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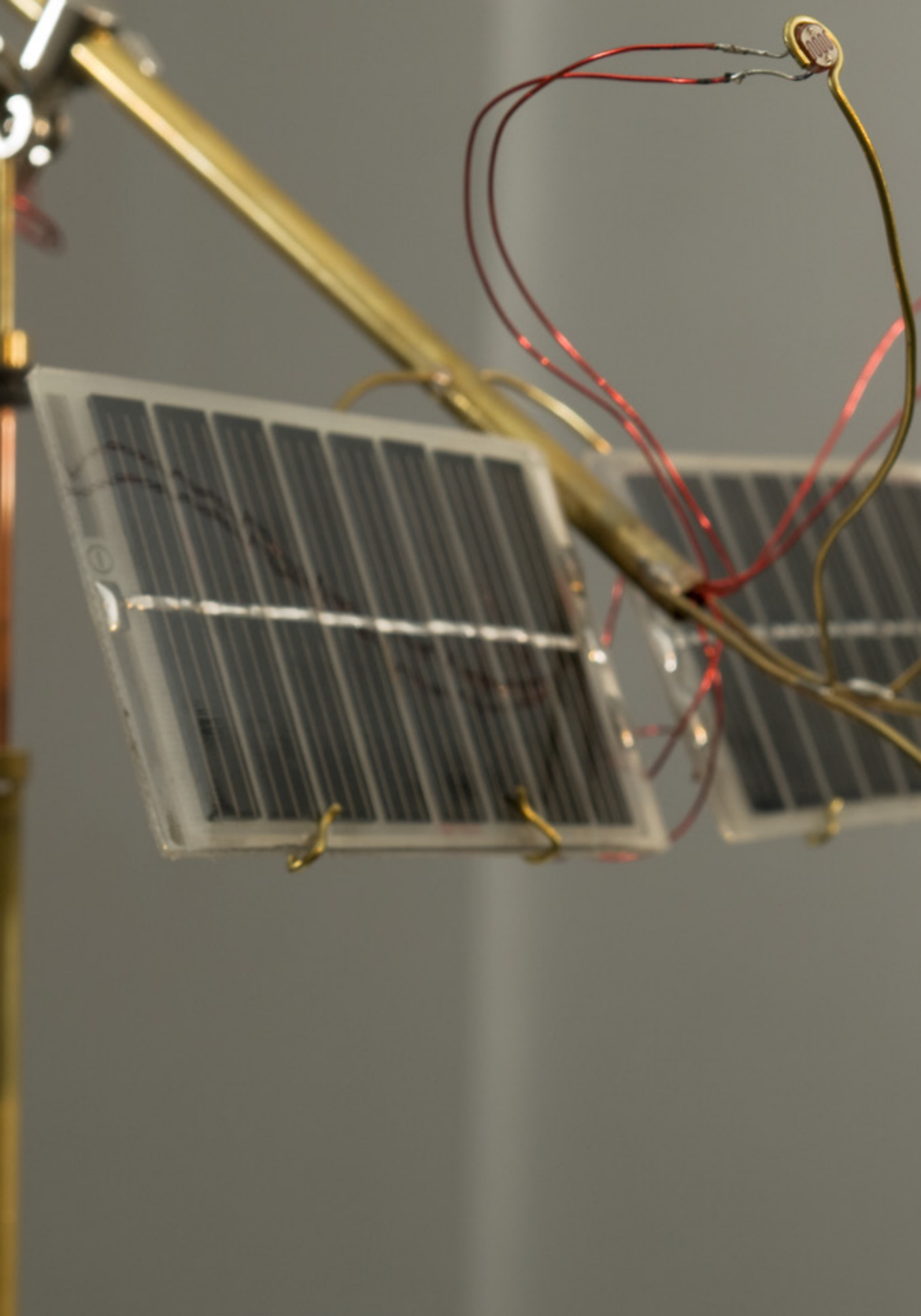

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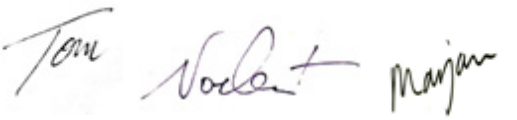
Editorial

Ebb and Flow is a common notion in both our natural and cultural world, and it is a shared theme for many of our contributors in this issue. Manuel Quiros, in the second of two parts of his paean to his local intertidal zone, describes this concept in its most literal (and littoral) sense. He informs us of some of the unique challenges and survival mechanisms found along the ocean shore and cites some of the human inventions these clever strategies have inspired. The ebb and flow of feedback and adaptation is an integral part of interviewee and artist/educator Guto Nobrega's work of combining plant, human, and machine components into an expressive synthesis of the living and the artificial. Astrobiofuturist Billy Almon, another of our interviewees, is most interested in the mutual flow of design ideas between nature and mankind, particularly in the realm of space travel. He wants to know how nature will affect space travel and how space travel can inform more sustainable living on earth. Karen Frasier Scott, Manuel Quirós, and Richard MacCowan review Margo Farnsworth's book, *Biomimicry and Business: How Companies are Using Nature's Strategies to Succeed* and its case for the value of biomimicry in business, citing five case studies. Frédérique Swist is our featured portfolio artist and her sophisticated and mathematically derived images of geometry and color vibrate intensely. You will find that the dominant patterns within her work will ebb and flow in your brain as you look at them. Finally, our own Heidi Fischer, in her Science of Seeing regular feature, explains how some scientists are combining the healing power of art and education to humanize scientific careers and salve the pain of "ecogrief".

Happy reading ×



Tom McKeag, Norbert Hoeller and Marjan Eggermont

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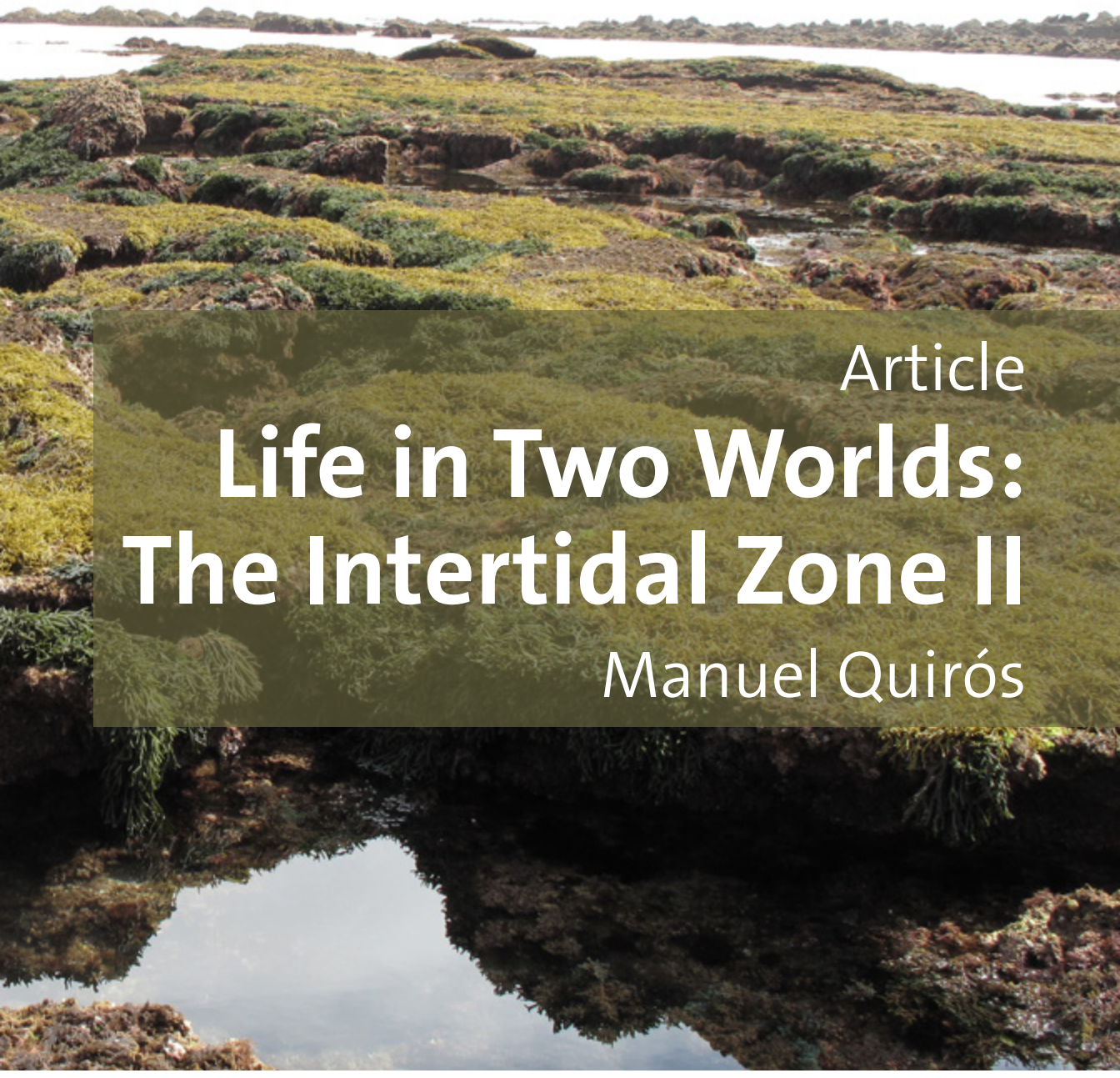
Oyambre beach | M. Quirós



Article

Life in Two Worlds: The Intertidal Zone II

Manuel Quirós

Life in Two Worlds: The Intertidal Zone II

Manuel Quirós

The first part of this series, "Life In Two Worlds: The Intertidal Zone" (https://zqjournal.org/editions/zq29.html p. 32), described the environment of the intertidal zone near the town of Trasvia (part of the Beaches of Oyambre) and how the constant cycle of the tides creates specialised and complex microhabitats that are colonised by a wide range of species. Exploring how these species have evolved and adapted presents an extraordinary opportunity to reveal nature's lesson for biomimicry practitioners, to reconnect with nature, and even as part of play with their kids.

Although a complete understanding of adaptation requires understanding genetics, biochemistry, physiology, and ecology (Figure 1), exploring the structure of organisms and how they interact with their environment can help us tease out the design principles that have been favoured by evolution. For example, autotrophs use sunlight to combine simple inorganic substances into complex organic compounds, while heterotrophs rely on the chemical energy stored by autotrophs. Although there are cases like anemones and algae that are somewhere in between, the choice between autotrophy and heterotrophy constitutes one of the primary design principles in the wave-swept Intertidal zone.

The principle "form fits function" needs to include the adaptive responses of organisms to their environment. The 19th

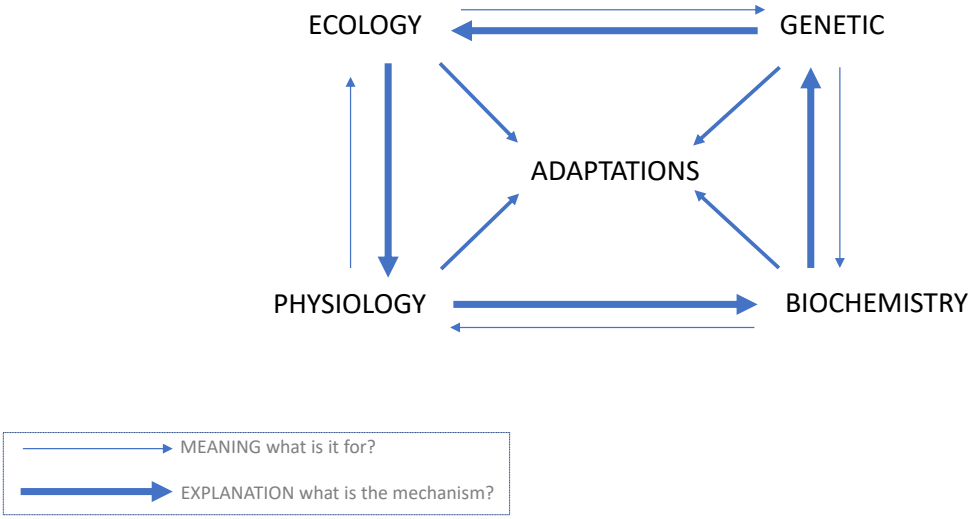


Figure 1: Relationship between general biological disciplines in the study of the adaptations of organisms to changes in a particular occupied habitat. | M. Quirós

Oyambre beach | M. Quirós.

Life in Two Worlds: The Intertidal Zone II

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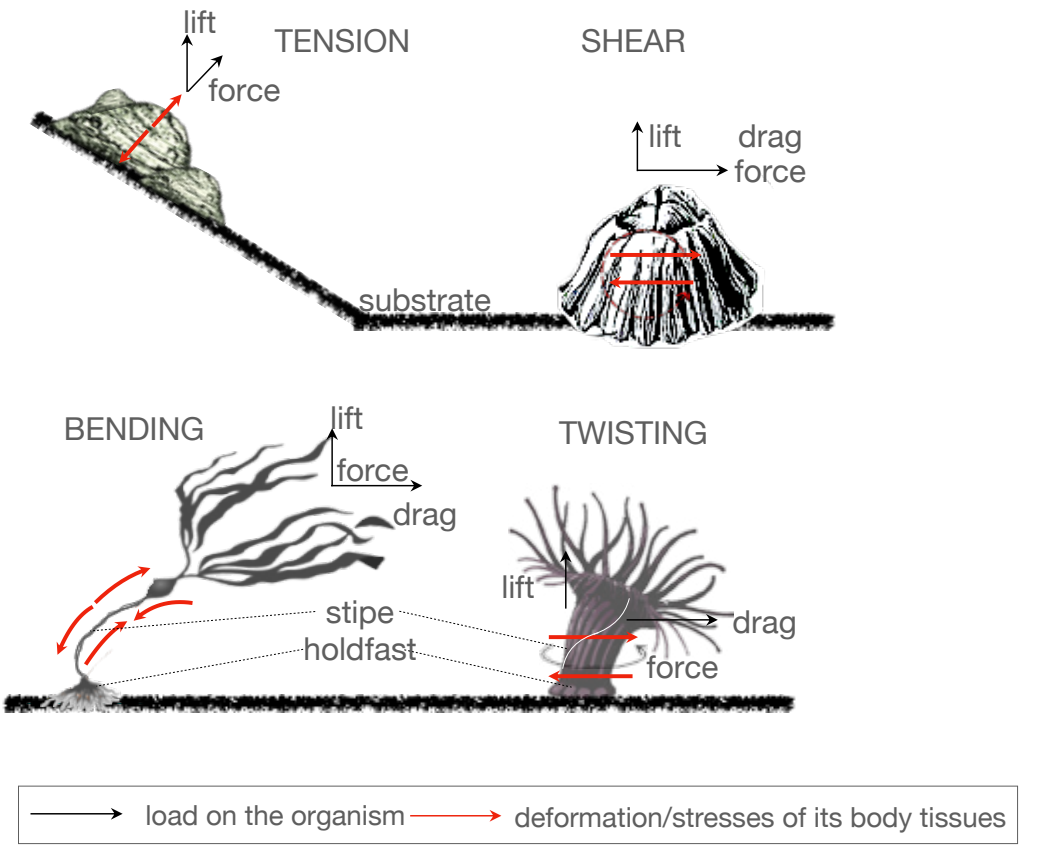

Figure 2. Effects on rigid or flexible sessile intertidal organisms. Organisms not at scale. | M. Quirós, from Koehl (1982) & Denny (1988)

century French physiologist Claude Bernard contributed to the scientific method in medicine through his experiments but also argued against reductionism and explored how organisms function as systems. He promoted the concept of the "internal environment" (milieu intérieur) as a system that maintains a stable state (homeostasis) while interacting with a changing environment. His work led to the field of systems biology (https://doi.org/10.1113/expphysiol.2007.038695).

Sessile organisms that are fixed to the rocky surface are constantly buffeted by waves and surf as well as the ebb and flow of the tides. The flow of the water and the shape, size, and texture of these organisms determine the magnitude of tension, shear, bending, and twisting forces. Smaller organisms in slow flows conditions are largely affected by surface drag due to the friction between their surface characteristics and the water. Large organisms in fast flows are also affected by form drag due to interaction of the water with the shape and size of the organism – form drag is usually stronger than surface drag. Lift can also be a factor.

Littorina (common limpet) is a tiny mollusk gastropod air-breather, unlike its other close marine relatives. In place of gills, a highly vascularized mantle cavity provides O_2 and CO_2 exchange in much the same manner as in land snails. Limpets use a single muscular foot to move and also produce a multifunctional mucus that is both a lubricant and a glue, allowing the limpets to resist the flow of water (https://phys.org/news/2020-06-limpet-power-mucus-muscle.html). Limpets that live lower in the intertidal zone are more exposed to waves, so their shells are flatter and broader to present less resistance to the waves and increase the area of the foot. Limpets higher on the shore are less exposed to waves, allowing them to have higher shells with a narrower base.

The mechanical forces of water flows affect the growth and development of intertidal organisms, helping to mould their bodies into the adult forms seen in such abundance on rocky shorelines. Exploring the relationship of water flows and the features of intertidal organisms can inspire innovative applications (Figure 2).

Temperature is another crucial environmental factor determining the rates of all biological processes of intertidal life, accelerating the speed of biochemical reactions as the temperature increases, or conversely, retarding them if it decreases. Intertidal organisms are ectothermic, which means that they lack the ability to generate body heat. However, they are able to tolerate much higher environmental temperatures

Life in Two Worlds: The Intertidal Zone II
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than their non-intertidal relatives. Most littoral mollusk species can tolerate temperatures up to 30ºC. Some limpets can survive body temperatures exceeding 36ºC through a combination of strongly ridged and peaked shells (Harley et al., 2009).

In some cases, mobile intertidal animals can move towards areas protected from direct solar radiation, looking for shadows under algae or in crevices, or even immersing themselves in existing tide-pools created by other organisms such as limpets or sea urchins (Photo 1).

Some intertidal sea snails, like periwinkles, tend to cluster in significant numbers so that individuals occupying the centre of the group lose water more slowly than solitary individuals (Photo 2).

Intertidal animals that live fixed to the rocky substrate tend to close their valves or shells to avoid dehydration, causing their body temperatures to increase significantly to levels above those of the environment, especially if they are dark in colour in the case of mussels. The danger of death is more likely due to dehydration from the joint action of solar radiation and the wind than the increase in body temperature.

Some animals can draw on a reservoir of water for cooling. Barnacles hold additional

Photo 1: During the low tide, a large rock cave traps water filling tide-pools showing a coloured zonation according to the different dominant organisms. | M. Quirós

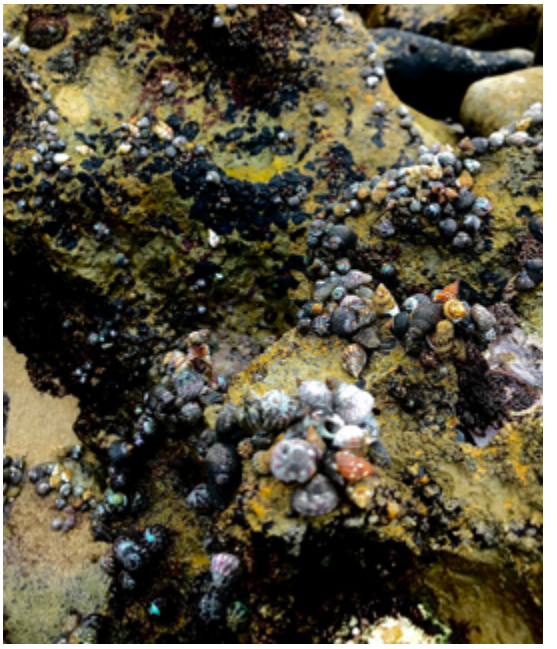


Photo 2: Aggregation of gastropod snails (periwinkles and hermit crabs) slows down the loss of water during the low tide; encrusting calcarean algae; a cluster of acorn barnacles, and black remnants of a 2002 oil spill. | M. Quirós

water inside the mantle cavity of their shells. Limpets settle into a self-made 'home scar', a depression in the rock where the limpet will return before being uncovered by the falling tide. This home scar can contain a tiny reservoir of water that the animal can use for evaporative cooling. The rays or ridges of limpet shells help the re-radiation of heat by providing a greater surface area for cooling similar to some desert barrel cacti. Similar to barnacles, the taller shell of limpets found higher on the shore provides space for additional water that can help slow dehydration.

