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About Zygote Quarterly

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Cover art
Cover: Fragile Future detail modules. Courtesy of Carpenters Workshop Gallery | Studio Drift, 2012 | pp. 2-3 & pp. 104-105: Installation view Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam. Materialism, Dandlelight, 2018. From largest to smallest amount of raw materials: steel, Manganese dioxide, zinc, paper, copper, dandelion seeds, polyvinylchloride (PVC), acrylonitrile-butadiene-styrene (ABS), lacquer, polyolefin, silicone, epoxy, tin, aluminum, phosphor, gallium nitride, gold. | Collection Studio Drift, Amsterdam | Photo: Gert Jan van Rooij

Design
Marjan Eggermont
Colin McDonald

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Paper Wasp Nest | Photo: Ben Grantham, 2010 | Flickr cc

Editorial

A lot of this issue is about functional capability: how to measure it, achieve it, and experience its effects. Our case study details engineer Grace Gu's search for the materials of the future and better ways to design them. Along the way Dr. Gu destroys a lot of samples of structures based on nature.

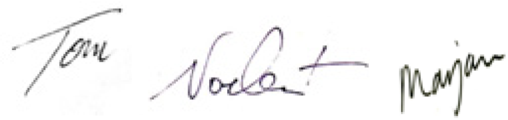
The elegant seeds of the Sonoran desert are highlighted in a photo essay from Arizona State University in another article. Here, the spare beauty of raw efficiency is shown in stunning form.

Three responders to our recent series "Stories from the Trenches" are concerned with another form of functional capability: how does one translate a great idea from nature into a phenomenon that will survive in today's commercial market? Perhaps it is not so very different from the challenges of a windblown seed in the desert of the southwestern United States.

Our portfolio features a pair of artists from the Netherlands who comprise Studio Drift, a techno-informed performance art studio provoking reflections on the nature of Nature.

Finally, three reviewers outline and comment on a recent book by Maibritt Zari that examines regenerative urban design and ecosystem biomimicry.

We also had 30 of our readers respond to our last issue number 23 in our now-regular reader survey feature - thanks for your comments and Happy Reading! ×



Tom McKeag, Norbert Hoeller and Marjan Eggermont

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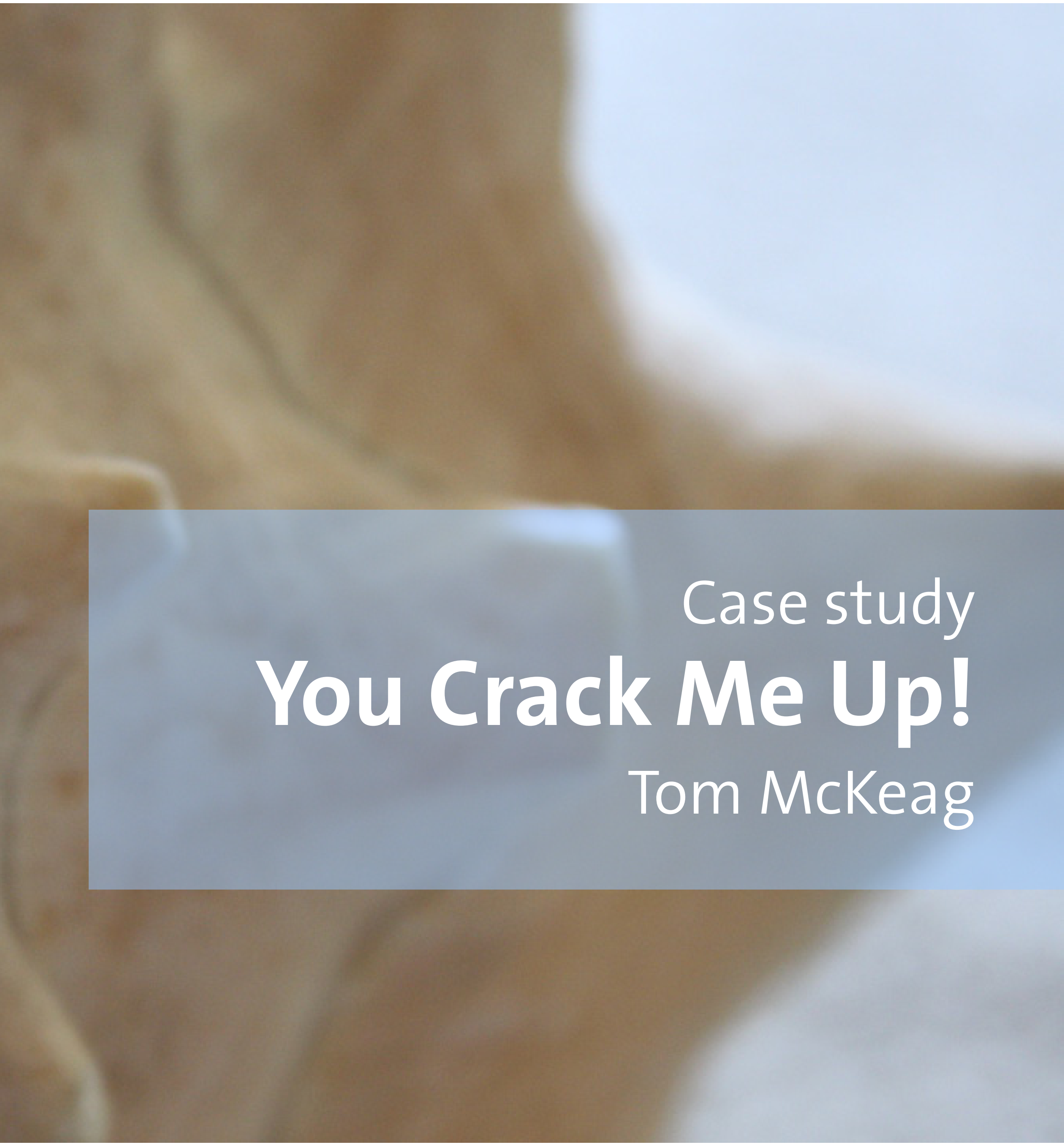
Spiral Conch
Photo: Sarah Turman Photography, 2009 | Flickr cc



Case study

You Crack Me Up!

Tom McKeag

You Crack Me Up!
Tom McKeag

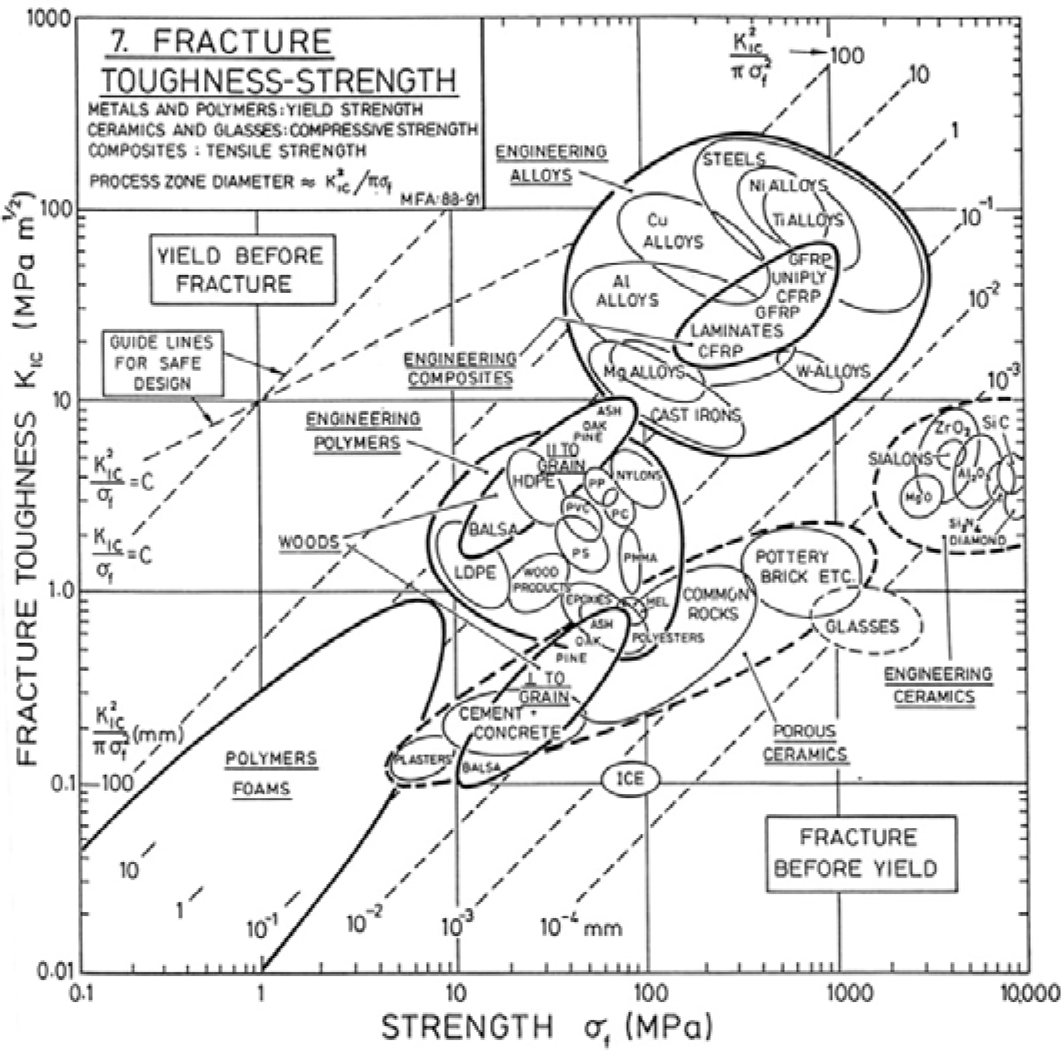
Grace Gu's Search for the Next Generation of Composite Materials

Dr. Grace Gu is an assistant professor in the Department of Mechanical Engineering at the University of California at Berkeley, and she spends much of her time figuring out how things will crack...or won't, and how engineers can design new materials and methods that will control those cracks to our advantage. Not surprisingly, she has looked to nature for some suggestions. She has also combined traditional material testing, algorithm-driven optimization and machine learning to push the boundaries of material design in the realm of additive manufacturing.

