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Editorial

Our current issue travels the scales from the very small to the very large. Inside you will find stories of painstaking scientific research and of courageous proposals to solve our largest societal issues. No one had better epitomized this facility of thinking across scales (and communicating it to the rest of us) than E.O. Wilson, renowned biologist and author.

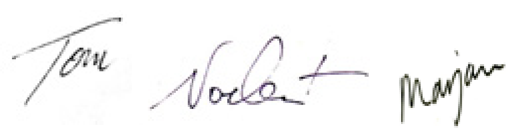
This issue, therefore, includes a special supplement about Dr. Wilson, including an introduction to the man and one of his public projects, the Encyclopedia of Life. You can also read a transcript (and link to the original recording) of a 2010 interview with Wilson by Ari Daniel Shapiro, and personal insights into the work of two young scientists who have been inspired by Wilson, Adrian Smith and Clint Penick. Both were fellow graduate students at Arizona State University, who now continue Wilson's legacy of bringing the results of rigorous science to general audiences. Clint will tell us how he became an ant barber in his zeal to understand the natural world, and Adrian will tell us how he brings the everyday wonders of leaping cockroaches, tumbling springtails and intriguing ants to the public.

In a similar vein, we hear from Dennis Dollens in an interview with ZQ. He is an architectural theorist who has spent many years studying the morphology of plant structures and developing ontologies of building strategies from these observations. He makes the case for the potential benefits of using so-called metabolic architecture to evolve our built world into a more adaptive and resilient infrastructure.

We offer two book reviews this time; both are focused on the impending peril to planetary life, but emerge from very different perspectives. Sarah Ichioka and Michael Pawlyn's book, *Flourish*, is a call for changing the dominant design paradigms held by all of us who determine our built world. *A Natural History of the Future* by Rob Dunn, is organized by what the author believes are the important laws of nature that will likely determine the fate of our species. These laws, according to the author, could serve as guides for our collective and corrective human behavior.

Finally, Rolf Müller, renowned expert on the morphology and behavior of bats, relates the great potential of applying his deep research to the field of autonomous robotics. He describes the incredible sensing and navigational capabilities of this highly successful family of animals (making up one-fifth of all mammal species) and how emulating their skills could speed the employment of robots in the complex and unpredictable outdoor environment.

Throughout, this issue illustrates the importance of rigorous and steady scientific research to our larger societal challenges, to design innovation and to the enrichment of our cultural community. Happy reading! ×



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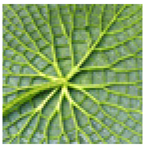

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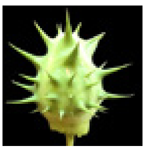

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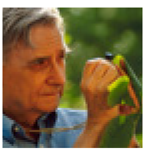

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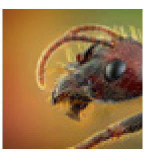

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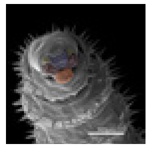

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Giant Lily Pads
Photo: Michael Levine-Clark, 2020 | Flickr cc

Book review

Flourish: Design Paradigms for Our Planetary Emergency by Sarah Ichioka and Michael Pawlyn

Reviewed by Tom McKeag

Flourish: Design Paradigms for Our Planetary Emergency

Reviewed by Tom McKeag

My friend Michael Pawlyn and his colleague Sarah Ichioka have given us a thoughtful, well-informed and well-written book that proposes a cultural transformation in the way we think about our built environment. "We", according to the authors, means just about all of us, involved in one way or another with shaping the spaces in which we live. They propose five paradigm shifts to support this transformation and have organized their book chapters accordingly, discussing: "possibilism", uncertainty and maximizing agency; co-evolution as nature, stewardship and living systems; a longer "now" and an expanded view of time; "symbiogenesis", mutualism, citizen activism and public luxury; planetary health, addressing growth and finding a new lode star for economies.

This book was prompted by their alarm over the state of the world's environment, coalesced in the reading of the 2021 IPCC report, *Climate Change 2021: The Physical Science Basis*. Their perception is that solutions and management schemes being practiced currently have been insufficient. The book's main thesis is that only a radical shift in thinking and subsequent action by individual designers will resolve the existential threat of climate change; each person acting within his own sphere of agency. In particular they echo William McDonough in disparaging the acceptance of built projects that are merely "less bad". The regenerative approach, therefore, is a significant element in their prescription, as is biomimicry, and systems thinking. This book seeks to change hearts and minds, because "...the obstacles to a regenerative future are not technological or financial; they are social and political".

The authors have assembled an impressive array of sources and curated these sources to fit their newly bundled set of principles. Throughout they have given clear and helpful provenance to each of these ideas and have explained how they fit into the book's narrative. Moreover, they include some excellent case study references and carry the reader forward to consideration of each of the chapter memes. Readers can expect many lists of often newly coined terms produced by what seems to be a modest cottage industry of sustainability "thought leaders". Thankfully, the authors provide a very useful summary of the book's key concepts in their concluding chapter.

The authors do a good job of laying out what they perceive as the fundamental and underlying sources of some of our greatest global problems, climate change, destruction of the natural world, overconsumption and anti-social competition. They also provide some excellent models of alternative behavior and projects and give


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full credit to those who have led the way towards new ways of thinking and acting.

It may have been beyond the scope of the authors' intentions, but what I did not read within these pages was a finer grain and studied analysis of the drivers of current problem-creating behavior, either individual or collective; how they came to be, and how we might change these fundamental drivers.

This absence leaves words like capitalism, colonialism and "extractivism" as black monoliths, mysterious evils that should somehow be replaced with better ideas. Changing the paradigm is important, and citing successful alternate models good, but knowing how to manipulate these social/ political/ material mechanisms, looking under the hood (OK Michael, "bonnet") as it were, is going to be key, not only to implementing big ideas, but to convincing people to try them in the first place. The authors rightly mention how cities across the globe are in the forefront of many of the innovative ideas to address climate change, citing Singapore, for instance. In my opinion, this is because just such street-wise analysis is being done everyday within a manageable scale (perhaps the ancient Greek city-state design parameters were right after all).

There is a danger, in a book where many divergent ideas are selectively bundled around the authors' themes, of confusion about the extent of the authors' endorsement and the bounds of their own message. For example, do the authors themselves believe, as the quoted Glenn Albrecht does, that "...the whole capitalist development paradigm... is at the dark heart of maldevelopment – that which undermines and destroys the very foundation of all life on earth."? It was difficult for me to know while traversing the converging corners of their various quoted sources.

Similarly, in such advocacy of change, there is a slight tendency to favor the newly defined and named over what has gone before. In quoting Freya Mathew's ideas on an philosophical extension of biomimicry as a design motive, the book offers some new terms, but from my reading I could not help recalling the basic political principles of Hobbes and Locke, 18th century "thought leaders" who were fully ensconced in the previously disparaged Classical/Christian/ Cartesian world.

On a more personal level, I thought some omissions of historical antecedents significant. As a previously registered landscape architect, town planner and student of both Ian McHarg and Luna B. Leopold, I did take exception to the short shrift given the foundational work done in environmental planning. This preceded by decades the relatively aspirational ecological performance

Giant Lilypad | Photo: Jürgen Priebe, 2008 | Flickr cc

Flourish: Design Paradigms for Our Planetary Emergency
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criteria concepts cited. I thought the book could also have included a wider selection of initiatives, such as the UN Environmental Programme, Cities as Sustainable Ecosystems (CASE), built upon the work of Boyden and Celecia, for example, in the early 1980s, or the UN University Institute of Advance Studies, *Defining an Ecosystem Approach to Urban Management and Policy Development*.

As even-handed as this book is, and the authors are to be commended for avoiding a moralizing tone in any of it, I would have liked to have seen more acknowledgment of some of the more obvious limitations of some of these concepts. Vernacular architecture, cited here, is an example. It has been the darling of academic architects for some time, and there is much to be learned from the methods and materials used, whether a Dogon village or Inuit igloo. It is my opinion, however, that the really clever people were the ones who built their shelters in pre-industrial conditions, not the wealthy post-industrial professionals who copied them for show pieces. The combining of traditional wisdom and modern expertise is to be applauded, but I would be more willing to see them as solutions if these typically one-off projects could be replicated at various locales and brought to scale.

So, how does one accomplish a cultural transformation for the good of the planet and its inhabitants? The model here seems to be acts of individual agency from persons of like mind, organically aggregated into large scale change (ala Paul Hawken's *Blessed Unrest*). I will leave it to the reader to judge how effective this model might be at achieving lasting change within our evolving geopolitical and geocultural environment...and he or she will have to do it without any help from the authors: they nearly completely skirt any discussion of organized political or social movements. This is particularly curious given their belief that it is cultural/political change, not technological, that will be key to solving our current crisis. This would make an excellent follow-up book, in my opinion.

If the authors' goal was to illicit three things from their readers: "consider these facts", "agree on some shared principles", and "translate to your individual agency within your particular sphere of influence", then they have succeeded completely on the first count with me, with mixed success on the other two. Perhaps that is the best you can hope for from any one reader, but they have sparked, at least in me, an active reading of what they offer thoughtfully and a consideration of many new perspectives on how we assume our world ought to be. This is an important and thought-provoking book with much to share and discuss on our collective road to the future. As the authors urge, we all have a part to play. ×

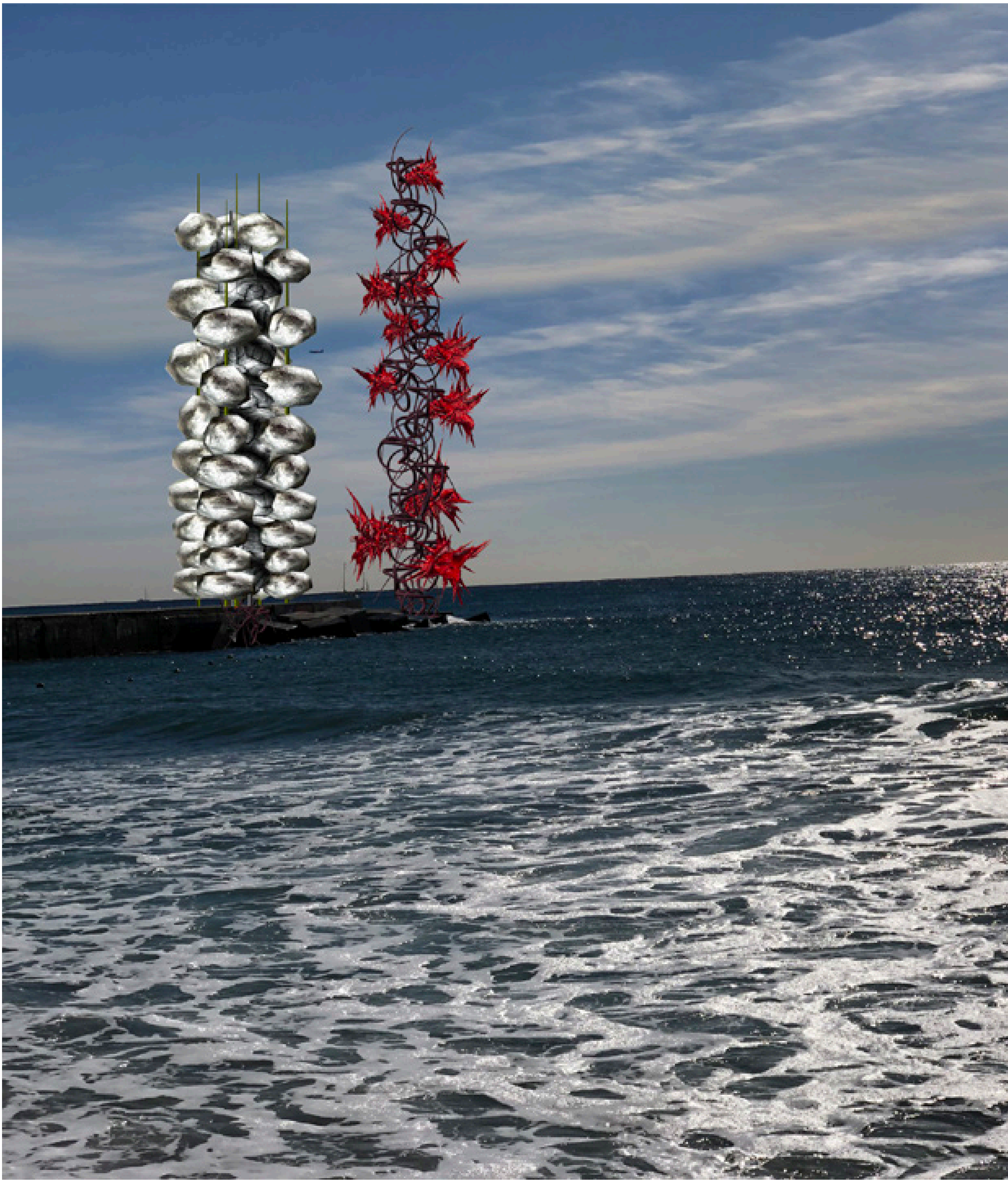
For more: https://www.flourish-book.com

About the authors

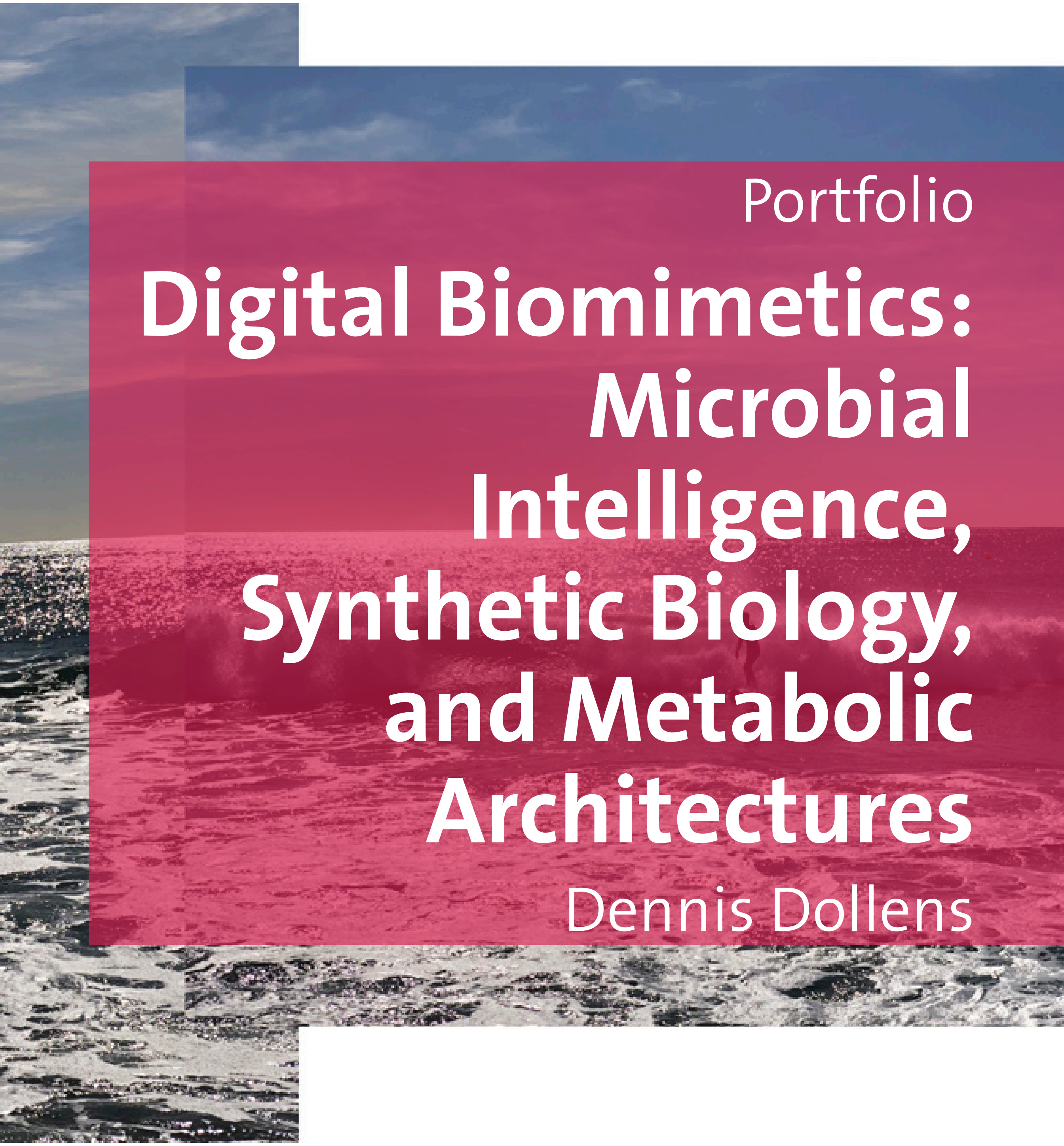
Sarah Ichioka is a strategist, urbanist, curator, writer, and the founding director of Desire Lines, a consultancy for environmental, cultural, and social-impact organizations and initiatives. In previous roles, she has explored the intersections of cities, society and ecology within leading international institutions of culture, policy and research. Sarah has been recognized as a World Cities Summit Young Leader, one of the Global Public Interest Design 100, a British Council / Clore Duffield Cultural Leadership International Fellow, and an Honorary Fellow of the Royal Institute of British Architects. Raised in California, and currently based in Singapore, she holds degrees from Yale University and the London School of Economics & Political Science. www.sarahichioka.com

Michael Pawlyn is the founder of the firm Exploration Architecture and a pioneering architect in regenerative design. His first book Biomimicry in Architecture was, for four years in a row, its publisher's best-selling title, with an updated and expanded second edition published in 2016. He delivers frequent keynotes on innovation and his TED talk has had over 2 million viewings. He has also been profiled in the Financial Times and Wired, and his projects have been featured in The Economist, The Guardian and National Geographic. In 2019, Pawlyn co-initiated Architects Declare / Construction Declares (AD/CD) — a global call to action to declare a climate and biodiversity emergency, which has since launched in 27 countries and is supported by over 6,000 companies. http://exploration-architecture.com/

We would appreciate your feedback on this article:



feroxTowers. Ongoing. Barcelona. Carbon-capture machines lofted by eTree masts and housed in over-scaled *Datura ferox* fairings for maximum surface (intake) area.



Portfolio

Digital Biomimetics: Microbial Intelligence, Synthetic Biology, and Metabolic Architectures

Dennis Dollens

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What's your favorite motto or quotation?

"Never take the 'I shan't see it' attitude. By exercising a little vision you will come to realize that the tree, which has a possible future, perhaps a great one, may be more important than yourself." Christopher Lloyd, *The Adventurous Gardener*.

Could you tell us about how you are inspired by nature? What kind of techniques do you use for your work? And, what are you working on right now?

Proposing that nature is pervasive and that metabolic architectures are embedded in nature, I situate texts and theory as responses to techniques/methods for operational and research procedures. This text is thus a companion to my ongoing Metabolic Architectures campaign for

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thinking about, theorizing, and designing digital-biomimetic structures dialectically related to biology, technology, intelligence, and environmental bioremediation. In that categorization, theory is integral to the tasks of defining and evolving generative metabolic architectures and urbanisms as equal to the project's drawings and models.

I started by building analog branching systems with plant and tree limbs — sometimes skinning their sculptural forms with environmentally strong, handmade yucca paper (Fig 1). This was in the early 2000s. My intention was not to create structural efficiency, but to evolve expressive branching that fused, bonded, and distributed force to create tension/compression, treelike scaffoldings hosting performative surfaces. I drew those structures in Rhinoceros 3D (Rhino) thinking that once structural systems were rooted in digital space, plant algorithms, and living infrastructures, facade panels could be designed and prototyped as bioarchitectural case studies.