Limpets help create the very first cracks by grinding away rock (Photo 3) with a set of tough teeth, called a radula (Photo 4), and also keep algae populations at bay to open space for other colonizing organisms. The radula is the strongest biological material found so far (Barber et al., 2015) with great potential for inspiring next generation biomaterials for dental restoration, aircraft parts, hulls for boats, and the automotive industry.

The acorn barnacle, part of the subclass Cirripedia, is the only known sessile crustacean (Photo 5). The fertilized egg develops into a microscopic free-swimming

Photo 3. Radula scrape marks on the rock (Photo by Palmequipmenteurope)

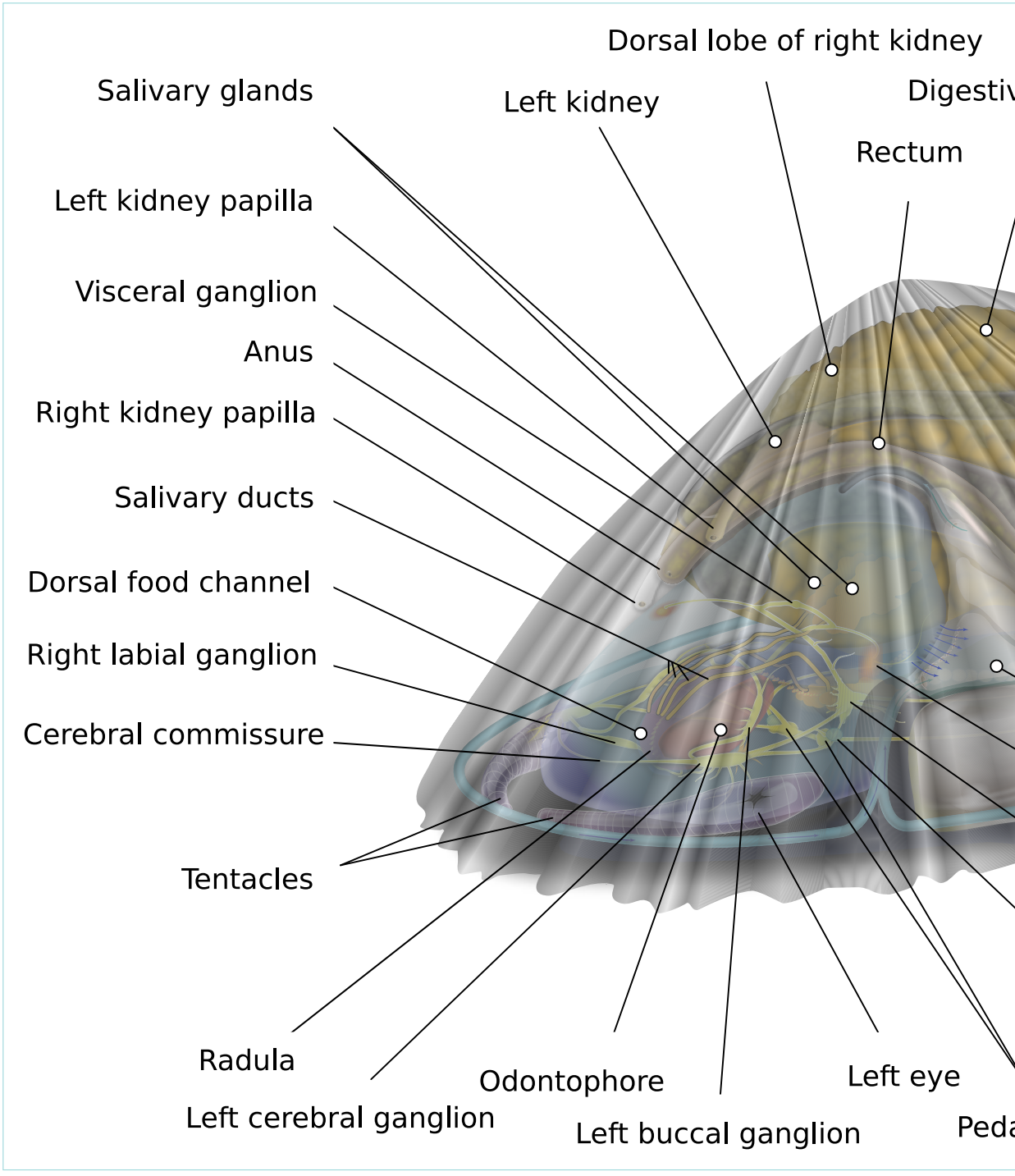
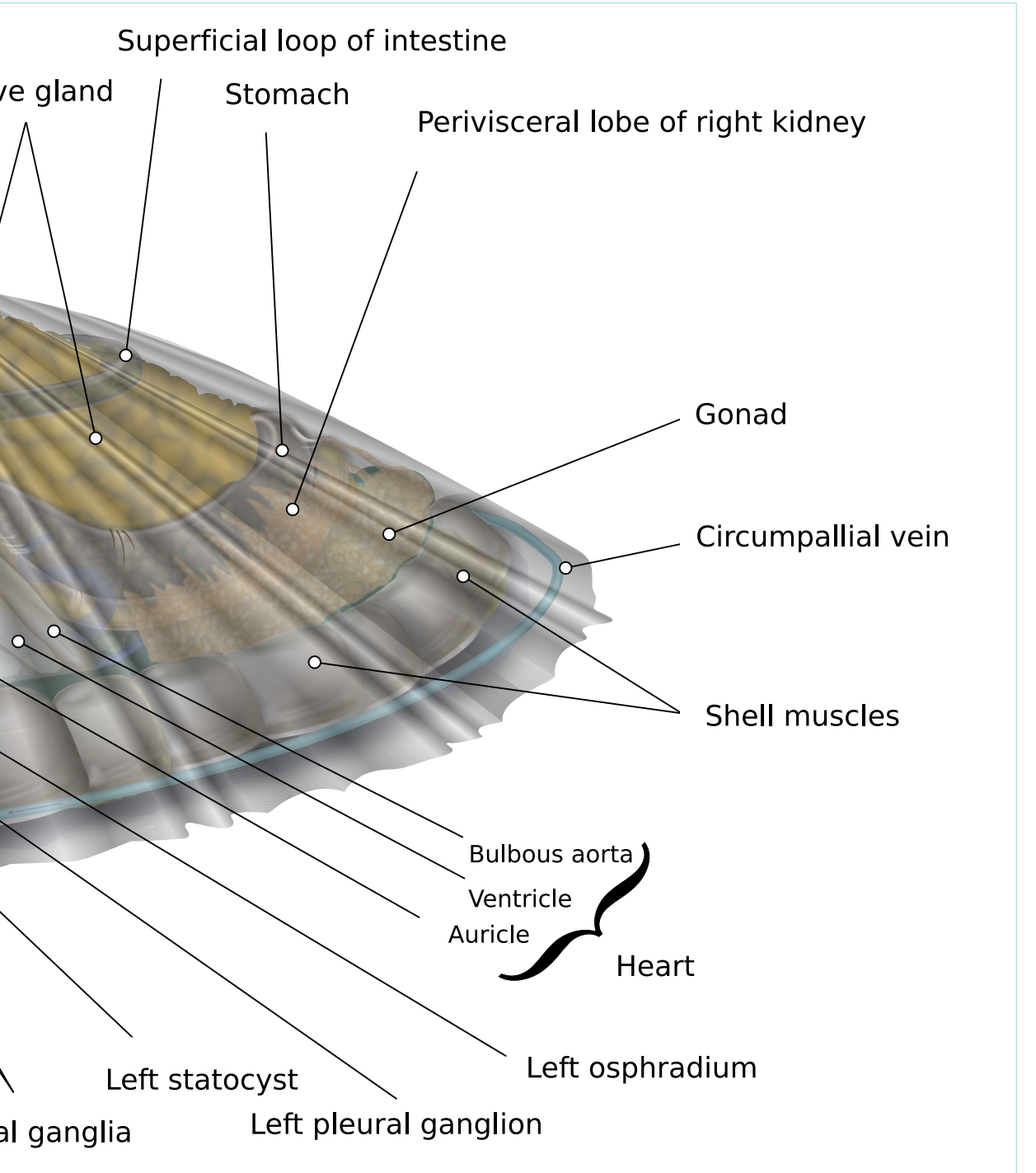


Diagram of the basic anatomy and arrangement of internal organs of the saltwater limpet *Patella vulgata*. Illustration: Own work based on the text and diagrams of Patella, the Common Limpet (1903, Ainsworth-Davis and Fleur) and the 2015 photographs taken by I. F. Smith of similar species, e.g., here (note that *P. depressa* is nearly identical to *P. vulgata* in terms of its morphology). KDS4444, 2013 | Wikimedia Commons


Superficial loop of intestine
ve gland
Stomach
Perivisceral lobe of right kidney
Gonad
Circumpallial vein
Shell muscles
Bulbous aorta
Ventricle
Auricle
Heart
Left osphradium
Left statocyst
Left pleural ganglion
al ganglia

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planktonic larva, called a nauplius, that goes through a series of moults of which the cyprid is the final stage. The cyprid larvae need to find a settlement site with the right surface properties, aeration, nutritional supply, and wave orientation for the adults which subsequently never move. It remains a mystery how the microscopic free-swimming larvae travel that last short distance to contact the substratum in surf water velocities of 1-10 m/s which is 10x the swimming speed of the planktonic larvae.

Once the larva has settled, it undergoes metamorphosis, initiating the calcification process to form the barnacle's shell plates, and cementing the barnacle permanently to the substrate with a transparent rigid layer a few µm thick (1 µm = 0.001 mm) comprised of six cement proteins. The complex process and composition of the adhesive are different from those of the mussel byssus or tube-dwelling worm. Fouling by acorn barnacles causes damage to marine coastal infrastructure and increased drag on ships, requiring toxic antifouling products and hours of tedious manual labour. A better understanding of the process and biochemistry of barnacle attachment could lead to significant savings.

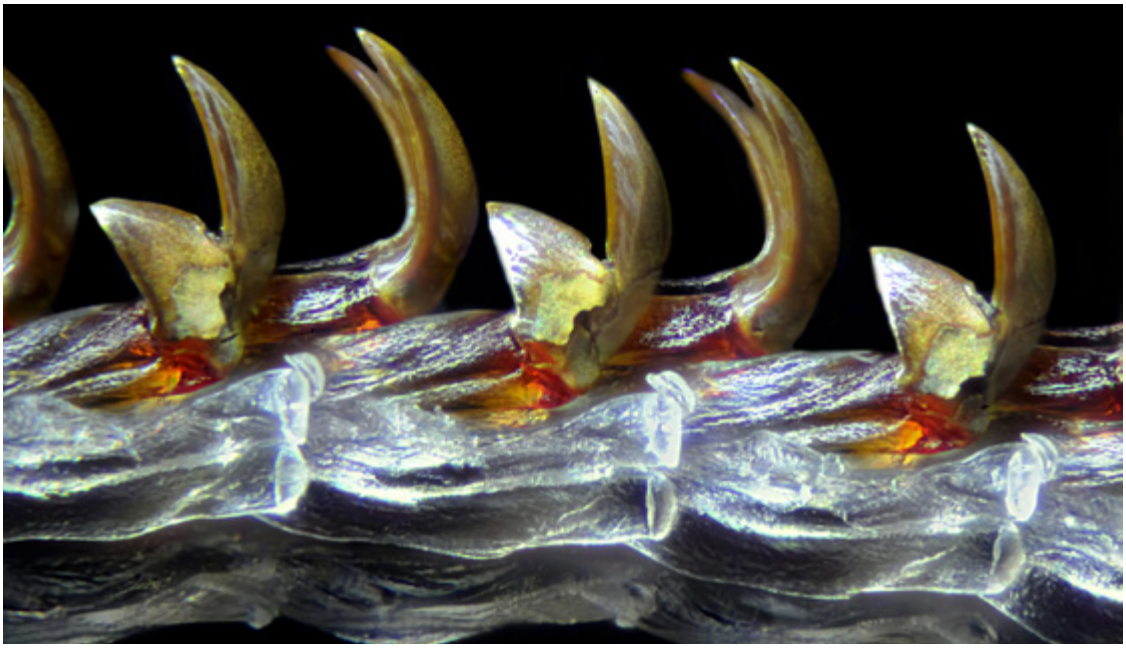

Photo 4. Photomicrography of a limpet's radula (feeding structure), 40x. (by Michael Crutchley ©: Image of Distinction 2015 Photomicrography Competition) | Radula (feeding structure) of an aquatic snail (Limpet))

Mussels (Mytilus spp.) are found in the rocky intertidal shore anchored to the substrate with low rounded profiles that minimize resistance to breaking waves. After settling, the free-swimming young mussels trail over the bottom, seeking improved conditions before attaching themselves with 50-100 strong, elastic-silky byssal threads (Photo 6) formed from a fluid secreted by the byssal gland. On contact with seawater, the fluid quickly toughens to form an attachment plate and a thread. This unique wet surface attachment inspired Pure Bond, a formaldehyde-free glue for wood.

Byssal threads also have self-healing properties. Instead of the normal cross-links seen in collagen structures, the byssus core uses ligand-metal complexes that are half as strong as covalent bonds but can be broken and reformed many times (Holten-Andersen et al., 2011). The cuticula contains large numbers of small granules which play a central role in preventing crack propagation. Scientists have already produced a polymer with high elasticity and self-healing properties much like the mussel thread cuticula with potential applications for self-healing materials in a wide range of applications.

Photo 5. Acorn barnacle cluster and attached-colonizing limpets. | Manuel Quirós

Photo 6. Mytilus mussel with byssus showing, on a rock. Photo: Brocken Inaglory, 2008 | Wikimedia Commons

Photo 5. Detail: Acorn barnacle cluster and attached-colonizing limpets. | Manuel Quirós

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Echinoderms, including sea stars and sea urchins, are among the most familiar sea creatures. The phylum contains more than 7,000 living species, all exclusively marine and predominantly bottom dwellers, grouped into five classes: the asteroids (sea stars), the ophiuroids (brittle stars), the echinoids (sea urchins and sand dollars), the holothuroids (sea cucumbers) and the crinoids (sea lilies and feather stars, not found in the Beaches of Oyambre). The tube feet or podia found in every echinoderm species are used for food capture, attachment to the substratum, and also locomotion. Sea cucumbers also have clusters of fine tubes that are ejected when the sea cucumbers are stressed. These Cuverian tubules have a fast-acting adhesive that can entangle a predator. These two systems rely on different types of adhesion and therefore

Photo 7: Sea anemones sit in an almost dry pool during the low tide sharing spaces with gastropods, and different algae species. Notice the different colouration among the same species.

differ in the way they operate, in their structure, and the composition of their adhesive, which may have applications in soft robotics. Almost all animals can repair minor tissue damage quickly, but starfish can shed limbs in defence and regenerate another limb on the resulting stump.

Lastly, anemones (Photo 7) are easily found in tide-pools where they show their crown of tentacles coloured red, green, and brown thanks to the symbiosis with algae (zooxanthellae). Anemones are carnivorous, catching food using tentacles with stings powered by high-pressure liquid. The algae convert solar energy into nutrients when other food is scarce. Anemones have no brain but a primitive nervous system that allows them to be surprisingly active. When threatened or when the tide goes out, they retract their tentacles and shrink to the size of a cherry. When relaxed, they become much more prominent, opening like flowers showing their more than 200 tentacles distributed in six crowns that can insert a piece of food in the anemone's mouth and reject it if the flavour is not acceptable.

Unfortunately, climate change largely caused by human activity upsets the ecological balance. Some species will displace others, reducing biodiversity. Although many species can tolerate wide temperature swings, the increase of CO_2 in the oceans increases acidity and causes weakening of the exoskeletons of crustaceans and mollusks. Rising ocean temperatures will force species to migrate further north. The Anthropocene and associated climatic instability put all life on Earth at risk, no matter how adaptable it may be.

Studying and observing the complex intertidal habitat and the survival strategies of its animals and plants can help us better understand and adapt to global climate change that is bringing more storms, torrential rains, hotter days, and other climate extremes.

Rocky shore organisms can inspire innovation in new materials, better coastal defences, and processes that do not rely on toxic materials. The majority of human coastal defences are specifically made smooth to reduce marine fouling. Instead, textured surfaces such as ECOncrete (https://www.bbc.com/future/article/20200811-the-eco-friendly-alternatives-to-ocean-concrete) can increase surface complexity, encouraging marine regeneration and biodiversity. At a personal level, the intertidal zones are magical and accessible spaces to explore, representing a vital opportunity to reconnect with the planet, increase our eco-consciousness, and marvel at the genius of the organisms with whom we share the Earth. ×

Life in Two Worlds: The Intertidal Zone II
Manuel Quirós

Manuel Quirós BSc, MSc, PhD is a passionate nature living conservationist. He guides, as an independent teacher in several universities in Spain, inspiring classes through Sustainability and Biomimicry education as a transformational behavior strategy towards regenerative culture. He runs NIU (https://www.natureinspireus.com/), a biomimicry consultancy, and is a cofounder of Red Internacional Biomimesis (RI3: https://redinternacionalbiomimesis.org/) and Biomimicry Iberia (https://zqjournal.org/editions/zq19.html). He participates as a speaker in many international symposia like ONU-Habitat and COP 25. Contributing editor of Zygote Quarterly since 2013.

