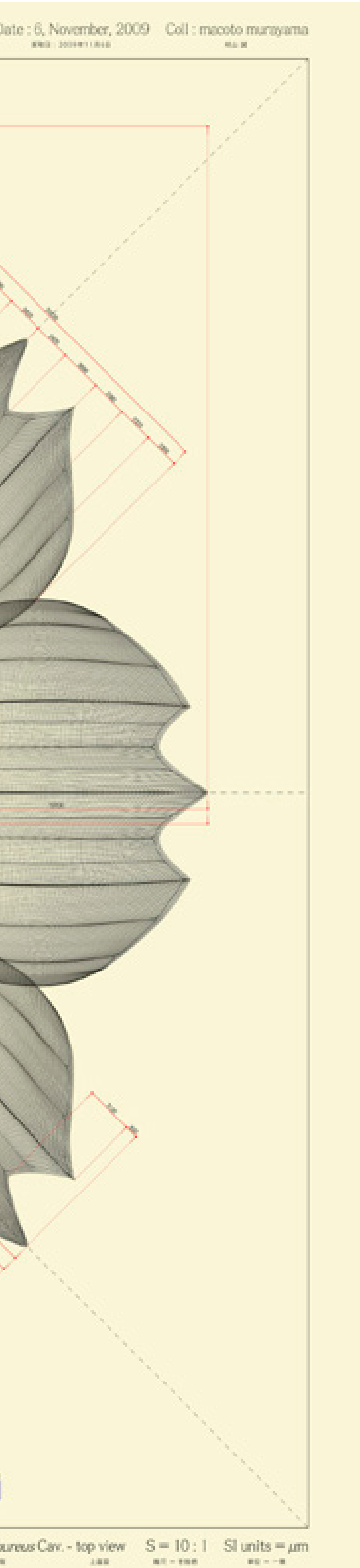




Narcissus tazetta L. var. chinensis M.Roem - right side view - ow (and detail) | Macoto Murayama | Courtesy of Frantic Gallery