In return, early works started reconfiguring my thinking about triangulated (truss) systems as irregular, curving and branching units — what I called eTrees (Fig 2). This motivated the transformation of post-and-lintel, load-bearing construction into biomimetically inspired components, based on interwoven vines or intermingled tree branches. And, although far from living, the models took on properties of skeletal organisms with environmental resilience — modules intended to partner with and sequester intelligent organisms capable of autonomous, bioremedial functions. Those trusslike models can be seen as steps toward computational and STL-fabricated eTrees plotted as material and structural concepts.

Drawing, modeling, and scanning thereafter opened as pathways for generative architectures envisioned for machine fabrication and AI-regulated support systems nurturing onboard microbial or plant life. The resulting artificial/real disjunctions inherent in all bioTowers (Figs 3, 4) finds precedents relative to human/nature dichotomies and biomimetic design feats existing in our colonization of inhospitable sites in the Arctic/Antarctic, interstellar capsules, submarines, and in polluted cities. These habitats evidence a line of design sometimes relevant to extreme climate change, contributing lessons for the development of bioremedial housing and offices. Furthermore, design data technologically supports biomimetics for remediating urban structures based on feedback from worsening heat waves, forest fires, tsunamis,

Fig 1. Yucca Paper Canopies installed at the Santa Fe Art Institute. 2001. Abstract trusses (reconfigured tumbleweed, *Salsola kali*, branches) supported by membranes of handmade *Yucca glauca* paper stabilize and strengthen strut-skeletal construction. The canopies are physical templates for the panels evolved as the Almond Monocoques (Fig 7) and later in the interlocking facade panels of the L.A. Tower (Fig 9)..

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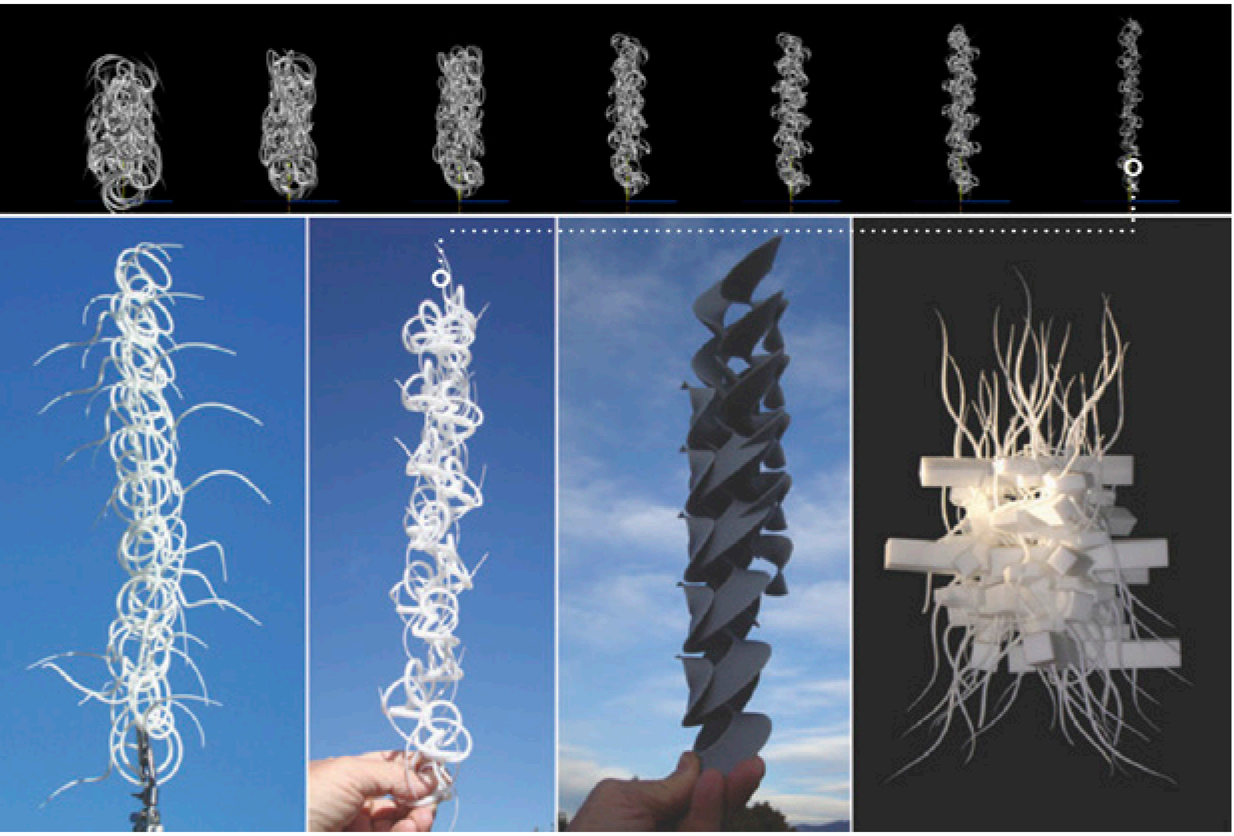
Fig 2. eTree and STL Prototypes. Branch and tendril development evolved as multi-directional, flexing structural trusses whose tree trunks are sometimes phased out — ghosted. The branches sprout secondary algorithmic simulations based in mathematics of flowers, leaves, tendrils, and pods.

Fig 3. bioTower Frieze. Ten bioTowers generated from eTree algorithms depicted as design propositions involving biomimetic extrapolations for building facades capable of biorobotic, AI, and/or microbial/plant intelligence.



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hurricanes, pollution, food scarcity, and political instability. Such dystopic events linked to weather shifts are verified by the U.N. as increasingly frequent and destructive in each of its six IPCC[1] assessment reports — including the March 2022 report on the intensifying climate chaos and failing governmental legislation.

Investigating plant morphology for bioresponsive, metabolic data includes examining phyllotaxy and allometry in branching and leafing, along with research probing existential strategies of plants. Specifically, for early works, this takes in the flight paths generated by double- and mono-winged seedpods. (I will return to this below.) One tree species I studied, *Tipuana tipu*, convinced me to survey botanic flowering and reproduction because of their unique displays of structure and functions. From then on, encountering how nature provisions its myriad plant/seed forms with myriad types of movement and self-defense, I concentrated on morphology and ways it contributed to seedpod fortification I could redeploy for architectural and aesthetic variations in Rhino.

With the spiked *Datura ferox* pods, scanning electron micrographs (Fig 5) revealed one of nature's differing methods of botanic fabrication as executed by cellular growth. Under scrutiny, the *ferox* pods divulge defensive spike properties structurally grown differently from the pod's shell-like body they sprout from — an example of dissimilarities in physiology expressed though genetic variation. Moreover, the spikes are formulated and morphologically determined to resist multidirectional tension and compression while the spherical or ovoid podshells resist exterior, inward directed, compressive forces. In this way, CAT scans and SEM images, along with direct observation, revealed biological development in one of nature's most common typologies — seeds — as they supply data and insight into phase-changes, spatial partitions, and differing material operations.

The pairing of eye-to-hand observation with advanced technology resonated for

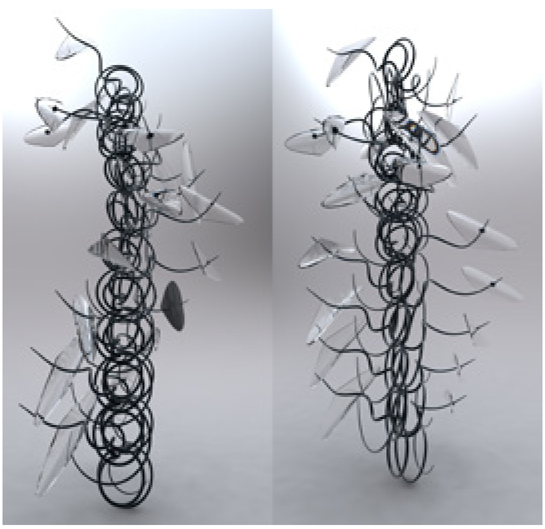

Fig 4. 2008-Ongoing. Algorithmically generated glass leaves digitally sprouted from eTree simulations (Fig 2, STL truss #6) in a study for populating and surfacing branch structures with scalelike, glass panels. (See Figs 14, 15 for recent eTree evolution).

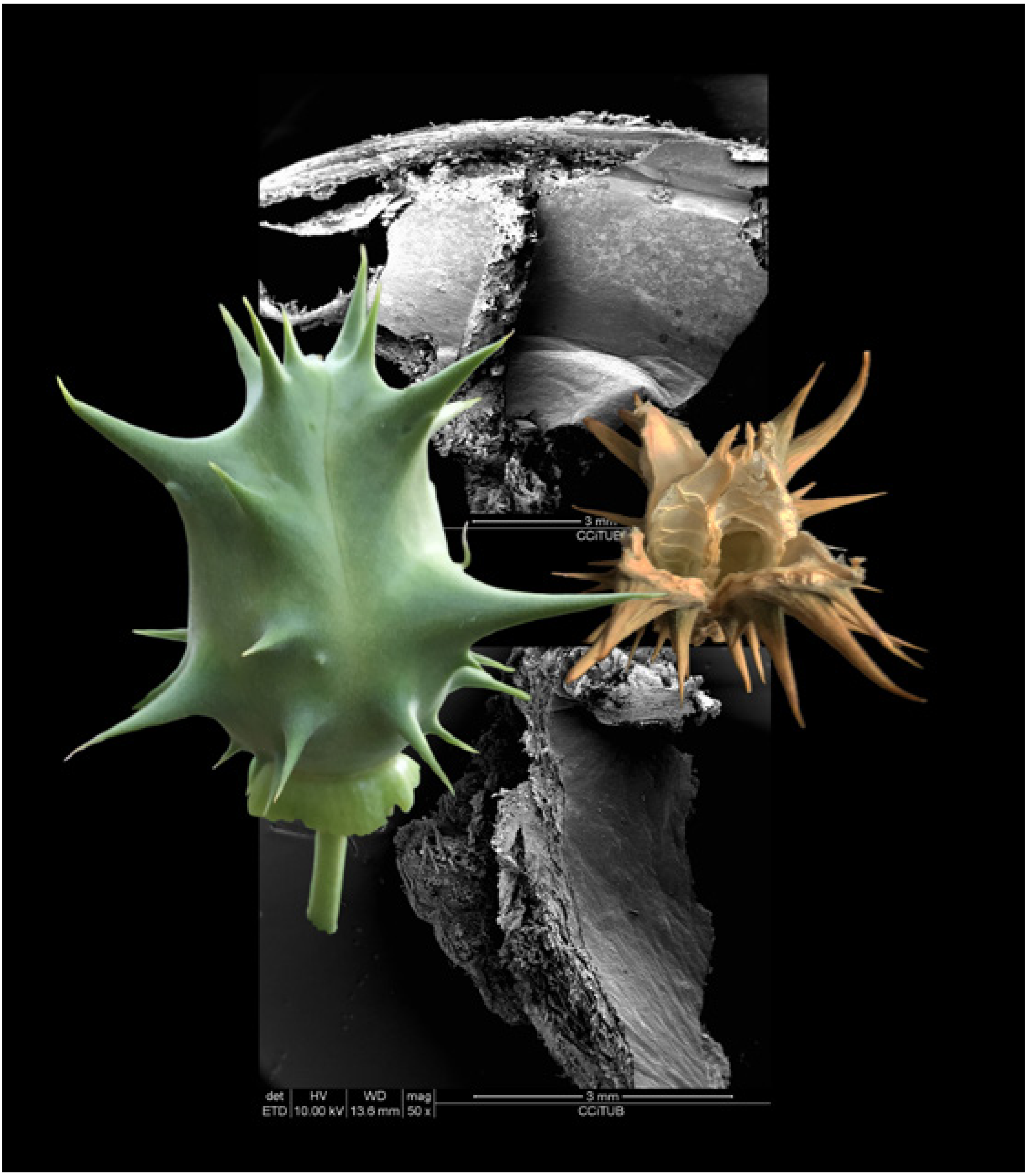

Fig 5. Botanic Print #4. *Datura ferox*. This print illustrates a maturing *ferox* seedpod in front of two scanning electron microscope sections of its interior walls. The SEM images are scanned from sections of a dried seed-pod to the right and reveal details of the pod's interior and exterior material composition, e.g., the plate-like laminations seen in the broken edge in the lower *ferox* image. SEM Images: Estévez/Dollens, 2016.

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me, enabling the construction of dialectic designs and textworks integrating Marx's critique into my 2020 paper "An EcoMarxist Cast: Biointelligent Architectures."[2] That paper considers metabolic rift and human labor updated through autopoiesis and Foster et al's analysis of Marx's concepts found in *The Ecological Rift*.[3] By acknowledging theoretical and philosophical stances, I reassert design labor as a force of nature helping to combat climate change with nature's matter/intelligences in concert with tools evolved by humans.

How the global environmental crisis then begets a revolutionary design force is not yet clear. Nevertheless, I see a need for aligning social, political, and ecological systems vis-à-vis long term climate mitigation. That alignment of architecture/design with nature supports the introduction of organic agents tasked with, for instance, ocean detox or massive reforestation — including urban forestry — spun out to nurture communities, buildings, and jobs tasked to break-down fossil-fuel capitalism.

The above schematic couples metabolic rift with ecological rift — I use both to theorize metabolic design. Metabolic design embraces living organisms as mitigants that reduce airborne, soilborne, and waterborne

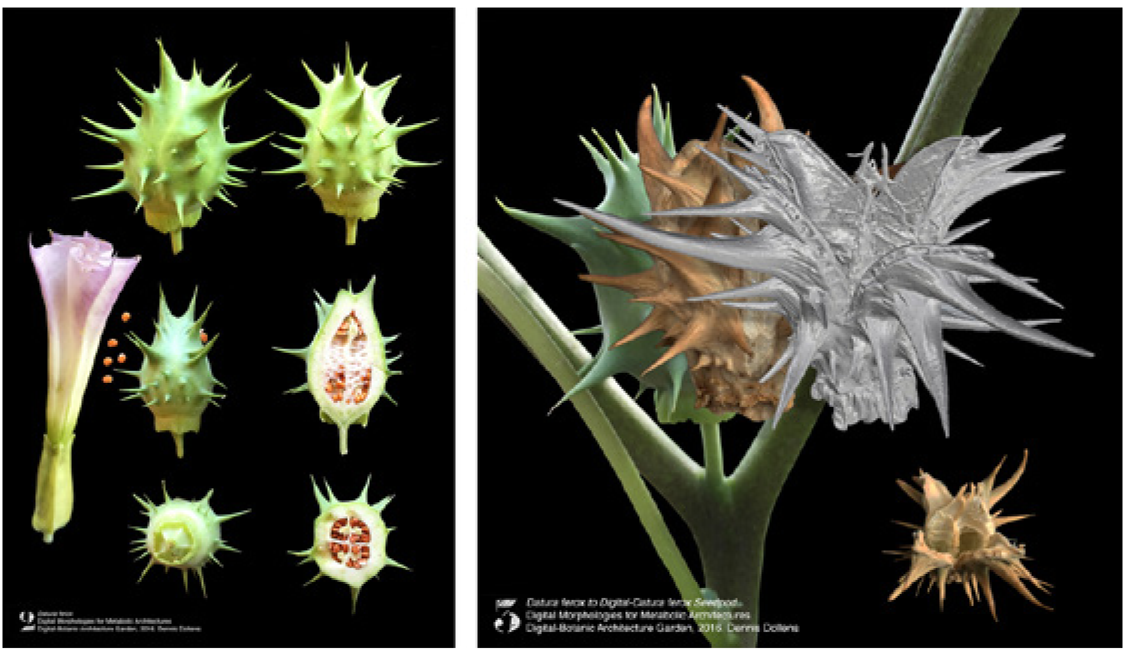

Fig 5a. Botanic Prints. Left: *Datura ferox* fruit before it fully matures, illustrating the morphological and spatial ambients seeds develop in. Right: Botanic Print #3. A companion to Fig 5 illustrating growth phases with a near-exact CAT scan ported to Rhino for architectural simulation in CAD.

pollutants. My goal is to theoretically link biomimetics with technology and science in order to formulate design ontologies — ways-of-being and ways-of-designing — and consequently translate biointelligent microbial/plant agents into regenerative partners for bioactive architectures.

In this perspective, hybrid technology, science, and design offers living properties to buildings and cities by appropriating biological/biochemical approaches from nature's adaptable organisms. This appropriation is consistent with the environmental heritage I cull from science and technology as they delineate human labor factored into nature by Marx — his "metabolic rift" is partially described as the "exchange between humanity and nature."[3] To this I add Engels' point from *Dialectics of Nature*, that "dialectics . . . constitutes the most important form of thinking for present-day natural science."[4] Metabolic architectures thus stands on the shoulders of material/historical dialectics, biomimetics, digital biomimetics, cognitive science, and synthetic biology to theoretically draw out Marx's concept of alienation from nature and to process history as social forces impacting present design cognition.

The dialectic rift operates for current design projects in conjunction with biomimetic and digital-biomimetic procedures. It sets debatable oppositions/binaries to clarify procedures for assembling data for multidisciplinary design research. The rift also facilitates empirical observation, providing us with insight to coordinate design strategies with cellular agents cultivating bioremedial architectural feedback loops — e.g. microbes digesting environmental toxins to sustain their own life. In these project realms, medical/industrial imaging equipment and scientific literature is used to grasp tree/plant, seed/pod, and soil/fungi relationships through which metabolic architectural ideas may begin to be acquired. Existing in this niche, design data from metabolic feedback supports visualization efforts involving exploratory technologies applied to, for example, the morphology/physiology of seedpods interpolated to inspire biofunctional urban architectures. Consequently, those visualization efforts reveal nature's tiny (seed) architectures as models illustrating genetically programmed gynoecia biologies/spaces (Fig 5a, bottom left).

Technological imaging for examining living forms then comes into play when field/studio observations are moved into laboratories with light microscopes, X-rays, scanning electron microscopes, and CAT scanners to join fablab equipment. Imaging technologies for design reveal complexities

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and clues for studying physiological abilities pertinent to the design of bioactive/bioremedial materials and structures. Early on, those studies induced me to concentrate on shape-grammar extrapolations from cedar cones (Fig 6) and morphological extrapolations from almond shells (Fig 7). I designed a series of monocoque panels by looking at cross sections of the almond pods, revealing different interior/exterior material composition bridged by fibrous struts — a natural monocoque with breathing/off-gassing pores venting the pod's interior seed chamber. Later, the almond shell fibers prompted material experiments formulated with piñon pine resin (sealer), fermented cholla cactus (binder), adobe, and paper pulp for strong, lightweight cladding. Aggregated, those materials reinvoked historic earth-based amalgams realized with traditional, if makeshift, papermaking processes or pressure-sprayed exterior surfaces.

Fig 7. Almond Seedpod Monocoque. Almond shell interior, exterior, and cross-bracing structure illustrates one of nature's structural monocoques. Below, a biomimetic response in the form of a facade panel for interior and exterior air exchange — an ancestor of the self-shading L.A. Tower's parametric skin (Fig 9).

Fig 6. Beach Pavilion, Barcelona. A shape grammar exercise using a cedar cone as a model for a first studio assignment demonstrates biomimetic-to-*digital biomimetic* extrapolation and development for application in CAD and generative systems.

Investigating eTrees through direct observation gave rise to my selection of the *Tipuana*'s winged-seedpods as data generators for the design of a footbridge in the French Pyrenees (Fig 8). The project was conducted in partnership with the Barcelona-based architect and professor Ignasi Pérez Arnal. Our aim was to unfold observations of an in-flight seedpod whose mono-blade wing (common to many species) facilitated helicopter-like trajectories off-and-away from the mother tree. We observed and charted the winged pod's always divergent aerial paths (determined by wind velocity and moisture) as biomimetic data to visualize the bridge's helicoidal spirals. Physical and STL models followed after we committed to an on-site catenary — like that of a rope-bridge — to establish the bridge's deck curvature.