Grace Gu

In mechanical engineering and materials science, toughness is defined as the ability of a material to absorb energy and plastically deform without fracturing: how much energy can a given unit volume of that material absorb without rupturing? Fracture toughness is defined as the ability to resist the creation of cracks in the material. Often this characteristic is plotted on a so-called Ashby Plot, an X-Y grid comparing two properties, such as strength versus toughness. The Ashby Plot perfectly captures the structural contradiction that engineers and nature face continually: how to balance strength, the ability to resist stress, and toughness, how to yield just enough to avoid breaking and therefore remain intact and operational.

It's hard to have both; often materials might be quite strong but brittle, or be quite malleable but lack useful strength. Different classes of materials have different strength to toughness relationships. For example, in some materials, like metal alloys, an increase in strength might mean a decrease in fracture toughness, while the opposite may be true for materials like certain ceramics. Nature and engineers rely on composites to solve this contradiction, using a combination of materials with different structural characteristics in order to achieve the required performance balance. In the built world, reinforced concrete is a common example: concrete has high compressive strength, but weak tensile strength, so steel



Fracture toughness vs. Strength.
Graphic: M. F. Ashby, 1992 | Wikimedia Commons

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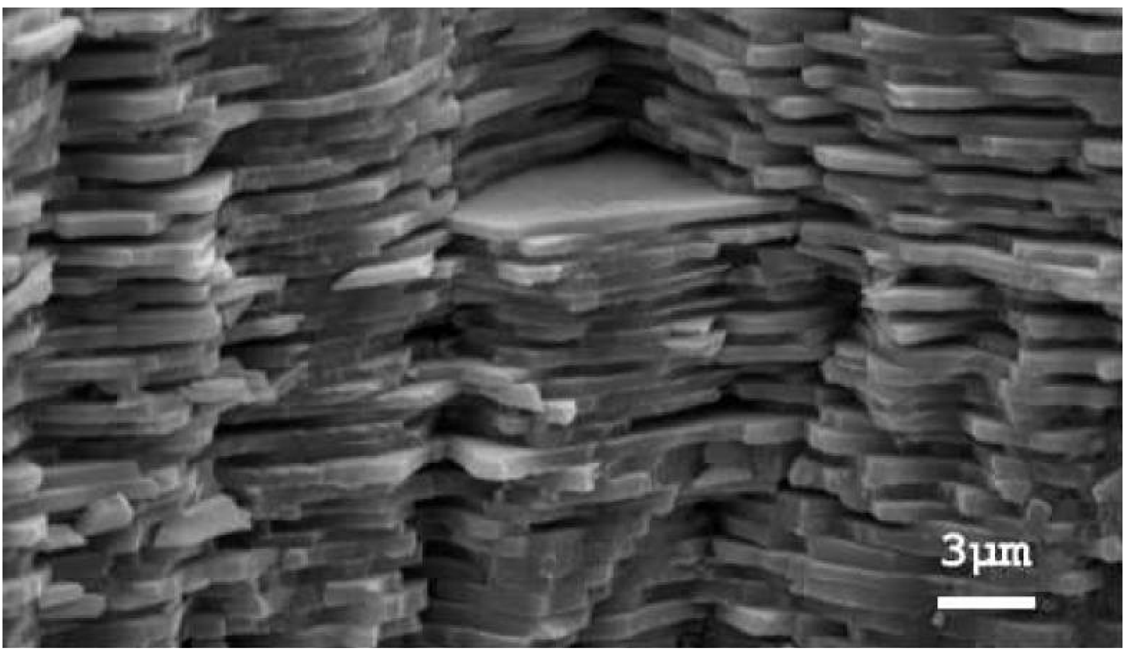
rebar is added to the concrete to improve its ability to be stretched without failing.

Natural organisms must cope with stress of all kinds, including compressive, tensile, and shear. Shear stress is the result of two surfaces or parts moving in opposite directions to each other. An example is the stress put on a filled teapot as you hold its handle. The loaded teapot wants to go down with gravity and the handle, with your finger in it, wants to go up. The resulting stress, at the interface between the teapot body and where the handle loop joins it, is where the pot is most likely to break. Shear stress is the cause. Strategies to resist these stresses can be put in one of two broad categories: intrinsic mechanisms that resist the crack before it occurs, and extrinsic mechanisms that mitigate the crack after it has started. In all, the name of the game is the dissipation of energy from its area of concentration. A simple example from the built environment is the carpenter's trick of drilling a small hole at the lead of a small crack in wood. The hole widens the point of the crack and lowers the concentration of forces there, relieving the kind of pressure that would make the crack deeper.

In response to these stresses the living world has developed myriad tactics to



SEM of mother of pearl lamellae
Photo: Fabian Heinemann, 2007 | Wikimedia Commons

prevent failure from cracks at all linear scales, and the abalone is a stellar example. Abalone are marine snails, belonging to the Phylum Mollusca, class Gastropoda, family Haliotidae, genus *Haliotis*. The abalone shell has evolved to survive in a demanding intertidal zone that includes impact from waves, and attacks by formidable predators like sea otters, octopuses, wrasses and stingrays. Abalone attach themselves to a rocky surface by means of a strong foot muscle, protected from above by a dome of remarkable composite material. Their shells are made of polymorphs of calcium carbonate: aragonite and calcite; set in two layers, an outer prismatic layer and an inner nacre layer. Nacre is the shiny mother-of-pearl used in jewelry and furniture. In the nacre layer aragonite tablets are set in a protein matrix. It is the combination of these soft materials to form an emergent hard shell that has fascinated researchers for many years. The nacre in the abalone shell has been shown to be 3,000 times stronger than the base material aragonite itself, far surpassing any man-made material.

At the macro scale the dome itself serves to deflect compressive loads much like domes we use in buildings. At the micro scale, mineral prisms set normal to the shell surface absorb impacts in the outer layer while separate tablets of aragonite are laid in brick-like fashion between thin layers of protein in the inner nacre layer. Blows to the shell cause these tiles to slide within their layers dissipating the impact energy into the more yielding protein matrix. Cracks that do develop are mitigated by several strategies: micro-voids, undamaged platelet layers that bridge across the gap and crack deflection within the offset protein "mortar" between the bricks. Moreover, the individual tablets or platelets themselves are not entirely free-floating. At the nano scale, "mineral bridges" of aragonite of less than 50 nm thickness connect the platelets in two directions: across the layers and with each other end-to-end within a layer.

The nacre of the abalone shell has been a prime focus of Dr. Gu's work. In particular, Gu and her colleagues have been interested in how the tablets of minerals stacked within the shell were connected within the protein matrix and how that arrangement might be mimicked or improved. First, the structure of the natural material is studied and copied into a computer model. From that model both computer simulations and synthetic material are made: the model is tested for stresses in simulation and the actual material is put into a tensile testing machine. Finally, the results from simulations and real testing are compared. This last part is important since the team is

3D printed composite based on Conch structural hierarchy adapted from Gu, Grace & Takaffoli, Mahdi & J Buehler, Markus. (2017). Hierarchically Enhanced Impact Resistance of Bioinspired Composites. *Advanced materials* (Deerfield Beach, Fla.). 29. 10.1002/adma.201700060.

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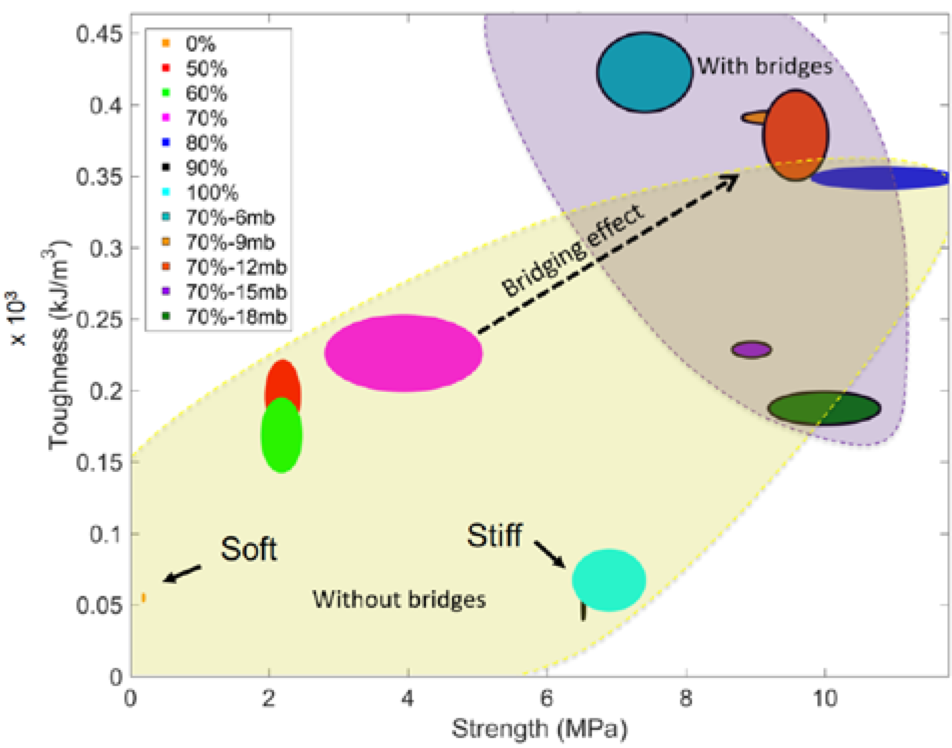
looking not just for a better material, but for a better way to design high performance materials.