Manuel Quirós

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Additional reading

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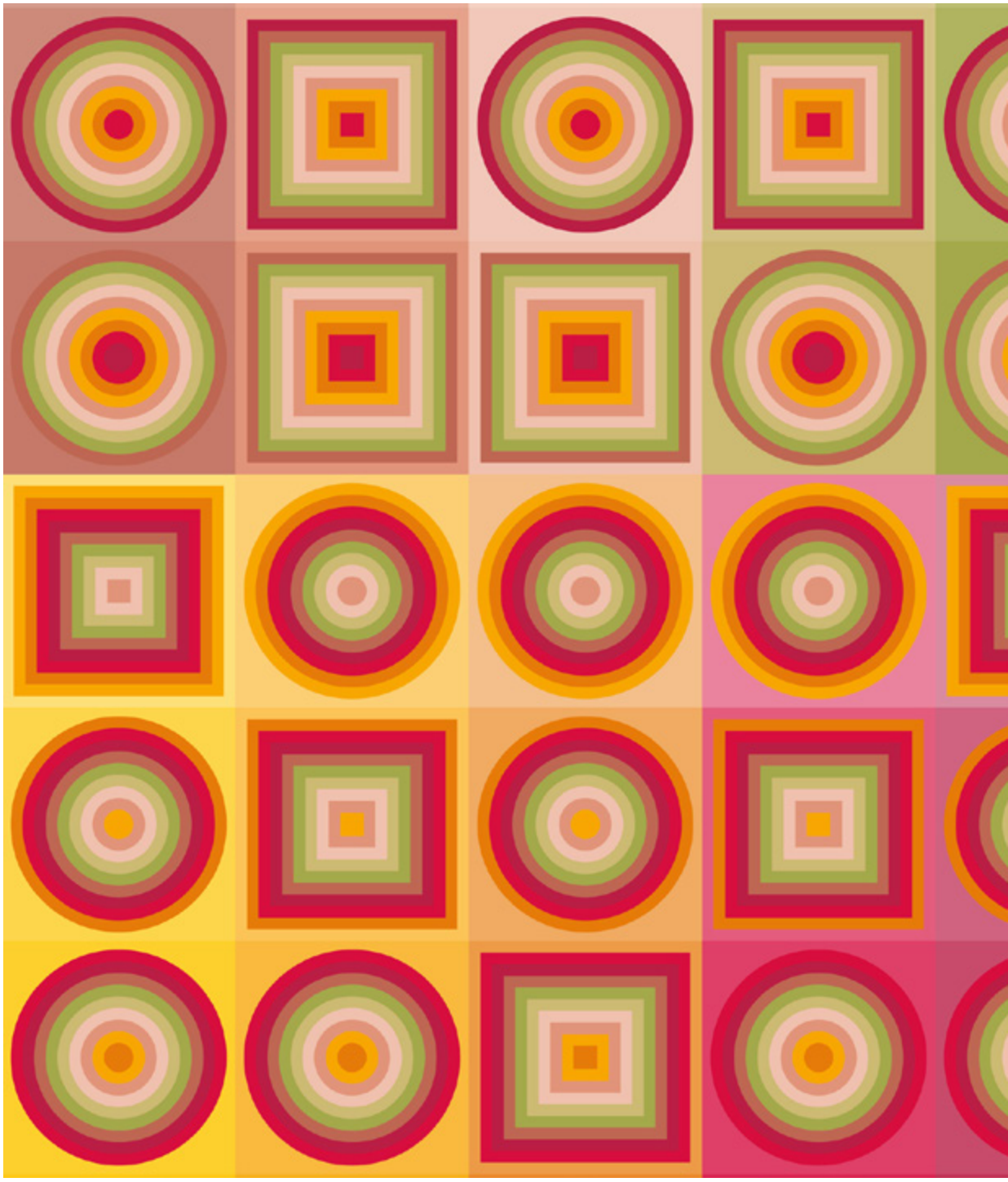
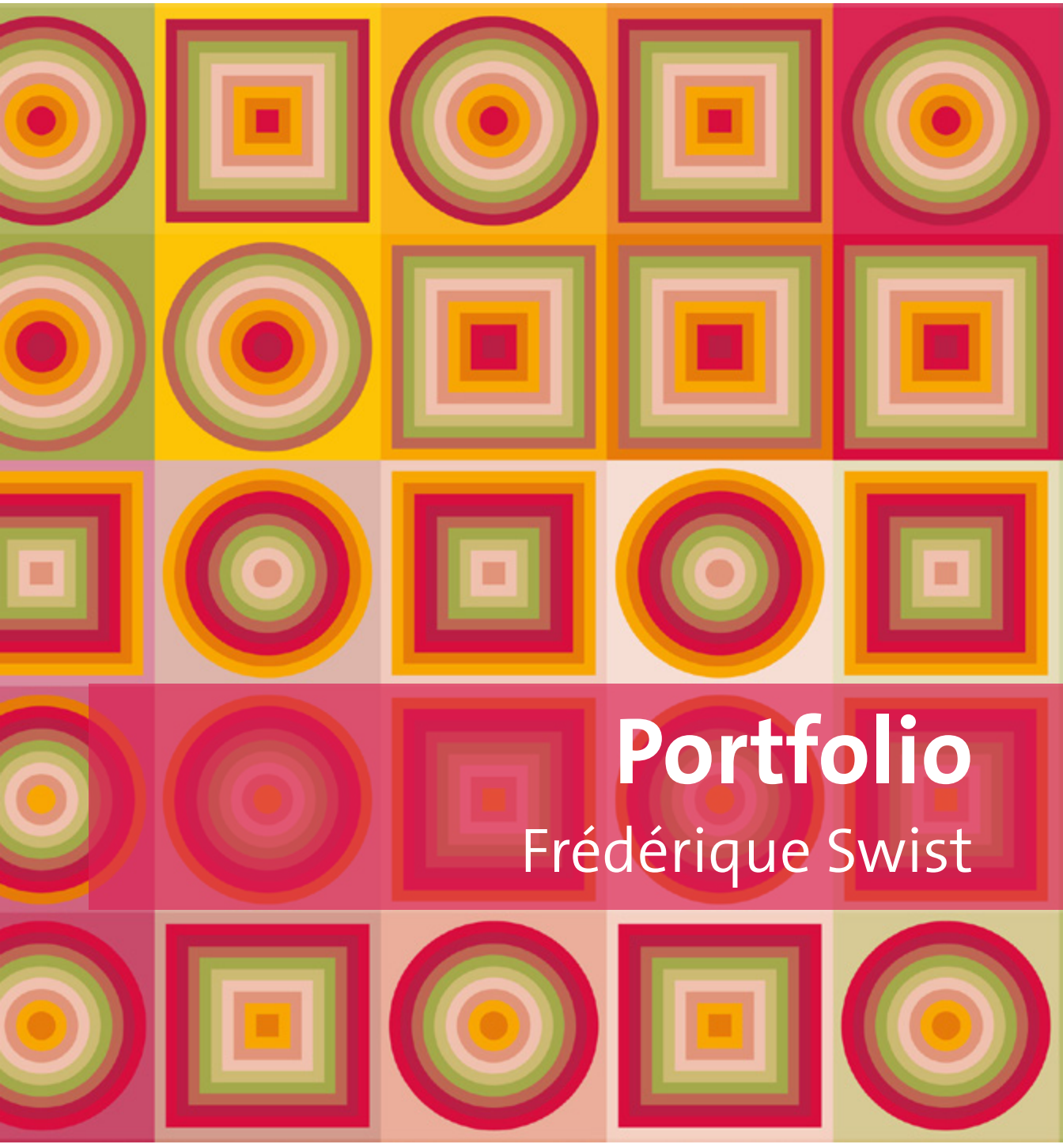


*Hommage à Vasarely: l'Unité Plastique N*1 (2008)*
Frédérique Swist



Portfolio

Frédérique Swist

Portfolio
Frédérique Swist

Could you tell us about your background?

Born in France, I spent my childhood years in the suburb of Paris, before my family relocated to the South of France. After an Applied Arts Baccalaureate, I continued my studies in graphic design and visual communication and worked for a couple of years in Marseille. I moved to the UK in 1997 to pursue a career in graphic design; in London for a year, then in Bristol. Joining the in-house art department at a science academic publisher in 2000 has been an important turning point. It is in this very specialist environment that I quickly developed a particular interest for scientific content and imagery. This interest heavily informed my design work and led me to explore creative opportunities further, to become my art practice.

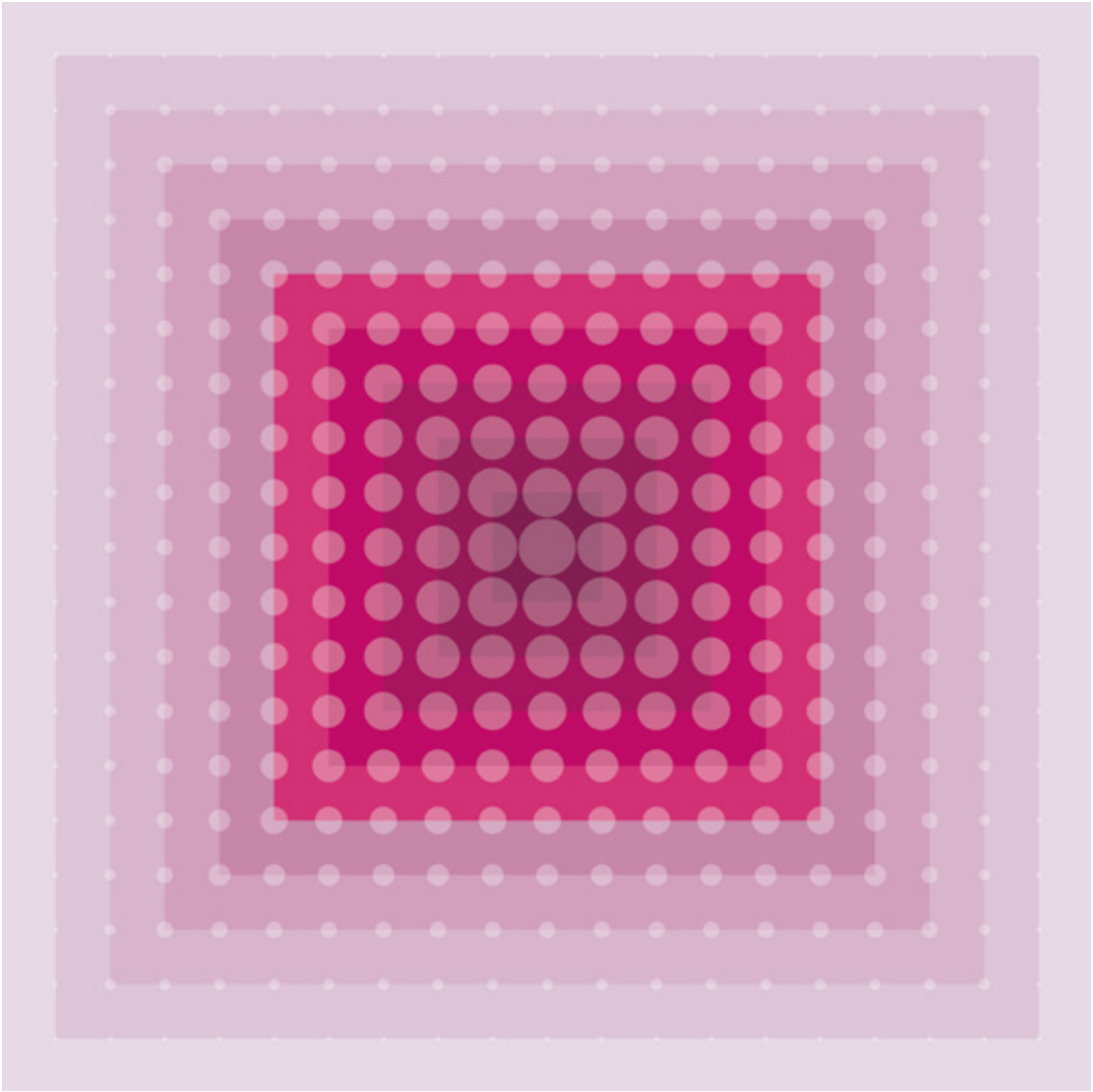
Committed to investigate this field further, in 2007 I undertook a Practice-Led Doctoral study at the Faculty of the Arts, University of the West of England, Bristol, which I completed in 2014. My research explores the concept of visuality as a shared notion between artistic and scientific production, and more precisely "how meaning can be transformed between one domain and another, using the visual as its mode of mediation".

In 2020, I decided to relocate to the South of France, where I now live and work as a freelance designer and artist.

Frédérique Swist

What kind of techniques do you use for your work?

Over the years I explored many techniques, often starting with sketches and notebooks, but I've always been interested in printing processes. Early work was produced in screen-printing, after which I moved towards vector graphics for the creation of imagery and fine art digital printing for the production. I do enjoy the raw qualities of mechanical printing, but digital processes offer exceptional precision which has naturally led me in this direction. With current



*10 x 361 N*32 (2008)*
This piece is part of a series that explores the effect of colours and variation in their intensity, from the basis of a simple geometrical structure, deployed as a blueprint. This work is heavily influenced by Victor Vasarely's visual system and his mathematically-driven research into colour and geometrical combinations.

technologies it is now possible to reach such a level of accuracy in terms color and printing quality – aspects that have become central to my work.

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

When I discovered specialist technical literature – as part of my job at my former employer – it felt a little intimidating. Fortunately, I was surrounded by great colleagues (publishers, editors, journalists, production staff) and I had the opportunity to work directly with authors, so I often discussed scientific content and imagery with them. Over time, I became more confident in the ways that I "manipulate" scientific notions, first in my design work (with a more illustrative approach), then gradually feeding into my art practice, where I explore scientific content with more creative freedom.

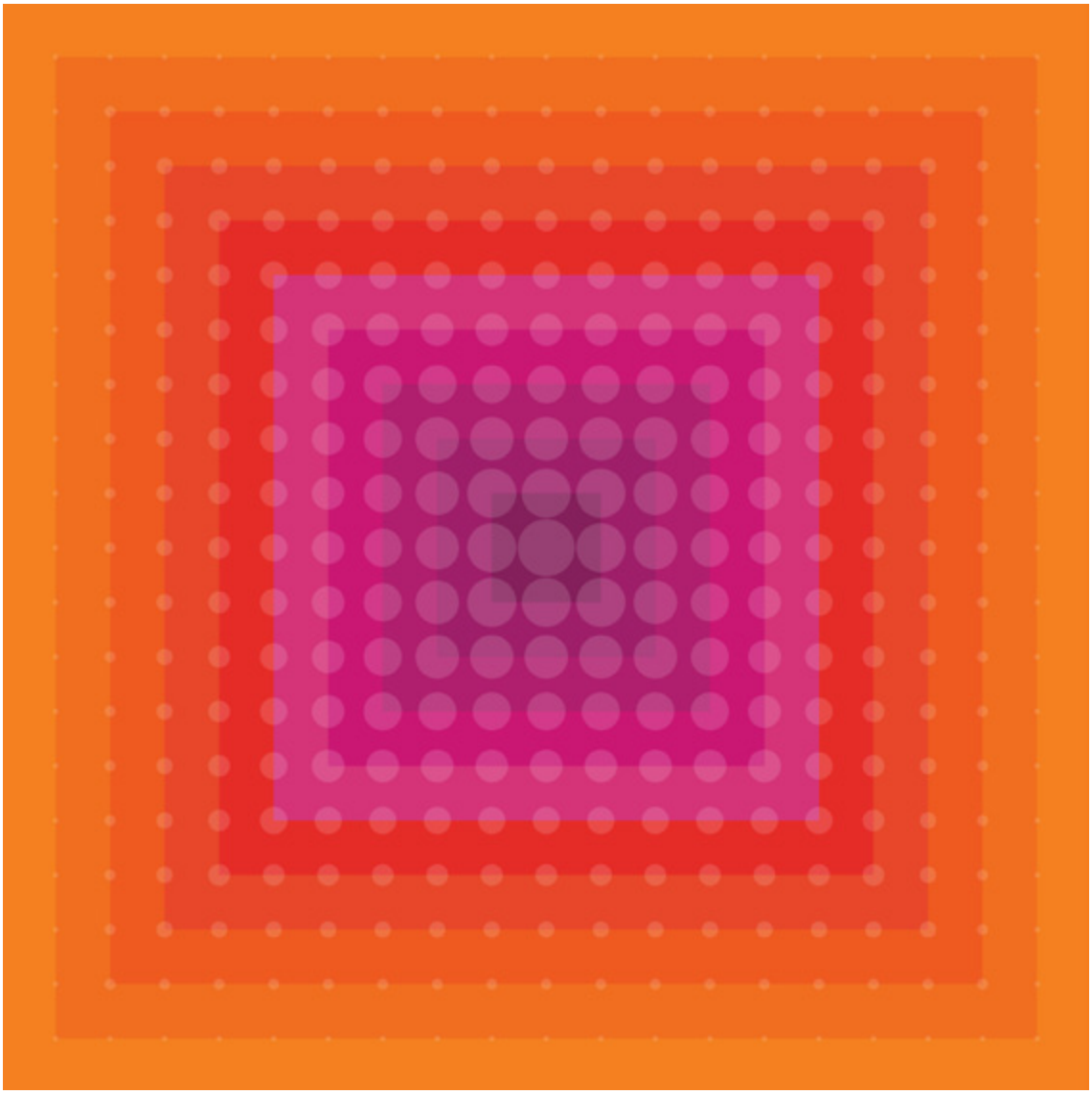
When I take inspiration from technical figures, I always accompany the artwork with a caption directing to my reference source. As the work evolves, some pieces only retain traces of my source of inspiration. I feel that the artwork becomes something else, with only remnants still present, often hidden to the viewer, that only I can identify from the long journey of investigation that led me to the finished piece.

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

I'm not sure how to answer this, perhaps it is more the other way round. I've always been a very "visual" person (i.e. visual sensitivity, memory), and I feel that it is this fascination for visuality that influences how I engage with my work and feed my creativity.

Can you tell us more about the exploration of scientific notions positioned beyond the threshold of the picturable as mentioned in your artist statement?

This is a phrase taken from the book *Six Stories from the End of Representation* by the American scholar James Elkins. It was a key concept that I identified when I was studying for my Doctoral thesis. I was struggling to articulate my own engagement with scientific content and imagery, and Elkins' discourse on the subject resonated deeply with what I was trying to make sense of at the time. I'd find it quite difficult to explain this briefly and do it justice, so I would recommend the book to anyone interested



*10 x 361 N*30 (2008)*
This piece is part of a series that explores the effect of colours and variation in their intensity, from the basis of a simple geometrical structure, deployed as a blueprint. This work is heavily influenced by Victor Vasarely's visual system and his mathematically-driven research into colour and geometrical combinations.

Portfolio
Frédérique Swist

in this subject. But here is a modest attempt: Elkins wrote extensively on the domain of images, where he questions their very nature, both in terms of production and reception, with a particular attention to what he calls non-art images. In *Six Stories*, Elkins investigates different types of scientific images (in reference to extreme scale or distance) captured through the most sophisticated techniques/processes. These pictures tend to offer very little in visual terms – he defines them as "frail" – but they carry crucial information to the trained eyes, the scientists.

Elkins' analysis has informed my own approach and helped me to feel more at ease engaging creatively with highly specialist notions that I couldn't fully understand as a non-scientist.

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

Like most creatives, I tend to think that inspiration often comes naturally from our surroundings. I still spend considerable time looking through scientific and technical publications, online and in print. Not always reading them, I have a special interest in "dissecting" technical figures, graphs, diagrams...

What I "feed" on the most is probably the process of research: the lengthy journey of exploring infinite combinations of color, form, composition, exhausting nearly every possibility, in order to reach something close to a perfect balance between the colors and the shapes that carry them.

Perhaps more than the completed artwork, I enjoy this long and difficult path to get to it. The opportunity to slow down and take the time needed in order to fully explore and reflect on the many possibilities within the creative process, I feel is something rewarding, and a good contrast with the general fast pace of daily life.

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

Following the move from the UK back to France less than a year ago, I focused my time in setting up my freelance design work as a priority. It is only recently that I've been able to go back to my art practice with the time and space that it needs. I do have new work in progress, which I'm aiming to release towards the end of the year.

What is the last book you enjoyed?

The Order of Time by Carlo Rovelli – a very enjoyable and engaging book.

What are your favorite 3-5 websites, and why?

www.fondationvasarely.org: Hungarian-born French artist Victor Vasarely has always been a significant influence throughout my career, both in art and design, and I love sharing my interest for his work and legacy. The Fondation Vasarely is probably the best place to find out more about his oeuvre, the building itself was designed and constructed under his direction, as its distinctive architecture testifies.

www.lohse.ch: Swiss-German Richard Paul Lohse is another artist of great influence, he was a painter and theoretician, and like Vasarely, started his career as a graphic designer.

www.ottographic.fr: I'm also very interested in illustration, and among the many great talents out there, I was fortunate to have met German graphic artist Dettmer Otto and am following his work ever since. Influenced by Russian Constructivism, his art spans across editorial illustration for international publications, poster designs, and artist books. I admire his ability to express difficult concepts in a visually engaging way, combining a distinctive style with the raw qualities of screen printing and other graphical techniques.