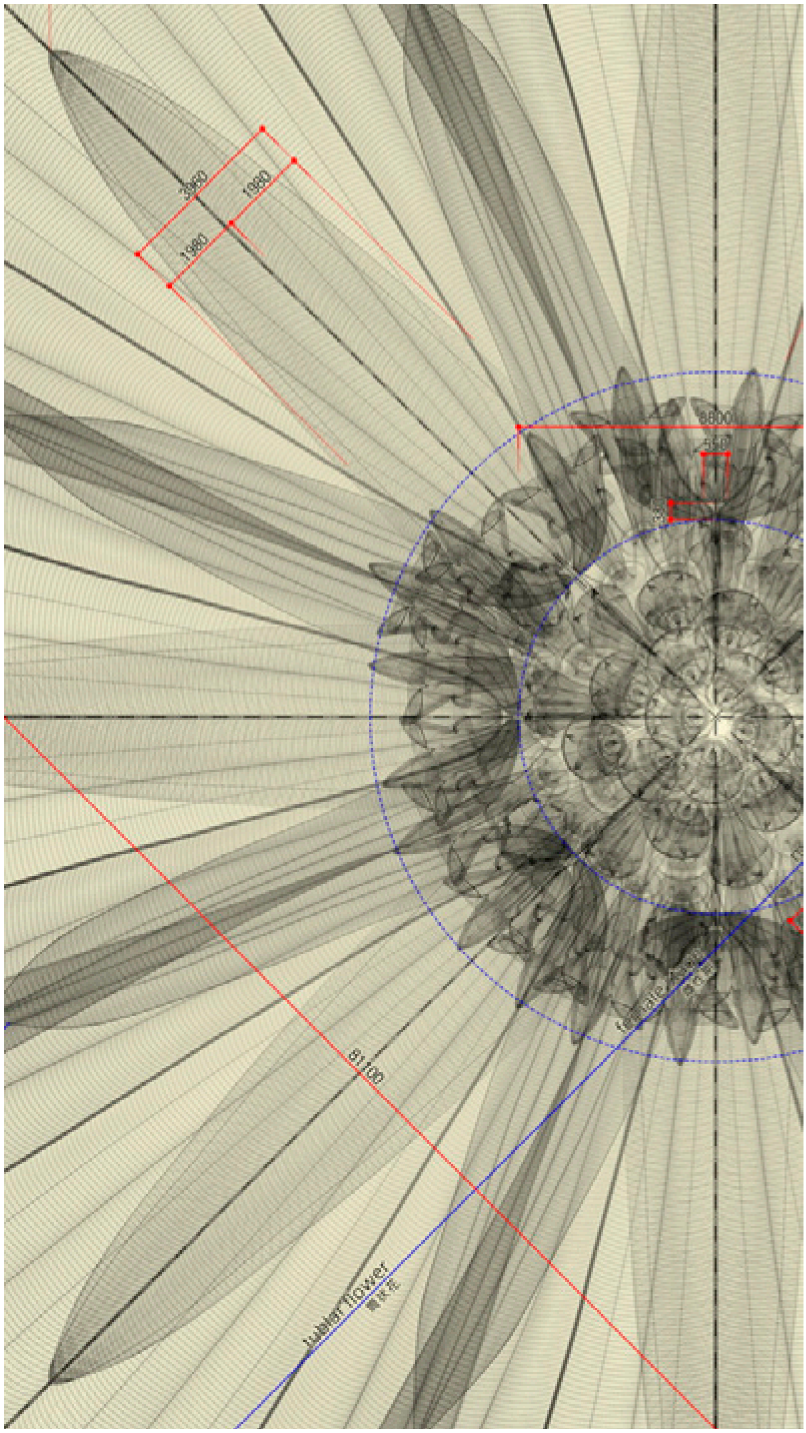

1st-600fr
3 x
upper
stamen
anther
filament
pollen
3 x
lower
stamen
anther
filament
inner tepal x3
corolla tube
grandular hair
outer tepal x3
outer perianth


Loc : GIFU Pref, beside roadside of the brook which diverged from "Hiranoi river", in Ryoke-cho, Ogaki City
Japanese Global-Datum : 35° 23' 33" N. , 136° 37' 18" E.
Alt : 10 m
tubular corolla
capitulum
ligulate corolla
Plantae > Magnoliophyta > Magnoliopsida > Asterales > Asteraceae > *Cosmos* > *Cosmos sulphureus* Cav.
Inorganic flora - Botanical diagram -