Did the stiff volume fraction, or the presence of the mineral bridges make a difference in strength and durability? If so, how much of a difference and what seemed to be the optimal configuration of these materials? These are some of the questions that the team have been investigating. The team printed and tested various ratios of hard to soft material (material fraction), and samples with and without the interconnecting mineral bridges.

The results of this first-ever comprehensive study were dramatic. In analyzing the parameter of stiff material fraction, the team found that 70% was optimal and that the mineral bridges significantly increased both strength and toughness, vaulting the material into the upper right corner of the Ashby Plot, the region where materials are



Ashby Plot: Tuning interfacial design with mineral bridges can strengthen and toughen interface adapted from Gu, Grace & Libonati, Flavia & Wettermark, Daly & J. Buehler, Markus. (2017). Printing Nature: Unraveling the Role of Nacre's Mineral Bridges. *Journal of the Mechanical Behavior of Biomedical Materials*. 76. 10.1016/j.jmbbm.2017.05.007.

both strong and tough. These results now offer a promising pathway for composite material enhancement based on the design of these interconnecting bridges.

Dr. Gu earned her PhD at MIT under the mentorship of Markus J. Buehler (https://zqjournal.org/editions/zq13.html p. 8). The study of composites during her Masters work had led her to optimization investigations; these, in turn, led her quite naturally to mentors in nature, since many materials in nature are composites that outperform synthetics. She became fascinated with these examples, specifically the shells of the abalone and the conch. "What excites me about them is that they offer both models for the best way to mimic material and also how to fabricate it". During most of her PhD work, Gu focused on fracturing, toughness and the tunability of mechanical properties of materials.

Beyond acquiring knowledge of the mechanical properties of the abalone shell, Gu honed her problem-solving skills during her PhD work at MIT. The most important overall lesson? "Keep at it - don't be discouraged!" says Gu with a determined demeanor, "Just as in life, gaining a PhD comes with its highs and lows, but you must stay resilient and steadfast in accomplishing your goals". More specifically, she relates the sequence of first spotting a novel concept and assessing whether an investigation is worth doing; forming a hypothesis and plotting one's methods and desired outcomes. Moreover, she has found that unpacking a complex material structure problem into its different orientations, optimizing and testing these and then comparing them has taught her much about salient design principles.

The development of her problem-solving path has comprised three parts: the study of nature for clues to optimization, the actual experimentation and testing of these parameters, and finally the evolution of synthetic optimization techniques. This path has brought together the fields of bio-inspired design, traditional mechanical engineering testing, algorithm-based modeling and machine-learning. She has coined the acronym BADD, bio-inspired algorithmic-driven design, to summarize this search to design the next generation of composites. It is a novel combination of investigative techniques, combining the conceptual of algorithmic modeling and machine learning with the practicality of additive manufacturing and material testing.

As excited as Gu and her colleagues are about the results of their work on abalone, they are equally enthused about current investigations into the conch shell. Another

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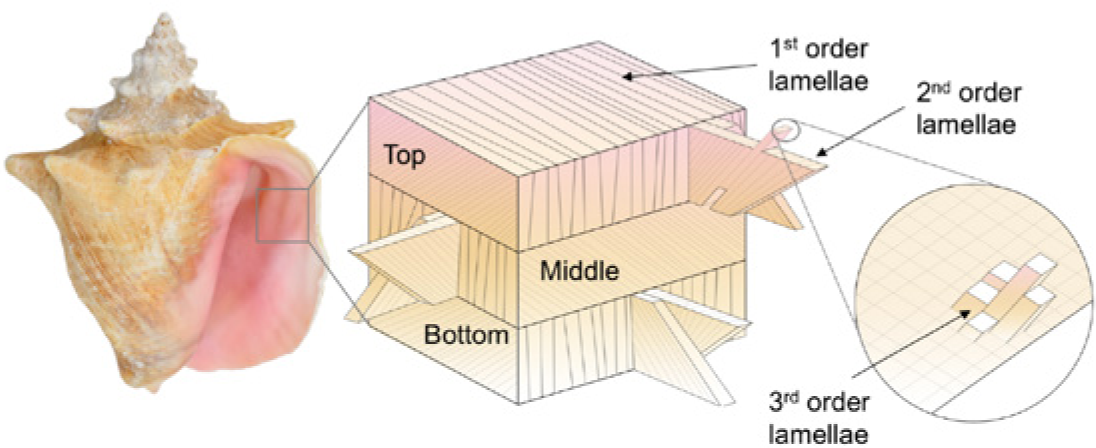
gastropod, or “stomach foot”, in the family Strombidae, Strombus sp., and related species like the Queen Conch (*Lobatus gigas*) possess a shell that is ten times tougher than the nacre of the abalone. Intriguingly, while it is made up of 99% stiff material, it is 1,000 times tougher than the individual stiff material. Excessive stiffness often leads to brittle behavior rather than more toughness, but not so in this case. Gu and her colleagues are investigating this phenomenon and how it might be used to make higher performing materials. Their findings so far have revealed that hierarchical structure plays a key role.

The conch shell has not been studied as much as the abalone and the reason, says Gu, is the complexity of its architecture. Like the abalone, the material is a layer composite, and it is built in a hierarchy of linear scale. This means that at each scale level there is a structure that reinforces the performance capability of the next layer up. Each of us possess numerous examples of this in our bodies. A human hair, for instance, is actually a system of materials bound together across scales. Keratin proteins are repeatedly twisted , entwined, bundled and sheathed in successive scale levels and it is this structure, rather than material, that gives one’s hair its tensile strength.

In the case of the conch, layers or lamellae of composite mineral and protein are arranged in three scale orders. At the first order of scale, layers of composite are laid over each other with the direction of their individual second order lamella running in



Conch shell hierarchical structure adapted from Gu, Grace & Takaffoli, Mahdi & J Buehler, Markus. (2017). Hierarchically Enhanced Impact Resistance of Bioinspired Composites. *Advanced materials* (Deerfield Beach, Fla.). 29. 10.1002/adma.201700060.


Eiffel Tower (also see https://zqjournal.org/editions/zq09.html p. 8) | Photo: Grace Gu

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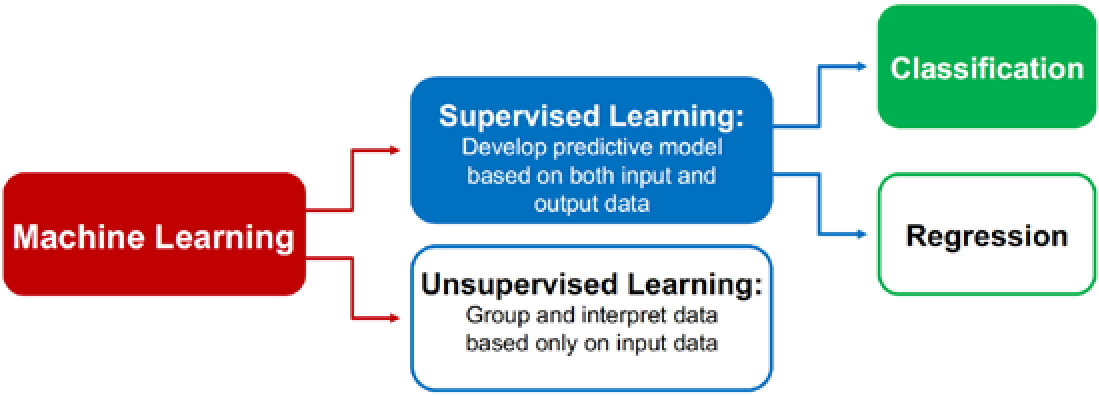
different directions, much like the alternating wood grains in the layers of plywood. These second order lamellae are also made of individual sheaths or lamellae and these are oriented at a 45 degree angle to the first order layers, and alternate their directions, so that adjacent lamellae are always cross-grain to their neighbors. The second order lamellae are further divided into a third order with similar characteristics. While this complexity is described from the larger scale to the smaller, it is important to note that that is not how Nature builds things, but rather from the small to the large, from the bottom up. In a bird's forming an eggshell, for instance, nucleation at sites on membranes starts the protein scaffolding that enables mineralization in different layers and arrangements.