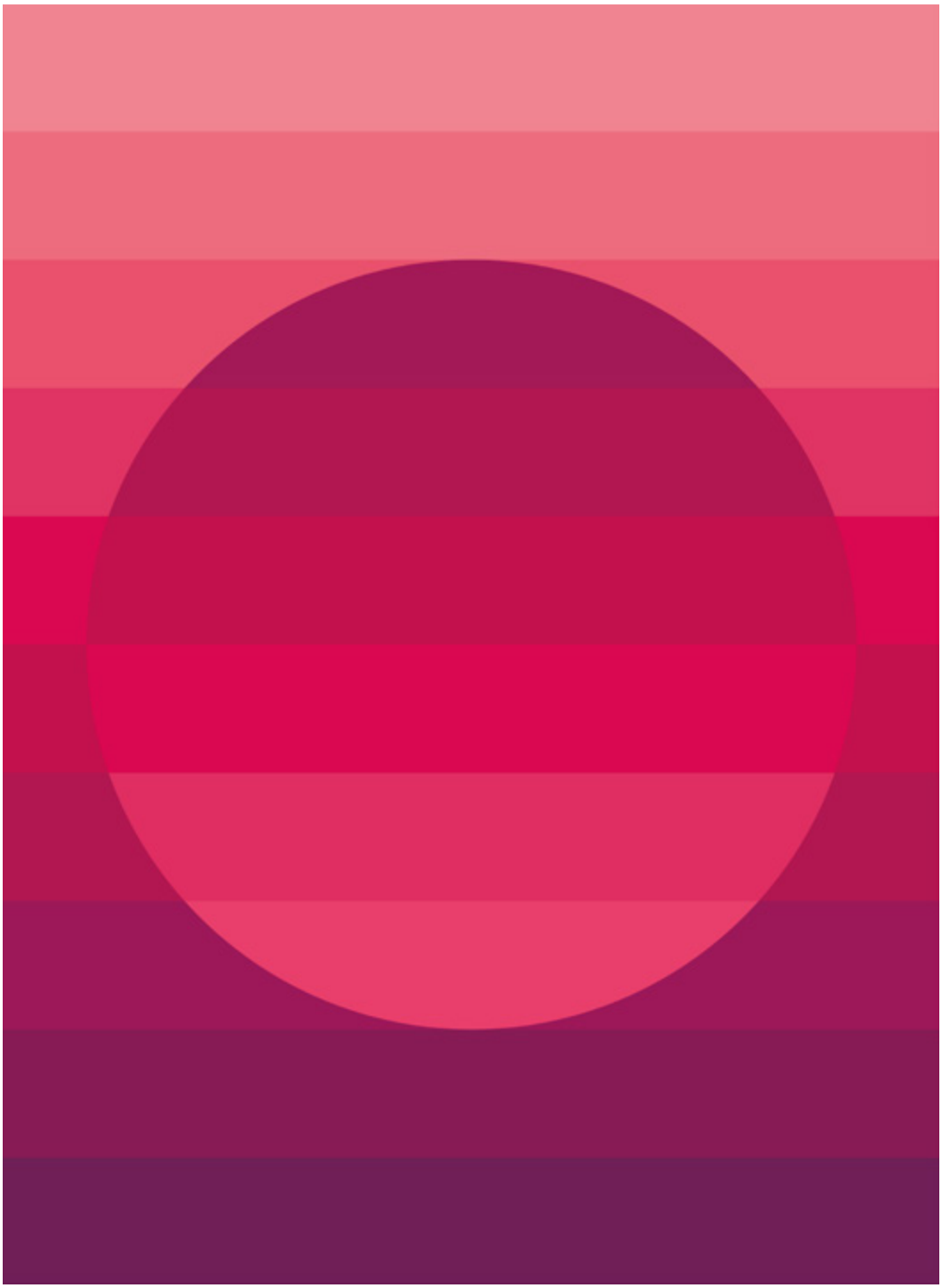
What's your favorite motto or quotation?

Of course, there are many. Perhaps this short quote from German product designer Dieter Rams resonates well with me: "weniger, aber besser", "less but better". It could sound a bit like an advertising slogan (!?), but going back to its original context, it captures the vision of a designer who stayed committed to the questions on form and function throughout his prolific career.

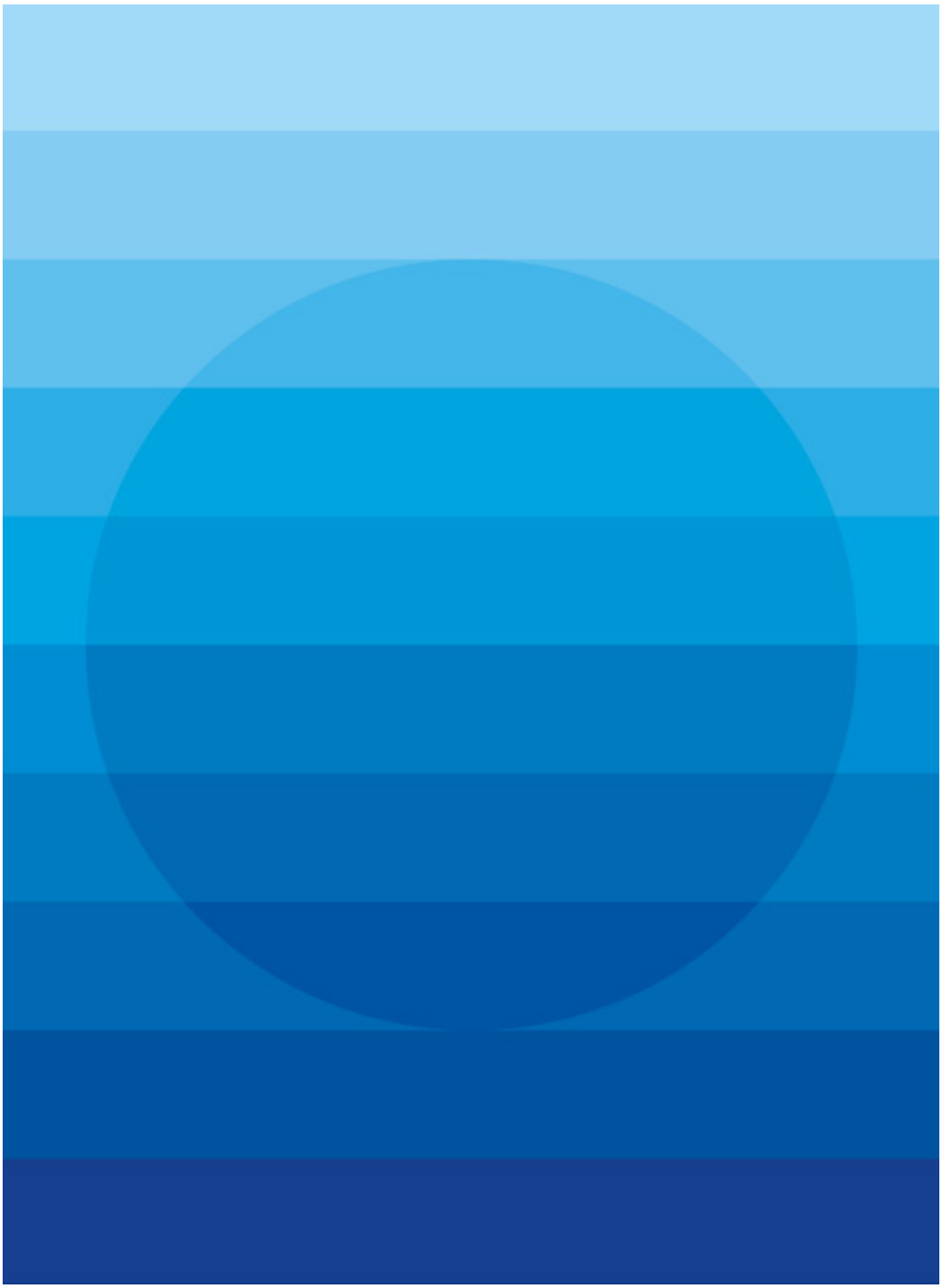
Without being a particular advocate for minimalism, here I like the idea of removing, leaving out, abandoning what may be considered as unnecessary/superfluous, in order to focus on the essential. In creative terms, this often implies taking the more difficult path, the longer journey in any (artistic) investigation, but one that could lead to a more meaningful result, as well as a richer and a more rewarding experience. On a small level, this is what I try to achieve in my art practice. ×

For more of Frédérique's work please see: https://frederique-swist.com

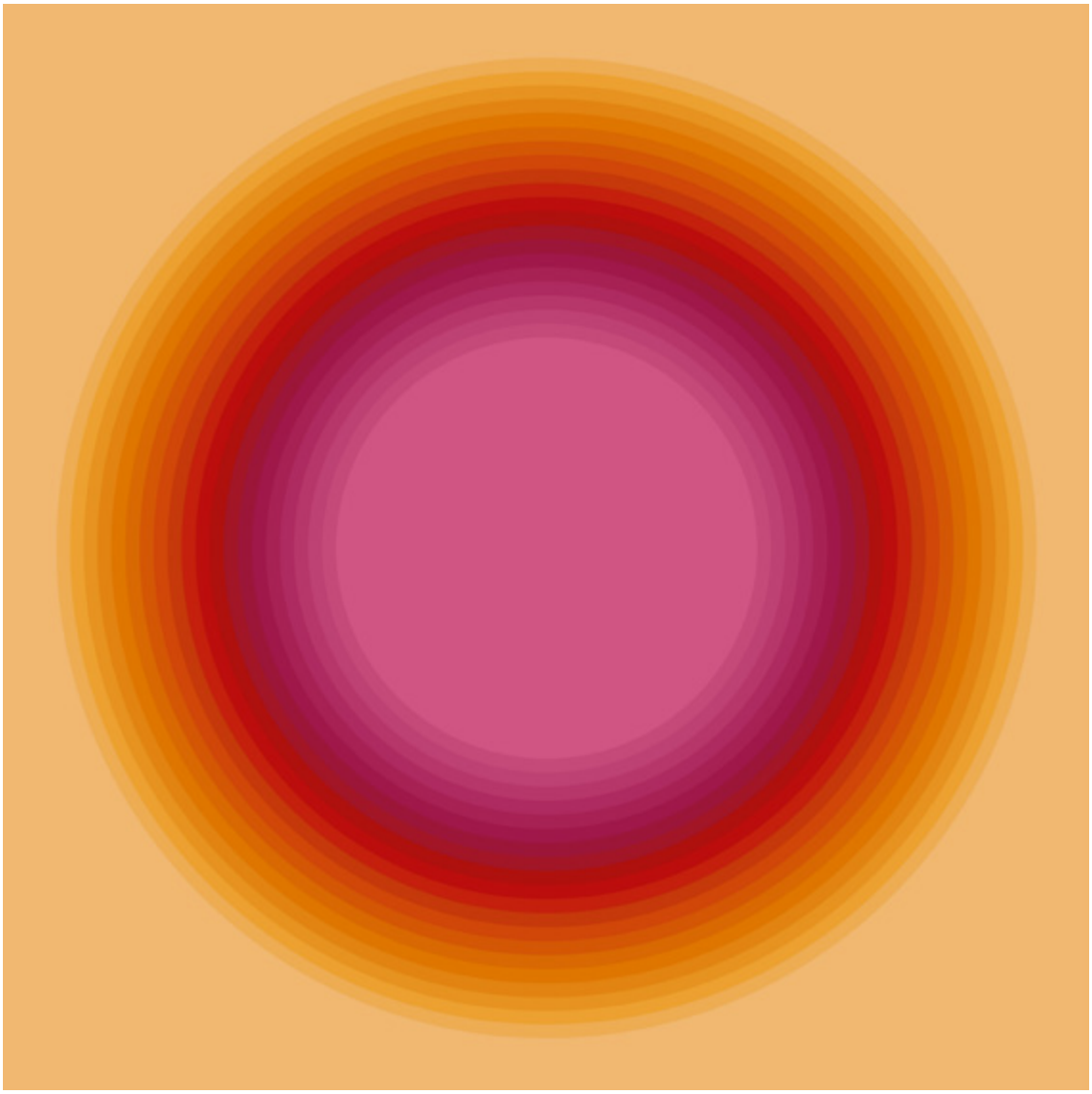
We would appreciate your feedback on this article:



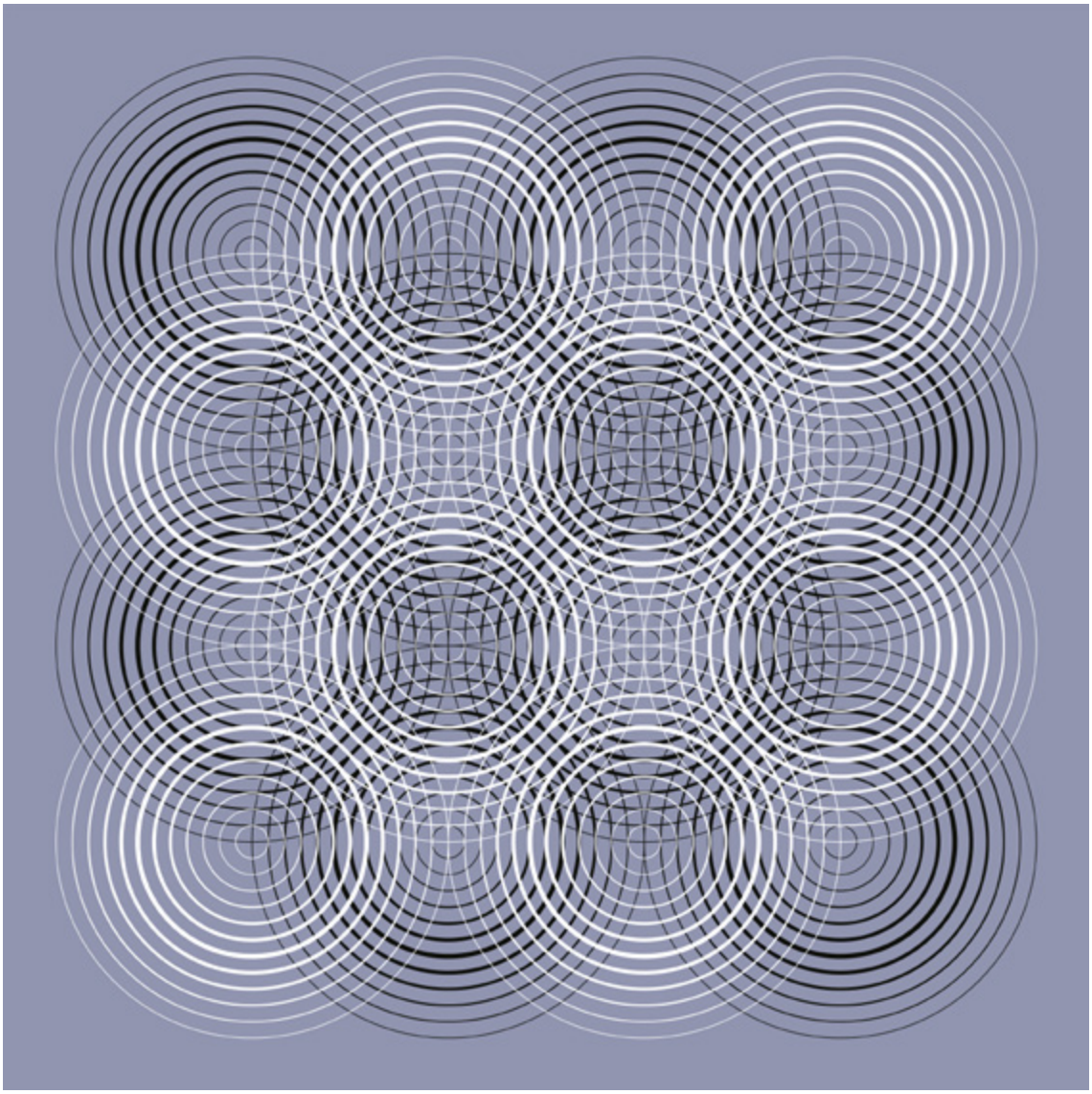
Diatonic N°2 (2013)
From the series Diatonic, this artwork is part of a wider research that focuses on a visual mimesis of gradual tones, here expressed through a proportional arrangement of flat colours – the aim is to reach a near-perfect visual balance between each phase and simulate a gradient.



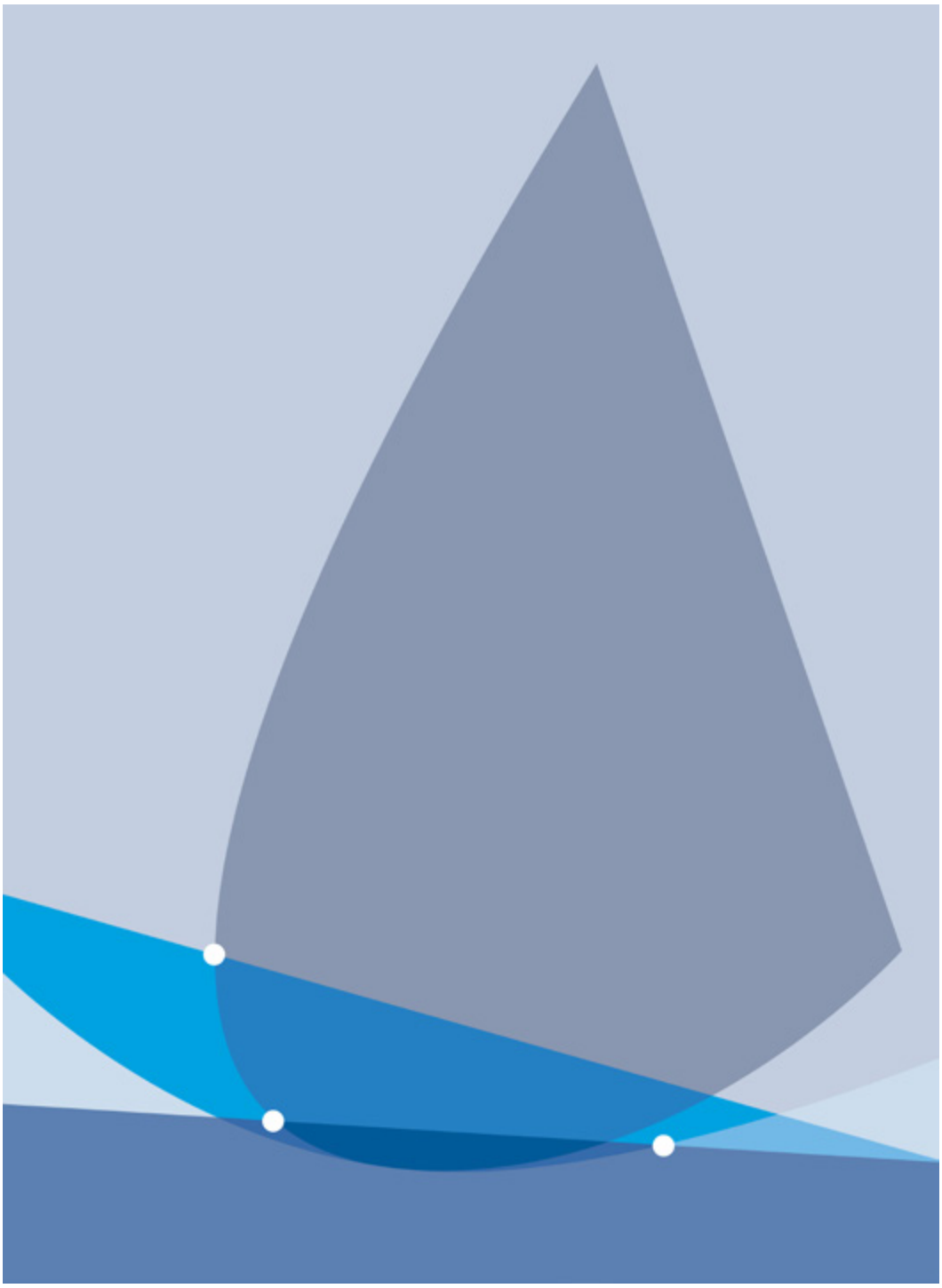
*Diatonic N*3 (2013)*
From the series Diatonic, this artwork is part of a wider research that focuses on a visual mimesis of gradual tones, here expressed through a proportional arrangement of flat colours – the aim is to reach a near-perfect visual balance between each phase and simulate a gradient.