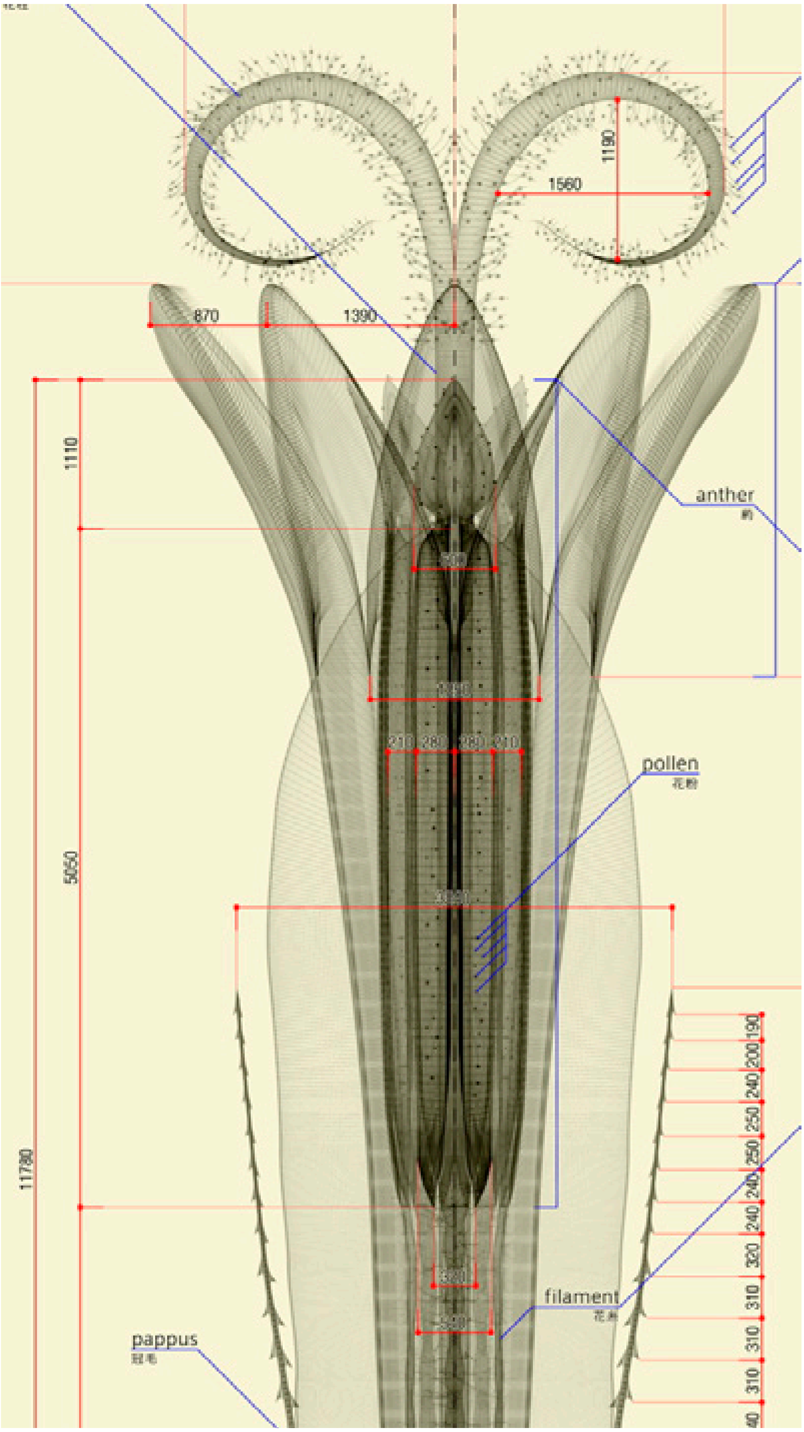
Cosmos sulphureus Cav. - top view - ow (and detail)

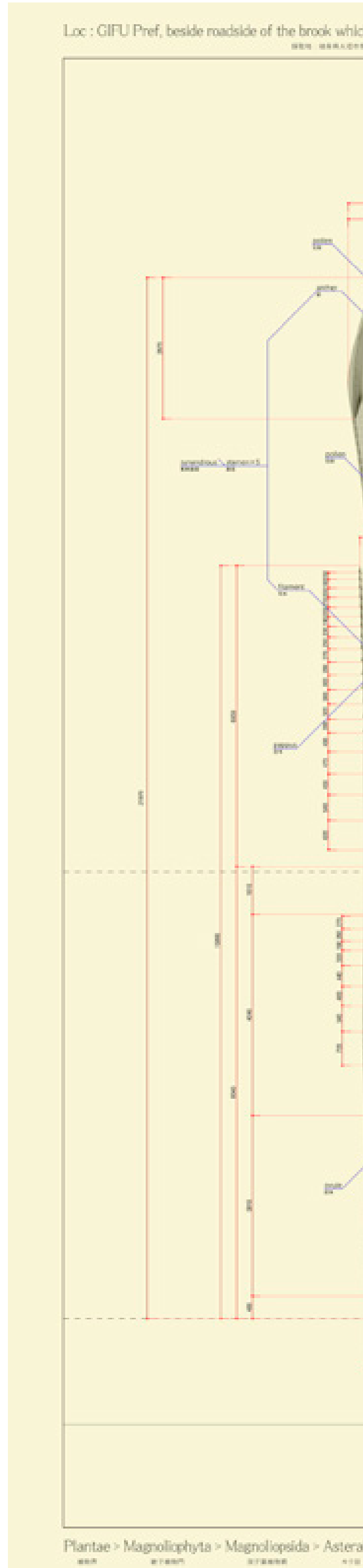
Macoto Murayama | Courtesy of Frantic Gallery