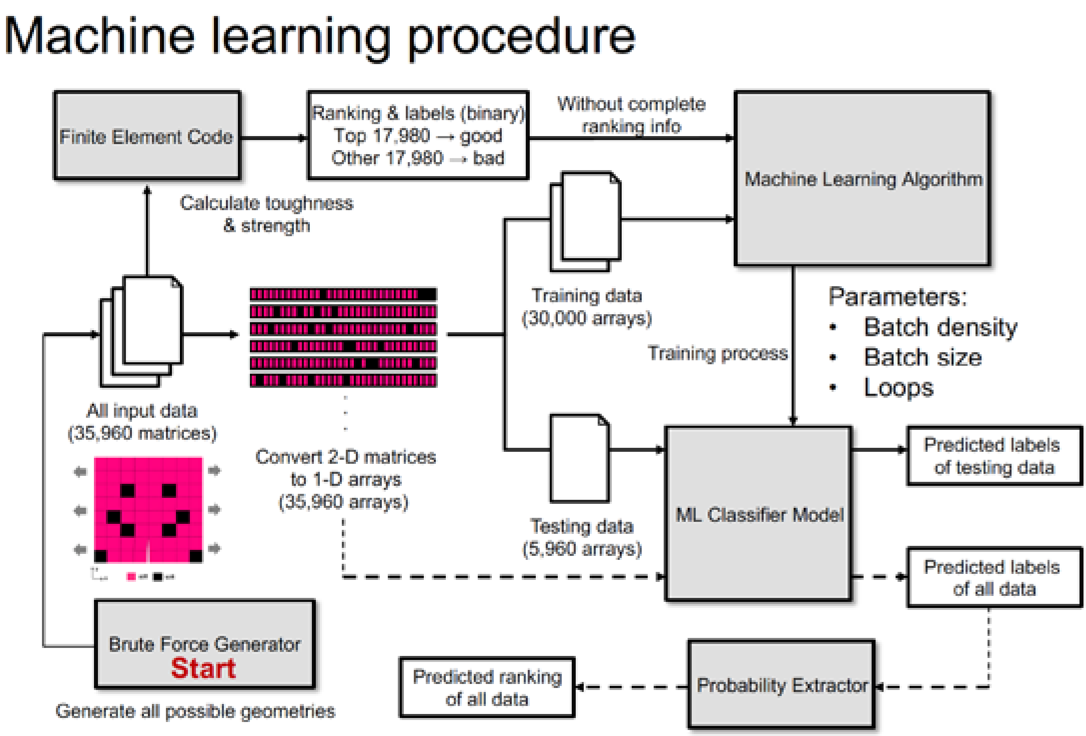
Gu and her colleagues at MIT carefully mimicked the complex offsetting of these many ordered lamellae within a digital model so that they could attempt to build a synthetic physical sample. They 3D printed two types of soft and hard materials, acrylic-based photopolymers, to replicate some of the complexity of the shell, namely the two-part composite, alternating layers and multi-directional orientation of the flexible interstices.

They then tested synthetic samples in a 10 mm diameter, 5.6 kg drop tower series, and found the conch-inspired materials to be significantly stronger than the abalone-inspired samples. Moreover, the team was able to demonstrate that deflection of cracking in their synthetic samples was optimum at a threshold angle of 50 degrees at the soft-stiff material interface. Clearly, the incorporation of natural strategies like offset interfaces and angles and linear scale hierarchy within a material were routes to greater performance.

Dr. Gu sees three challenges in the composite field: interfacial failure or delamination, the vulnerability of composites to impact damage and the large design space, meaning that the complexity of certain high-performing natural materials makes the analysis of key parameters demanding and rigorous synthesis difficult. The Gu team has demonstrated progress on interfacial design by mimicking the mineral bridges of the abalone, and on impact resistance by replicating the material hierarchy and alignment of the conch shell's layers. On the last score, addressing the wide performance analysis required to design, they have turned to machine learning to accelerate the iterative process of modeling and testing,

The team is training a machine learning algorithm using actual test and modeling data to classify and rank combinations of





Machine learning to optimize for toughness and strength adapted from Gu, Grace & Chen, Chun-Teh & J. Buehler, Markus. (2017). De novo composite design based on machine learning algorithm. *Extreme Mechanics Letters*. 18. 10.1016/j.eml.2017.10.001.

Conch | Photo: Sailn1, 2014 | Flickr cc

finite elements for a prediction of the best choices for issues like crack propagation. This is despite the algorithm not "knowing" what the mechanics of the problem are or even that the model geometry has a given crack edge. Gu claims that the model they are using for prediction is above 95% accurate for both toughness and strength. Future work includes using machine algorithms to design materials for other properties beyond mechanical, such as electrical and thermal properties.

As to the future of both bio-inspired design and her work, Dr. Gu thinks that both are going in the same direction: to "smart". Materials will be multi-functional and responsive lattices perhaps. As importantly, they will have been designed in a more streamlined fashion, with more auto-optimization built in. Gu is a firm believer in combining modeling and physical testing and this has brought her team significant results.

There are still limitations, to be sure, particularly in the mimicking of multi-scale hierarchies with artificial systems made in additive manufacturing, and the working with more bio-friendly substances like hydrogels. For most of her experimentation Gu has employed a Stratasys Connex 3 Objet 500 printer. This is a so-called polyjet printer, a multi-head inkjet printer that lays down material in layers and then uses UV light to set each layer into solid form. A solid object is thus built incrementally, and because of the multiple nozzles, can be built from different materials. While the ability to use different materials together in one form is a plus and the printer has good adhesion, the materials made are relatively weak and it is hard to demonstrate their characteristics. Gu looks forward to having a wider range of materials and material combinations to experiment with, particularly metal/ceramic mixes.

Dr. Gu is most proud of her recent work in machine learning and multi-scale modeling. Of the latter she says that being able to extract lessons from one scale and bring it to another is very gratifying to her. Solving difficult problems is what seems to make Gu tick: when asked what drives her, she responds that she is in constant pursuit of the secrets waiting to be discovered in the natural world; within arms-reach and beyond. "I will say to my team members, 'Oh, this is so ambitious - but let's do it anyway!'" ×

We would appreciate your feedback on this article:

Chilopsis linearis (Desert-Willow) Seed
Photo: Taylor James, 2018

Photo essay

Designed to Move

Photography by Taylor James

Designed to Move

Photography by Taylor James

This photo essay is adapted from the exhibition "Designed to Move: Seeds That Float, Fly or Hitchhike through the Desert Southwest," organized by the Biomimicry Center at Arizona State University in collaboration with the Desert Botanical Garden, Phoenix; ASU's Herbarium; ASU's School of Arts, Media and Engineering; and ASU's Design School.

Ethnobotanist Gary Paul Nabhan got it right. Plants are nouns, he once wrote. Seeds are verbs. Plants are rooted in place. Seeds are designed to move.

This is the inherent paradox in the life of most plants. They are attached to the earth, but their offspring must travel to find a safe site in which to germinate and flourish. Faced with this dilemma, seeds have evolved ingenious solutions to the challenges and opportunities of moving through their environments—whether in a tundra or prairie, forest or grassland, chaparral or desert.

Some plants are able to disperse their seeds over great distances by using seedpods that latch on to the fur of passing animals. But furred animals are just one of the many free taxis that transport seeds to safe sites. Amazonian fish disperse seeds. Dung beetles do it. Galapagos tortoises, earthworms, lizards and rattlesnakes do it. Even frogs do it. Seeds slide through the meandering drainpipe of a bird's digestive tract. They are carried one by one in the vise-like jaws of tiny ants. They are tucked away in the cheek pouches of roaming kangaroo rats.

Seeds are also lofted by the wind. They parachute into flowing water. They are slowly buried in arctic soils by frost heave. Some seeds just bide their time inside capsules that gradually tighten and tense as they dry. Then one day—pow! The seedcase snaps open, catapulting its contents into the air like a slingshot flinging a load of stones.

As these photographs by Taylor James demonstrate, one of the greatest troves of untapped design potential can be found in the seeds of desert plants. In the desert, rainfall is sparse and sporadic. Sunlight is intense. Temperatures can soar to 120 degrees F or drop below freezing. Yet places like the Sonoran Desert of the American Southwest and Mexico host more than 2,500 species of plants. It is one of the most botanically rich deserts in the world. How do these plants meet the extraordinary challenges of this harsh environment with such robustness?

Part of the answer lies in the cunning design of their seeds which are exquisitely fitted to the constraints of the circumstances in which they live. New visualization technologies are giving us access to this time-tested genius. Their lenses zoom in on the intricate designs that are largely invisible to us as we casually stroll through the desert. In the process, they uncover a storehouse of possibilities for solving many human challenges. Studying how seeds float, fly or hitchhike is inspiring innovation in newly engineered materials, robotic design or mechanisms for more efficient flight.

But as every good designer knows, a successful design does not separate considerations of function from those of beauty. Desert seeds are no exception, as these photographs reveal with startling clarity. "An object's beauty emanates in part from how well it works, how snugly it fits its function, and how elegantly—with a minimum of effort or extras—it is made," writes Janine Benyus, author of *Biomimicry: Innovation Inspired by Nature*.