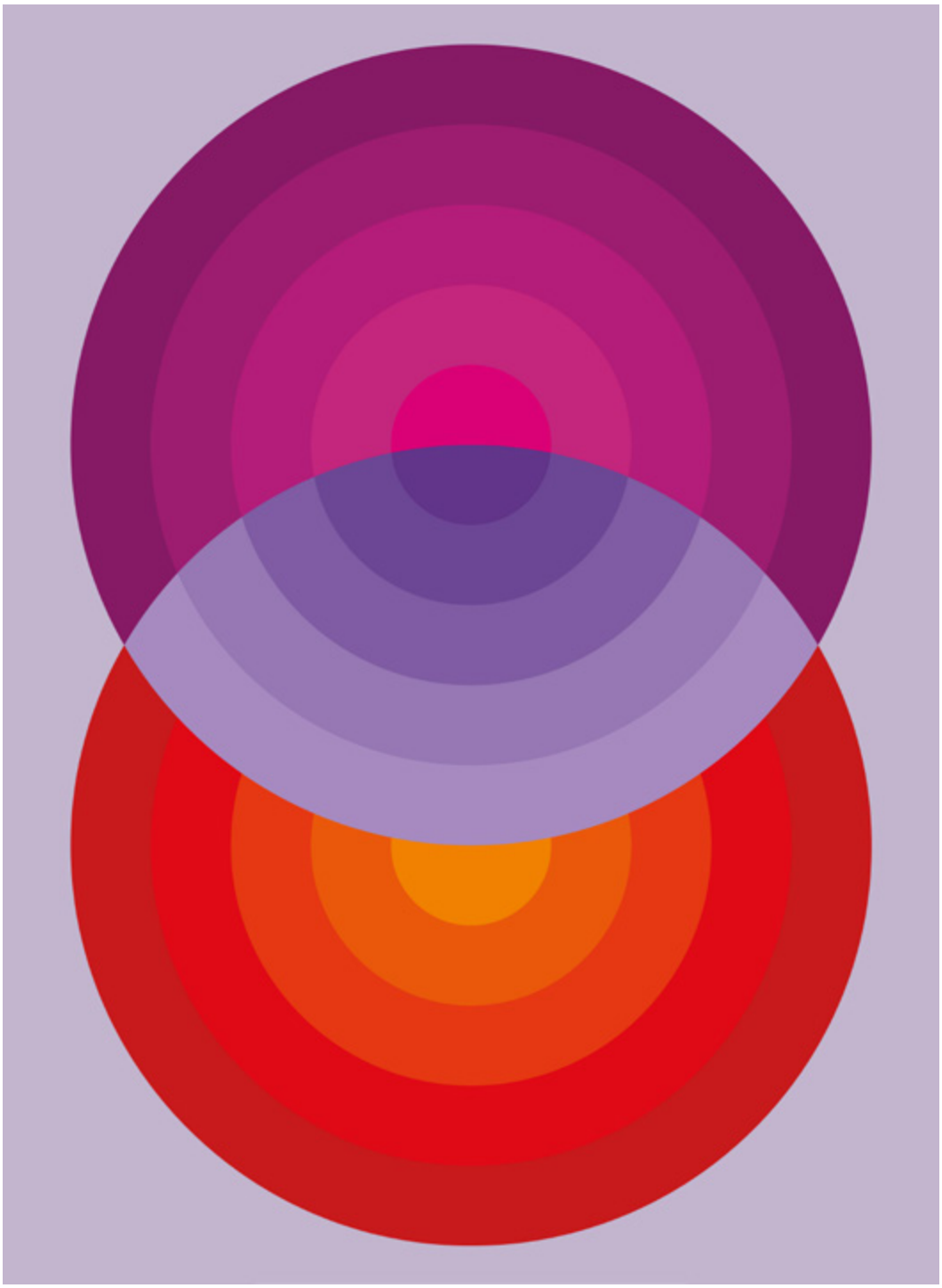
Pulse (2021)
From the Latin pulsus ‘beating’, from pellere ‘to drive, beat’. A single vibration or short burst of [colour], sound, light or energy.



Good Vibrations (2010)
This artwork refers to the construction of individual (but intertwined) linear sub-systems resonating and oscillating among one another, as effects of resonance or "pulsation" emerge from the underlying structure – transcending the binarity normally associated with oscillation.



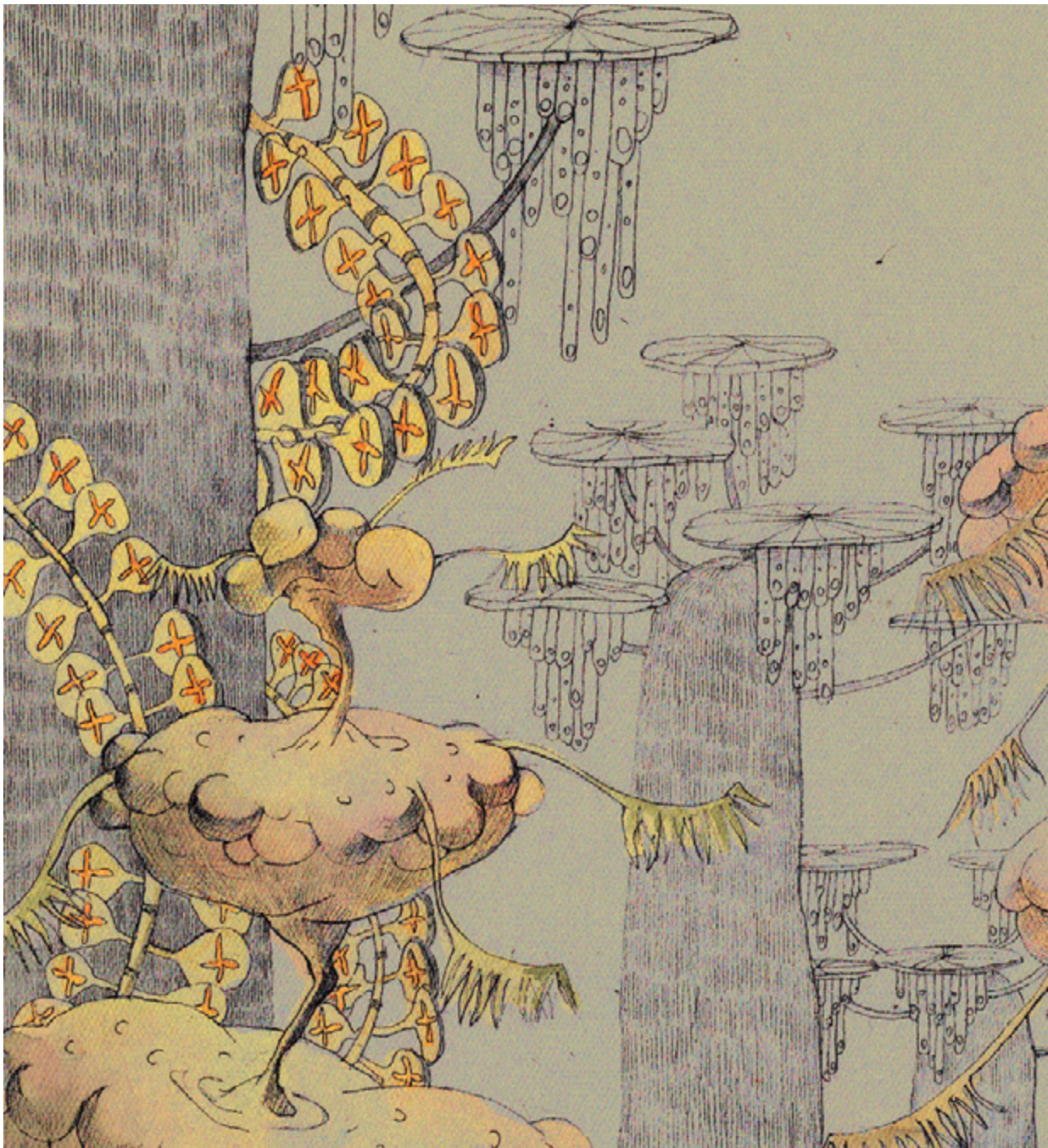
Entropy N°1 (2012)
Artwork inspired by intersecting curves of particle energy, from the article "The entropy of dense non-communicative fermoins gases" J N Kriel and F G Scholtz 2012 *Journal of Physics A: Mathematical and Theoretical* 45 095301.



*Entanglement N*1 (2013)*
This composition is inspired by the physical phenomenon of quantum entanglement: the study of the interaction and behaviour of particles in relation to each other at the quantum level, where they can be described only approximately in terms of their position, momentum, spin and polarisation.

*The Measurement of Time versus Voltage and Current N*1 (2020)*
Artwork inspired by a schematic model exploring how response current is affected by direct and alternating electrical pulses in the human body. From the article by Hung et al *Nanoscale Research Letters* (2020) 15:146.

*The Measurement of Time versus Voltage and Current N*2 (2020)*
Artwork inspired by a schematic model exploring how response current is affected by direct and alternating electrical pulses in the human body. From the article by Hung et al *Nanoscale Research Letters* (2020) 15:146.



Pataplant layers
Illustration: foam, 2009 | Flickr cc

Interview

Billy Almon

Interview
Billy Almon

Billy Almon is an Astrobiofuturist, exploring biology-inspired solutions to improve the human condition for those of us on earth and those who will travel to the stars. He speaks to multiple generations of inventors, designers, scientists, and engineers on designing the future they wish to see. Previously, Almon was a creative director at Walt Disney Imagineering, leading efforts to develop immersive experiences and environments around the world. He is an inventor and holds a master's degree in biomimicry from Arizona State University and bachelors's degree in architecture from Howard University.

Almon is a member of the Biomimicry Institute Board of Directors.

Billy Almon

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

I always feel like biomimicry is on the cusp of breaking through the zeitgeist. We're at an interesting point where we're exploring not just what nature-inspired design can be, but how to make it sustainable, functional, and appealing to designers that haven't traditionally paid attention to the natural world.

I think we're close to a break-through in terms of biomimicry, even if it's called another name, becoming mainstream out of necessity for our planet's survival.

What do you see as the biggest challenges?

I think one of the biggest hurdles to biomimicry is getting our timescale to be more competitive with other approaches to design and innovation.

The questions I'm always thinking about is, "How do we (biomimics) identify biological models faster?" and "How can we make sure that the biology we're choosing to serve as inspiration for a solution is the best one to go with?"

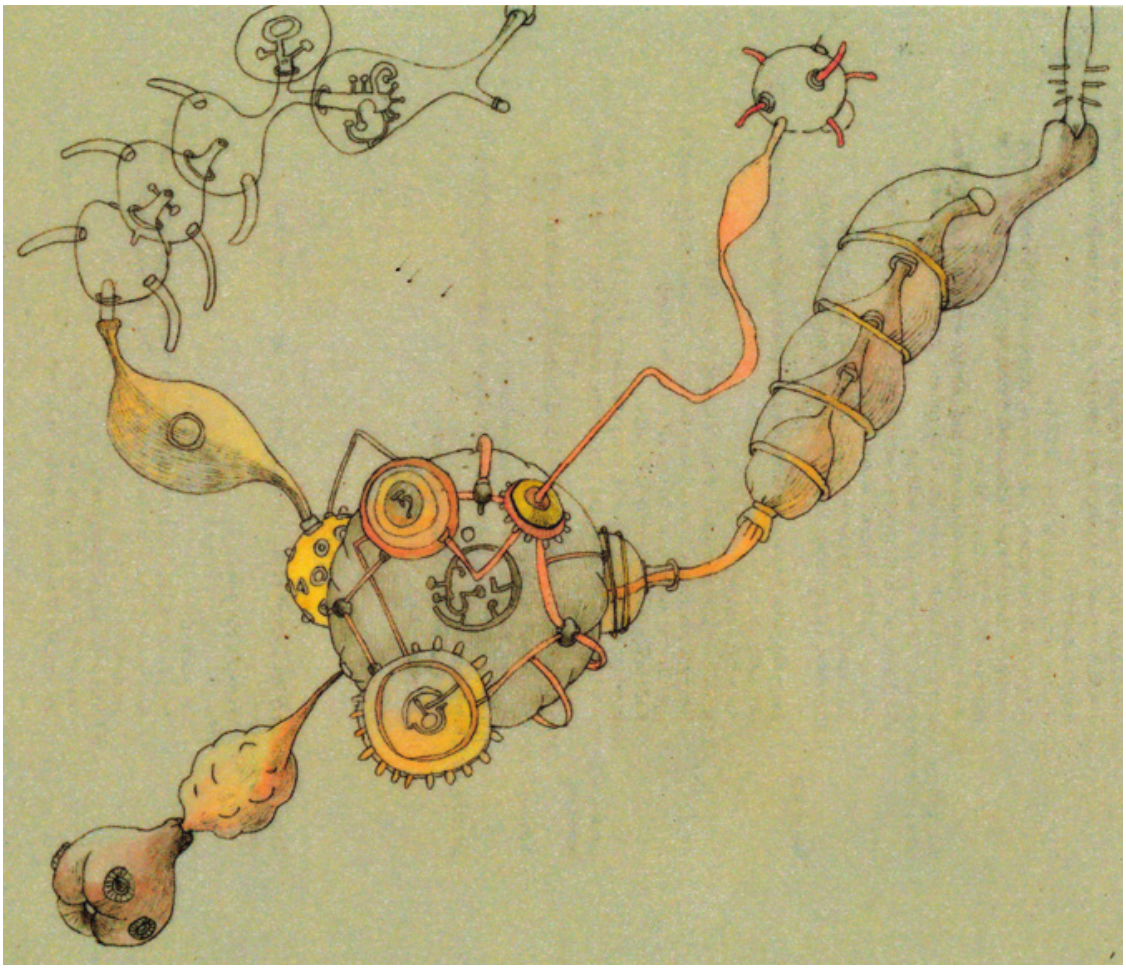
Seed | Illustration: foam, 2009 | Flickr cc

Interview
Billy Almon

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

To get more adopters of biomimicry, we have to make the process easier to understand. We have to make tools that help identify biology and their abstract design concepts much more user-friendly than they are now.

That includes making it easier to pull nature's principles into design and translate them into products, services, and systems the world needs today. The more accessible we make biomimicry, the easier we make it



Rhizosphere
Illustration: foam, 2009 | Flickr cc

for people to jump on and adopt the idea of utilizing nature-inspired solutions, the faster we'll have more people jump on and adopt this idea of nature-inspired solutions.

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

I'm constantly reading, scouring articles, and engaging peers in the space to stay on top of how the industry is evolving. Come join me on Clubhouse in the "Biomimicry Club" room. There are always lively discussions happening and we're open to anyone hosting a talk or even just participating in one.

What is your best definition of what we do?

Simply, we help people find solutions to problems. That's what we do.

How we do it is by looking to nature for inspiration as a guide in developing solutions that are inherently efficient and sustainable because that's how the natural world operates.

By what criteria should we judge the work?

I think there are a couple of different ways that biomimetic work should be judged. First is sustainability. Is the solution we're delivering sustainable or is it just as wasteful as another version that wasn't biomimetic.

Second, and most importantly, are the solutions we're proposing actually solving the problem at hand?

For me a biomimetic solution is sustainable and solves the problem. If it only does one of those two things, then it is just imitating an organism, not actually working within a system to address an issue, which is what nature does.

What are you working on right now? And can you tell us about being an Astrobiofuturist?

Right now, I'm looking into all the different ways that nature has influenced space exploration and how we will need to utilize nature to survive in space, on Mars, and on the Moon. I'm also looking at which technologies that were originally developed for space travel can be used to address some of our human challenges on Earth.

A number of questions drive my work at the present moment. They include: How might we create experiences for people that improve their overall mood (psychological health) while living in space? How do we make the experience of living in space more enjoyable? That means: What needs to be

Pataforest | Illustration: foam, 2009 | Flickr cc

Interview
Billy Almon

NASA concept art
Creative Director: Billy Almon, Artist: Christopher Lee

developed to create enjoyable lifestyles in space which are influenced by nature? Lastly, how can we use the technology created for space to improve life here on Earth?

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

It was 2006 in the aftermath of Hurricane Katrina. I found myself an architecture student at Howard University looking for ways to design things that would prevent these kinds of things from happening, particularly to black and brown communities and low-income communities.

That's when I came across Janine Benyus' book, *Biomimicry: Innovation Inspired by Nature* and I learned how mangroves prevented hurricane wind forces and tidal waves from destroying property. It was a huge influence on me and it opened my mind up to the infinite possibilities that exist when we turn to nature for solutions to design technology and innovation.

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

If I can plug my own work here, I recently created concept art for a presentation to NASA. In it, I illustrate how space modules can be designed (with virtual reality and soft robotics) to mimic earth to help strengthen the emotional and mental health of space travelers. This concept art is the first time I've visualized my ideas and I'm really proud of how it turned out.

What is your favorite biomimetic work of all time?

Researchers at Technical University of Munich, University of Freiburg and University of Stuttgart in Germany have designed buildings inspired by the pinecone. The building facades essentially open and close or breathe the same way that pinecones breathe, depending on humidity. Given the energy demands that air conditioning makes on buildings, this could be an important use to duplicate in a world dealing with climate change.

In terms of fantasy and science fiction, I like the space suit in Will Smith's movie *After Earth*, which changes colors and texture like the golden beetle and octopus.

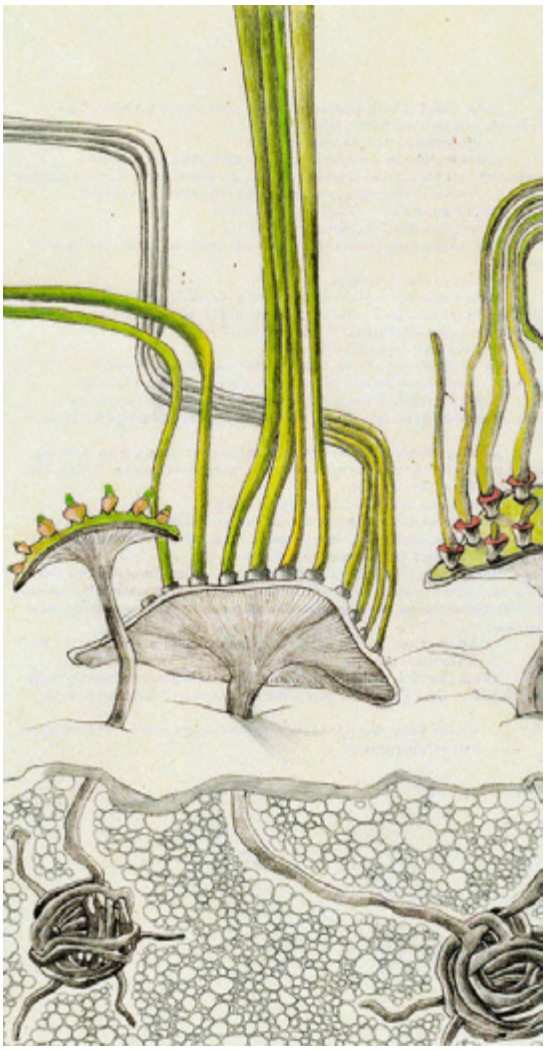
What is the last book you enjoyed?