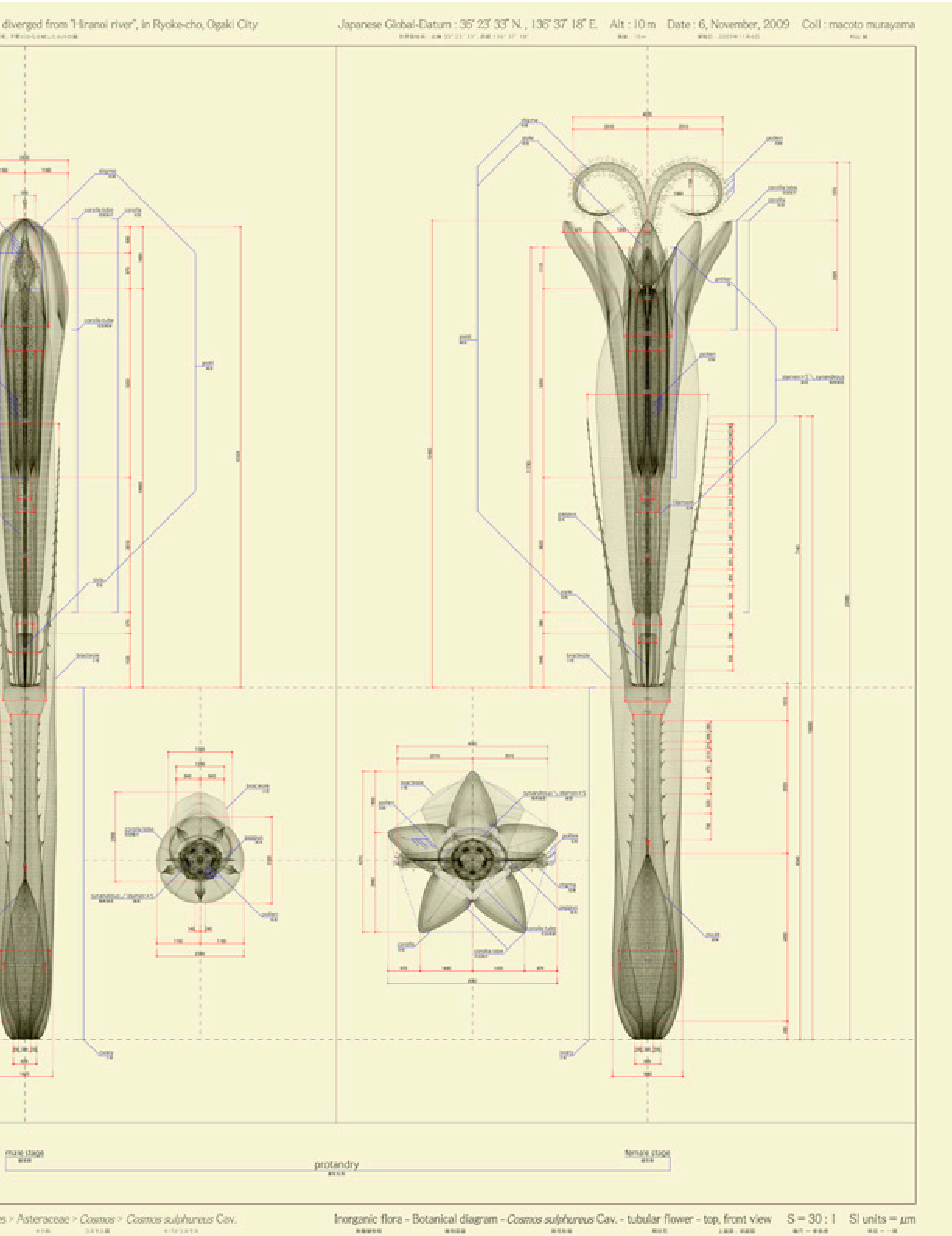


Cosmos sulphureus Cav. - tubular flower - top, front view - ow (and detail)

Macoto Murayama | Courtesy of Frantic Gallery






diverged from "Hiranoi river", in Ryoke-cho, Ogaki City
Japanese Global-Datum : 35° 23' 33" N., 136° 37' 18" E.
Alt : 10 m
Date : 6, November, 2009
Coll : macoto murayama
male stage
protandry
female stage
s > Asteraceae > Cosmos > Cosmos sulphureus Cav.
Inorganic flora - Botanical diagram - Cosmos sulphureus Cav. - tubular flower - top, front view
S = 30 : 1
SI units = μm

Canopy

Photo: *Tom*, 2009 | Flickr cc

Article

Why Don't Solar Panels Look Like Trees?