Beautiful, elegant and functional. These are design's highest ambitions. The inspiration for realizing these ambitions lies all around us. Imagine the possibilities! ×

Adelheid Fischer, Exhibition Organizer

We would appreciate your feedback on this article:

Quercus sp. (Oak) Nut
Photo: Taylor James, 2018

Asclepias subulata (Desert Milkweed) Seed | Photo: Taylor James, 2018

Cenchrus ciliaris (Buffelgrass) Fruiting Structure | Photo: Taylor James, 2018

Tamarix aphylla (Salt-Cedar) Fruiting Structure | Photo: Taylor James, 2018

Krameria bicolor (White Ratany) Fruiting Structure | Photo: Taylor James, 2018

Castela emoryi (Crucifixion Thorn) Fruiting Structures | Photo: Taylor James, 2018

Erodium cicutarium (Filaree) Seed | Photo: Taylor James, 2018

Proboscidea parviflora (Devils Claw) Fruiting Structure | Photo: Taylor James, 2018

Ptelea trifoliata (Common Hoptree) Fruiting Structure | Photo: Taylor James, 2018

Seed Reflection
Photo: CatDancing, 2015 | Flickr cc

Article

Perspectives on "Stories from the trenches"

Pete Foley, Margo Farnsworth, & Arndt Pechstein

Perspectives on "Stories from the trenches"

Pete Foley, Margo Farnsworth,& Arndt Pechstein

The "Stories from the Trenches" series followed several examples of biomimetic innovation from ideation and proof-of-concept (https://zqjournal.org/editions/zq21.html p. 38), through business model generation and market entry (https://zqjournal.org/editions/zq22.html p. 8), and across the Valley of Death to commercialization and scale-up (https://zqjournal.org/editions/zq23.html p. 22). The last article included a call for other voices. Three authors with extensive experience engaging the business community and 'making biom* real' responded and share their insights. - Ryan Church, Rachel Hahs, and Norbert Hoeller

Leveraging the Broader Innovation Community by Dr. Pete Foley

Kudos to the authors of "Stories from the Trenches" for writing a detailed 'warts and all' evaluation of three biom* concepts. As useful as simple, easily communicated case studies are in communicating the potential value of biom*, the fuzzy, complicated, real-world examples 'from the trenches' will better help us as practitioners to more consistently turn biom* ideas into viable products, services, and businesses. These case studies are neither clear-cut successes nor failures, and that's what I believe makes them valuable. The real world is frequently messy, and these kinds of examples provide us with the all-important opportunity to understand what can go wrong, as well as what went right.

One of the insights contained in the articles is that "execution is (often) more important than ideation." I believe that this may be key to unlocking the challenge of mainstreaming biom*. We spend a lot of time focused on how uniquely difficult it is to translate nature's solutions into viable designs that are compatible with human technology or systems. But what if we are focused on the wrong problem? I'm not suggesting translation is easy, it isn't, but what if the bigger problem really is execution in a broader sense? If true, maybe the answers to many of our challenges already exist in the innovation community, and all we need to do is explore some different collaborations and partnerships.

All innovation is hard: For sure, biom* derived innovation is hard. But so is all innovation. In the startup world, failure is the norm rather than the exception. Research from Shikhar Ghosh (https://www.fastcompany.com/3003827/why-most-venture-backed-companies-fail) suggests

droplet parachute | Photo: frankieleon, 2009 | Flickr cc

Perspectives on "Stories from the trenches"
Pete Foley, Margo Farnsworth,& Arndt Pechstein

that about 75% of venture capital backed companies fail to return cash to investors. And failure is not unique to startups. Failure rates for new products in general sit somewhere between 80-95% (https://www.publicity.com/marketsmart-newsletters/percentage-new-products-fail/). As with biom*, many ideas fail because they cannot be effectively reduced to practice, but many more fail as the innovation funnel narrows, and ideas are shepherded from the front end of innovation to the commercial market. They fail because of financial, competitive, communication, and scale up challenges, because we misunderstand consumer needs, or because we don't innovate in a vacuum, and other innovations overtake us or simply fit better as the world evolves around us. These are the types of issues described in the articles, and they are not unique to biom*.

So, is this where we are missing expertise, and could we solve this, at least in part, by working more closely with the broader innovation community?

But isn't biom* different? Aren't the challenges of turning nature's creative solutions into human technologies unique? And aren't our goals different? To the first point, yes, there are certainly unique elements associated with the transformation of nature into human designs. Steven Vogel and his wonderful book, *Cats Paws and Catapults*, was a huge influence on my original interest in biom*. In that book, he certainly made a compelling case for some specific challenges in converting aqueous, carbon-based innovations, with life histories and micro scales, into practical humanizable innovations. Some of those challenges may recede as nanotech and 3D printing come into their own, but they undoubtedly still exist, and are part of the challenge we face. However, nearly all innovation requires some form of translation from an inspiration domain into the target domain. For example, James Dyson needed 15 years and 5,127 prototypes to translate the cyclonic filtration of a sawmill into a vacuum cleaner. Binary punch cards, used in early computers, and foundational in the formation of IBM, were adapted from the Jacquard weaving loom, which was in turn derived from musical organs. But this adaptation, as you can imagine, was far from fast or simple. So while the specifics may be different for biom*, the challenge of adapting an idea from one domain to another is far from unique. I'd argue instead that this kind of analogical bridging is ubiquitous in innovation, and that as a general rule, the bigger the gap between the source and executional domain, the bigger the innovation potential, but the bigger the translation challenge. In that context, it is a shared challenge with the rest of the innovation world. The specifics are different, and we do need unique expertise at the specific nature-human tech interface, but our biggest challenges lie further down the innovation pathway.

Are we focused on the wrong problem? This is based on the “Stories from the Trenches” case studies, and my own experience. Technology transfer between domains is hard, but the bigger challenges often lie in the details of reducing an idea to commercial practice: challenges that come after the basic design and translation work has been done. And at this part of the innovation process, biom* has more in common with ‘the rest of‘ innovation than it has differences. The good news is that we don’t necessarily need to become experts in this; all innovation faces downstream challenges such as determined incumbents, challenges producing supporting data, and unexpected technical hiccups during scale up. But much of the expertise to manage this already exists, if we can form the right partnerships.

Universal principles: Universal principles and generalizable insight for navigating the path to commercialization already exist within the general innovation community. It’s far from a precise science, and the failure rates I mentioned earlier are daunting for all innovators. But at least we don’t have to start from scratch. Instead, I believe we need to more deliberately tap into this pre-existing expertise, especially the ‘back end of innovation’ community, and become active collaborators and students. In practical terms, we don’t need to talk to ourselves via biom* conferences and networks, but instead we need to be a part of the broader innovation community. They are not our competitors but are instead potential allies, enablers, and cheerleaders.

Pre-existing methodologies: We also don’t need to create methodologies. Plenty of these already exist. Processes like Design Thinking and Innovation Labs already have a great deal of traction in the innovation business community. And because they already embrace the transfer of ideas from one domain to another, biom* is a good fit with them. Adopting and integrating with existing methodologies comes with several other advantages. The familiarity they carry with innovation leaders, the decision makers who hold the purse strings, mitigates much of the risk associated with investing in a ‘new’ innovation process. It is somewhat ironic, but innovation managers are often risk averse, and prefer to fund and resource established methods and proven innovators.

Perspectives on "Stories from the trenches"
Pete Foley, Margo Farnsworth,& Arndt Pechstein

Adopting existing methods and collaborating with existing innovators could therefore help us to secure funding, gain a seat at the table, and begin the process of becoming a default option for innovation. Getting that foot in the door is crucial, as it potentially triggers a virtuous cycle, leading to more case studies, more successes, and ultimately cheerleading from inside the venture capital and corporate innovation world.

Leveraging existing expertise: The more we integrate with the existing infrastructure; the more we can leverage their expertise. Venture capitalists, for example, contribute far more than financing to early-stage firms. They also provide advice on scale up strategy, business models (https://en.wikipedia.org/wiki/Business_model), strategic partnerships, consumer communication, and marketing strategies

Aren't our goals different? Maybe, and certainly most people who are engaged with biom* have a stronger than average commitment to sustainability. But what I read from the case studies is that when the rubber hit the road, it was performance numbers that drove investment and ultimately commercialization. I know not everyone agrees with this, but I personally think we can have a bigger impact as advocates for sustainability inside the existing innovation community, or selling high performance sustainable innovation to venture capitalists, than we can by sitting outside of the mainstream, and making sustainability rather than performance our primary goal. Sustainability is important, but we'll get more broad-based traction, and make a bigger impact, if we sell on performance, and build in sustainability, without making it a tradeoff.

What should we actually do?

- Become insiders rather than outsiders in the innovation community. If I go to an innovation conference today and say 'Design Thinking', or 'Innovation Labs', it requires no further explanation. If I mention 'biomimicry', or 'bio-inspired', I often still have to explain what I'm talking about. If we want to achieve the familiarity and acceptance currently enjoyed by popular methods, we need to proactively reach out. Attend, and ideally speak, at more general startup, innovation, and design conferences, write more blogs on innovation and design web-sites. Perhaps reach out to the National Venture Capital Association (NVCA, https://nvca.org/), or become active in the Front End (https://marketing.knect365.com/feiusa/) and

Moth, Ant, and Dandelion | Photo: Josh More, 2008 | Flickr cc

Perspectives on "Stories from the trenches"
Pete Foley, Margo Farnsworth,& Arndt Pechstein

Back End of Innovation (https://marketing.knect365.com/bei/) communities.