I'm in the middle of reading a few that I want to share. The first is *Packing for Mars* by Mary Roach. The other is Leland Melvin's *Chasing Space*. A few more I'm enjoying are

Interview
Billy Almon

Art Instinct by Denis Dutton and *Sleight of Mind* by Stephen L. Macknik.

All of them explore the intersection of psychology, design, and space.



Climbers and roots
Illustration: foam, 2009 | Flickr cc

Who do you admire? Why...

Lanny Smoot at Walt Disney Imagineering. He's a prolific inventor and a literal genius. Even with all that he's created and designed, I admire his character. He's also a genuinely great friend and mentor; I'm lucky to know him and to have learned from him over the years.

What's your favorite motto or quotation?

"Do the thing and you shall have the power." I'm not sure who said it first, but what I take away from it is the idea that once you've tried, you know how to try it again and iterate on it. Even if the first time you did it was bad, now you know it can be done and you can take the lessons to improve on your process again and again.

What is your idea of perfect happiness?

Being in British Columbia with my family; being immersed in the great outdoors and showing my girls the wonders in the world around them. They are 6 and 1 years old now and one of the things I'm most proud of as a father is their connection with nature. My eldest is a pro critter catcher. Lizards are her favorite to catch (and release.)

If not an Astrobiofuturist, who/what would you be?

This is a great question. If I couldn't be an Astrobiofuturist, I think I'd still be a designer in some forward-thinking company's R&D lab. The only difference is that being an Astrobiofuturist, I can develop whatever's in mind in collaboration with a number of companies working on inspiring ventures. ×

We would appreciate your feedback on this article:

Robotanics
Illustration: foam, 2009 | Flickr cc

Channa Argus
Guto Nobrega

Portfolio

Guto Nobrega

Interview by NOUS Ecossistema

Guto Nobrega
Interview by NOUS Ecossistema

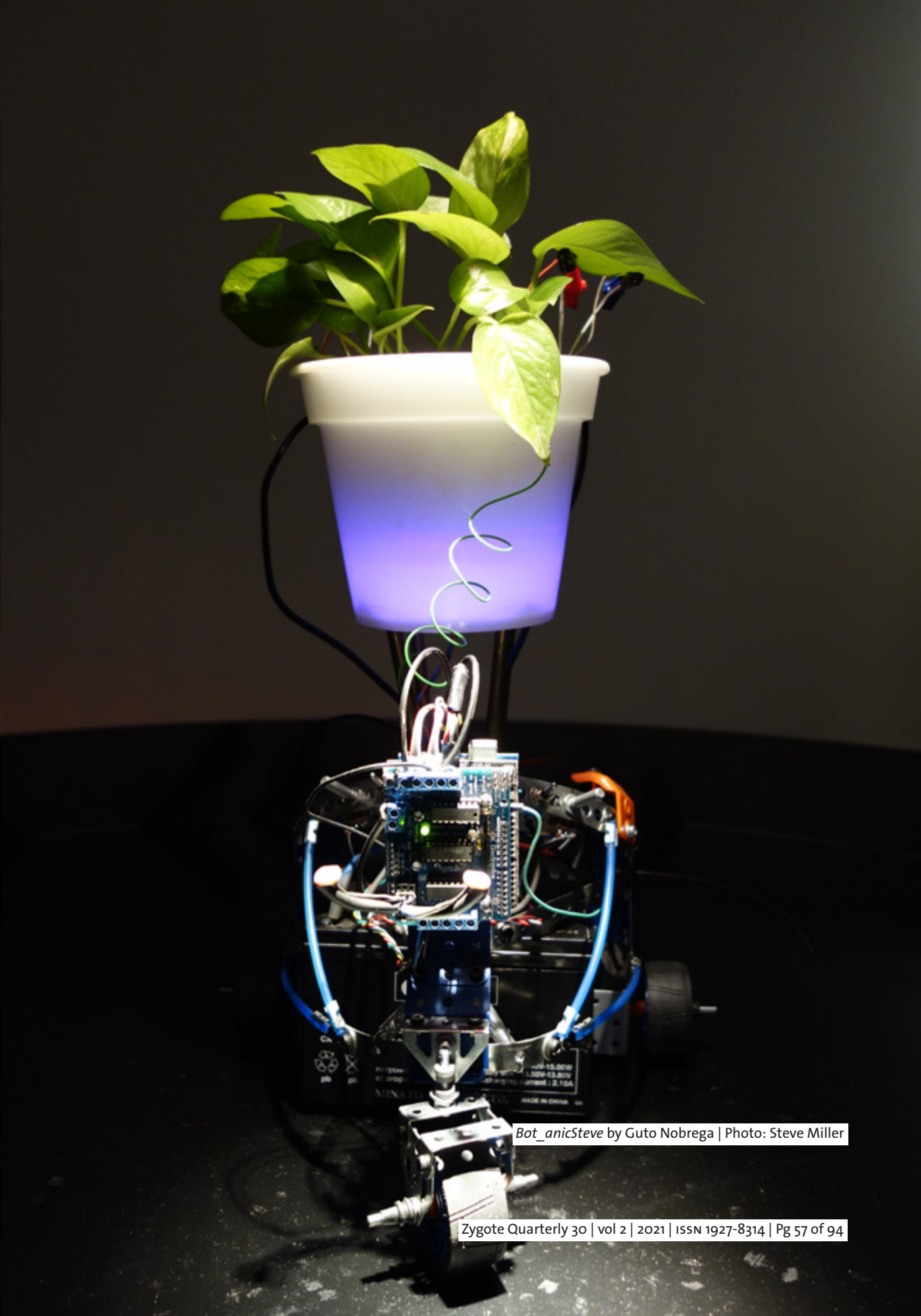
I am an artist, researcher, and educator. I have a post-Doctorate degree in Art and Technology from the University of Brasília PPGAV/Unb (2019) and a PhD (2009) in Interactive Arts from the Planetary Collegium Graduate Program, University of Plymouth, UK, under the supervision of Professor Roy Ascott. I am also a Research Productivity Fellowship CNPq - Level 2. I am the founder of NANO - Núcleo de Arte e Novos Organismos (Nucleus of Art and New Organisms), a research lab facility for investigation and artistic creation, coordinated by myself and Malu Fragoso. I would like my work to be considered and contemplated from an art perspective, a sensorial experience, a poetic encounter with the world. It is about a consensual exchange between entities. The artwork is a trigger but is not the experience itself. The experience is organic and emerges from this encounter, this exchange. Lygia Clark talks about this relationship. She says that "We [artists] are proposers: We are the mold, it is up to you to blow inside of it the meaning of our being." The time for these encounters and exchanges must be created.

Guto Nobrega
Photo: Steve Miller

Lately I've been fully committed to education, both research and artistic creation. I teach and advise undergraduate and post-graduate students. I also develop theoretical and practical research on hybridization between living and artificial organisms, an area called biotelematics, which foresees a technology assisted intercommunication between organisms. I am about to release a book resulting from my doctoral thesis based on this subject.

What are your thoughts about the current status of biomimicry/bio-inspired design?

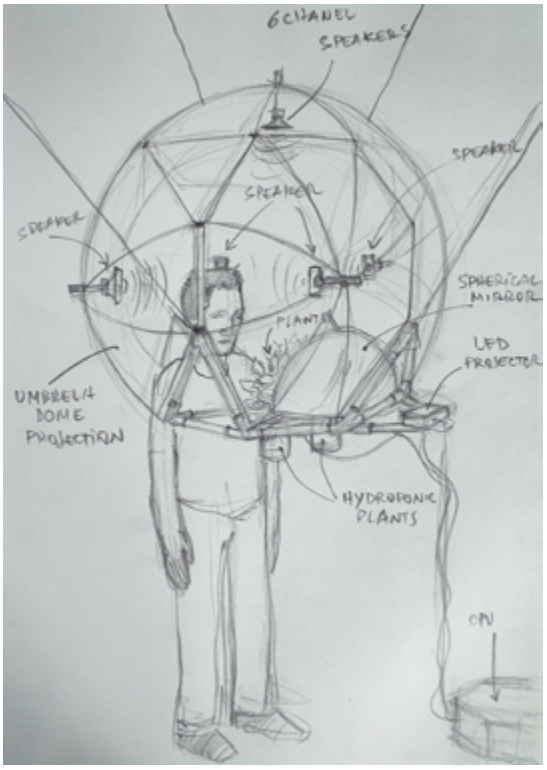
Nature, more precisely the organic aspects of life, was more than only an inspiration for me. It was actually a strategy, a research methodology. I was after a philosophical starting point, a functional model that



Bot_anicSteve by Guto Nobrega | Photo: Steve Miller

Guto Nobrega
Interview by NOUS Ecossistema

would allow Art and the fundamental relationships of its structural basis, the triad: artist - work of art – observer, to be put into perspective. The starting point was considering this model as an organic being. From an organicist, integrative, coherent vision of the living, I was able to think of art as an aesthetic organism. In these terms, I understand "bio-inspired" as a conceptual perspective, rather than a structural/formal one. I believe that every creative process is fundamentally organic because we are natural organisms (maybe here we can ask, for how long...?). Regardless, we can either look at form and function, or we can look deeper and consider logic, the autopoietic sense (based on Maturana's autopoiesis concept) of life. Which means to be alive, being capable of autoregulation, to reproduce autonomously, to be coherent internally and externally with "the whole". These are my inspirations and I believe that it continues to be a challenge to hold a dialogue with nature in this way.



VRS design sketch | https://www.gutonobregart.work/vrs

In your opinion, what are the biggest challenges?

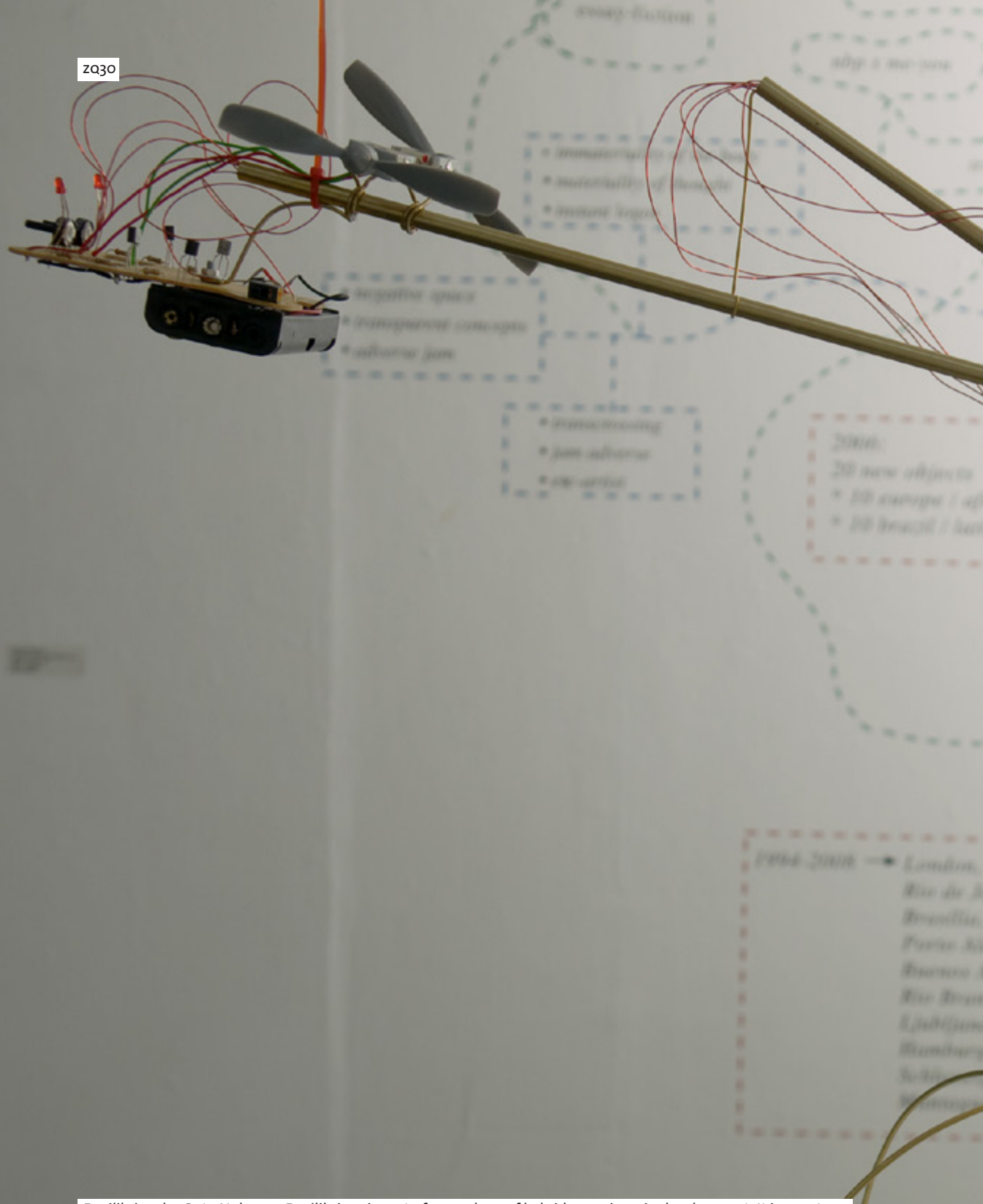
As I said previously, if we look at the internal logic of certain organisms - the natural processes that conduct their existence and co-existence - the biggest challenge will be to understand them beyond our humble capacity to understand reality. What do we really know about life and its mysteries? Science and technology provide us a great advancement in technical abilities and epistemology, but life exceeds the boundaries of what we know and the capability of applying it as a model. A century ago, plants were considered to be organic but different from animals due to their inability to express memory, intelligence or any other activity that depends on the nervous system

as we knew it. Today we have a different perspective. This change is not happening due to our increasing instrumental and investigative arsenal, but because we ask different questions that don't start from the same anthropocentric point of view, that accept the other as a mystery to be revealed, and not as an answer to our questions and desires. What is a plant? What is a rhizomatic network? What does it tell us about plant life, or more importantly, about us as part of this whole ecosystem?

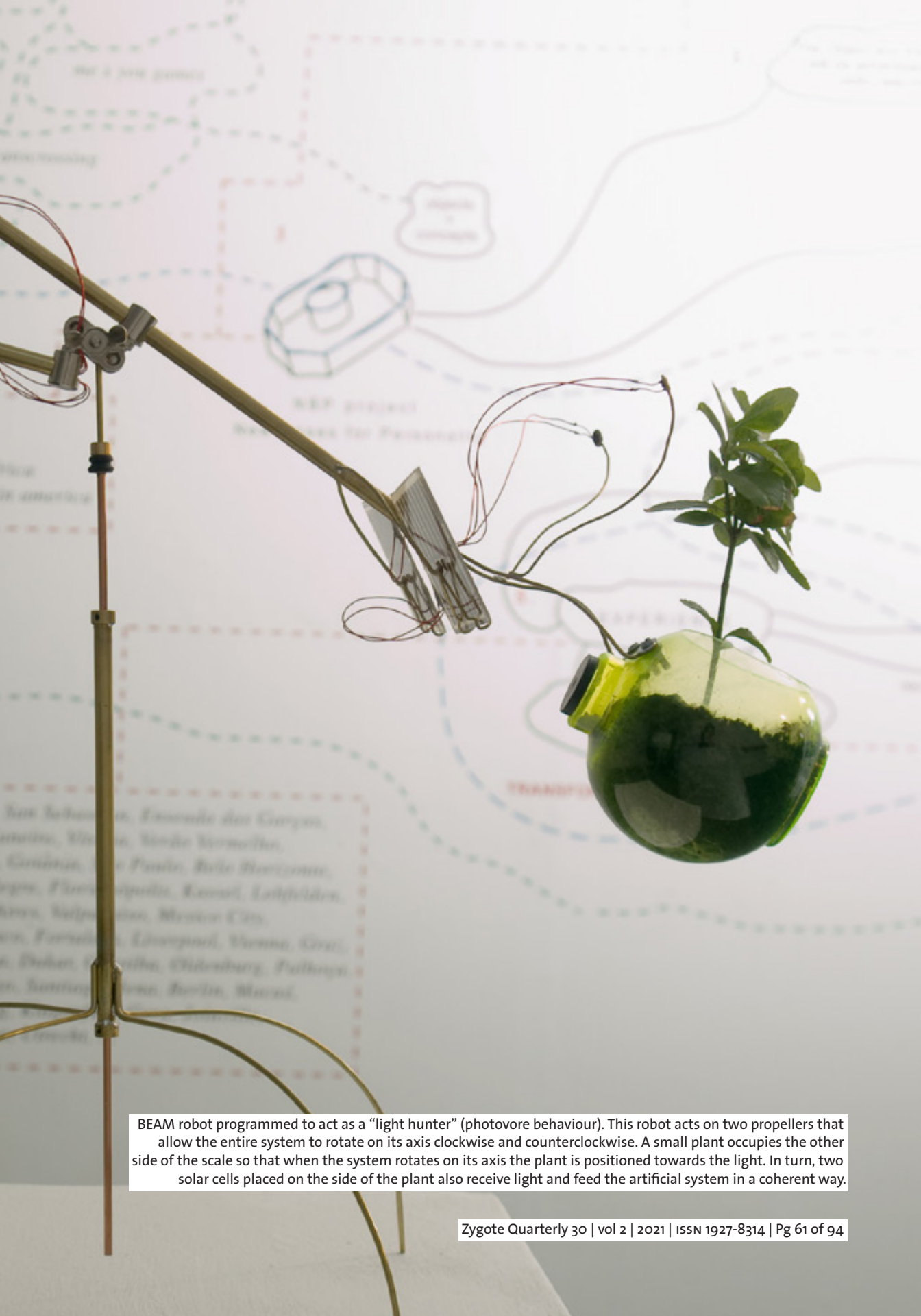
On which areas should we focus to enhance the field of bio-inspired art as a way to raise interest in the natural world?

If one searches for inspiration in nature, it should incorporate each and every form of knowledge, both contemporary and scientific as well as ancestral and mythical, knowledge which comes from local civilizations, native to each place. These are forms of knowledge forgotten with time, waiting to be accessed and applied. They consider the subtle dimensions of life, of the environment. This interests me because, as mentioned before, form and function can be dynamic and behavioral expressions of life, but do not define Life. Life is more than that. We can understand it simply if we consider that at the core of Gestalt's conceptualization of "Form", there's the idea of "diagram of forces". To contemplate the form is to contemplate a diagram of forces in movement. A structure can have a specific and stable shape, but its form is alive and speaks about its own nature. If this diagram of forces is present even in the "dead things", imagine what we might discover in the living ones. This is its metaphysical dimension that I seek to infuse on my artistic creations.

VRS design work | https://www.gutonobregart.work/vrs



Equilibrium by Guto Nobrega: Equilibrium is part of an ecology of hybrid organisms in development. It is a system in which a plant and an artificial mechanism share a mutual relationship. This hybrid system is composed of two small motors, solar cells, microchip, lights, photoelectric sensors and a plant. Every system is organized in the form of a scale whose axis can rotate like a compass. One side of this scale is occupied by the artificial system, a small



BEAM robot programmed to act as a “light hunter” (photovore behaviour). This robot acts on two propellers that allow the entire system to rotate on its axis clockwise and counterclockwise. A small plant occupies the other side of the scale so that when the system rotates on its axis the plant is positioned towards the light. In turn, two solar cells placed on the side of the plant also receive light and feed the artificial system in a coherent way.