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vol 1 | 2016

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Why Don’t Solar Panels Look Like Trees?

“I think that I shall never see, a poem lovely as a tree.”

Even the non-bucolic and non-pastoral among us have shared the century-old sentiment behind Joyce Kilmer’s words. For that matter, nature shares the sentiment, too. Tree-like plants of wood have evolved repeatedly, and include the largest organisms that have ever existed. A tree provides wood, long our most versatile structural material, seeds and fruits we find nourishing, cover against excessive solar exposure, and shelter against erosive and chilling winds. A tree, then, must obviously be a good design, one suitable for large-scale structures—such as we humans construct.

Or should we regard their design as terribly flawed? A hundred feet of trunk gets the photosynthetic machinery no nearer the sun, reflecting simply the inability of trees to collectively negotiate a trunk-limitation treaty. That height requires an enormous and ultimately non-productive investment in wood. It also means giving the drag-prone crown a long lever arm to facilitate breaking the trunk or wrenching the tree from the ground.

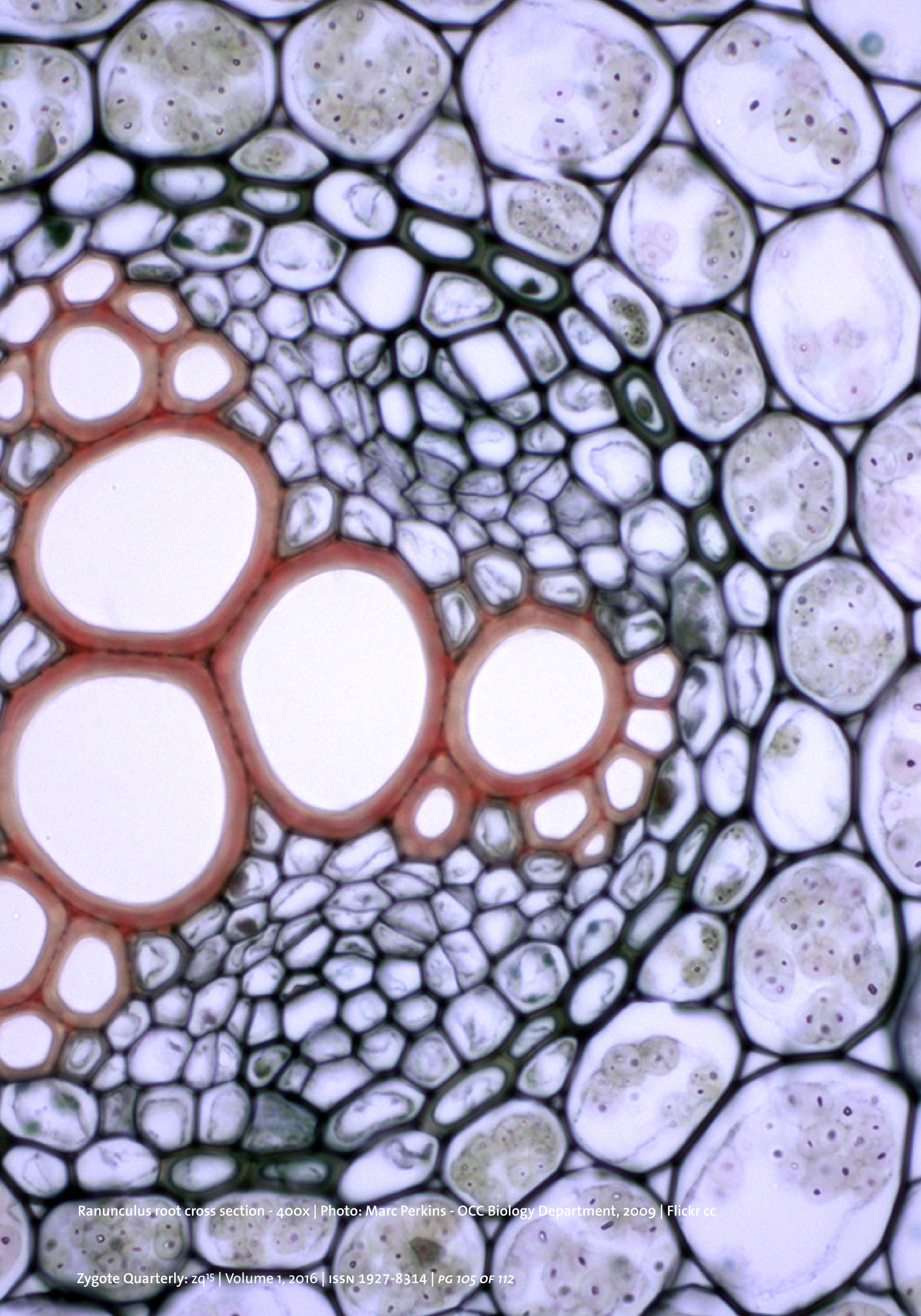
Leaves are typically divided, thin, and flexible, since they deal with the problems of weight aloft and, for many, the cost of annual replacement. They are arrayed in layers because they appear unable to form a continuous absorptive surface. Moreover, they are held out on expensive branches protruding from a single trunk because almost no trees form efficient, braced frameworks.