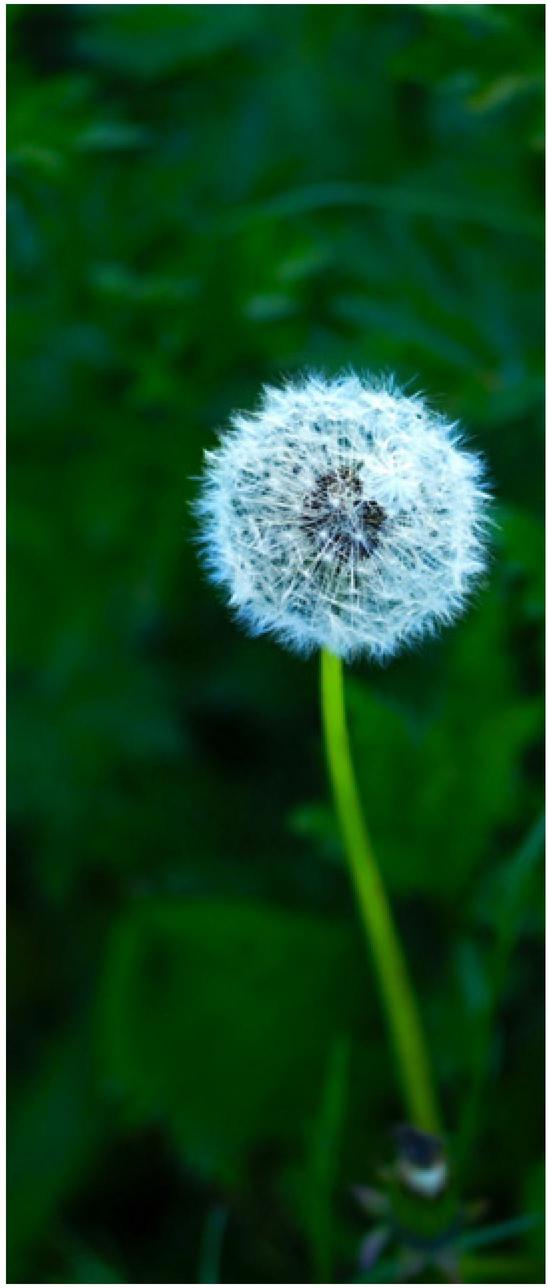
- Partner with existing innovation providers. A lot of companies provide innovation services. Can we reach out and offer biom* as an option to them? Ideally, we may want to run a Design Thinking workshop built primarily around biom*, but to simply introduce biom* as one of the lenses in that process would start to build that essential familiarity. Seek out colleagues who teach innovation, and offer biom* as a module to be included as part of broader innovation studies. Become a presence in the open innovation community, via, for example, http://openinnovation.net/, https://www.innocentive.com, or via knowledge transfer partnerships, such as the UK's http://innovateuk.org.
- Work on our externally facing branding. Biom* as terminology is a useful internally facing tool to encompass biomimicry, bio-inspired innovation, biomechanics, bio-utilization, etc. And while these all have distinct characteristics, the differences between them are largely irrelevant to the outside world. This is a tough one, but if we are to build familiarity and fluency, I believe we need to work on consistent externally facing branding.

Familiarity and fluency. I do want to add a side note on the importance of familiarity. Humans, and most animals for that matter, like the familiar. It's safer, requires less thinking, and reduces risk. The Mere Exposure effect (1) in psychology tells us that we implicitly like things simply because we've encountered them before. The flight to the familiar effect shows us that when stressed, people migrate towards proven solutions and products. Even innovation and R&D managers are human, and innovation is a very stressful business, full of uncertainty. While they are hopefully more open than most to new ideas, they still migrate towards established and proven practices, especially when large sums of money are involved. We need to feel familiar if we are to become mainstream, just like any other leading brand.

The illusion of uniqueness. It's easy to fall into the illusion of uniqueness, or even to fall victim to a superiority bias, even if it's only the superiority of our challenges! This is a very human bias. For example, a survey by Svenson in 1981 (https://www.sciencedirect.com/science/article/pii/0001691881900056) showed that 93% of drivers the U.S. thought that they were better than average. But instead of focusing on our uniqueness, would we be better trying to integrate ourselves with the broader innovation community? Innovation is never going to be easy, and for many of us, that's part of its attraction. But just as we use analogy to bridge between nature and human centered innovation, shouldn't we also use it to bridge between biom* and the broad innovation community, and become part of something bigger, and more familiar?

1. Zajonc, R. B. (2001). Mere exposure: A gateway to the subliminal. *Current Directions in Psychological Science, 10*(6), 224–228.

About the author: Dr. Pete Foley is an Innovation Consultant who specializes in applying Psychology, Behavioral Economics and Perceptual Science to business challenges. He draws on experience gleaned from 25 years as a serial innovator at Proctor & Gamble where he published over 100 patents, and spent 8 years working with some of the world's experts in the Behavior Sciences to apply their insights to business needs.



Dandelions (detail)
Photo: Thorston Hartmann, 2013 | Flickr cc

Field Perspectives on "Stories from the Trenches" by Margo Farnsworth

The authors of "Stories from the Trenches" got it right when they said, ". . . innovation is hard, and innovation developed using biomimicry can face unique challenges and opportunities." Any brand of innovation faces challenges: financing, timelines, proof of concept, buy-in, marketing, identifying customers and evolving with their needs, selecting the right professionals for the innovation process at the right time and place – including leadership – and then of course, sales. There are also additional challenges relative to innovation for start-ups compared to pre-existing businesses. Regardless, it is the merging of those needs and challenges that serve as, if not critical driver for this important methodology, at least the business cogs that can make it work. After all, there are a lot of workable methods for rounding up cattle, but if you don't have someone to sell them to and a way to get them to market, you're going to go broke pretty darn soon.

Methodologies for any part of business are just that – part of business. The promise of biomimicry is the potential to do well by doing good – for people, for the planet and for your business. It is this very promise of triple bottom line improvement over the financial-gain-only-business-as-usual model that sometimes blinds biomimicry practitioners to business challenges. "It just makes sense", practitioners and students of the meme say. However, most current practitioners hale from the beds of science and design. Add to this, as a standard tool in business, biomimicry is still young. We can learn much by observing the professionals using biomimicry methodologies currently in their businesses, and we would do well to study the lessons they have learned.

In the first example, the Trenches team opened the window on Dr. Frank Fish and Dr. Phil Watts' work applying the efficiencies of whale tubercles to windmills. When he lectures, Dr. Fish notes he saw this first on an artist's sculptural rendering – and thought the artist had made a mistake. Thus began the journey toward innovation. He discovered a natural phenomenon or model in nature and began investigating. From there, he examined design principles and potential applications before emulating them on wind turbines. These are four of the steps biomimics use when following the design spiral that leads from biology to design (https://biomimicry.org/biomimicry-design-spiral/).

The duo began testing their airfoils in air instead of water, the element where the strategy actually evolved. This required time for adjustments and knowledge not just of biology but of physics, biomechanics, and engineering as well as design. Although some of their research and development showed promise, the sociology of the wind generation profession, like many, was skeptical of innovation developed outside their corral. Because of this, when their field studies failed to align with industry standards of rigor and technology standardization, the stage was set for a rejection of the technology within the industry. Had the team studied the business "organism" of wind harvesting as beautifully as they did the humpback, they might have addressed future challenges (like where they should test to gain credibility and how their innovation fit into already existing businesses) in order to make a more seamless transition from the lab to a company home.

When the rights were eventually sold to Tubercle Engineering Group (TEG), that company tested in a well-known facility and marketed the product in the niche of retrofitting to avoid challenges previously encountered. They are on a road to a slightly different kind of success than was originally envisioned, but still moving forward. This is not an outcome path unique to biomimicry, but to many types of innovative endeavors in business.

Although execution and adoption by a sufficient customer base are critical to commercial success and potential benefits to people or planet, ideation should not be judged as failing or flailing based on immediacy of success. DaVinci never flew, but the ideations he conceived no doubt influenced those who eventually did.

Ryan Church used the second of two design spirals when he launched into renewable energy. He identified a problem connected with wind turbine design first and immediately began examining two strategies (used by owls and hawks) to emulate, when a completely new and different problem to be solved came into his view. This challenge-interruptus happens all the time in business as well as in science. Rarely in problem-solving do things progress smoothly from alpha to omega.

As he pursued this new challenge, he was inspired by a third organismal strategy – the efficient tactic of maple keys spiraling to the ground. Once applied, his innovation performed admirably, achieving important energy-efficiency goals.

Perhaps having learned from others' biomimetic forays into business or perhaps simply because of his own exposure to business models, Church began integrating

Moth and Dandelion | Photo: Josh More, 2008 | Flickr cc business people and practices with the scientific elements of the PowerCone™ process early in his innovation cycle. His team sought the advice of wind professionals, tapping their experience and identifying industry needs. This in turn drove further decision-making on Church's part. His team united science with business goals and tools while diligently searching for early adopters to begin creating both cash flow and a track record.

Both these examples moved from the bio-inspired into the realm of biomimicry as they synced up with Life's Principles (https://biomimicry.net/the-buzz/resources/designlens-lifes-principles/). They are both resource/energy efficient, using low energy processes, and fitting form to function. They both adapt to changing conditions through redundancy and decentralization of the final structures. And both are locally attuned, harnessing freely available energy.

It is true they fail to meet three additional Life Principles, but biomimicry is simply not yet at a point where it can be stated that a specific number of these principles must be met in order to achieve biomimetic success. This question is one that continues plaguing both biomimics and business people trying to apply the method. When is something biomimicry and when is it bio-inspiration? That question in turn, drives another frothing discussion over whether and how one is better than the other. Some would say creating a business solution based on inspiration from nature is at least pulling humans and the rest of nature onto the same page. Others resolutely insist Life's Principles should be met. Perhaps there is a third option, a continuum of care where we can step on a conveyor belt-like series of practices at any point, then always aim to do better. Whatever the case, in making biomimicry real, language and environmental effects of our biomimetic products and processes matter.