Following the bridge, I concentrated on tall buildings — what I call bioTowers (Fig 3) sampled here with the LA Tower (Fig 9) and the Glasgow Tower (Fig 10) — as ecological/architectural trials exploring potentials for biointelligent urban structures. The towers' structural eTrees are based on plant/tree algorithms programmed to support microbe sensors and actuators while what would have been phloem/xylem channels mark

Fig 8. Footbridge for the Pyrenees. Dennis Dollens and Ignasi Pérez Arnal. Based on three intersecting helicoids whose data was captured from flying seedpods; the bridge strives to fit onto the site with minimal sculptural presence and no destruction to the land or existing trees.

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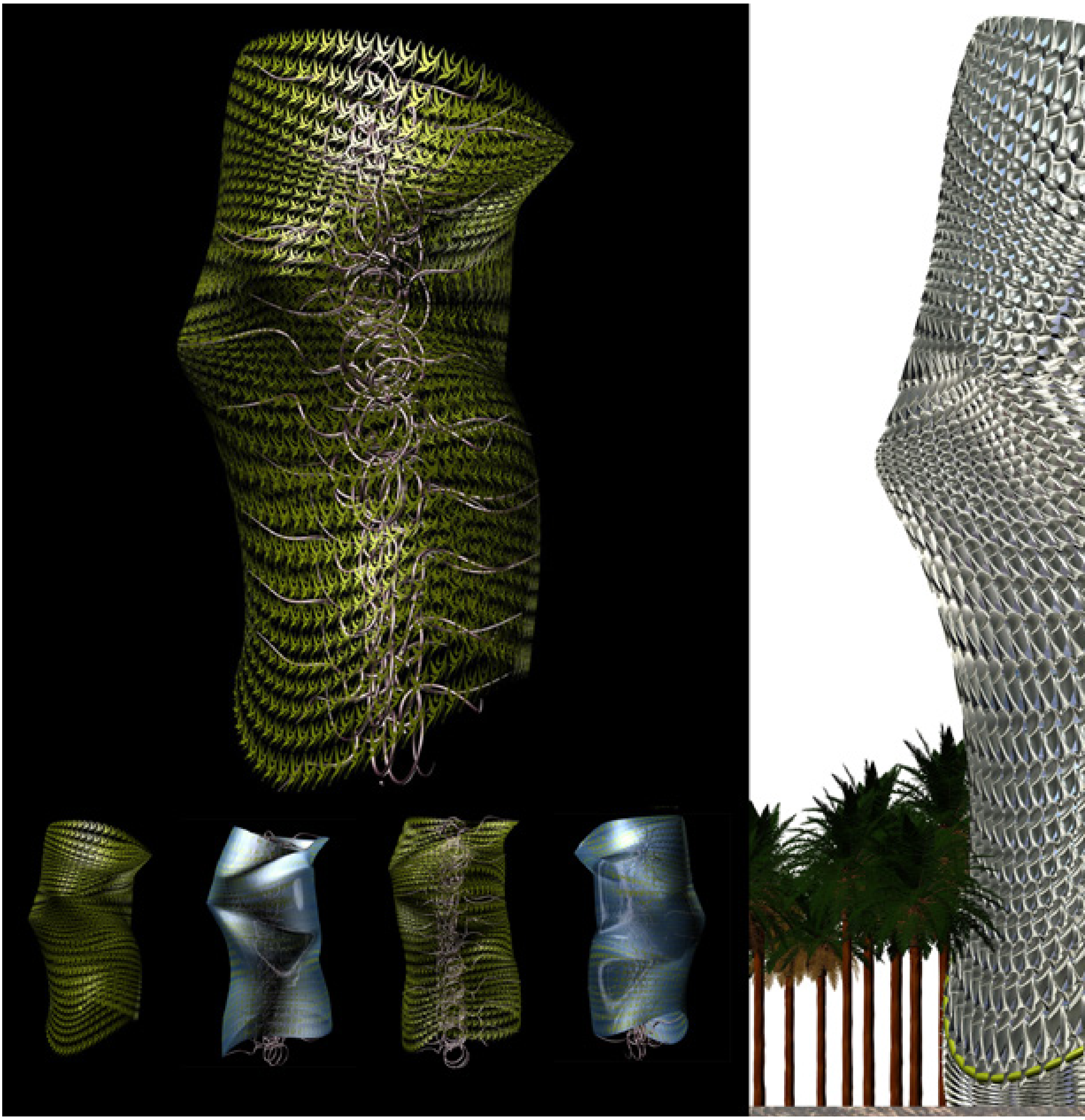


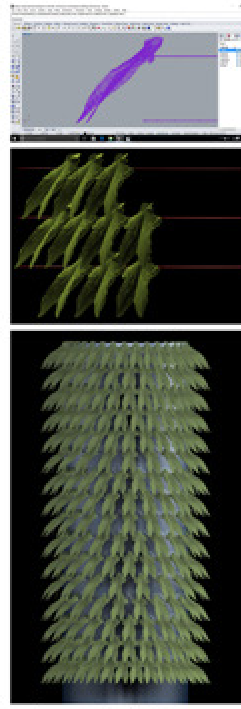
Fig 9. L.A. Tower. Right: The eTree is populated with parametric 3D components generated as individual, linked monocoques. The panel/monocoques are inspired by the fusion of almond shells (Fig 7) and the structures of airplane wings. Left: The L.A. Tower's glass sleeve before generating its leaf forms into monocoque volumes for the tower's 2,000+ differently sized panels. The chainmail monocoque is a prototype investigating operation in areas such as passive ventilating and shape-shifting curtainwalls capable of responding to wind direction, light intensity, and filtration duties.

Fig 10. Glasgow Tower. An apartment building along Glasgow's Strathclyde River, Scotland. *Yucca glauca* and *Penstemon palmeri* flowers and seed-pod clusters influenced the morphological pattern, airflow, and light distribution as digital-pods transformed into habitation units.

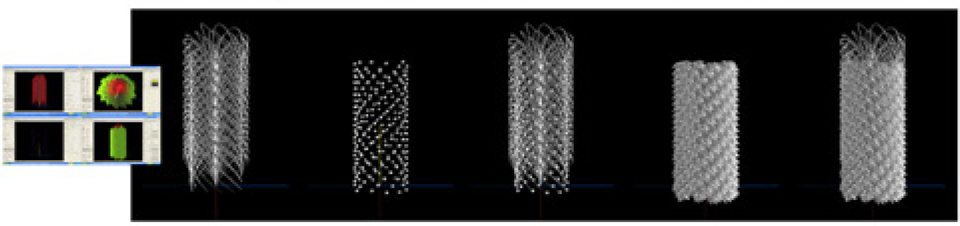
Urban Pure: BioTowers

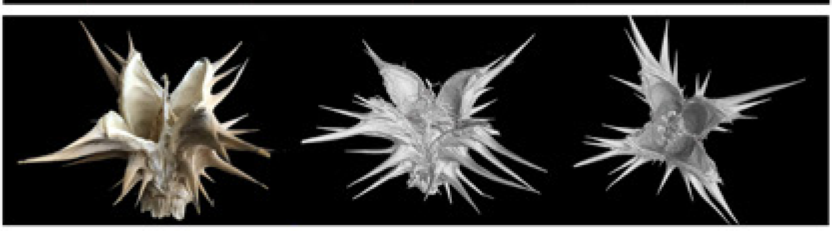
Metabolic Architectures autonomously learn from biology, AI, living technology, computation, & digital morphology to sense & bioremediate urban pollution while biointelligently balancing interior environments. This is an autopoietic approach to biomimetic design research for new typologies underwriting living structures.

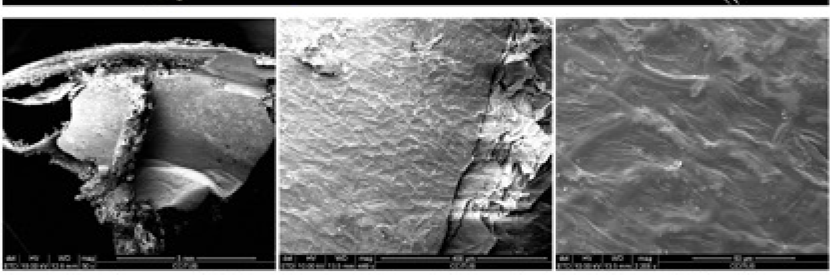
The hybrid, metabolic/machine aspect of these towers is applicable to urban environments where spaces for housing, education, community organization, & start-ups demand biological/computational efficiencies. Here architecture is conceptualized as part of nature biotechnologically plugged into smart cities.



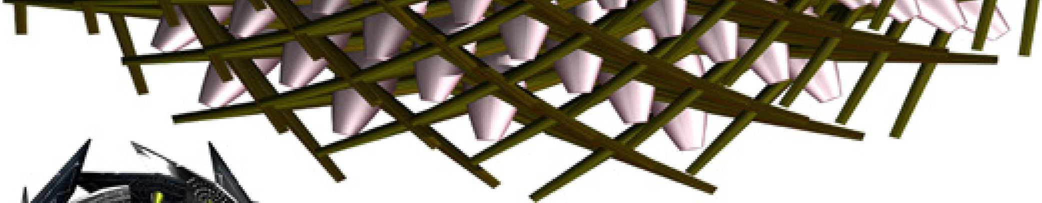
Performative leaf substrates prototyped as host-surfaces for plant or microbial intelligence.







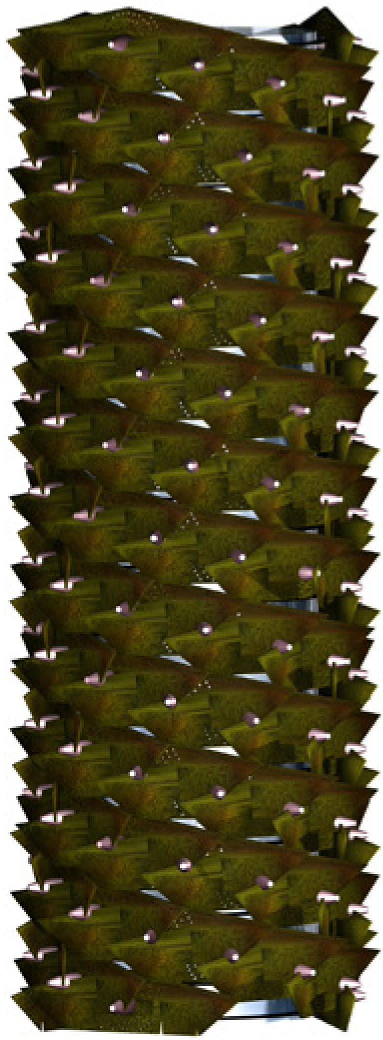
Generative eTrees as a bioTower frame; CAT scan _Datura ferox_; SEM images _Datura ferox_. Top row. Structure, biorobotic controllers, & leaf panels generated from tree & plant algorithms for the above bioTower. Middle. Dried, *Datura ferox* seedpod (left), followed by two industrial CT scans for digital-morphological investigations. Bottom row. Scanning Electron Microscope studies of *Datura ferox* for panel design to physically support microbial agents as biologically intelligent sentinels hybridized for biochemical, environmental actions.



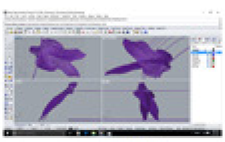
BioTowers
are living, intelligent architectural systems engaging climate change for global monitoring & biological participation in urban bioremedition.

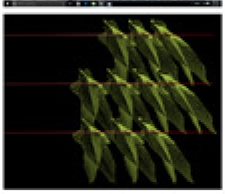
Technologies represented here exist, some in advancd stages. I source science for synthetic biology, living technology, AI, plant neurobiology, digital morphology, & cognitive science for input into generative dgital biomimetics. The result is a design research system based in autopoiesis, Turing's morphogenesis & the theory of extended cognition.

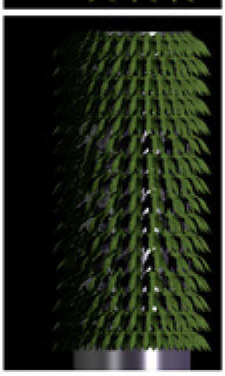
Above & right for example, I generated spiraling digitally-grown eTrees with leaf-like, double-skinned panels to experiment with microbial sensors & actuators for performative communication & intelligent bioactive systems.



Venting nodes & monocoques comprise interlinking units for one type of modular BioTower facades involving AI, plant, & bacteria-enabled pollution sensing & filtration.







Biohybrid panels derived from plant morphology colonized with bacteria to convert air-borne carbon dioxide into biofuels. The concept is modeled on bacteria used

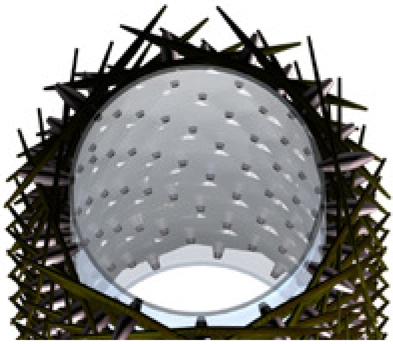
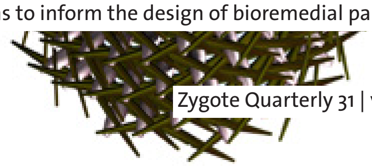


Fig 11. bioTower Anatomy. X-Prize and Inhabitat Biodesign Competition Panels. 2016. (Honorable Mention). Two microbial facade strategies whose data were derived from scanning electron microscope images and CAT scan investigations to inform the design of bioremedial panels tasked to eradicate airborne toxins.



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internal pathways for the delivery/removal of nutrients, fluids, bioelectricity, and data. Skinned, surfaced, or paneled, those eTree structures become candidates in later projects for hosting engineered bacteria, AI, or biorobotic agents making possible the inclusion of microbes as the towers' life-forms able to feed themselves on CO_2.

While bioTowers serve as idea mockups, they also take cues for embedded energy design from programs developed for biorobotics, for example, from "Towards Enduring Autonomous Robots via Embodied Energy."[5] By this route, the bioTowers hold potential for engaging in metabolic energy/signaling production as well as climate-change remediation and consequently become devices for exploring regenerative bioarchitecture and landscapes. In (Fig 11), the double panel (X-Prize, Honorable Mention) illustrates how two differently configured structures deal with surface and microbial/plant taxonomies. The tower on the right is fitted into an urban site while both towers influenced the imbricated (house of cards) panel design for the 2017 Microbial bioTower (Fig 12).

At the moment, I'm designing low-impact, modular, mast systems; one for temporary forest observations (Fig 13) and the others for elevated carbon-capture

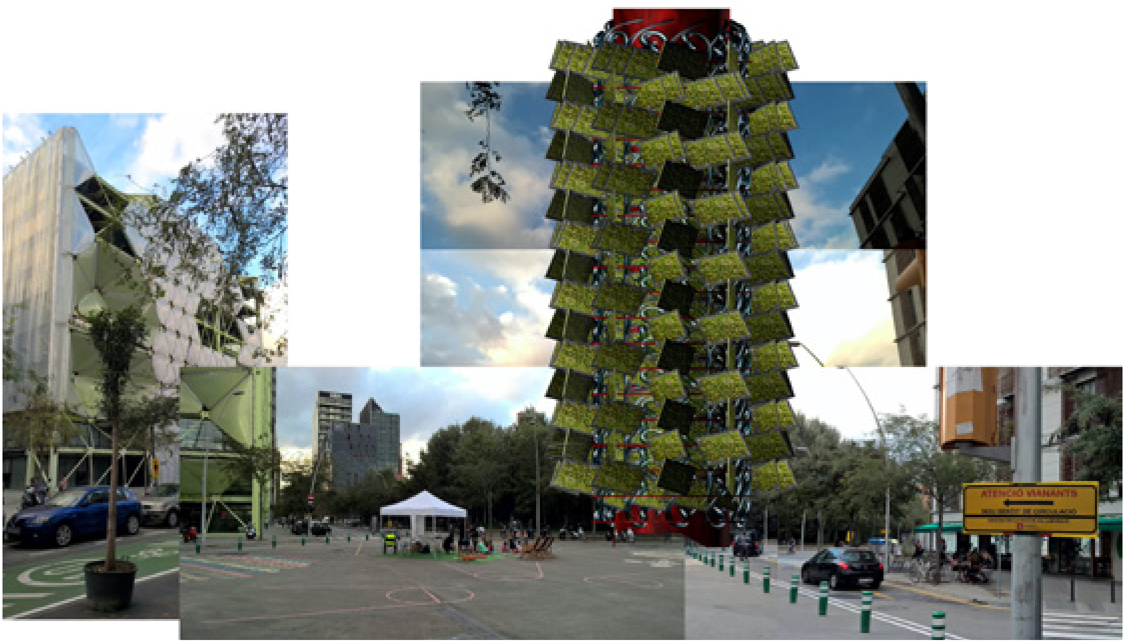

Fig 12. Barcelona (BCN) MicrobeTower. Ongoing. Algorithmically-grown eTrees hybridized as scaffolding and structure with microbially populated panels for sensing, activating, and bioremediating urban pollution. Advancing tactics developed for the X-Prize/Inhabitat Competition (Fig 11), this tower's living panels host organisms residing in interlocked and stacked — like a house of cards — consoles for maximum environmental exposure and maintenance access.

machines (Figs 14, 15). These in-process designs are cousins of the bioTowers intended to similarly house microorganisms currently existing only in laboratories and reported on in journals and newspapers such as *Nature* and *The Guardian*. Project-influencing articles, to cite two more examples, have discussed "The Promise of Multi-cellular Engineered Living Systems"[6] and "How 'Super-Enzymes' that Eat Plastics Could Curb Our Waste Problem."[7] I read those and other papers as wakeup calls for near-future metabolic building propositions contemplated for the eradication of CO_2, CH_4, and other industrial toxins.

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

Teaching. For twenty-two years, up to the early COVID-19 lockdowns, I taught biomimetics and then metabolic architecture studios in the BioDigital Architectures Master at the school of architecture (ESARQ), Universitat Internacional de Catalunya, Barcelona. Beginning in 2000, we looked to biomimetic principles in order to evolve digital-biomimetic procedures that interlinked students' design observations with environmental, biological, and technological visualizations.

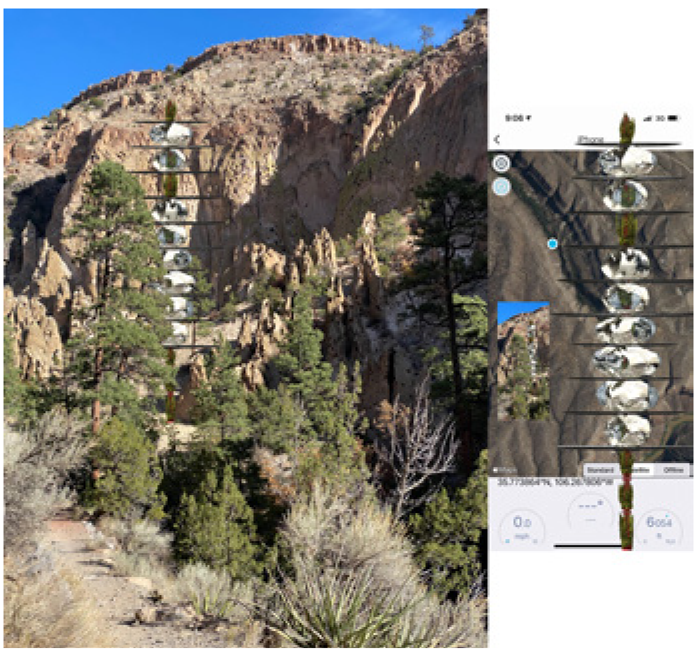

Fig 13. Forest PodTower Lookout. 2021-ongoing. Low-impact, light-weight tower for forest-canopy observation. Access is by tree-climbing tackle while the tower is anchored by guy-wires secured with low-impact anchor-harnesses.