Trees lift prodigious quantities of water, quantities far beyond what photosynthesis requires (for some reason water must diffuse outward if carbon dioxide is to move inward), even if the rates involved vary widely. They do this peculiar task with a unique, solar-powered pump having no moving parts. One can easily cite many more examples of their oddly problematic features.

These features, however, while arguably dysfunctional in the abstract, “make sense”. Indeed, they must make sense as the ipso facto products of natural selection. An organism has little functional reality out of its evolutionary and environmental context; concomitantly there’s little sense looking for functional devices without taking the context into immediate account. No amount of antiquity or ubiquity can make the design of a tree attractive for our solar panels, whether for generating heat, power, or photosynthesized chemicals. By contrast, the details of the design may hold more lessons for us than the overall scheme.

Consider that trunk. In comparison to our structural columns, trunks, especially young ones, flex easily. Most are solid, not hollow, thus avoiding the problems of ovalization and local buckling of our hollow tubes. Hollow bamboos culms, by the way, minimize the problem with the stiffest (highest Young’s modulus) of woods, as well as preventing ovalization with periodic diaphragms.

Typical tree trunk design offers multiple instructive details. As structures of anisotropic mate-



Ranunculus root cross section - 400x | Photo: Marc Perkins - OCC Biology Department, 2009 | Flickr cc

Bamboo | Photo: halbewelt, 2013 | Flickr cc rial with lengthwise fibers (as in our fiberglass), they withstand tension better than compression. Compensating for that is prestressing in tension: when saw bites trunk, the kerf opens rather than binds. As non-hollow columns, they are minimally sensitive to surface abuse or crack initiation, covering themselves with stretchy skins, divided soft bark that absorbs blows and provides a fire barrier, or overlapping scale-like coatings. As flexible structural columns, they are not only prestressed but often surrounded with a thick and continuous bark whose Poisson's ratio is close to zero, not the 0.3 typical of ferrous metals or the isovolumetric 0.5. Thus bending the columns does not cause buckling on the concave side. We take advantage of cork's peculiarity when we make cylindrical stoppers from it, ones that can be pushed inward without causing temporary girth increase. If we do want to build columns that are flexible or that might have vulnerable surfaces, then some of these devices might hold attraction.

Wood itself would be considered strange and wonderful were it not so familiar. Even dried and sliced it retains peculiar mechanical properties, often a nuisance for carpentry and cabinetry. For instance, an elongate piece of wood typically twists more easily than it bends, with a twistiness-to-bendiness ratio about four times higher than that of our ordinary metals and plastics. In nature that probably makes a tree less vulnerable to the torsional loading that will occur in irregular winds or on trees with asymmetrical crowns from breakage or bad pruning. By instructive contrast, the woods of roots and vines twist and bend in more familiar ways. We ought to find lessons of particular value here: in the way in which the structural anisotropy of a trunk contributes to this unusual behavior and as anisotropic composites become ever more efficiently manufactured.