So does context. The Trulstech, Inc. Molecular Heat Eater team was seeking to develop a flame retardant for Proctor & Gamble but failed to adhere to one basic requirement in the process. Since the customer is always right, it didn't matter that they were moving in a promising direction. The full context required by the customer wasn't being met. This was bad for that particular business solution – and for Trulstech's immediate success – but not necessarily for the innovation and their eventual commercial success.

Still, they persisted. Wes Jackson, a biomimic working on developing and deploying perennial crops, reminds us to utilize the three P's as we move forward in our work, "Patience, persistence and passion." It could be argued that anyone working in biom* (biomimicry or any of its cousins – bio-inspiration, bio-utilization, bionics, bio-TRIZ, etc.) deals in these three capacities unendingly! It also underscores the importance of always having a Plan B. In many ventures, a Plan C and D are advisable as well.

To achieve their triple bottom line goals, the group examined digestion and the "combustion process" seated in the Krebs cycle of respiration for their mimicry. Although they used food-based materials which threw their solution partly into the arena of bio-utilization, their resulting flame retardant is one of the few examples to truly use green (life-friendly) chemistry. Not biomimicry alone – but definitely useful!

Like Church, the Trulstech team examined their strengths and based business decisions around them: in Trulstech's case, by selling the rights to their innovation and providing tech support. Despite that positive focus on a specific strategy, management challenges slowed growth. Accepting this reality, the team broadened their definition of target markets by tapping into startups hungry to augment their needs with Trulstech's innovations, and government agencies with similar needs and adequate capital. Their decision and ability to adjust market focus midstream may help their company secure their goals of supplying a needed product that works for business while simultaneously serving people and the planet.

"Adapting to Rising Water Levels" is the final example the Trenches team examined. Reducing flood risk is growing to be an ever more critical systems level problem. Examining it as anything other than a system has historically proved to be less than optimal. The solution path created in this example importantly assigns humans a place as part of nature – not apart from nature. It utilizes biomimicry without providing a detailed approach and combines it with hydrology, soil science, meteorology, engineering, design, sociology, and community management. This stew of experience and expertise is a critical amalgam for solution-building too seldom used, but slowly building traction. Recognizing and respecting the elements and combined elegance of how natural systems work and how we can work with them – by using what we have learned across numerous disciplines emerging and maturing across time – is a critical method to deploy across more of our challenges here on this home we call Earth.

Into the yellow | Photo: Umberto Salvagnin, 2010 | Flickr cc

Perspectives on "Stories from the trenches"
Pete Foley, Margo Farnsworth,& Arndt Pechstein

So, what are the take-aways? How do we make biomimicry and biom* real in the business world?

Recognize that any kind of innovation faces common challenges described earlier: financing, timelines, proof of concept, buy-in, marketing, identifying customers and evolving with their needs, selecting the right professionals attached to the innovation at the right time and place including leadership – and of course, sales.

Understand that things rarely progress smoothly from alpha to omega in problem-solving or anything else.

Integrate people skilled in business with those having scientific experience and expertise early in the innovation cycle. Recognize the value and necessity of those combined skills to breed success.

Language matters. Work to get it right initially and keep checking to see that people understand the problem at hand – and each other – along the solution pathway.

The customer is always right. Know it. Deal with it – or find a new customer.

Identify humans as part of nature – not apart from nature. Use this paradigm to advance your sustainable business.

About the author: Margo Farnsworth is a writer, biomimicry instructor, and Fellow for the Biomimicry Institute. She invites readers into nature, offering strategic ways to live with wild neighbors through biomimicry and other practical methods. Her work has appeared in the book *Wildness: Relations of People & Place* along with magazines like *EarthLines*, *The New Territory*, *TreeHugger*, *Zygote Quarterly*, and blogs like the Center for Humans & Nature's City Creatures. She is currently writing a book on how corporations discover and use biomimicry; and lectures at universities, business groups and sustainability organizations. She works from her Missouri farm which she shares with her husband, assorted pets and wildlife.

Mining bee on dandelion | Photo: Rachael Bonoan, 2017 | Flickr cc

Perspectives on "Stories from the trenches"
Pete Foley, Margo Farnsworth,& Arndt Pechstein

Four reasons why biomimicry and innovation don't always go together by Dr. Arndt Pechstein

Innovation is a key driver to stay afloat as a business by continually challenging the status quo. It serves to constantly challenge products, services, and experiences with the ultimate goal to improve (living) conditions for users and within systems. In recent years, innovation has not only been a necessity to drive economic survival in terms of product offering, but on a more systemic level it has become an essential mechanism to adapt to an increasingly complex and hyperdynamic world.

The essence of innovation is to enter the market successfully with something people need, something that creates value. That, though, requires a thorough understanding of market dynamics, the ecosystem, and importantly the needs of the target group.

Biomimicry provides a revolutionary yet logical approach toward innovation by taking inspiration from biological systems. This promises to be both radical and sustainable if done correctly. However, many biomimetic inventions don't make it all the way to a successful product and can therefore be called innovations. Here are four reasons why biomimicry often fails to create success stories.

A biased sense of reality and the lack of business expertise

The beauty of biomimicry is that it combines a rigorous, iterative process based on scientific evidence from biological systems with a mindset of systemic and sustainable/regenerative change. That attracts people who want to have a positive impact on our world and create a livable and fair future. This noble and necessary mindset naturally also comes with an idealism to disrupt existing systems in order to make a change. Unfortunately, sometimes this idealism is not paired with a solid sense of the current reality and business ecosystems. It thus fails to convince critical stakeholders or plug into existing practices in order to scale.

A lack of integration with other holistic approaches

While biomimicry offers perhaps the most comprehensive and scientifically sound approach, there are other methodologies and approaches that build on similar values or aim at complementary outcomes. Circular Economy, Cradle-to-Cradle, permaculture, industrial ecology, and Blue Economy are just a few. Instead of branding and running them all in isolation, the networks, communities, and tools should be combined to gain traction and impact.

A lack of user-centeredness

Biomimicry promotes a beautiful narrative about functioning systems in nature and how those can be adapted to human design endeavors. That is very captivating and inspirational. It also establishes a needed counter-pole to the negative media and dystopias about our future. Yet, storytelling alone is not enough to make it actionable. People and especially decision makers are (sadly) often driven by other concepts and Key Performance Indicators, not values and visions. In order to place visionary and more holistic products or practices in the market, it is fundamental to understand and (somewhat) speak the language of the users and stakeholders. And to know their actual needs. They are not looking for biomimicry, they are looking for getting their problems solved. Biomimicry happens to be one (maybe even the best) approach.

Bug in Dandelion Bush
Photo: wormy lau, 2009 | Flickr cc

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The inertia of running systems

Many established markets are vertically integrated systems that are hard to disrupt. Infrastructures and value streams are established, practices in place, relationships and contracts built and accepted. To overcome this inertia, biomimicry practitioners require an in-depth knowledge of opportunities or weaknesses that is fundamental to either find niches, hack infrastructures, or disrupt strategically.

Takeaways to improve biomimicry success:

- Pair biomimetic invention and development with solid and strategic business expertise.
- Join forces with existing initiatives and approaches to leverage scaling effects.
- Turn the communication around. From: we have a method (biomimicry) that can solve your problems – you should use it. To: these are the problems we see you have, we have the expertise (and evidence) to solve them, and by the way, biomimicry offers us untapped potentials.

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About the author: Dr. Arndt Pechstein is a B3.8-certified Biomimicry Specialist and a passionate biomimicry catalyst. Arndt is an energetic blend of a scientist, serial entrepreneur, and business coach. He holds a PhD in neuroscience, a diploma in biochemistry & biotechnology, and has specialist backgrounds in Agile & Design Thinking, Circular Economy, and digital business models. As founder and managing partner of the boutique consultancy phi360 and founder & director of the Biomimicry Germany Think Tank, he advises companies and organizations on agile transition, innovation, adaptive leadership, new work, bio-inspired disruptive innovation, and a new digital mindset. Arndt's mission is shaping a just, sustainable, and desirable future.

We would appreciate your feedback on this article:

Dandelions (detail) | Photo: Thorston Hartmann, 2013 | Flickr cc

Drifters, a film by Studio Drift and Sil van der Woerd, Film still

Portfolio
Studio Drift

Portfolio
Studio Drift

Studio Drift (http://www.studiodrift.com) was established in 2007 by Lonneke Gordijn (1980) and Ralph Nauta (1978), who both graduated from the Design Academy Eindhoven (NL) in 2005. In their installations and interactive sculptures the relationship between nature/human/technology is key. Gordijn's fascination for nature and that of Nauta for science fiction and technology intersect in an intriguing way. Over more than a decade of their existence, Studio Drift's work in product and furniture design has evolved into increasingly larger, often site-specific and moving installations which they have realized all over the world. The works occupy a wholly unique place between disciplines such as tech art, performance, and biodesign. Data and algorithms derived from natural phenomena often form the basis for Studio Drift's work – the flight patterns of a flock of birds, for instance. With the help of state-of—the- art technologies they translate this data into poetic, meditative experiences. Their ideas regularly anticipate technological possibilities. This is why they collaborate with scientists, programmers, engineers, and other specialists in the development of projects.