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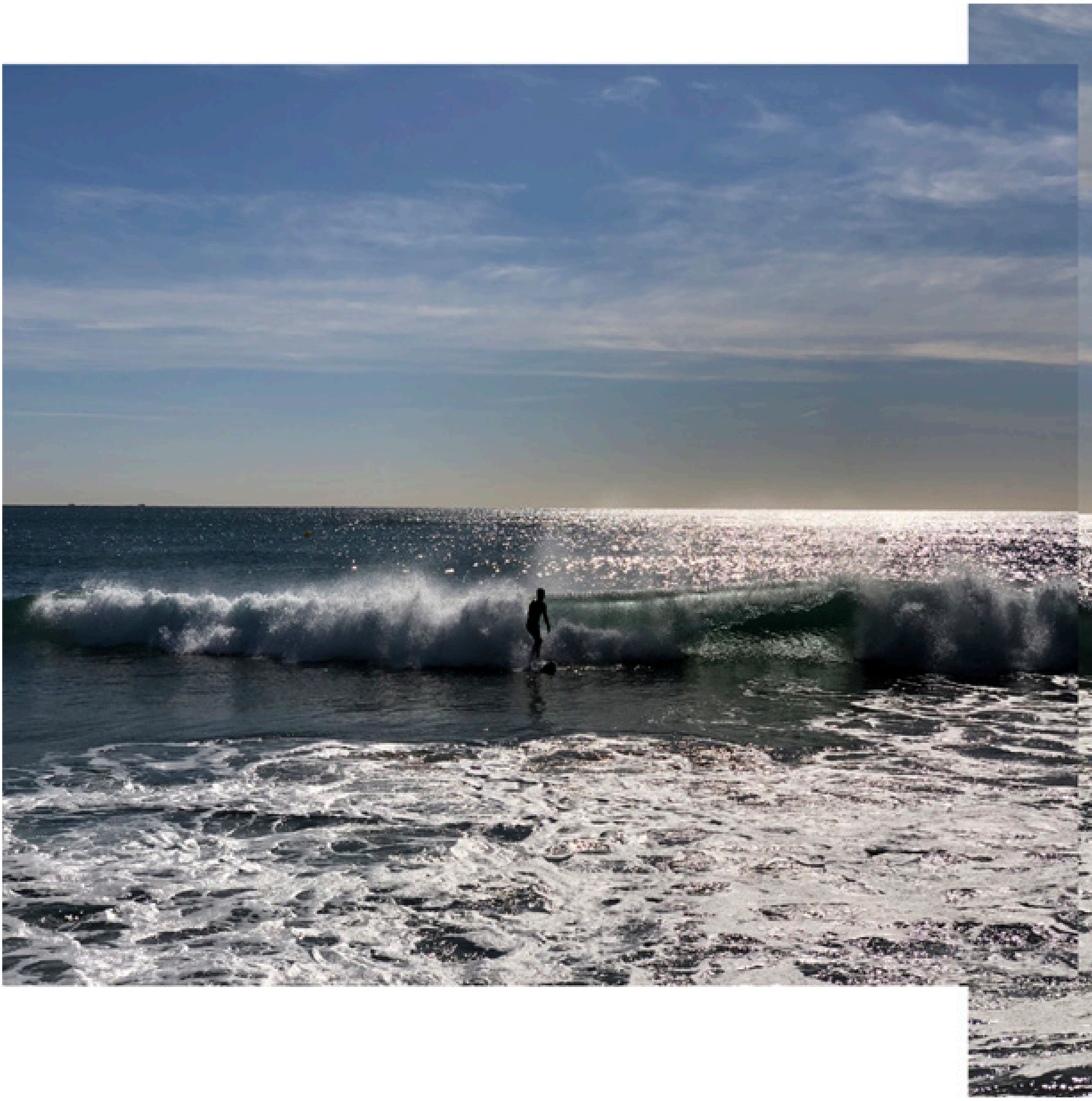
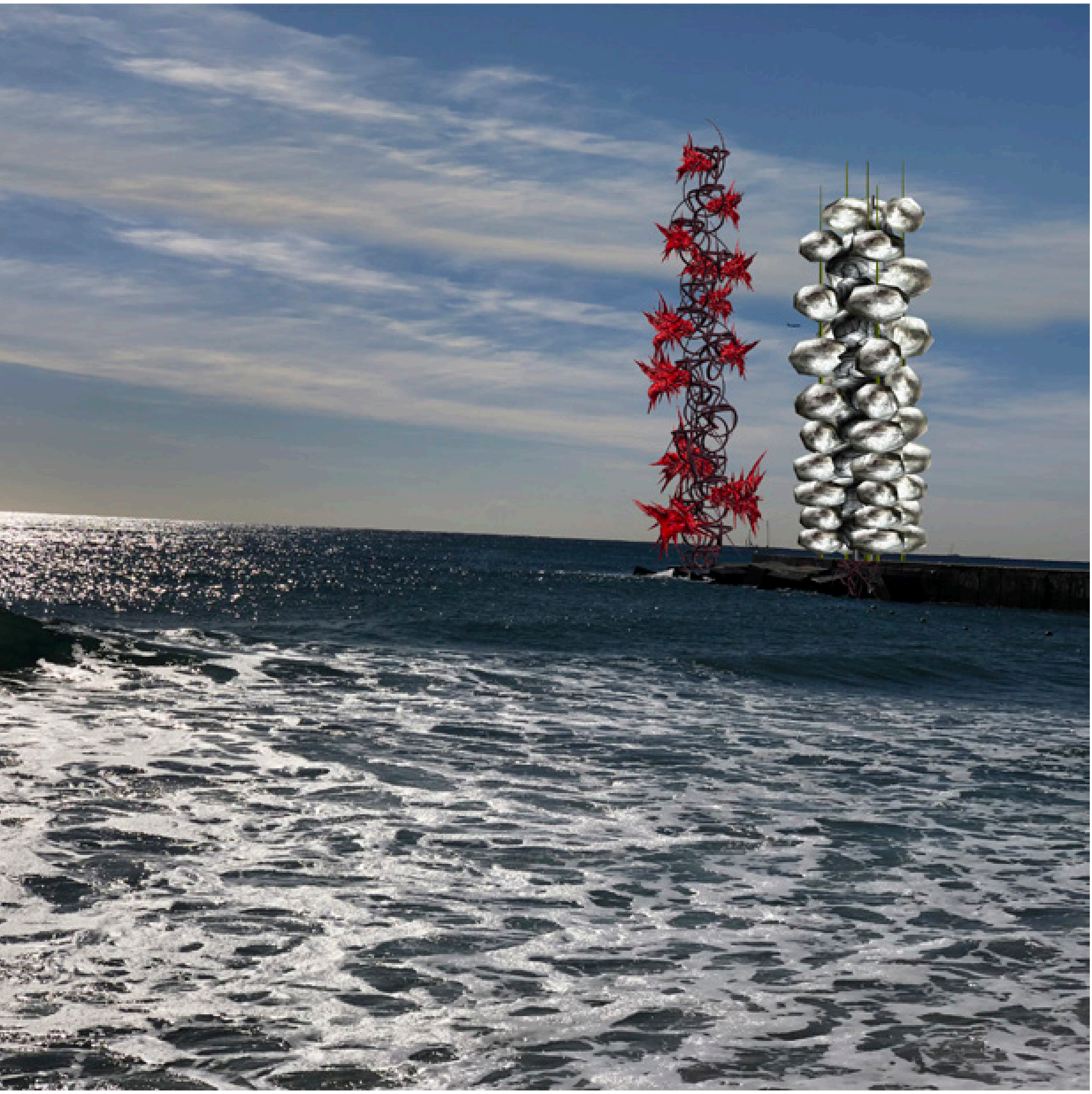


Fig 14. Surfer & *feroxTowers*. Ongoing. Barcelona. Carbon-capture machines lofted by eTree masts and housed in over-scaled *Datura ferox* fairings for maximum surface (intake) area.



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At the same time, we enhanced our understanding of synthetic biology and AI by surveying multidisciplinary research discoveries. In 2017, we began discussing how Suzanne Simard's interspecies-forest communities[8,11] demonstrates intelligence in signaling and resource sharing (shades of Turing's intelligent machines and code-breaking efforts come to mind, and I shall return to them). In the same discussions, classes considered urban forestry and urban agriculture in relation to buildings, city, and environmental infrastructures. Progressively, students became adept at interpreting/designing architecture and urbanisms as systems in nature, easing their way toward conceptualizing buildings with agency and extended cognition.

Propositions driving the Metabolic Architectures Studio orbited around defining (neurological vs. non-neurological) intelligences (Fig 16) we used to conceptually reform autopoiesis, the main theory behind my work and research papers. *Autopoiesis and Cognition: The Realization of the Living*[9] is the biological theory of life/cognition by Humberto Maturana and Francisco Varela. The book plots a biophilosophy for differentiating types of living intelligence divided between, and distinguished by, neurological or non-neurological organisms. Critically, it provides a theoretical scaffold for considering pan-life systems — from bacteria to whales to sponges to giant sequoias — as variously intelligent.

For autopoiesis, every cellular organism is living and thereby cognitive. In Maturana and Varela's complexly argued theory, species of microbes or fungi[10] have perception and motor abilities, make decisions and carry out sensory reactions dependent on their inherent biochemistry and environmental conditions — all requiring degrees of metabolic memory/intelligence.

Lesser degrees of intelligence in non-neurological life is a difficult concept for humans. Who/what is biointelligent outside

Fig 15. Ferox Carbon-Capture Tower. Barcelona. Ongoing. Part of a series of temporary, dispersed inner city infrastructural carbon capture machines deploying eTree masts and *Datura ferox* fairings.

of creatures with neurological systems? How can living intelligence be situated in organisms without brains? (As a case-in-point, contemplate jellyfish — they have a basic neurological system but no brain or heart). For an answer, we need new categories of what non-neurological, intelligent biosystem are — forest ecotones, microbial colonies, biofilms, etc. In addition we need research on how species are aided in intelligence by their environment and how they biochemically or bio-electrically communicate.[8,11] Those questions are only starting to elicit answers from research universities but already produce implications and challenges for future biodesign remediation efforts.

With autopoiesis as a philosophical anchor, I grandfather-in scientific dialectics surrounding the construction of intelligent (Turing) machines and his botanic simulations that are foundational, first for digital biomimetic, computational biology and then for metabolic architectures. I concentrated on Turing's biological algorithms from the early 1950s — what he termed computational morphogenesis. By theoretically locating and amending his propositions, drawings, and papers from the likes of "Computing Machinery and Intelligence"[12] to the 1951 BBC broadcast, "Can Digital Computers Think?"[13] — I traced his botanic algorithms and simulations in an issue of *Leonardo*[14] and still use them as templates for ways-of-thinking, designing, and writing appropriate to metabolic architectures. Recognizing Turing's research, John Reinitz wrote in *Nature* — this is germane to digital biomimetics, environmental simulation, and metabolic architectures — that Turing's algorithmic models were, "the first

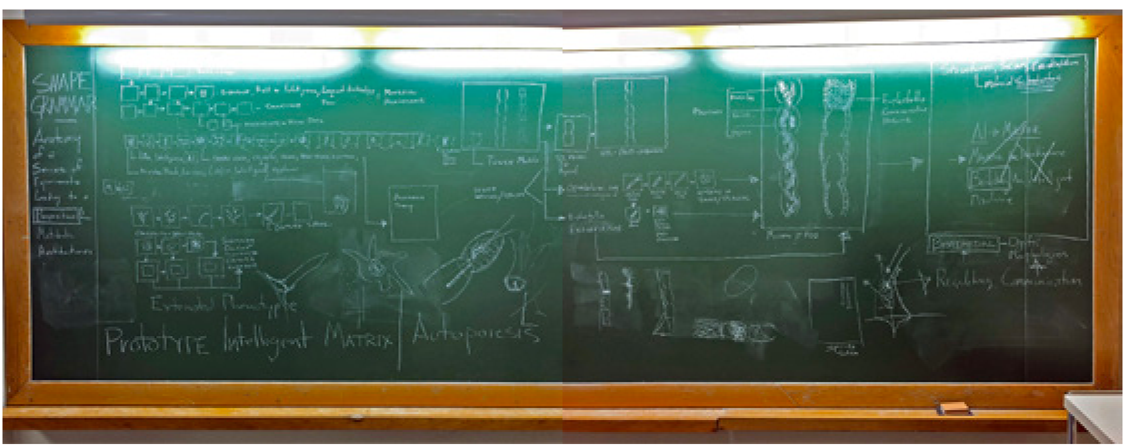

Fig 16. Chalkboard, Dennis Dollens' Metabolic Architectures Studio, 2017. BioDigital Architecture Master, UIC. Participating in the development of a dialectic for metabolic architectures, the drawings illustrate interlinked concepts revolving around biological and technological disciplines for defining and debating autopoiesis, intelligence, and metabolic life as applied to AI, machines, buildings, cities, and objects.

computer simulations of [biological] pattern formation."[15] Reinitz continued, "What Turing should receive credit for is opening the door to a new view of [computational] developmental biology."

Synchronizing with the above, one of my overall aims is to dialectically open up the conception of digital biomimetics by designating technological/scientific procedures linked to algorithmic generation as practices epigenetically embedded in nature. In that case, tools (up to and including electronics and genetics) are part of our own evolution supporting categories of machine-, computation-, and AI-aided research having both a biomimetic heritage and a bioremediating future.

My task of apprising autopoiesis as a foundation for digital biomimetic theory continues to reference Turing's theories of machine intelligence by categorizing buildings as machines and thereby nesting architecture in his question: "Can machines think?" — I ask, can buildings think? — Related, I searched for a third system that could dialectically account for perception, memory, and objects in environments feeding data to human cognition. That system turned out to be articulated in the concept of extended cognition developed by the theorist/philosopher Andy Clark. Clark's book *Supersizing the Mind: Embodiment, Action, and Cognitive Extension*,[16] revealed methods compatible with environmentally enabling autopoiesis. The book also originated a theoretical underpinning that syncs with Turing's versions of machine intelligence and current AI amenable to jump-start bioremedial, intelligent, Metabolic Architectures.

What is the last book you enjoyed?

The most exciting, engaging book I've read since *The Overstory* by Richard Powers is *Treeline: The Last Forest and the Future of Life on Earth* by Ben Rawlence. For theoretical updates to extended cognition and philosophy, I'm reading *Reality: Virtual Worlds and the Problems of Philosophy* by David Chalmers. And, keeping a link to West Coast (where I grew up) environmental-Zen philosophy, I'm reading Gary Snyder's 1990, *The Practice of the Wild*. ×

We would appreciate your feedback on this article:

Fig 5a detail. Botanic Prints. *Datura ferox* fruit before it fully matures, illustrating the morphological and spatial ambients seeds develop in.

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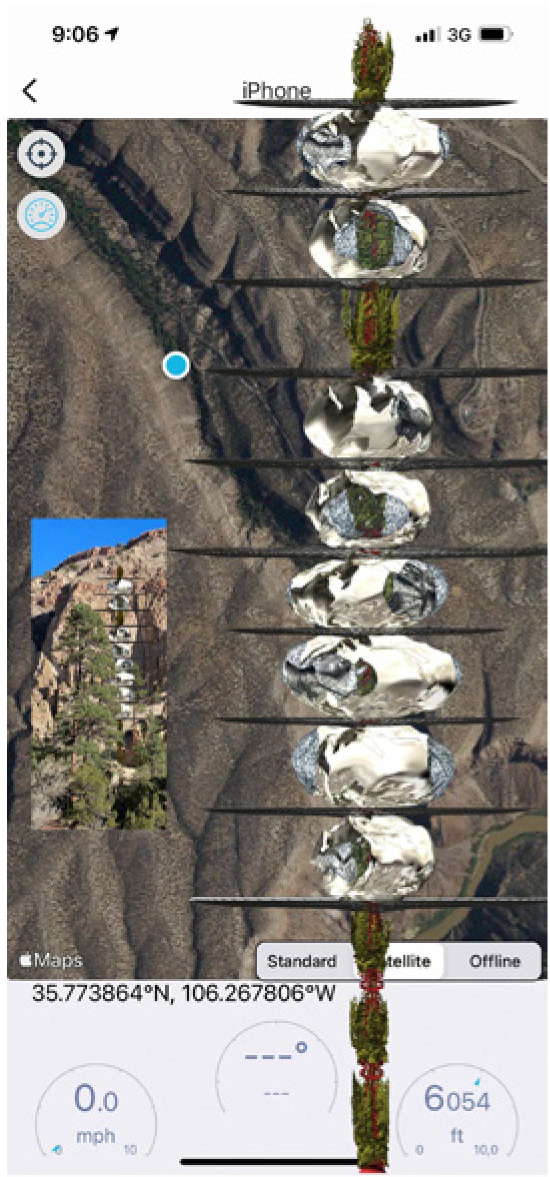

Fig 13 detail. Forest PodTower Lookout.

Red ants
Photo: Magdalena Smyczek, 2019 | Wikimedia Commons

E. O. Wilson Introduction

Tom McKeag

E. O. Wilson Introduction
Tom McKeag

Edward Osborne Wilson, biologist and Pulitzer-prize-winning author, champion of biodiversity and expert on ants, passed away in December, 2021. In his wake he leaves a deep legacy of scientific research and advocacy for a natural world that he saw as both wonderful and highly threatened. He began his career as an evolutionary biologist in the 1950s, at a time when the discipline was in thrall of the latest discoveries of the previously unseen worlds of DNA and proteins. Many in the field followed the siren call of molecular investigation as a way to make sense of the living world, but Wilson sought instead to make his more traditional approach of direct macroscopic field study relevant, rigorous and impactful.

E. O. Wilson in 2003
Jim Harrison, Wikimedia Commons

He would write over 30 books in his field of expertise: insects, animal behavior, biodiversity and conservation. In 1979, he won the Pulitzer Prize for *On Human Nature* and again in 1991, with his colleague Bert Holldobler, for *The Ants*. He was a pioneer in the study of biological diversity for which he had devised a mathematical formula, and pushed the bounds of behavioral science by making an inductive connection between his observations of insects in the field and the behavior of all species, including humans.

Graduated from the University of Alabama, where he grew up, he enrolled in a PhD program at Harvard in 1950, and six years later became a member of the faculty where he would stay for 46 years. His early research travels took him to far-flung places: Cuba, Mexico, New Guinea, and the islands of the South Pacific. Always, he looked for patterns in how species arose and declined and why. He and his colleague, Robert MacArthur of the University of Pennsylvania, would go on to formalize their field research in *The Theory of Island Biogeography*, in 1967. It would become a landmark in the field of ecology, and their metrics for prediction would be applied to a wide range of circumstances in the field and form a founding principle of conservation biology.