Guto Nobrega
Interview by NOUS Ecossistema

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

Everything began with a hypothesis that bringing a live organism into the development of an artistic work would be a way to cross systems and provoke a "short circuit" between two intelligences, one artificial and one natural. It would be something like "hacking" the system, incorporating the natural "noise" of a living being in its logic. In the search for a living being for my artworks, I've found plants and the research about their controversial existence. What can a plant be? A conscious and intelligent being? Why are they apparently static around the whole world? How do they communicate, how do they express their feelings (if any)? Why, for centuries, have plants been connected with human culture, whether in the form of food, medicine or knowledge? My journey into plant technology has started with these questions.

What is your best definition of what we do?

I believe that to be inspired by nature, in its most different forms of existence and solutions to life, is a consequence of the questions that we pose to ourselves. It turns back to itself, in our creativity, our challenges of understanding the magic of our world. When I was still an art student, I was fascinated with Roger Dean's work, an English illustrator who created vinyl covers and futuristic scenography for music

VRS assembly process | https://www.gutonobregart.work/vrs

concerts. My fascination happened when I realized that many of its futuristic propositions were heavily influenced by a thorough observation of nature and its surroundings, especially micro scale, insects, natural hinges/joints, movements, structures that were mostly unseen by the inattentive.
That means we live a future inside our own present and past. It is not about creating something new, but about reconfiguring what already exists, giving a new meaning, creating different natures from this one that was given to us. In order to do that we need to rethink our awareness of the world. Most of the time we live in a fast-paced environment, passing through things and not even realizing they exist. We live in a constant attention deficit hyperactivity for paradoxically having created machines that flood us with images. We went from seeing the world with our own eyes into being blinded and flooded with images of it. This is an old crisis, but it has developed magical dimensions today. How to revert this magic and see things simply in their own time again?

How did you get started as an artist and when did nature become a source of inspiration?

I believe I've already answered these questions. Nature came to me in the form of plants, specifically a Devil's Ivy (in Portuguese *Jiboia*, same name for a constrictor snake). This plant took part in my work as a live organic sensor. From there on, the first hybrids between plant and machine were created. I've developed an electric impulse measuring system to monitor the resistance variation on the plant surface and used these variables to activate the legs of a robotic system. Changes in light, temperature, humidity by principle induce variation in the electric resistance of a leaf's surface, which will inform expressions "of the living" and create a curious relationship between this hybrid system and the observer. I'm referring to "Breathing", my first artwork in this field. It is named as such because after some tests I realized that air exhalation next to the plant triggered an immediate reaction in the system. The work draws upon the action-reaction loop between observer and the hybrid robot-plant. It integrates the observer into the system with the act of breathing. The hybrid is this strange creature which can no longer be defined as a plant or a machine. The creature is a result of the emerging junction of mechanical and vegetal systems.

Breathing by Guto Nobrega | Photo: Miho Hagino
A work based on a hybrid creature made of communication between a living organism and an artificial system. The creature responds to its environment through movement, light and noise. The act of breathing is the best way to interact with

the creature. This work is the result of an investigation into plants as sensitive agents in the creation of art. The intention of this work is to explore new forms of artistic experience through the dialogue between natural and artificial processes.

Guto Nobrega
Interview by NOUS Ecossistema

What initiatives are you working on?

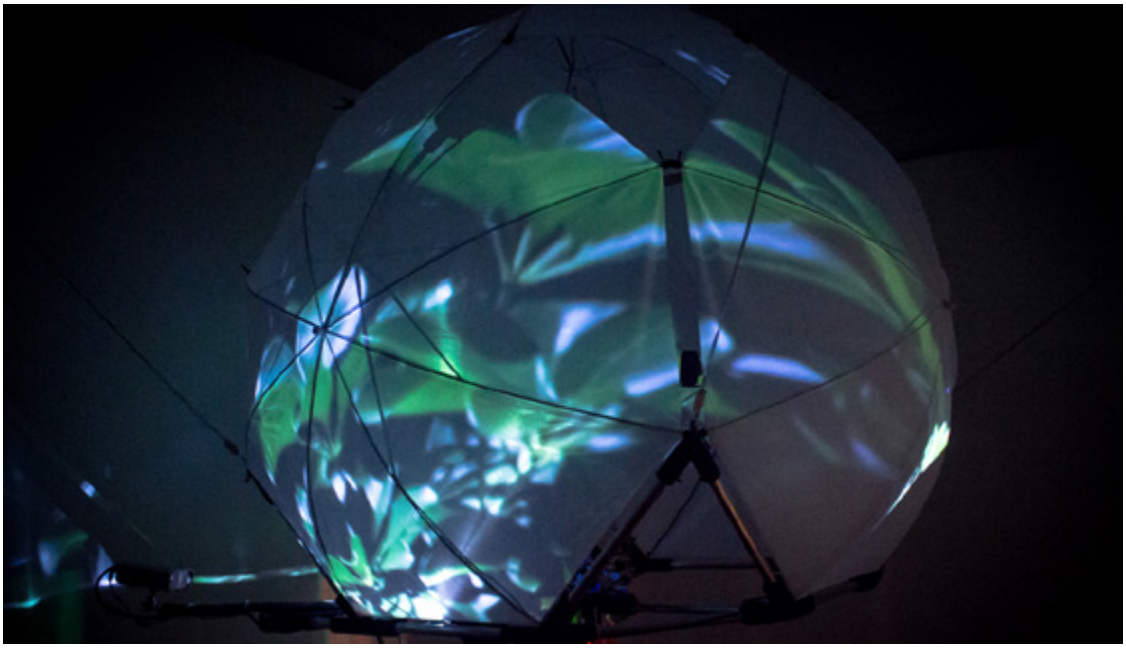
I'm currently working on a project in which I intend to research and capture the sounds emitted by plants. Scientific research on this subject shows that plants emit some audible “clicks”. Its purpose is not yet known, but it is believed to be something related to their awareness of space in relation to the environment. I've been researching planted aquariums as the organic nucleus/core for new hybrid artworks. I like to think of such structures as being like brains for new hybrid creatures.

What are your plans for the future?

To continue my research with plants, broadening this investigation to ancestral botanical knowledge, its mysteries, rituals and its role in the world we live in.

What is your geographical "reach", who is your network of partners?

I have been confined at home for two years already, with occasional national trips to set up my artworks. I've also been presenting my work in Brazil and abroad, whenever I'm invited. Lately the network around



VRS installation view | https://www.gutonobregart.work/vrs

telematics has increased due to the global situation we have been living in. This is actually good. Telematics has always been the flagship of our research at NANO Lab and of our main telematic event "*Hiperorgânicos*" (Hyperorganics). The event happens annually, it interconnects labs and online processes through our data server. Such possibility dematerializes territories and approximates process bringing materiality through data visualization.

Which work/image has recently grabbed your attention?

Kora-Ilysis by the Mexican Gilberto Esparza (https://creacionhibrida.net/proyecto-kora-llysis-arte-ciencia-y-tecnologia-para-crear-conciencia-sobre-la-importancia-de-proteger-a-los-arrecifes-de-coral/). It is an art and technology project that mimics coral reefs. It does so in an attempt to positively interact with the marine ecosystem, in a quest to find creative solutions for the maintenance and nourishment of biodiversity. All of this driven by art.

What is your favorite bio-inspired artwork of all time?

I'm fascinated by some of Festo's robotics, mainly the ones that float.

What is the last book you enjoyed?

In the Swarm: Digital Prospects by Byung-Chul Han

Who do you admire? Why...

All inventors, from the most modest, unknown - the ones that create for the pleasure of the act of discovering and being creative - to the most acknowledged, such as Nicola Tesla.

What is your favorite motto or quotation?

"If you can't explain it to a 6-year-old, you don't understand it yourself" Albert Einstein

What is your idea of perfect happiness?

Work.

If not an artist/researcher, who/what would you be?

Bored... ×

For more of Guto's work please see:
https://www.gutonobregart.work

We would appreciate your feedback on this article:

Hello
Photo: Scott Barlow, 2008 | Flickr cc

Book review

Biomimicry and Business by Margo Farnsworth

Reviewed by Karen Frasier Scott, Manuel Quirós, and Richard MacCowan

Biomimicry and Business by Margo Farnsworth
Reviewed by Karen Frasier Scott, Manuel Quirós, and Richard MacCowan

The Power of Story in Business

Biomimicry and Business: How Companies are Using Nature's Strategies to Succeed begins with the author telling us a story of how biomimicry can be used as a process that can help solve problems that embody the negative side effects of industrialization around the world. She begins her story by reciting her observations on Earth's environmental problems and how biomimicry as a process can lead to the creation of products, processes, policies, and lifestyles that solve design challenges sustainably and in harmony with all life on earth. Storytelling is an effective tool that has been used over the ages to influence, teach, and inspire. It has been used to forge connections between people, history, and ideas. The author uses this tool to convey how businesses have introduced and embraced biomimicry into their businesses to solve problems and provide new growth opportunities.

Intended Audience

The book is intended for businesspeople, entrepreneurs, and business students who are interested in learning about biomimicry but may lack a background in biology. The compilation of business case studies can also provide the general reader an accessible means to understand how businesses have benefited from biomimicry.

The author proposes that biomimicry can create healthy profits while at the same time delivering social and environmental benefits. The book promises not only to inspire businesses to try biomimicry but also to provide practical advice and resources to help businesses implement biomimicry.

How Is Biomimicry Introduced Into Businesses?

The author relates several different ways that biomimicry has been introduced into companies. She illustrates how these companies applied biomimicry at various times in the design process by conforming to the underlying physical, chemical, and biological requirements of the Earth in order to solve specific problems in innovative ways. Biomimicry was also introduced into companies as a suite of tools to make particular products or processes successful. It can guide a design process from a new product's beginnings. at any point in a business' development, or in operations to enhance products already on their way to market. The author illustrates that a company can be introduced to biomimicry through biomimicry "cousins" such as biomimetics, biophilia, bio-utilization, bionics, BioTRIZ, and bio-inspiration. Chapter 3

includes an overview of biomimicry through understanding and following nature's operating conditions and "deep unifying patterns".

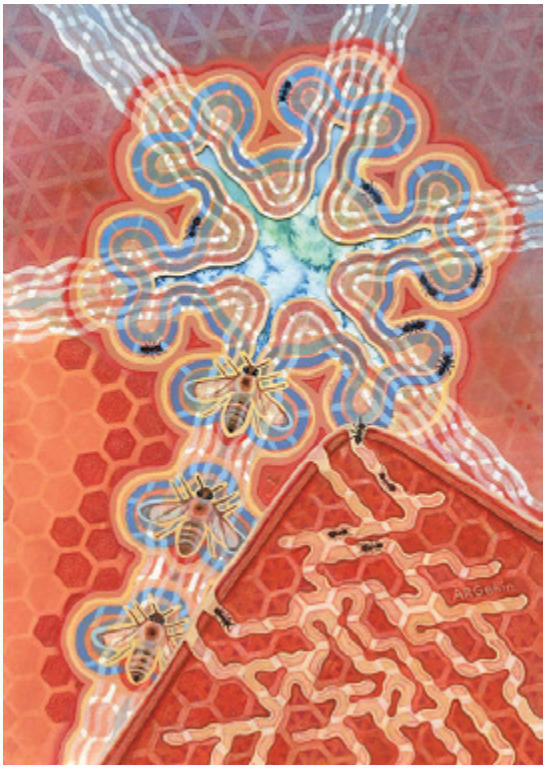
Business Case Studies

The author concludes her storytelling by relating specific examples of how five companies incorporated biomimicry into their company and products. Each chapter ends with a series of "lessons learned."

Nike started on its biomimicry journey with the Goat Tek shoe inspired by goat's hooves that provide traction on rocky outcroppings and smooth inclines. Chapter 2 highlights the work of Darcy Winslow who championed a sustainability framework at Nike that, with the help of Janine Benyus and Dayna Baumeister (co-founders of the Biomimicry Guild), led to innovations such as "green rubber" that not only reduced the toxic chemicals involved in shoe production but also reduced waste, directly affected the bottom line.

Interface wanted to design a carpet tile that would incorporate sustainability to meet the vision of Ray Anderson while increasing profit margins. Natural fibers would be cost prohibitive. To avoid visible seams, the standard approach had been greater uniformity, but that led to increased waste. Applying the principle of diversity led to the Entropy™ carpet tile that camouflaged the seams and could be laid in any direction. Interface is continuing to implement a wide range of sustainability initiatives.

PAX Scientific grew out of Jay Harman's fascination with flows generated by natural geometries, first applied to his Wild Thing boat design and subsequently the "lily impeller" that moves fluids more efficiently by reducing turbulence. The impeller has



Biomimicry and the Bee
Cover artwork: Amanda Gehin ©, 2018

Biomimicry and Business by Margo Farnsworth
Reviewed by Karen Frasier Scott, Manuel Quirós, and Richard MacCowan

been used to mix water in large municipal storage tanks using only 300 watts of power, as well as in other applications requiring fans.

Sharklet developed a micro-structured surface that mimicked the ability of shark skin to avoid fouling by marine organisms. It was initially explored to keep boat hulls clean. The company found Sharklet would also inhibit bacteria from colonizing surfaces, reducing the risk of infections from medical devices such as catheters and endotracheal tubes.

Encycle wanted to help reduce high energy charges driven by peak usage, which might only occur for a short period of time. Instead of relying on expensive, centralized building management systems, they distributed control among multiple devices that coordinated power usage using emergence and swarm theory, even though academics advised them that the science was not mature enough. In addition to reducing customer bills by flattening usage peaks, the controllers allow businesses to participate in municipal demand response management programs. An early version of this chapter was published in *Zygote Quarterly* 22 (https://zqjournal.org/editions/zq22.html p. 108).

Chapter 8 reviews the value of applying biomimicry principles not only for environmental and social benefits, but also to improve economic performance: a positive Triple Bottom Line. Chapter 9 provides guidance on "creating a new language and intentions" and overcoming obstacles, and includes an extensive list of resources. The closing chapter describes the value of "ecological reciprocity."

Perspectives

This book is a compilation of personal interviews with companies well known within the biomimicry community but not necessarily within the business community. Businesses today are under increasing pressure to not only be sustainable economically, but also socially and environmentally. Biomimicry can deliver innovative and potentially disruptive solutions not part of current technology, but more importantly can help businesses explore how they 'fit' into the ecological systems that are critical to our existence.

The book covers only five businesses. Two are multinationals: Nike and Interface have revenue of U$37.4B and U$1.3B. The other three are smaller with estimated revenues of U$0.6M-U$2M. The Entropy/i2 carpet tiles make a significant contribution to

Honey Bee Macro
Photo: Karunakar Rayker, 2010 | Flickr cc

Biomimicry and Business by Margo Farnsworth

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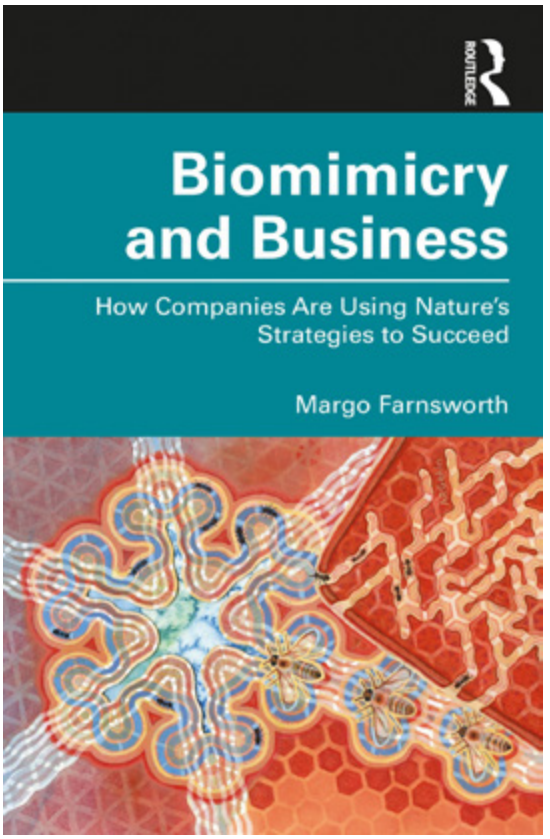
Interface's bottom line. Nike's Goat Tek shoe performed well but sold poorly.

The relationship of biomimicry to business sustainability remains unclear. Innovation inspired by nature is not necessarily sustainable - sustainability needs to be a clear and consistently applied business requirement. For a large business, making sustainability pervasive can require significant changes to business models, the full life cycle from product design through to product disposal, as well as the relationships with partners and supply chains [1]. Nike has made significant improvements [2], but sustainability is an established field of practice, making it difficult to tease out the influence of biomimicry without collecting long-term sustainability metrics such as greenhouse gas emission, resource consumption, waste generation, and increased circularity.



Farnsworth, M. (2020). *Biomimicry and Business: How Companies Are Using Nature's Strategies to Succeed* (1st ed.). Routledge. https://doi.org/10.4324/9781003092605

Biomimicry is a novel approach to explore new solution spaces and can help reconnect us with nature. This optimistic and inspiring book will create awareness and motivate some businesses to consider biomimicry, but getting businesses to practice biomimicry on a broader scale requires a closer look at the questions raised in chapter 1: "How are businesses experiencing success or failure with biomimicry?", "Can the principles of biomimicry be scaled up and if so, how?", and "Where are the speed bumps for adoption and integration of biomimicry into companies?"

It is easy to pick winners after the results are known. Innovation is inherently risky, especially when it crosses domains and the gap between domains is large. We also need to learn from businesses that tried to implement biomimicry but were not successful,

either because they chose the wrong projects, were unable to integrate biomimicry into existing design/business processes, did not implement biomimicry properly, or experienced challenges in completing the design to commercialization process. Additional research on a wider range of companies including a broad range of business metrics (time, resources, research expenditures, the chances of success, and the expected return) will help businesspeople make a rational risk/reward assessment on implementing biomimicry projects. ×

References

1. Nike is launching a guide to sustainability for brands–get it here (https://www.fastcompany.com/90350603/nike-is-launching-a-guide-to-sustainability-for-brands-get-it-here)

2. NIKE: Is it the Sustainability Transformation of the Decade? (https://digital.hbs.edu/platform-rctom/submission/nike-is-it-the-sustainability-transformation-of-the-decade/)

Additional Resources

Confessions of a Radical Industrialist by R. Anderson and R. White

Regenerative Leadership by G. Hutchins & L. Storm

Biomimicry in Organizations by F. Tazzi & C. de Rossi.

What We Learned in the Rainforest: Business Lessons from Nature by T. Kiuchi & B. Shireman

Companies that Mimic Life: Leaders of the Emerging Corporate Renaissance by J. H. Bragdon

Doughnut Economics by K. Raworth

Teeming: How Nature's Oldest Teams Adapt and Thrive by Tamsin Woolley-Barker

We would appreciate your feedback on this article:

Inside the hive | Photo: Rachael Bonoan, 2016 | Flickr cc

Dr. Karen Frasier-Scott who has recently retired was the President of EnviroTech Design. She is a Biomimicry Fellow and a founding member of Biomimicry TX. She taught Biomimicry and Design Workshops in the department of Industrial Design at the University of Houston where she was also the Associate Director of Research Planning and Development in the ID+ Incubator.