Consider those leaves, in particular the familiar deciduous ones. To intercept the most sunlight with the least material, they must minimize thickness. If they are to be shed annually, their investment in material should similarly be kept low. Both considerations suggest flexible rather than rigid structures.

Thin, flexible structures of great surface area exposed to wind might impose high drag on their supports, as do flags. Leaves minimize this by reconfiguring into low-drag shapes during periods of high wind. They are also likely to be prone to tearing, fraying, and shredding. Besides keeping down drag, anisotropic fiber reinforcement helps minimize these disabilities. What leaf can readily be torn across? Moreover, the edges, especially of indented parts of leaves, have an extra edge, giving some three-dimensionality to their flatness and increasing the difficulty of starting a crack, whether from wind or herbivory. If we want to make thin, cheap, structures for whatever purpose, some of leaves' devices suggest themselves—flexibility, extra edge, anisotropic fiber reinforcement, specific stress and turbulence-minimizing shape reconfiguration.

Less widely appreciated than the mechanical problems of leaves are their thermal challenges. Both sides of the energy balance sheet test their designs. Structures that must expose themselves to sunlight to function at less than perfect efficiency cannot avoid some thermal load. Even modestly elevated temperatures disable structures whose functional components—enzymes in particular—consist of thermolabile proteins. Yes, they do some evaporative cooling, but all too often the enormous expenditure of water is no option. Leaves avoid about half their potential heat load simply by not absorbing sunlight arriving at wavelengths too long for photosynthetic use; the near infrared, specifically. Convective cooling plays a major role, but it becomes problematic during lulls in the local air movement, especially since these thin structures have short response times, often heating by a degree every few seconds.

A suite of tricks in a variety of combinations almost always suffices to prevent thermal death. Many leaves have shapes, often lobed or elongate, that couple them to what air movement does occur and to their own upward free convective flows. In water-deprived places leaves are commonly small, which improves convective coupling, and thick, which increases their response times and thus lowers peak temperatures during brief lulls. Thin, non-lobed leaves commonly droop downward when hot and water-deprived, thus both reducing exposure to sunlight and improving convective coupling.