In 1963, Wilson read a paper by British graduate student William Hamilton, about ant colony behavior and "inclusive fitness", based on the idea that the behavior of the inhabitants of a colony was determined by their inherited genes, and that all behavior might be explained by the singular mission of passing on their shared genes for a subsequent generation. Wilson published *The Insect Societies* in 1971, and later *Sociobiology: The New Synthesis* in 1975. This book would frame animal behavior under

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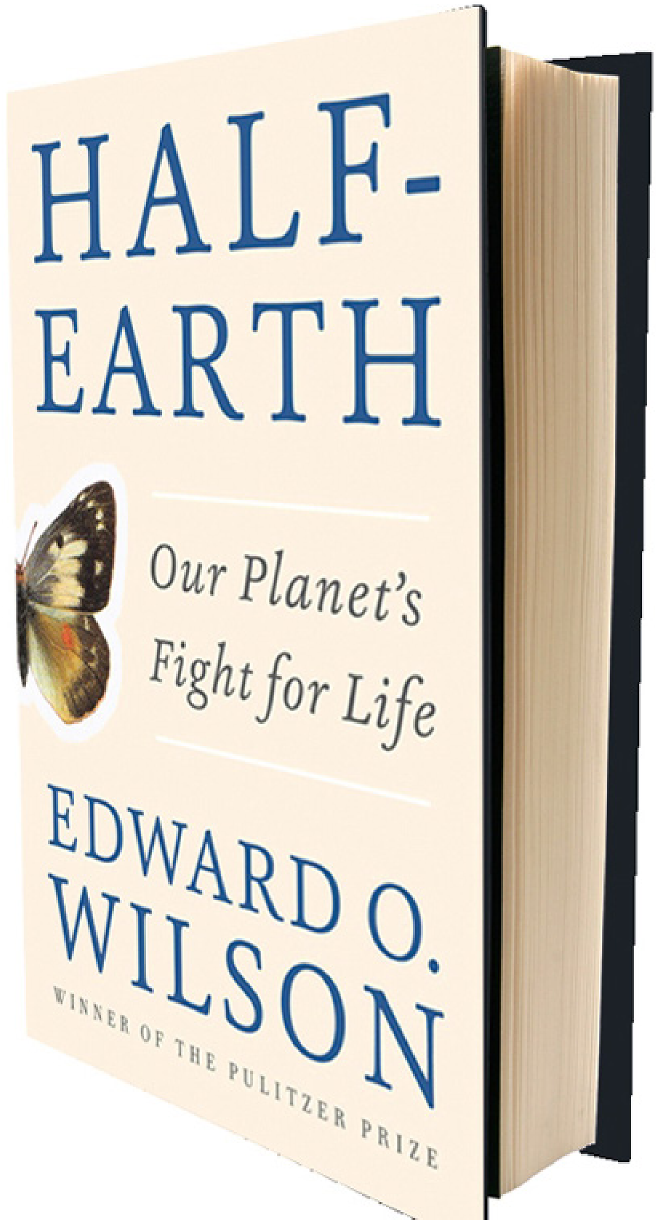
the wide umbrella of evolutionary genetics, with the organism seen as merely a tool in DNA's march into the future.

Wilson's sociobiology theories were his most controversial, and led to a bitter feud at Harvard between Wilson and others, particularly Stephen Jay Gould and Richard Lewontin. When a new biology department building was built the feuding factions were placed on different floors and graduate students were told to be careful where they got off the elevator. Critics accused Wilson of retreading "biological determinism" with all its social baggage of eugenics and racism. Despite subsequent research proving many instances of individual gene's effects on human behavior, Wilson's theory has yet to be confirmed universally across the wide and complicated spectrum of evolutionary biology. In an abrupt reversal in 2010, Wilson refuted his inclusive fitness theories, to the dismay and vehement refutations of dozens of evolutionary biologists, including Richard Dawkins, and published *The Social Conquest of Earth* in 2012.

In later years of his life, Wilson would champion biodiversity and sound the clarion call about mass extinction of species, traveling the world well into his 80s. In 2008, he established the Encyclopedia of Life (see page 48), a collective database of all the world's species, and in 2014 published *A Window on Eternity* after a trip to the Gorongosa National Park in Mozambique. His message to the world was straightforward: in order to avoid the predicted mass extinctions of species, humankind ought to set aside half of the planet for wild life. This formed the thesis of his 2016 book, *Half-Earth: Our Planet's Fight for Life*.

As a traditional biologist, forged in the field, Wilson would be most pleased to be remembered as a successor to Darwin. Large shoes to fill, to be sure, but he would spend a lifetime of dedicated research, reflection and advocacy to achieve. For the bio-inspired design practitioner, Wilson can inspire on myriad levels. How does one translate biophilia into action? What does Nature teach us, here and in other circumstances? What does it mean to be a scientist? How can one practice rigorous and deep observation? How should one tell this story of wonder? In all, Wilson was an exemplary model and will not soon be replaced.


HALF-
EARTH
Our Planet's
Fight for Life
EDWARD O.
WILSON
WINNER OF THE PULITZER PRIZE

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The Encyclopedia of Life (EOL) was established in 2008, and contains almost 13 million trait and attribute records, and includes over 1.5 million ecological interaction records. Clear provenance is provided for each record, including citations and organized searches are possible through taxon page overviews, data tabs and advanced search tools.

The site also has fora, organized into eight categories, including news/education, general discussion, specific pages, biodiversity news, and its open Data Portal, opendata.eol.org, allows sharing of information between viewers.

Biological organisms are located within a curated "EOL Dynamic Hierarchy" which lays out the branches of the tree of life per EOL staff, advised by experts within the community. The site also includes other classification systems for comparison.

Users have a chance to be curators (assistant or full) and make their own collections and add content after review by committees.

The EOL learning and education page may be especially useful to ZQ readers. It contains free resources, tools and services. Lesson plans, biodiversity cards, podcasts and Google earth tours are available. Resources also include partner links, such as to iNaturalist, a citizen science website run by the California Academy of Sciences and National Geographic.

We took a test drive of the site to better inform our readers of its features. Our first assumption was that the typical ZQ reader might be a well-informed generalist who was curious about an organism or its attributes. This reader, we imagined, would be searching either for a particular attribute, such as water shedding ability, or wanting to know more about a particular organism that demonstrates potential functional success or advantage. He or she would want to search, therefore, with one of two types of criteria:

1. Broadest criteria: search for a feature of an organism that could be investigated for functional advantage in the human world, whether by inspiration, mimicry or direct material use.

2. Narrow criteria: search for detailed information on a selected organism.

The EOL is, first and foremost, a crowd-sourced record of what is alive on our planet, where it lives and how it fits into the trophic ecology. Therefore, it should be seen as a supportive tool to learn more about the organism that you are curious about (search 2), rather than a search tool for functional attributes (search 1). Regardless, it offers very useful information about organisms and, as importantly, references for further academic research. We chose the Sacred

Lotus Seeds
Photo: WEAZ 73, 2010 | Flickr cc

Nelumbo nucifera | Photo: Ben Cheung, 2017 | Pexels cc

Lotus as our test example, given its significance to the history of bio-inspired design and our knowledge of many of its attributes. In the query bar at the top of each page, typing Lotus yielded several results including Lotus Family, which brought us eventually to the species we were seeking. It seems advisable, however, to have the full Latin or Linnaean name (Genus, species) in hand before searching EOL. This can usually be obtained from a quick look at Wikipedia or other internet reference search for the formal name to match the common name.

As in many encyclopedias the mere organization of information may be helpful for a user who is unfamiliar with taxonomy, nomenclature, and main issues in the germane science being investigated. EOL offers a rich introduction to such things and an example of this in the plant kingdom can be found here. In our example, a little knowledge about the lotus (that it is a flowering plant) brought us to click on the Angiosperms division of the plant kingdom on the initial overview page. At the Angiosperms overview page one can click on four additional tabs:

Data
Explains data structure within EOL, and filters of attributes established by EOL

- Habitat: where an organism lives
- Production: what it produces
- Trophic guild: where it fits in the trophic network ("food chain")

Media
Presents an array of photo images of plants submitted by 30 contributing organizations like the Arnold Arboretum, and the California Academy of Sciences. The images initially displayed do not appear to be in any particular order. You can, however, filter by license type, provider or type of media (image, map, video, sound)

Maps
The Maps splash page is similarly arranged with images and shows locator maps of specimen contributions from around the world that one can investigate.

Names
Will show where Angiosperms fit into the EOL Dynamic Hierarchy (taxonomic system) and its subsequent nine divisions (orders).

This format will be repeated as one proceeds to more and more specificity within the taxonomic system, from Domain through Kingdom, Phyllum, Class, Order, Family, Genus and Species. Each subsequent page will have links to the next, lower division.

Alternately, with the Genus and species known, typing in *Nelumbo nucifera*, in our case, brought us to the familiar format of six tabs (the five described above plus an "articles" tab), an interactive map of specimens documented, and data on 26 attributes, including growth form, habitat, leaf morphology, trophic guild and uses.

It is useful to note that the reference information presented is restricted by who had submitted it, thus this widespread Asian plant is described as an invasive species in some descriptions by submitters outside its natural range, the US Department of Agriculture (USDA) for example.

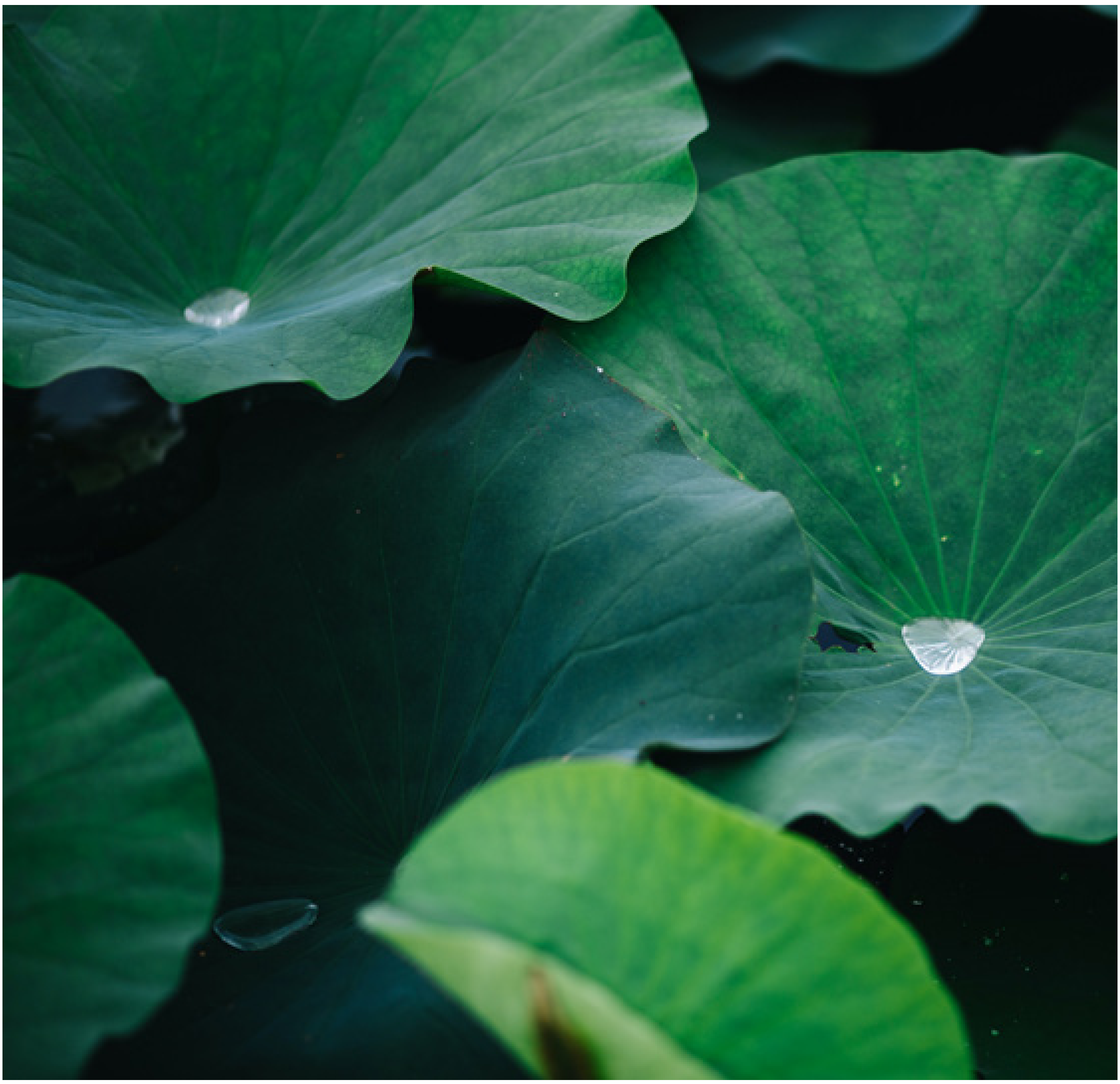
Similarly, images, though curated, are ultimately crowd-sourced from participating organizations, most of which are focused on specimen collections and taxonomy, and not necessarily on functional attributes. All of the images we reviewed were in the macro linear scale, focused on the visual identification of the whole plant or its flower, with a few showing water beading up on the Lotus leaf surface. Users interested in the "Lotus effect" of water shedding and self-cleaning and who might have been searching for micro or nano linear scale images or cross-sectional diagrams would not find them here.

We found the Articles tab to contain some useful references, and it was organized by topics such as distribution, flowering and fruiting, and habitat. This section, for this particular organism, relied heavily on Wikipedia EN for its informational text.

Overall, the EOL seems most useful for collecting basic taxonomic and general information for a subject at the organismal scale or, to a lesser extent, at the population, community and ecosystem scales. This is due to a format that includes trophic interactions. It does not seem to readily yield immediate results in a search for functional or physiochemical attributes. Some references, however, may yield leads to these traits in scientific literature.

The EOL has been designed as a community supported work in progress of tremendous ambition and wide breadth and should not be missed by those practicing bio-inspired design or education. For those exploring functional comparisons, or nature-based material or process inspirations, this tool would best be used in conjunction with other searches at sites such as AskNature.org, and a comprehensive key word search through scientific literature, including a review of journals devoted to the discipline, such as *Bioinspiration and Biomimetics*. ×

We would appreciate your feedback on this article:



Nelumbo nucifera plants growing in pond
Photo: Ansel Lee, 2019 | Pexels cc

Fourmi (Ant)
Photo: Pierre Anquet, 2017 | Flickr cc

Interview

Ari Daniel Shapiro talks to E. O. Wilson

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Renowned evolutionary biologist E.O. Wilson spent his long career cracking the code of ants. E.O. Wilson was 81 at the time of this interview. Ari Daniel Shapiro sat with him in his spacious library at the Museum of Comparative Zoology at Harvard. Shapiro came to see him not about the Encyclopedia of Life, but to have a conversation about his favorite organisms – ants. He began by telling him about the ants all around us.

Wilson: We are surrounded by mementos that I've accumulated over the years – gifts given to me, blown-up photographs, sculptures of ants, prizes for working on ants. It's a little museum of memorabilia – all myrmecological in nature. Myrmecology is the scientific study of ants. Ants are ideally suited for the study of advanced social behavior as it evolved in insects. They have among them the most elaborate social systems found in the whole world – next to human beings. They are so very strange. For example, they communicate almost entirely by pheromones, exchanging chemical substances one to the other in a way that's quite invisible to us.

E. O. Wilson and Ari Daniel Shapiro

Can you tell me about a species you've studied in the field where you've kind of seen this chemical communication in action?

One of the ant species that I studied a great deal was the one that I discovered when I was a 13 year-old boy in Mobile, Alabama. I was the one that found the first colony of the imported fire ant. Now that species of fire ant is throughout the south, in California, and parts of Australia, and southern China, and the West Indies spreading out as a major pest. I used that ant in the laboratory in the late 1950s and early 60s.

How did you determine that it was the chemicals they were using?

It became rather obvious. They weren't making any noises, they weren't singing like birds. Also, they weren't really tapping one another with their legs or antennae. So with all those sensory modalities removed except

Close-Up of Red Ant | Photo: Egor Kamelev, 2020 | Pexels cc chemical, it certainly seemed it had to be chemical.

Wilson's experiments clinched it. His fire ants laid chemical trails by dragging the tips of their abdomens over the ground. This behavior recruited other ants to follow them. So Wilson extracted the substance to make artificial scent trails. It was potent stuff. He could lure those ants wherever he wanted. When exposing the fire ants to an especially high dose, Wilson was able to clear out half the workers from a colony.

Wilson: The fire ant's correct name – scientific name – is *Solenopsis invicta*.

Why are these names important?

They're important because your name is important to you. They distinguish the species without ambiguity. For example, *Paraponera clavata* – the giant ants of Central and South America with a terrible sting. So one of the common names for them is "dos semana," which means two weeks. That's the time it takes to get over a sting from one of these ants. But you can't have that because it differs from one place and one person to another. So these scientific names are strictly chosen and monitored. You can't change them.

Myrmecologists have to be precise when naming ants. There are over 14,000 species of them. And they're crawling everywhere.

Whenever I hear of a person who's going to a very odd place like Bhutan or the mountains of southern China, I say, "Oh, while you're there, pick up some ants." I did that once with a film company that was making IMAX film of the tabletop mountains of the Lost World of Venezuela. I said, "Now, when you get up to the top, nobody's ever collected ants on any of these places. I want you to collect ants up there for me." And sure enough, he brought down the ants and I got them to look at them for the first time.

What continues to motivate you? You'd mentioned you were retired in quotes, but sounds like you still keep pretty active.

I think my life proves that if you are truly a dedicated naturalist, if you've known the joys of exploring biodiversity, and you've become fairly familiar with ecosystems that feel like home to you when you step into them – that home isn't just the house or the city – it's the land, the natural environment… that is a source of life-long pleasure, adventure, challenge, and excitement.

Paraponera clavata or dos semana
Photo: Pierre Anquet, 2018 | Flickr cc

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Head view of ant *Solenopsis invicta*
Photo: April Nobile | © AntWeb.org | CC BY-SA 3.0 | Wikimedia Commons

What do you study?

I suppose you can say my specialty is myrmecology, the study of ants and ant biology. But then in addition I am an entomologist. I have always had a broad interest and engagement in the study of insects. And beyond that, I am an evolutionary biologist, that is I am a biologist who spends a great deal of his time studying the evolutionary process, using the creatures that he is most familiar with. But beyond that I guess I am a biologist generally, because I write broadly across the areas of biology and the relationship of biology and the other branches of learning.

What do you do when you are not at work?

Each evening at 5:00 pm I shut down. I usually work very long and hard through the day and I tend to shut down and listen to music or watch a movie. And that turns my mind off and then the next morning, early I am ready to go again.

What do you love about science?

Science is not an odd and special human activity or set of beliefs in the same way that theology or dentistry are human activities that you think of as different in their own way and often among a host of other human activities and belief systems. Scientific knowledge is quite simply what we know for sure about reality. It is something that is shared by every human being whether they know it or not, their lives depend on it. And the activity of adding to science, which isn't just the realm of so called scientists, is the most important - now in our time of overpopulation and decline and shortages and continuing conflict - the most important activity I believe for the future of humanity. ×

With permission from EOL.