Manuel Quirós BSc, MSc, PhD is a passionate nature living conservationist. He guides, as an independent teacher in several universities in Spain, inspiring classes through Sustainability and Biomimicry education as a transformational behavior strategy towards regenerative culture. He is owner of NIU (https://www.natureinspireus.com/), a biomimicry consultancy, and cofounder of Red Internacional Biomimesis (RI3: https://redinternacionalbiomimesis.org/) and Biomimicry Iberia (https://zqjournal.org/editions/zq19.html). He participates as a speaker in many international symposia like ONU-Habitat or COP 25. Contributing editor of *Zygote Quarterly* since 2013.

Richard MacCowan is an award-winning designer with a background in international real estate finance and development, urbanism, and industrial design. He is the founder and biofuturist of Biomimicry Innovation Lab specialising in manufacturing, agriculture, and cities. This has culminated in work across North America, Europe, Africa, and Asia. Richard is also the founder of the non-profit Biomimicry UK, and the CEO of an equine technology startup, Smart Stable Limited. He combines this with extensive research development with international collaborators via the Design Society and the ISO Standards in Biomimetics.

Joshua Tree National Park.
Photo: Jarek Tuszyński, 2009 | Wikimedia Commons

The Science of Seeing

Scientists on the Front Lines

Adelheid Fischer

Scientists on the Front Lines

Adelheid Fischer

Marine biologist Tim Gordon could have decorated the walls of his childhood bedroom with posters of superheroes, star athletes or scenes of Hollywood-movie mayhem. Unlike many of his peers, however, he chose to surround himself with images of candy-colored coral reefs.

So candy color is what Gordon expected to see when he finally got a chance to conduct research on Australia's Great Barrier Reef in 2016. Reality, however, looked nothing like the pictures he remembered. In 2016 (and again in 2017), the Great Barrier Reef, one of the world's seven natural wonders and a UNESCO World Heritage area, experienced widespread coral bleaching caused by warming ocean temperatures. But it wasn't just the absence of color that unnerved Gordon as he surveyed the blanched corals in his study sites. It also was the silence. "A reef should be noisy" with the crunching, chomping, popping and scraping sounds of its numerous residents, he observed in a 2020 *ScienceNews* article. "Instead of documenting nature's wonders, I was documenting its degradation."

"One of the penalties of an ecological education is that one lives alone in a world of wounds," wrote Aldo Leopold in *Sand County Almanac*. Since Leopold penned these words in 1949, the challenges for the ecologically educated—environmental scientists like Gordon—have intensified. Planetary wounding has become more pervasive and egregious as climate change accelerates. And the trauma has deepened for those reporting from the front lines of the war on nature. Many scientists now spend their careers cataloguing its casualties in real time—with no end in sight.

But they are no longer suffering alone and in silence. Gordon, for example, teamed up with fellow scientists Andrew Radford and Stephen Simpson to daylight the emotional toll of their work in a 2019 issue of the prestigious journal *Science*. Their letter—"Grieving Environmental Scientists Need Support"—hit a nerve. Dozens of scientists responded with gratitude, praising the trio for their "emotional honesty."

The letter argues that biologists face unique challenges when it comes to environmental degradation. Science professionals, for example, are expected to check their emotions before entering the field lest they compromise the objectivity of their data collection and bias the results. But this "pervasive illusion that scientists must be dispassionate observers," they posit, "is dangerously misguided." Researchers often develop a deep bond with their study organisms. When they sicken or die, the loss is as deeply felt as that of a loved one. The

Roots 12 and fungi on vellum | Juniper Harrower

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Adelheid Fischer

Jtree forest on handmade paper.
Juniper Harrower

expectation of detachment only compounds the work-related stress.

But even when ecogrief is acknowledged, there are "few opportunities to address this grief professionally," they say, unlike "other professions in which distressing circumstances are commonplace, such as health care, disaster relief, law enforcement, and the military. In these fields, well-defined organizational structures and active strategies exist for employees to anticipate and manage their emotional distress."

That often leaves scientists to their own devices when it comes to navigating the trauma of climate change. Their stories can be heartbreaking. For some, however, the journey through ecogrief has also led to heartening breakthroughs. Juniper Harrower is one of them. A desert ecologist and director of the Art+Science Initiative at the University of California, Santa Cruz, her work exemplifies the emotional challenges faced by environmental scientists—and the ingenuity of their responses.

I first encountered Harrower's work in fall 2020 when I spent a month as an artist in residence at Joshua Tree National Park. Ever since camping out in a "forest" of Joshua trees several years before, I dreamed of spending long, uninterrupted hours once again in their company. These quirky yuccas with their shaggy arms akimbo

Joshua Tree at night | Photo: InceptedNoggin, 2017 | Wikimedia Commons

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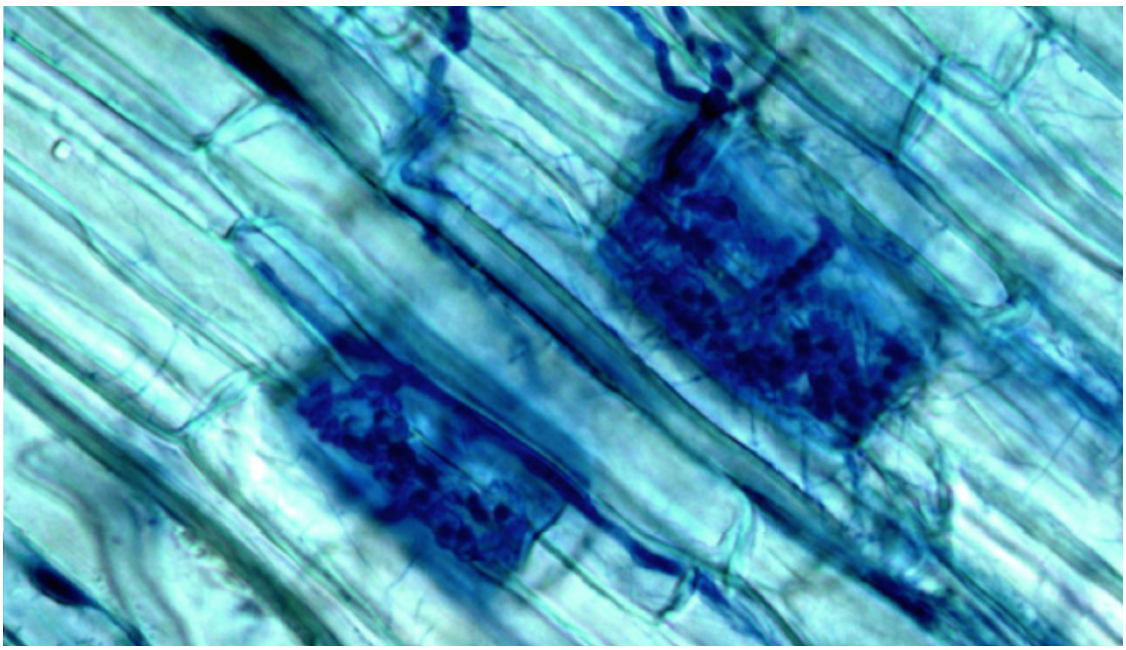
against the turquoise desert sky reminded me of exuberant Sufi dancers. Like the tall saguaros in my own Sonoran Desert, they seemed to have a kind of sentience. The opportunity to live for an extended period of time among them in their namesake park was, well, a dream come true.

Harrower had been part of the previous year's cohort of resident artists and her focus on Joshua trees caught my attention. Even more intriguing was this: her work as an artist drew on her research as a scientist.

As a doctoral student in biology at UC-Santa Cruz in 2015, Harrower encountered reports warning that warming global temperatures could compromise the long-term survival of Joshua trees in the park. Within less than a century, the science predicted that viable Joshua tree habitat would shrink to a mere two percent of its current range. The news hit home—literally—since she grew up just outside the park boundary. "That area of the desert and the Joshua trees specifically," she recalls in an interview, "played such a big part in forming my identity as a person that the climate threats felt like a personal attack."

So Harrower decided to focus her Ph.D. research on developing a more fine-grained understanding of the impact of climate



Mycorrhizal fungi in Joshua tree roots.
Photo: Juniper Harrower, 2018.

change on the relationships between Joshua trees and their critical partners, chief among them the yucca moth (*Tegeticula antithetica*). Joshua trees rely on these minuscule insects for pollination. The moths, in turn, depend on the trees' fruits and seeds as food and nurseries for their young, a relationship of mutually assured survival that has endured for millions of years. She also sampled the soil in which the plants grew, becoming the first to identify the 36 species of beneficial mycorrhizal fungi that live in association with the roots of Joshua trees. These mycorrhizae scavenge moisture and nutrients from the soil in exchange for photosynthetic sugars from the trees, helping the plants grow faster, stronger and more resistant to pathogens.

Harrower surveyed Joshua trees and their partners in three regions of the park: low, mid and high elevations. Her data revealed that both Joshua trees and their symbiotic moth partners flourished only within a narrow band of mid-elevation habitat. But under climate-change scenarios, these now-prime habitats are expected to become too hot and dry for the plants, forcing them to migrate to cooler, moister reaches in the park's higher elevations. The long-term survival of Joshua trees in these upper zones, however, depends on the ability of their pollinating moths to journey alongside them, an unlikely scenario since the tiny, peppercorn-sized insects are poor fliers.

To further complicate matters, Harrower's research showed that the makeup of the mycorrhizal communities also varied by elevation. The fungal networks in the mid-elevation habitats, like the pollinating moths, would require transplantation to higher ground. Harrower's prognosis was bleak: without human intervention the ancient relationship between Joshua trees and their symbiotic partners could be severed, causing these iconic plants to become extinct in the park within 100 years. But even with assisted migration to higher ground, questions remained: Would the linked trio of trees, moths and mycorrhizae be able to adapt to their new circumstances?

Harrower's grief over the uncertain future of Joshua trees was intensified by the fact that she was pregnant and gave birth to her first child, Jack, midway through her fieldwork. Riding in a backpack, he often accompanied her on research forays. One day as she and Jack stood in a study plot, Harrower suddenly realized: "Here I am collecting all this data, and I've got this brand-new little baby with me. Within a 100 years all the trees could be gone from this place where I'm working, and that's just

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basically his lifetime. I'll be gone by then, but what's it going to look like at the end of my son's life? It just felt so heavy and sad and overwhelming," she recalls.

Desperate to process the emotional implications of her scientific discoveries, Harrower received permission from her dissertation committee to expand the traditional deliverables of her science Ph.D. to include a suite of multimedia art projects. She began by painting a series of richly imagined scenes from the desert's subterranean realm, in which the mesh of plant roots threaded with their fungal partners were rendered in sumptuous brocades of earth-toned hues. Embedded in this rhapsodic beauty were both menace—and hope. Portions of the canvas, for example, were slashed and then stitched together with needles harvested from the leaf tips of actual Joshua trees.

Hey JTree project.
Juniper Harrower | https://www.heyjtree.com

In addition to the paintings, Harrower created an online "dating" site called *Hey JTree*. Mimicking the human marketplace of romance, it features compelling profiles of individual plants created by writers and musicians along with GPS coordinates and a list of pertinent scientific data. The goal of *Hey JTree* was to create a platform that would help the public "fall in love" with individual Joshua trees and thereby become more proactive about supporting climate-change solutions.

Among the most resonant in Harrower's suite of creative deliverables, however, was her stop-motion animation, *A Joshua Tree Love Story*. In it Harrower as a young scientist with her long black curls stuffed into a cap trudges through the desert carrying her infant in a backpack. The animation chronicles the various stages of Harrower's field work while Baby Jack, against the soundtrack of his actual giggles, explores the desert floor with her bug net. In other scenes, they lie side by side deep in sleep under the stars. At the close of the animation, Harrower digs up Joshua tree seedlings and directs Jack's attention to the

Stills from *A Joshua Tree Love Story*

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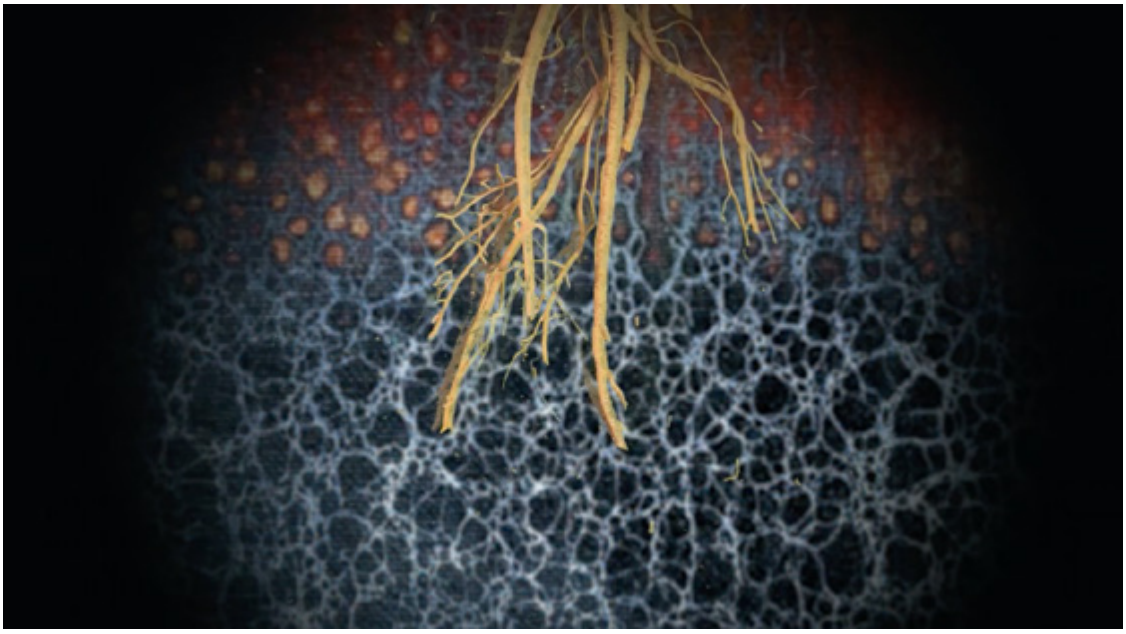
mountains on the horizon where they will be replanted. Skipping forward nine decades in time, the film concludes with Jack, now an old man with white hair and beard, climbing the mountain that his mother pointed out to him as a baby. Along the way, he ponders an old photograph of himself as an infant in his mother's backpack. Then he breaks into a smile as the scene opens up to reveal that Jack is surrounded by desert tortoises and birds. Beside him too are yucca moths and blooming Joshua trees, evidence that the assisted migration of Joshua trees to higher elevations was successful.

Harrower has screened the animation, exhibited her paintings and lectured widely on her scientific research, winning national media attention from such outlets as *National Geographic*. But raising awareness of the plight of Joshua trees has done more than warm hearts and fire up the resolve of desert lovers. The Center for Biological Diversity cited some of her research in its recent petition for legal protection of Joshua trees under the California Endangered Species Act. On September 22, 2020, the California Fish and Game Commission agreed to temporary protections for the plant pending the outcome of a yearlong

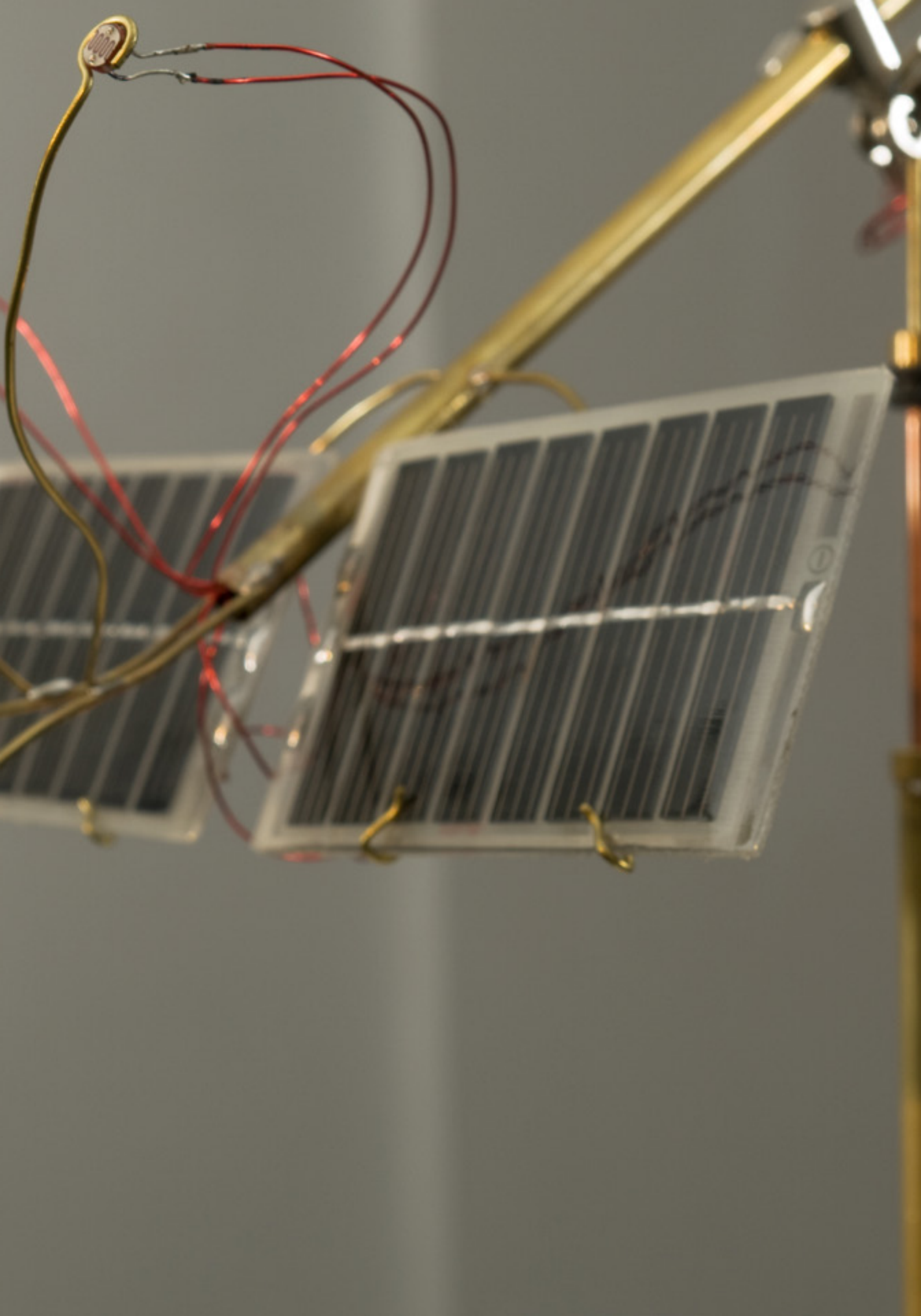


A Joshua Tree Love Story (https://www.youtube.com/watch?v=6elejGlqsuA).
Stop motion animation short by SymbioArtlab and Juniper Harrower

review of the latest science. If the ruling becomes permanent, Joshua trees will become the first species in the state to be protected due to climate threats.

Harrower is gratified that her research has contributed to efforts that will help Joshua trees persist on the landscape for the next generation of desert lovers. Her success, however, is as much due to her work as an artist as it is an environmental scientist. Completing a science Ph.D. is a stressful undertaking. “Everybody gets burned out at some point,” she observes. But today’s environmental scientists must cope with the added challenge of ecogrief. Innovative educational projects, like Harrower’s melding of art and science, could offer new models for helping students to manage their emotions while engaged in the rigors of field research. “If I hadn’t been able to incorporate the art part, I might have just left grad school. But having the art component really saved me,” Harrower reflects. “It gave me a way to humanize all the science.” ×

Still 'moth pollination' from *A Joshua Tree Love Story* (https://www.youtube.com/watch?v=6elejGlqsuA).
Stop motion animation short by SymbioArtlab and Juniper Harrower



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