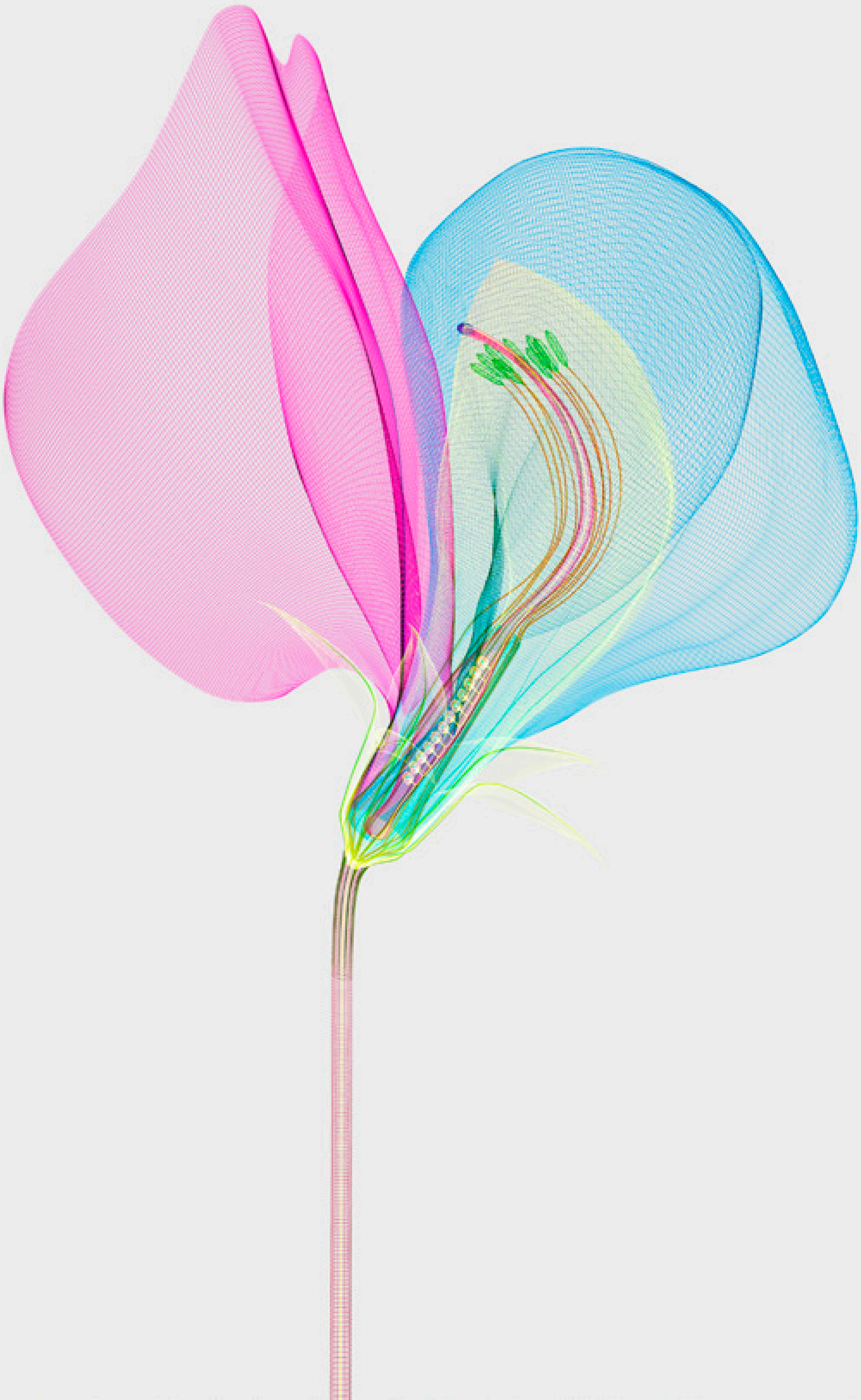
Still more subtle tricks deserve mention. Prolonged retention of water on the surfaces of leaves appears to be something they prefer to avoid, perhaps for its weight, perhaps for the growth of microorganisms it encourages. The hydrophobicity of leaf surfaces has received great attention recently, in particular because many are "superhydrophobic" — better than ordinary waxy surfaces, achieving this by combining chemical coatings with physical texturing. A feature recognized long ago was the shape of leaf tips, elongate and pointed, to shed the collected drop. A leaf with such a tip cut off retains more water. The long leaf tip is most common among leaves in tropical forests, where wetting may be at its worst; it is uncommon among higher latitude leaves, perhaps because the very tips that promote shedding of liquid water would promote formation of heavier icicles. We might well use such devices for structures that we prefer to shed water or to air-dry quickly.

For that matter, trees manage admirable control of local hydrophobicity. The mechanism by which sap is pulled up works only if the inner walls of the conduits, the xylem, are highly hydrophilic; otherwise those walls would provide nucleation sites and lead to rupture of the continuous liquid columns with their extreme negative pressures. The walls of the cells that line the air spaces within leaves must be similarly hydrophilic so that surface tension at their air-water interfaces can prevent air from entering the system and similarly disrupt the liquid columns. At the same time, the outer leaf surfaces, as already noted, work best if highly hydrophobic. Thus only a few micrometers separates surfaces of extremely different properties. Yes, we do worry about surface tension, but we do not often (if ever) build devices making use of both extremes in such close proximity, never mind devices that subject liquids to negative pressures of many atmospheres.

No, solar collectors should not look like trees. Starting with their terribly expensive height, too much of a tree's design solves problems of no concern to us. Trees are "a triumph of engineering over design", as put by biologist Martin Wells (of a family of facile phrase-makers) in an analogous context. They are, in so many respects, making the best of a bad deal. In that best effort, however, lie all manner of technologically attractive details. ×

Citrus leaf(crop): In common with other members of the family *Rutaceae*, *Citrus* leaves have translucent glands

Photo: Laitr Keiows, 2010 | Wikimedia Commons



ISSN 1927-8314