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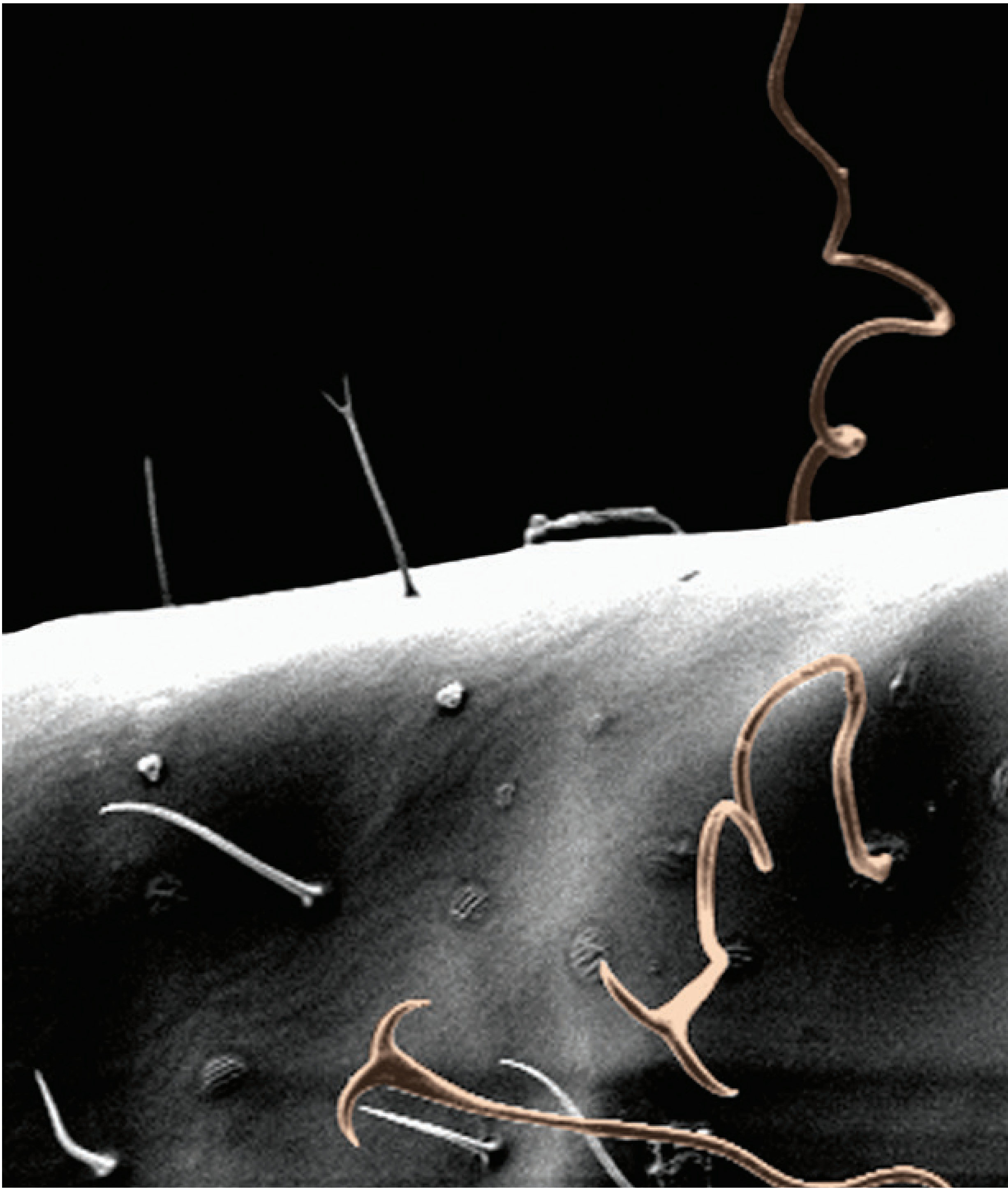

Larva anchor-tipped hair macro
Image courtesy of Clint Penick

Article

How E. O. Wilson helped me disappoint my parents and become a barber for ants

Clint Penick

How E. O. Wilson helped me disappoint my parents and become a barber for ants

Clint Penick

My dad always told me to go to college so that I didn't end up digging ditches. But when I went to college, I discovered the work of E. O. Wilson and decided to study ants. Ditch digging and ant research actually have a lot in common— both require a high-quality shovel, and both involve long hours digging holes under the hot sun. But becoming an ant scientist wasn't the end of my fall from grace. That happened when I became an ant barber.

To much of the world, E. O. Wilson was known as an ant expert, but among ant scientists, he was known for his expertise on an even narrower group—"big-headed ants" of the genus *Pheidole*. Wilson spent a large chunk of his career cataloging all the *Pheidole* species in the New World and naming more than three hundred new species himself. If an ant could capture E. O. Wilson's attention for that long, I thought they must be worth studying.

My chance to study *Pheidole* finally came when I was in graduate school. My lab inherited two colonies of the ant *Pheidole rhea* from Bert Hölldobler, Wilson's longtime collaborator, and I thought they would be an interesting group to work on. *Pheidole* are typically small ants whose colonies contain soldiers with very large heads, hence why they are called "big-headed ants." What makes *Pheidole rhea* different is that their colonies contain an additional soldier caste with even larger heads, which are called "super soldiers." The fact that super soldiers exist was already interesting, but what was even more interesting was that nobody knew why.

As I planned my study on *Pheidole rhea* super soldiers, I ran into a problem. The two colonies we inherited were no longer thriving, and they had stopped producing super soldiers altogether. I tried adjusting their diet, changing their nest temperature, and giving them more moisture, but nothing worked. Then when I thought all was lost, I received an email from my lab mate, Adrian Smith, with some exciting news.

Adrian had been visiting the workshop of Ray Mendez, an expert on ant-rearing who designed live colony installations for zoos and museums. It turned out that Ray had also acquired a colony of *Pheidole rhea* recently, and his ants were doing something he had never seen before. Typically, when ants move into a new nest, they group their larvae into a pile on the floor. But when Ray's *Pheidole rhea* colony moved into the new nest he designed for them, they did something different—they began to plaster their larvae all over the walls of their nest like a layer of living wallpaper.

After receiving this news, I went back to the Pheidole rhea colonies in our lab to see

Profile view of ant *Pheidole rhea*
Photo: April Nobile | © AntWeb.org | CC BY-SA 3.0 | Wikimedia Commons

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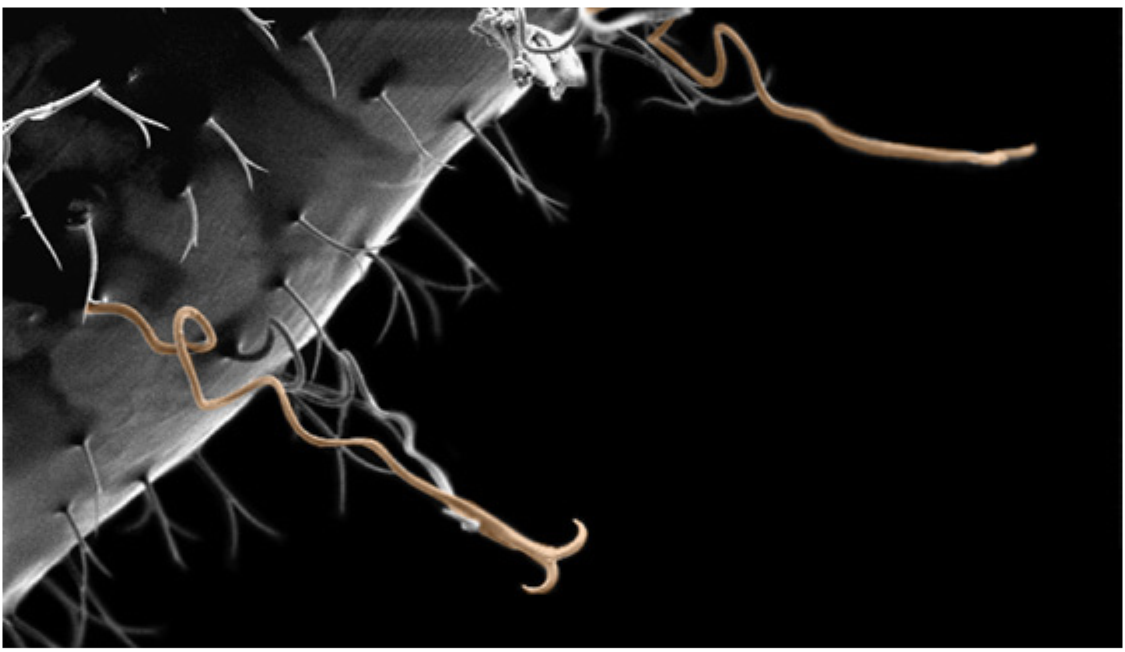
if they were doing the same thing with their larvae. They weren't. So what made Ray's colonies different?

When comparing our nests to Ray's, there were some major differences. Our nests followed the typical design for laboratory colonies with a nest chamber constructed from smooth dental plaster. But because Ray's colonies were destined to be used in museum exhibits, he constructed his nests to look more natural. Instead of making the walls smooth, he made them rough and bumpy. He also incorporated soil into his plaster mix to provide some color and give the walls texture. In the end, we thought there might be something to his nest design that made the ants behave more naturally.

Following Ray's instructions, Adrian and I built new nests for our *Pheidole rhea* colonies that incorporated soil into the plaster to give the walls a rough texture. Sure enough, when we gave these new nests to our colonies, workers began to hang their larvae on the walls just like Ray's colony had. What had been holding our colonies back all along was not something to do with their diet or temperature, but was our nest design.

Instead of switching back to the study I had originally planned on *Pheidole rhea*

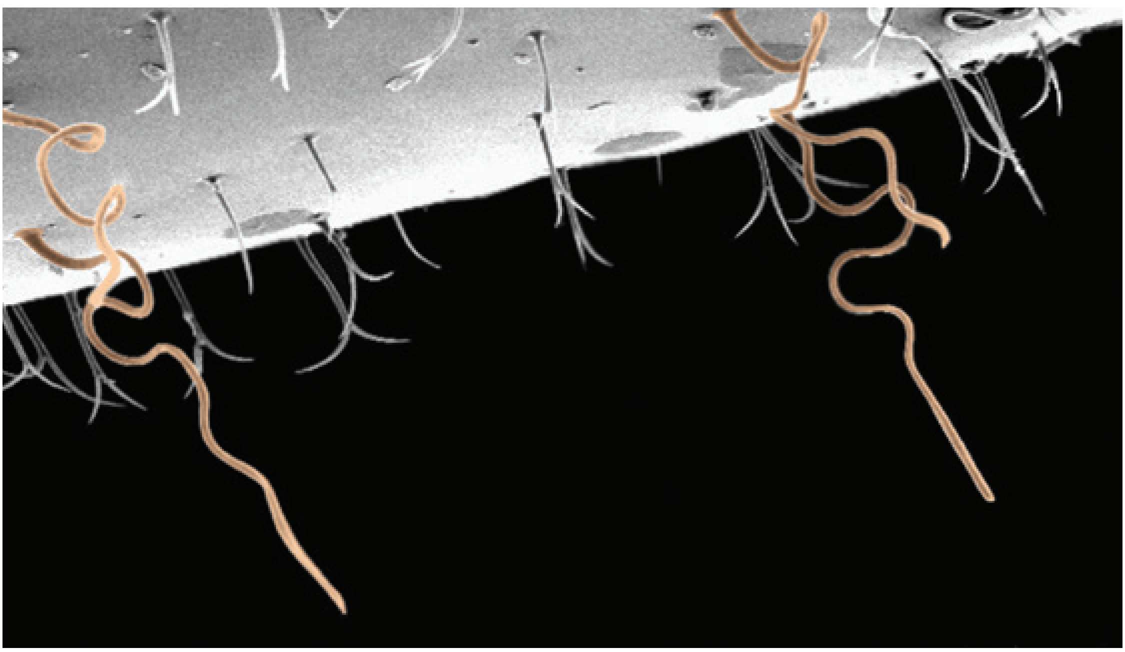


Larva anchor-tipped hairs
Image courtesy of Clint Penick

super soldiers, I was now more excited to learn about how their larvae stuck to the walls of their nest. My first thought was that the larvae must be secreting some kind of glue. Unlike adult ants, larvae are soft and feel slightly sticky to the touch. But when I looked at the larvae under a microscope, I noticed something else: on the back of each larva were several rows of long hairs that ended in two curved points. Could these hairs be what allowed larvae to stick?

When I dug into the literature on ant larvae, I found out these hairs had a name—they were called "anchor-tipped" hairs. Unlike typical larval hairs, these were almost five times as long, and they had a spring-like shaft that made them more flexible. While there was some speculation about how these hairs might be used, no one really knew.

Here is the part of the story where I became an ant barber. It seemed likely that these anchor-tipped hairs were involved in attaching larvae to the walls of their nest, but how could we know for sure? Adrian had an idea: give the larvae haircuts. If we cut the hairs of the larvae and they could no longer stick to the walls, then we would know that the hairs were responsible. So how does one go about giving an ant larva



Larva haircut
Image courtesy of Clint Penick

a haircut? We used tiny scissors (yes, really) and worked carefully under a microscope to cut off just the tip of each hair without harming the larva. Once the hairs were cut, we returned the larva to its nest to see if it would still stick.

Our experiment worked, and larvae with haircuts could no longer stick. The hairs were clearly responsible for allowing *Pheidole rhea* to hang their larvae, but how common could this behavior be? After going back into the literature, we found out that nearly every species of *Pheidole* has larvae with anchor-tipped hairs, and numerous other ant genera do as well. Even more distantly-related species appear to have evolved similar structures that serve the same purpose. These include “uncinate” and “hooked” hairs, which feature a single hook instead of an anchor tip, as well as structures called “sticky door knobs,” which are blunt knobs protruding from the backs of larvae that end in a sticky surface. When you put all these species and structures together, it seems common that ants hang their larvae, but no one had seen it because we had not given our ants proper nests.

Besides honing my skills as an ant barber, what I liked about this project was that we were able to use basic natural history to solve a mystery that had long gone unnoticed. This was exactly the type of science E. O. Wilson had promoted throughout his career. Wilson was a naturalist at heart who paid attention to the small things—his own theories on biogeography and social evolution grew from his deep knowledge of ant biology. It is no wonder, then, that so many scientists followed his example to study ants. There are now whole societies dedicated to ant research and other social insects, and surprising discoveries continue to be made every day.

And now that the world has machines to dig our ditches, it’s fortunate that Wilson inspired so many of us to keep the art of hole digging alive.

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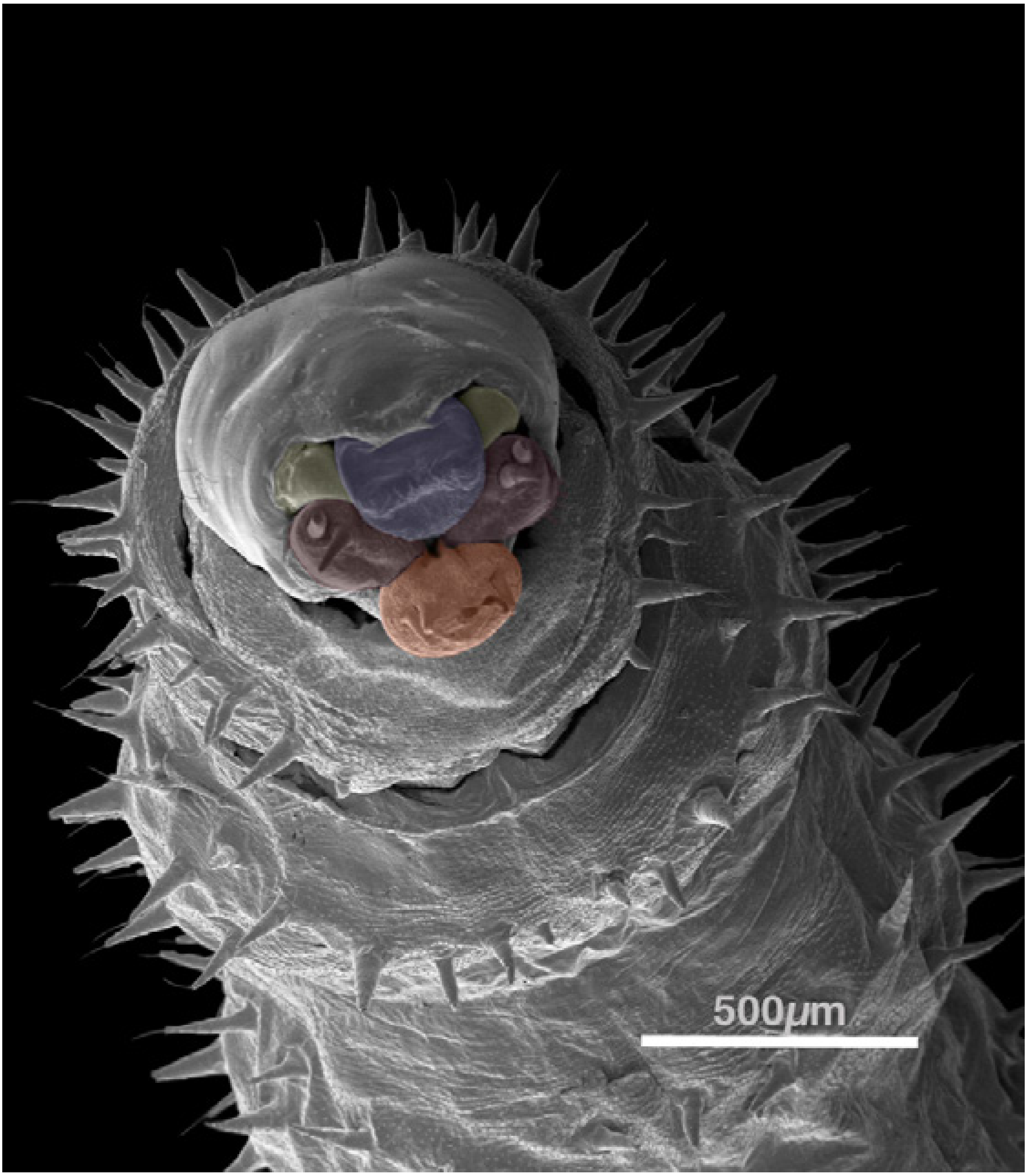


Larva head
Image courtesy of Clint Penick

Novomessor cockerelli queen (left) and worker (right)
Adrian Smith

Portfolio

Adrian Smith

Portfolio
Adrian Smith

Dr. Adrian Smith is Head of the Evolutionary Biology & Behavior Research Lab at the NC Museum of Natural Sciences and a Research Assistant Professor at NC State University. He is a biologist interested in insect behavior, ecology, and communication. His work has primarily focused on ants, with discoveries like describing the fast, spring-loaded jaws of vampire ants and describing the predatory behaviors of Florida's skull-collecting ants. More recently, his insect work has diversified into describing locomotory behavior in beetles and collembola. Dr. Smith produces and publishes media on the YouTube channel Ant Lab. Videos there focus on insect natural history and the stories behind the science and have been viewed more than 14,000,000 times.

Please tell us about your research and your social media presence?

My research lab is in a natural history museum and is actually glass-walled and on-exhibit. The idea the museum designers had was that real research science can and should be of interest to the science-interested public. For me, I extend this into my social media presence. My Instagram, Twitter, and, most of all, YouTube content is

Adrian Smith

Odontomachus brunneus | Adrian Smith

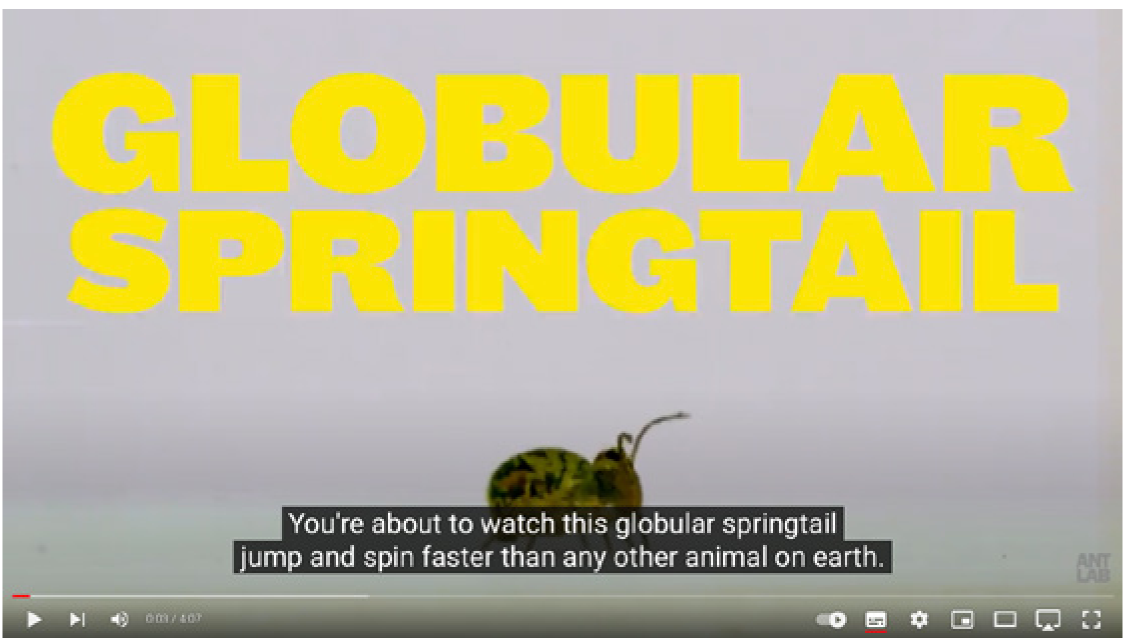
Portfolio
Adrian Smith

all about sharing science. Beyond sharing my research projects and the work of my colleagues, I try to also use the scientific tools I have to generate content that provides new ways to look at and appreciate insects.

Any interesting functional morphology, biomechanics and/or behaviour stories you can tell us?

Yes! I have been slowly working on a project with globular springtails. They are tiny soil arthropods that have a spring-loaded appendage tucked under their body that they use to catapult themselves spinning into the air. Their spinning jumps have them rotating at over 370 backflips/sec. I've published 2 videos about that project, and am continuing to film them and analyze their jumps. The best thing about them is that they are everywhere, and very little work has been done on this incredible aspect of their behavior. All of the work I've done on them, so far, has been from individuals I've collected from my backyard.

I've also started a project on cockroaches and the mechanics of their jumping ability. There's an incredible kind of roach from South Africa that is called a leaproach. It



Globular springtails jump and spin faster than any animal on earth?! | Ant Lab
https://www.youtube.com/watch?v=Quo1EUeE5PM

evolved grasshopper-like hind legs and a high-flying jump. There was a notion that these were the only true jumping cockroaches, but it turns out that even the most common pest roaches jump. No one has taken a close look at common roach jumping abilities, so we are doing that.

What interests me about both of these stories, beyond the research projects themselves, is that these are organisms that nearly anyone, almost anywhere can find. They are part of our everyday worlds, not something that hidden away in a remote jungle. Even with these common things, there are still new things to see and new things to discover. If my research can get us to view our own worlds in a new way and give us all a new perspective and a new means for appreciating the nature all around us, I think that makes it even more worthwhile.

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

It does change how I see things, in two ways: 1) Timescale. Insects often don't live and behave at our own speeds and scales. Sometimes, we physically can't see what

Cockroaches Jump & Fly?! I filmed it in slow mo, it's AWESOME | Ant Lab
https://www.youtube.com/watch?v=bnPWU-mqGL8

A trap-jaw ant *(Odontomachus brunneus)* queen (right) and her workers | Adrian Smith

Portfolio
Adrian Smith

they are doing because it's too small or too fast or over too long of a period to watch. So, video is a tool to visualize insects at our own, more clumsy, scale. That might be through high magnification, a week-long timelapse, or filming at 6,000 frames per second. I often get comments on my YouTube videos from viewers saying things like: "I usually hate insects but seeing them like this makes me appreciate them more." I think comments like that are 100% about scale. Filming a roach or a moth, up close and in slow motion gives them character details and makes their movements more intelligible and less chaotic (to us). It's seeing them in a way that is truer to what these insects are, rather than just what our limited perception allows us to normally see them as. 2) Stories. A lot of research is done for a peer-scientist audience only. A lot of interesting science stories don't get told to anyone besides colleagues at a conference convention center. That's a shame. Making YouTube videos to tell the stories of the science I am around everyday has helped me realize how many stories there are. It's overwhelming. So many stories to share and too little time to do it!

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

Outside of science, I am inspired by craft or work in any medium that reveals depth and detail the deeper you look. I love when there is a world and a practice I can learn about behind the surface of something I'm drawn to. This might be a meme account on Instagram, an expert appraisal of an oddity on Antiques Roadshow, or a video about sneaker culture on YouTube. I love the depth and detail and (often times) absurd levels of attention and consideration to seemingly insignificant things.

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

Video projects are always happening at various stages. There are bits of videos started on things like stonefly researchers and entomobryid springtails (the long ones, rather than the globular ones). I've also been working on a collaboration with an artist who works in photography. It's a longer-term project based on insect flight that has been producing some interesting test images. We're probably a year or so out from having something to show, but it'll be great when we are ready!

A trap-jaw ant *(Odontomachus brunneus)* queen (center) and her workers | Adrian Smith

Novomessor cockerelli queen (left) and worker (right) | Adrian Smith

Portfolio

Adrian Smith

What is the last book you enjoyed?

A Swim in a Pond in the Rain by George Saunders. This book is a distillation of his creative writing course focusing on Russian short stories. I could not put it down and found so much in it that was relevant to my work and media making. An incredible reading and learning experience.

What are your favourite 3 websites, and why?

YouTube – it's all there. What else could you want on the internet?

Twitter – it's nice to feel a little in-the-loop, sometimes

ShopGoodwill.com – browsing the virtual shelves for treasures hidden amidst a sea of donated junk? Sign. Me. Up. ×

See Ant Lab for Adrian's YouTube videos:
https://www.youtube.com/antlab

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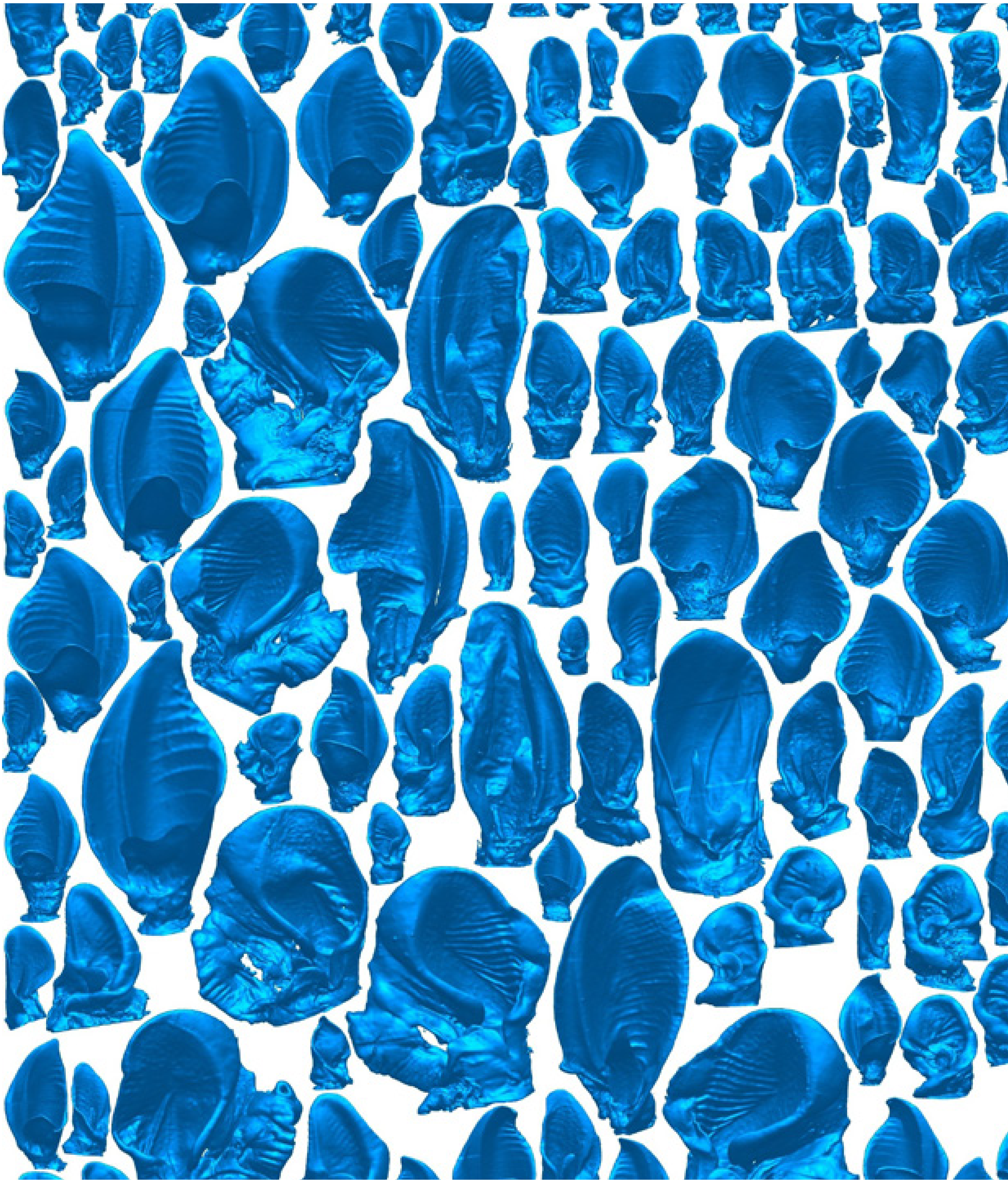
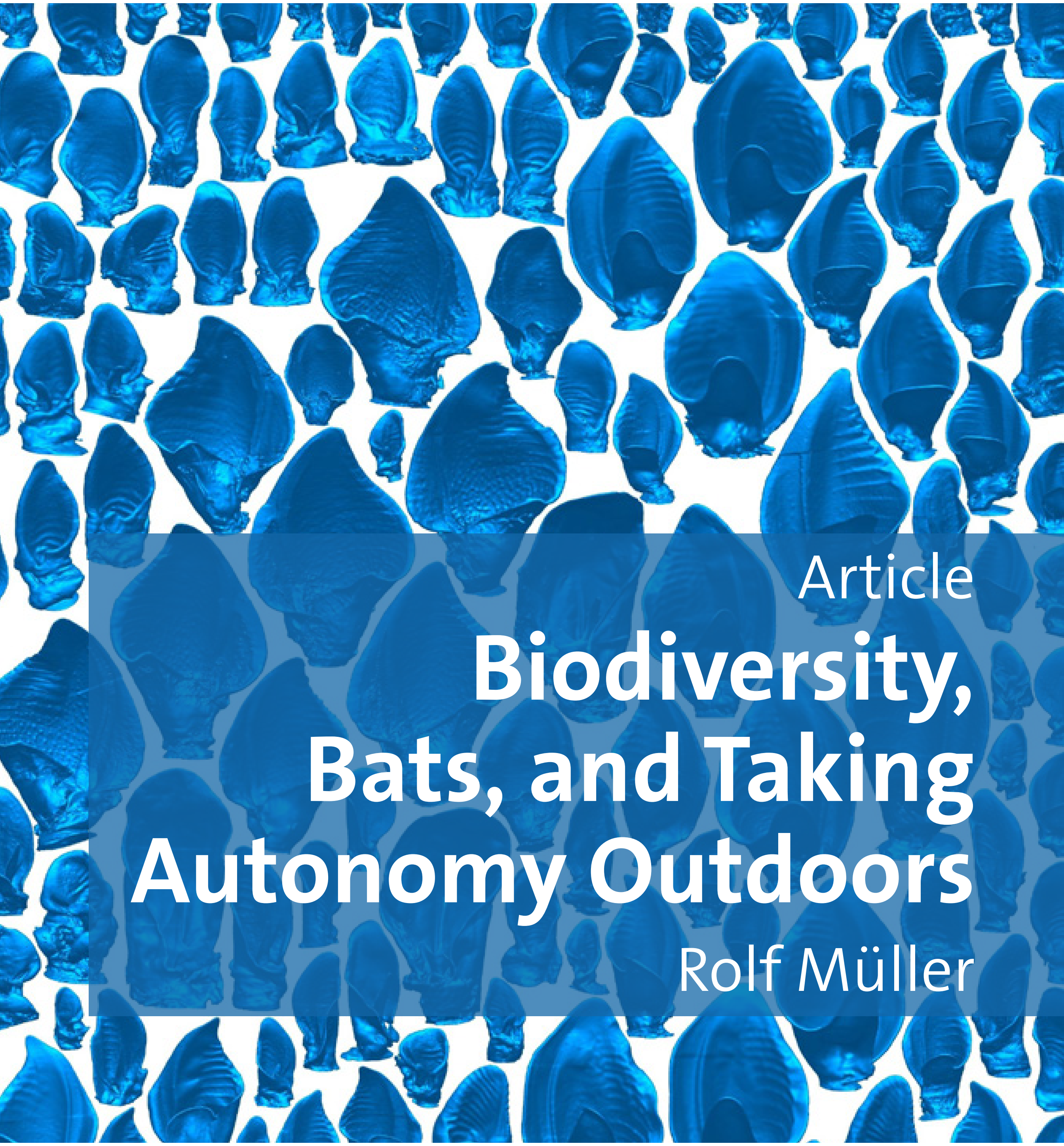
A trap-jaw ant worker (*Odontomachus ruginodis*) and winged male (right)
Adrian Smith



Data set of digitized bat pinna shapes
Image courtesy of Rolf Müller



Article

Biodiversity, Bats, and Taking Autonomy Outdoors

Rolf Müller

Biodiversity, Bats, and Taking Autonomy Outdoors

Rolf Müller

Bioinspiration, or obtaining insight for technical solutions from the study of biological systems, already has a fair number of success stories that can testify to the potential of the approach. Beyond the often-quoted examples of bioinspired products, there is a more fundamental reason why biological systems can provide valuable insights to engineering that cannot be obtained in any other way. Biological systems are the result of an evolutionary process that operates on a temporal scale exceeding anything engineers are capable of by many orders of magnitudes. At the same time, it has operated on an astronomical number of species and individuals, each of which has been evaluated for its fitness through extensive testing in the real, physical world. The enormous scope of the evolutionary process makes it possible to search parameter spaces for possible solutions that are much larger than what engineering can handle given its much more limited resources. Hence, looking at the outcomes of evolution has the potential to solve engineering problems that have resisted conventional approaches due to their complexity.

The world's biodiversity contains millions of species each of which could be regarded as an evolutionary solution to a high-dimensional optimization problem. Since some of these optimization problems will overlap with the technological needs of humanity, biodiversity could be a natural resource for engineering innovation. While using biodiversity to satisfy societal needs such as raw materials, food, or medicine has happened throughout human existence, turning to biodiversity for technological insights is still in its infancy. So far, bioinspiration has only scratched the surface of this natural resource, because it has focused on a small number of model systems that is negligible compared to the number of species that make up the world's biodiversity.

The limited number of accessible biological model systems makes it likely that the best model for any given problem may not have been analyzed and a better solution may hence still be waiting to be found. However, the value of biodiversity for bioinspiration could well go beyond just providing a gargantuan repository for evolutionarily optimized solutions. The world's biodiversity is not just a miscellaneous collection of unconnected species, but also contains a tight nexus of phylogeny, ecology, and common functional principles that are derived from common physical principles.

In the biological sciences, exploiting the nexus of biodiversity to find common principles and understand individual specializations is known as the "comparative method" and has been used with great success over many decades. For example, biologists may look at the differences between two species that are phylogenetically close but occupy different ecological niches to determine how the specifics of their ecological niches have shaped these species. Individual projects in bioinspired engineering are typically based on a single species or very coarse abstractions of biological function. An equivalent to the comparative method of organismal biology has yet to take hold in the field.

In my laboratory's research, we are using a comparative approach towards the engineering goal of achieving autonomy in natural environments. Taking autonomy outdoors could have important impacts on areas such as agriculture, forestry, as well as environmental monitoring and clean-up. However, production-level autonomy solutions have so far been limited to tightly controlled environments such as factory

The noseleaf of the greater horseshoe bat | Rendered by Dane Webster, Virginia Tech
Image courtesy of Rolf Müller

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floors and warehouses. Overcoming the difficulties imposed by the poor predictability of complex natural environments such as dense vegetation will require new approaches that can encode the required sensory information and turn it into dexterous and reliable mobility.

A biological model for these abilities can be found in bats. Bats are an evolutionary success story that has resulted in slightly more than one fifth of all currently living mammalian species, second only to rodents. This success is commonly attributed to a unique combination of effortless mobility in three dimensions with reliable and powerful yet parsimonious biosonar sensing. This means that the evolution of bats has found a way to compress all sensory information that is needed to support the bats' mobile lifestyle into pulsed trains of short biosonar echoes and to process these echoes into neural signals that can control the world's most complicated flight apparatus, flapping wings with about 20 degrees of freedom for non-rigid motions.

Because of the large number of species, bats could be a great opportunity to put the use of biodiversity for bioinspiration to the test. Bats are highly diverse in various aspects of their ecological niches which includes different food sources (insects, vertebrates, nectar and pollen, blood) as well as different habitat types. This latter diversity in habitat types could be exploited in a comparative approach to identify the right mix of sensory and motor capabilities that can deliver reliable autonomy in natural environments.

Among the different ecological bat types, two closely related groups of bats, the horseshoe bats (family Rhinolophidae) and the Old World leaf-nosed bats (family Hipposideridae) stand out for their ability to navigate and hunt for prey in dense vegetation. Both groups are highly diverse with about 200 species that occur exclusively in the Old World and include the largest number of species in the tropics. The biosonar systems of these bat species are characterized by a number of unique features missing in bat species that operate under less demanding conditions and could be candidate adaptations for encoding the sensory information needed to master these demanding habitats.

Among the defining features of bat biosonar in these bat groups are sonar signal designs with a time-frequency structure that is particularly well-suited for picking up signal features due to motions of a prey insect (Doppler shifts). However, the superb navigation abilities of the animals are still far from understood. Again, a comparative approach hints at features that are absent from other bat species. An obvious example are the interfaces through which these bats emit their biosonar pulses and receive the returning echoes. Bats in these groups emit their pulses through nostrils that are surrounded by "megaphone shapes" that do not only have geometrical detail such as grooves but can also change their shapes under muscular actuation. Similarly, the outer ears that collect the returning echoes are equipped with about 20 muscles that make these structures change their shape in one tenth of a second, about three times as fast as the blink of a human eye. These dynamic structures can be mimicked by so-called "soft robots" that seek to approximate the flexibility of biological tissue and how they can be deformed by muscles using materials such as silicone and pneumatic or tension-based actuators (image 1).

Building such soft robots based on horseshoe and leaf-nosed bats and taking them to the field has already demonstrated interesting capabilities. For example, the ability to map locations under foliage cover with a precision comparable to GPS and to find passageways in foliage that are far narrower than the biosonar beam. In addition, the fast ear motions like the ones seen in bats can generate Doppler shifts that can be used to determine the direction of a sound using just a single acoustic frequency, a single receiver, and a single flick of the ear. It is likely that the diversity among these forest-living bats will yield more interesting insights into how sensory information can be encoded into short ultrasonic pulses and used to control mobility in three-dimensions within highly irregular, confined spaces.

The evolution of bats is a great example demonstrating that substantial portions

Image 1: Biomimetic robots inspired by bats. a) design that reproduces the flapping flight of bats (Image by Anshool Pradhan), b) biomimetic sonar system with deformable emission ("noseleaf") and reception structures (ears)(Image by Richard Carter).

Biodiversity, Bats, and Taking Autonomy Outdoors

Rolf Müller

Hipposideros speoris (Schneider's leaf-nosed bat)
Photo: M. Brock Fenton

Asellia tridens (Trident bat)
Photo: M. Brock Fenton

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Plecotus (Long-eared bats)
Photo: M. Brock Fenton

of the world's biodiversity have not been accumulating continuously but are due to "outbursts of evolutionary creativity" that are not only intense but also short (on a geological time scale). All modern "types" of bats were created about 50 million years ago over a time window of about three million years. If these so-called "adaptive radiations" could be understood from an engineering perspective, this could lead to ways for engineers not only to mimic the outcomes of the evolutionary process but also the secrets of its unique "creativity".

Since my 2014 *ZQ08* interview (https://zqjournal.org/editions/zq08.html p. 38), I have continued to focus on biodiversity, going beyond discovering new functional principles from individual case studies to explore how a single principle can be adapted to multiple uses. The time is right to explore biodiversity as a natural resource for bioinspiration on a large scale to help identify solutions to the growing number of complex problems we face. ×

Additional Reading

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Rolf Müller has studied various aspects of bat biosonar from the perspectives of biophysics and bioinspired engineering for about 20 years and has (co)authored over 120 peer-reviewed, full-length publications on the topic. In particular, he has worked on statistical signal processing of sonar signals in complex, natural environments, biosonar beamforming, as well as biomimetic sonar systems. The overarching goal of his current research is meeting the sensory information needs of autonomy in complex natural environments. To achieve this, he is focusing on dynamic information encoding in the physical domain using soft-robotics replicas of bat biosonar and extracting useful information from complex "clutter" echoes using deep-learning techniques. In addition, he has a growing research program on the kinematics of bat flight. He is currently a professor in the Mechanical Engineering Department at Virginia Tech and directs the Bioinspired Science and Technology (BIST) Center, an interdisciplinary effort that involves over 40 faculty members from across the university. In his international efforts, he directs the University of Brunei - Virginia Tech International Laboratory that is dedicated to the engineering analysis of biosonar, flight, and system integration in bats. His international work has been recognized by the Friendship Award of the People's Republic of China (2010), the Dean's Award of the VT College of Engineering (2011), Virginia Tech's Alumni Award for International Research (2016), and a Fulbright award (2022). He has been a Fellow of the Acoustical Society of America since 2019.

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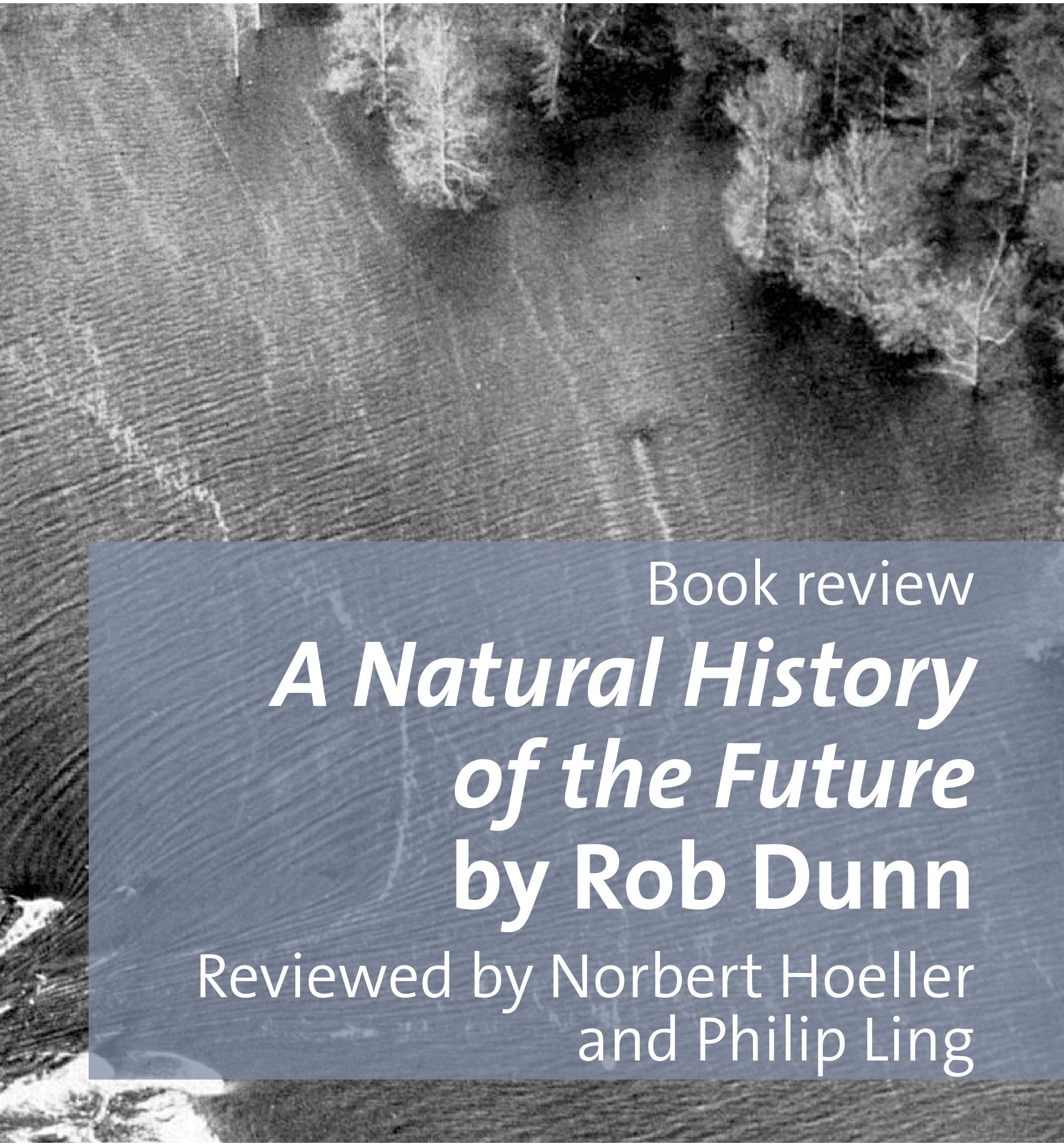
1927 Mississippi Flood Levee Breach
Photo: Steve Nicklas, NOS, NGS | Wikimedia Commons



Book review

A Natural History of the Future by Rob Dunn

Reviewed by Norbert Hoeller and Philip Ling

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Rob Dunn starts *A Natural History of the Future: What the Laws of Biology Tell Us about the Destiny of the Human Species* with the story of his grandfather who was nine years old when the Great Flood of 1927 washed away the town of Greenville in Mississippi. We need to find reasons for disasters, and the Great Flood was no exception, with blame attributed to people from Arkansas dynamiting the Mississippi levees to protect their levees, the wrath of God, or that the levees were not high enough. Dunn argues that the root cause is human hubris - we think we can subdue nature, such as our attempts to tame the Mississippi River. The meandering, regularly flooding Mississippi River, whose fertile delta created the state of Louisiana, was not compatible with the human need for consistency and predictability to support growing towns, cities,

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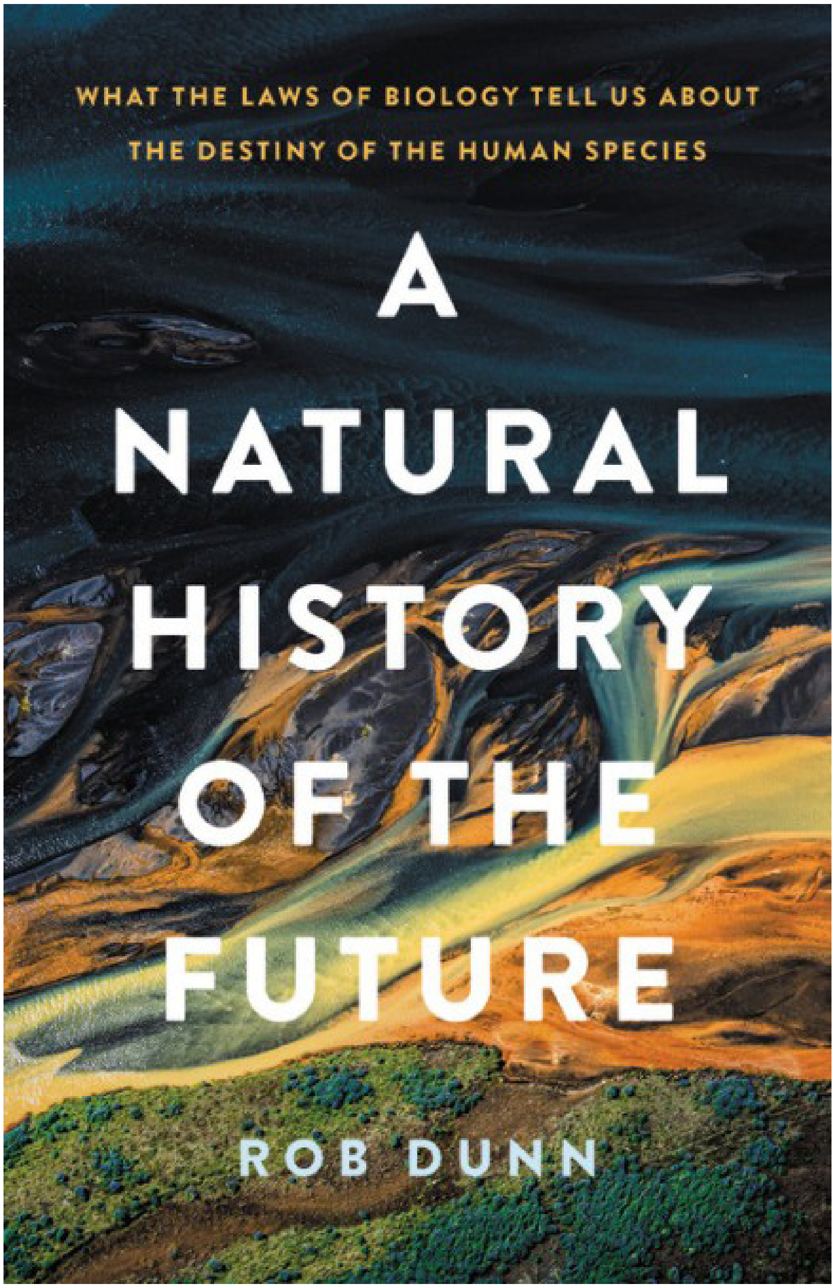
ports, and industry - and somehow we are surprised when levees break during extreme natural events.

In the predominant vision of the future portrayed in movies, nature is no longer visible, either because we have replaced it by design through technology, or destroyed it through an apocalypse of our own doing. Dunn argues that thinking we can build levees or other technologies to keep out nature is both futile and “at our own expense.” He proposes that we learn and understand the “laws of nature” to help make predictions that guide our actions and “create a world that is more forgiving of our own existence.”

Structure

The law of natural selection underlies many of the other laws described in the book. Contrary to the view that natural selection is associated with geological time, Dunn demonstrates that it happens all around us, particularly in species that reproduce quickly, such as bacteria. The chapter “Blindsided by Life” on Erwin’s law argues that nature is neither like us nor well understood. We may understand vertebrates reasonably well, but our knowledge of the diversity and importance of insects, fungi, bacteria, and viruses is woefully limited. We tend to simplify complex situations, to view


WHAT THE LAWS OF BIOLOGY TELL US ABOUT
THE DESTINY OF THE HUMAN SPECIES
A
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Crows
Photo: Jennifer C, 2019 | Flickr cc

all life through a human lens, and assume we have risen above nature through our intelligence and technology.

"Urban Galapagos" introduces the work of EO Wilson and his collaborators who not only observed nature but tried to understand the underlying mechanisms, leading to the species-area law that relates the size of islands to the rate at which species arrive, evolve into new species, and become extinct. This law applies to any isolated natural, rural, or urban habitat - the smaller they are, the more likely extinction will occur faster than species can arrive or evolve. Conversely, large habitats like farms and urban areas are home to a growing number of species. Unfortunately, these biologically uniform and heavily managed farms and urban spaces tend to favour pests and parasites.

"The Inadvertent Ark" explores ecological niches that encompass a species' needs. As habitats become increasingly constricted and climate change makes habitats unsuitable, corridors between habitats help species migrate. Ecologists tend to emphasise natural corridors - their interest is in natural spaces, avoiding the "messiness of the human-centered world." Dunn and his colleagues studied how our megacities and global transportation systems are creating corridors for species particularly well-adapted to urban, human life. The chapter "The Last Escape" explores the consequences when species move to regions that pests and predators have not yet colonised or find unsuitable, such as drier and cooler areas where malaria cannot thrive. As we become more connected, it becomes easier for our enemies to catch up with us with potentially disastrous consequences. At the same time, changes in the geographic distribution of niche habitats due to climate change are expanding the warmer and moister areas in which more diseases and pests can survive. Under some climate models, Miami could become like cities in tropical Mexico and therefore vulnerable to tropical diseases. "The Human Niche" explores our preferred niche: moderate temperatures and relatively dry. Despite our technological advances, our niche has become more concentrated due to the growth of agriculture. Climate change will further restrict the niche in which we thrive.

"The Intelligence of Crows" describes one adaptation to variability and unpredictable change: big brains that enable novel solutions. Crows have some of the largest brains as a percentage of body size. Human inventiveness should help us deal with change, but Dunn argues our individual cleverness has been stifled by institutions that developed in a world of climate stability and economic growth, where the

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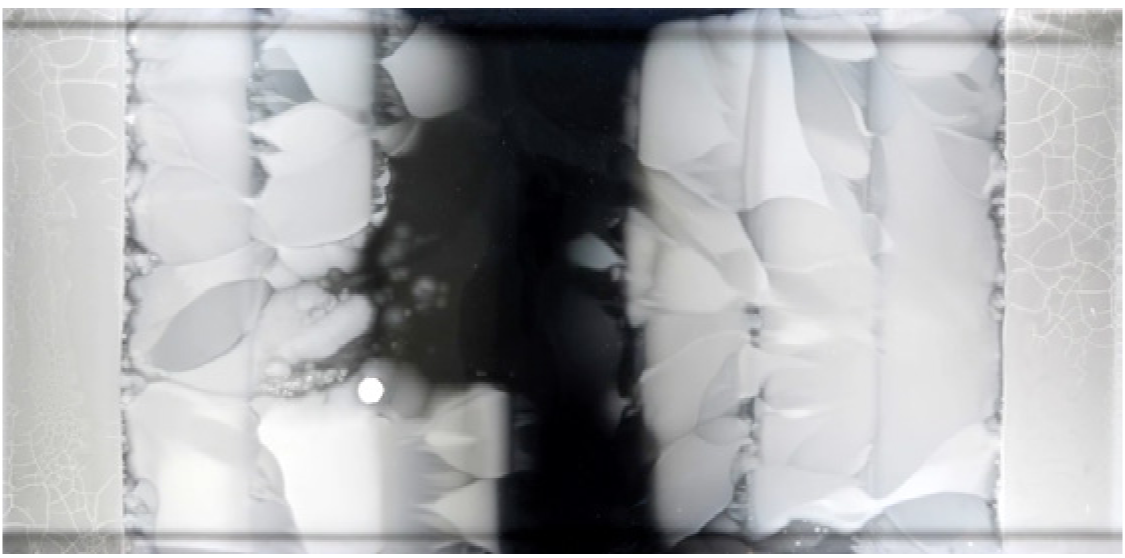
cost of flexibility outweighed the benefits. "Embracing Diversity to Balance Risk" describes our agricultural system that has been successful through controlling variability, yet research shows that countries with high crop diversity with an even distribution of crop species delivered more stable and high average yields.

"The Law of Dependence" emphasises that despite our technological prowess, we remain dependent on nature. Dunn explores how we develop a diverse gut microbiome that can have a significant impact on our health, just as many of our crops and domestic animals are dependent on their microbial communities. "Humpty-Dumpty and the Robotic Sex Bees" points out that we are good at taking systems apart, but less successful at putting them back together. Attempts to recreate nature have rarely been successful - it is better to protect a watershed than try to recreate the purification services provided by that watershed. When we are forced to create technical solutions for natural systems that we have broken, the results are often not what we expect because we have a simplified model of how nature works.

"Living with Evolution" explores bacterial resistance through an example of real-time evolution in the Harvard "megaplate" [1] experiment that exposed bacteria to increasing concentrations of antibiotics. The animation below is mesmerising and



The Evolution of Bacteria on a "Mega-Plate" Petri Dish
Video: Harvard Medical School, 2017 | https://vimeo.com/180908160

reminiscent of the river deltas from the Introduction. The implications are ominous: in every experiment and using different antibiotics, it took only a matter of ten to twelve days before the bacteria became resistant to concentrations thousands higher than would kill the bacteria in the wild. The same evolution is happening when we misuse pesticides and herbicides.

In “Not the End of Nature", Dunn describes Sean Nee’s Evolutionary Tree that highlights lineage rather than species, and it puts in perspective how insignificant the human strand is - the end of humans is by no means the end of nature. “No Longer Among the Living” argues that “Our end is far nearer than is nature’s end.” Although we are driving some species to extinction, particularly those of interest to us, most of life will survive, especially simple multi-cellular and the vastly more common unicellular life that can live in extreme conditions. Dunn makes predictions on which species will survive and flourish after we are gone. With increasing levels of unpredictability that do not favour our big brain intellect, the future will belong not to the smart, but to the lucky and fast reproducing.

Perspectives

Dunn emphasises that despite our technology, our existence depends heavily on nature, and nature is very much a part of us. Our understanding of nature is woefully inadequate, partly because we ignore large parts of nature that do not attract our attention. He follows in the footsteps of EO Wilson in going beyond observing patterns in nature by diving into a broad range of observational and experimental studies of diverse natural systems that form the basis of his “laws of nature.” Each chapter explores how these complex and interdependent laws relate to a world increasingly shaped by humans, makes testable predictions of how these laws affect nature and more importantly humans, and describes research supporting these predictions.

The closing chapters are intended to be a wakeup call given the recent human trajectory, summarised by Dunn’s lucid comment: “We are still a young species. This suggests that if we last an average amount of time, our road is still long. On the other hand, it is the youngest species that are most at risk of extinction. Like puppies, big-eyed and not yet wise, young species are prone to fatal mistakes.” Yet overall, Dunn is optimistic that the future is not fixed but depends on our actions. He provides numerous

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Reprint from ZQ issue 21: Megan Thoemmes (Dunn Lab) sampling E.O. Wilson
Photo courtesy of Clint Penick

examples: building diversity, resilience, and adaptability into agriculture, industry, and business; protecting watersheds rather than trying to replace them with technology; maintaining a diverse microbial community to slow bacterial resistance; and deploying scalpels (such as bacteriophages) instead of hammers. Returning to the challenge raised in the Introduction, the three part "Stories from the Trenches" series in ZQ21 [2], ZQ22 [3], and ZQ23 [4] describes several ways in which we can learn to live with water instead of trying to control it with channels and levees.

The overarching message is that we need to protect "wild species on which we depend or might depend." We need to slow the rate of climate change to give wild species and humans time to adapt. EO Wilson's Half-Earth project (https://www.half-earthproject.org/) to protect half the land and sea sounds impossible, but even small steps including planting native species and creating corridors between habitat islands can make a difference.

In *The Design of Everyday Things*, Don Norman explains how incomplete or incorrect "mental models" can impact our ability to effectively interact with and gain full value from products and services. Designers and engineers that have adopted "human-centred design" help users acquire or develop accurate and effective mental models. Dunn encourages us to develop new mental models of our relationship with nature based on science rather than our desire for dominion over nature. Instead of relying on simplistic metaphors, we need to deeply understand nature and our place in it, not just through an ethical lens but also for the continued existence of the human species. ×

Robert Dunn is a biologist, writer and professor in the Department of Applied Ecology at North Carolina State University. He has written several books and his science essays have appeared at magazines such as *BBC Wildlife Magazine*, *Scientific American*, *Smithsonian Magazine*, *National Geographic*, and others. He has become known for efforts to involve the public as citizen scientists in arthropod surveys and bacterial flora studies. His projects include studies of belly button biodiversity, mites that live on human faces, ants in backyards, and fungi and bacteria in houses. For more see: http://robdunnlab.com

We would appreciate your feedback on this article:

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1. https://baymlab.hms.harvard.edu/media.html

2. https://zqjournal.org/editions/zq21.html p. 49

3. https://zqjournal.org/editions/zq22.html p. 29

4. https://zqjournal.org/editions/zq23.html p. 36

Crows
Photo: Mary Bailey, 2012 | Flickr cc

Philip Ling is a nature bug, electrical engineer, social entrepreneur, and philanthropist (Biomimicry Specialist 2012). Twenty-five years ago, he co-founded Powersmiths, a cleantech company manufacturing power system products that reduce environmental impact and energy waste, He remains as strategic advisor after its sale in 2018. Community service is important to him. His present focus is the Maitland Tower development in Eastern Ontario, following the Living Community Challenge. It will be a destination for regenerating our connection to nature, a field station and marine lab focused on the health of the St. Lawrence River, a hub for social entrepreneurs developing nature-based solutions, and an adaptive basecamp for nature-based recreation. He recently co-founded and is Board Chair of DoorNumberOne.org, an Eastern Ontario non-profit focused on climate action.

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Photo: Stephany Hildebrand

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