Studio Drift: Lonneke Gordijn en Ralph Nauta.
Photography: J.W. Kaldenbach

Could you tell us about how you are inspired by nature?

Nature is the real high tech in our world! In Drifter, we see a gigantic block of concrete of 2 x 2 x 4 meters behaving as if it was completely natural, it floats. It makes us wonder if our build environment with all its squares and solid structures is really the best place for a human being to live in. If you look at this floating concrete block it feels so natural and calming.

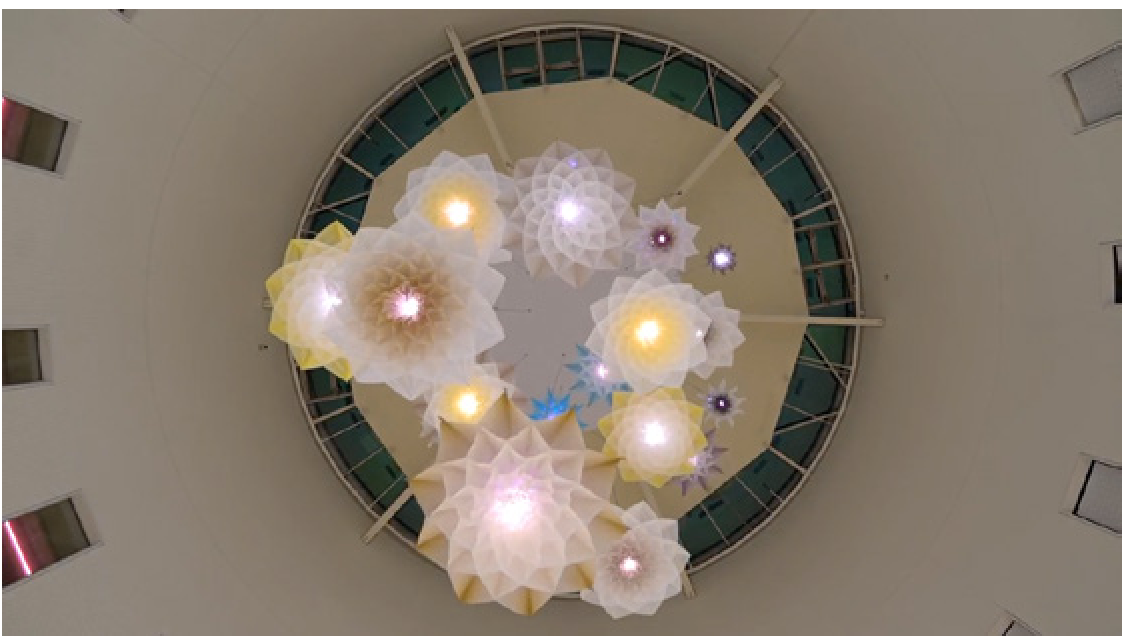
What kind of techniques do you use for your work?

If you look at the work 'Fragile Future', we literally merge dandelion seeds with electronics and circuitboards. Here the natural world connects with the technical man-made world and this goes unexpectedly well. It looks totally in balance. Technology comes directly from nature. We are nature and our technology helps in our existence and evolution. The more we have worked with technology to recreate natural processes in our work, the more we understand how incredibly advanced nature is compared to the technologies we use. In our work we use technology, but it is never about the technology. The technologies we use help to translate a natural process to a situation that we can partly control and bring to an audience.

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

Going back to nature is a constant source of inspiration.

With each new work we come closer to understanding life and the world around us. Step by step we build up our knowledge by experimenting, coming to the same and



Studio Drift *MEADOW*

new conclusions and finding truth in what we do and see, feel and experience.

Most of our understanding comes from recognizing in the nature around us exactly what we are trying to achieve.

We constantly learn and take the knowledge gained from previous works with us in new projects. It is an ongoing process that keeps on changing. Always on the move.

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

We have always been interested to investigate how we can actually make a difference in the world. Through our artworks we discovered that people can connect to our works very easily and if you can establish a connection between people and between people and the world, this can be used in a

Studio Drift's *Franchise Freedom* at Burning Man 2018 | Film by Xinix Films, Cadier Films and Sergio Abuja
https://studiodrift.com/work/franchise-freedom/

very valuable way. If you can connect with your surroundings, then you can care for it. If you can connect people, they care for each other. We need a lot more care for ourselves, each other and for our nature.

With the knowledge we have gained now, we try to work on projects where new technologies can develop meaningful connections and a true contribution to human lives. We are also interested in architecture that contains life and which makes us part of the environment in a natural way. Currently we are working on several architecture projects, on a larger scale then we used to so far.

What is the last book you enjoyed?

Do Androids Dream of Electric Sheep? by Philip K. Dick.

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

- www.studiodrift.com: It shows us what we have achieved over the last decades
- www.wired.com: Like to stay up to date.
- www.wallpaper.com: It ticks all our interests

What's your favourite motto or quotation?

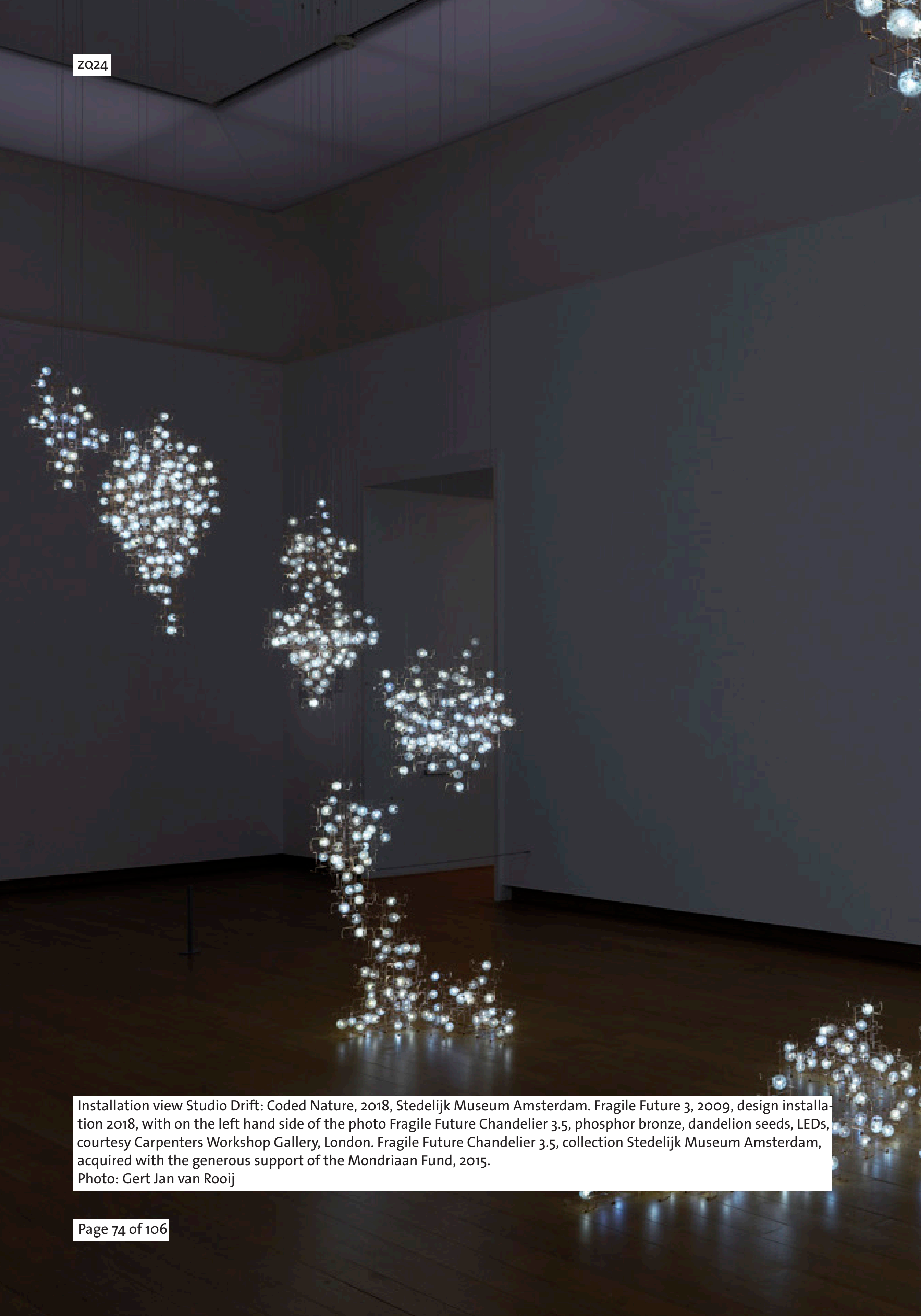
The world is one big exhibition if you only care to look. ×

We would appreciate your feedback on this article:

Installation view Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam. Meadow, 2017, choreographed in 2018.
Aluminum, stainless steel, printed fabric, LEDs, robotics.
Collection Studio Drift, Amsterdam, courtesy collection DELA, Eindhoven.
Photo: Gert Jan van Rooij

Installation view Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam. Meadow, 2017, choreographed in 2018.
Aluminum, stainless steel, printed fabric, LEDs, robotics.
Collection Studio Drift, Amsterdam, courtesy collection DELA, Eindhoven.
Photo: Gert Jan van Rooij

Installation view, Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam. Flylight, 2009, glass, custom made fittings, LEDs, algorithm, electronics, sensors
Courtesy Carpenters Workshop Gallery, London.
Photo: Gert Jan van Rooij

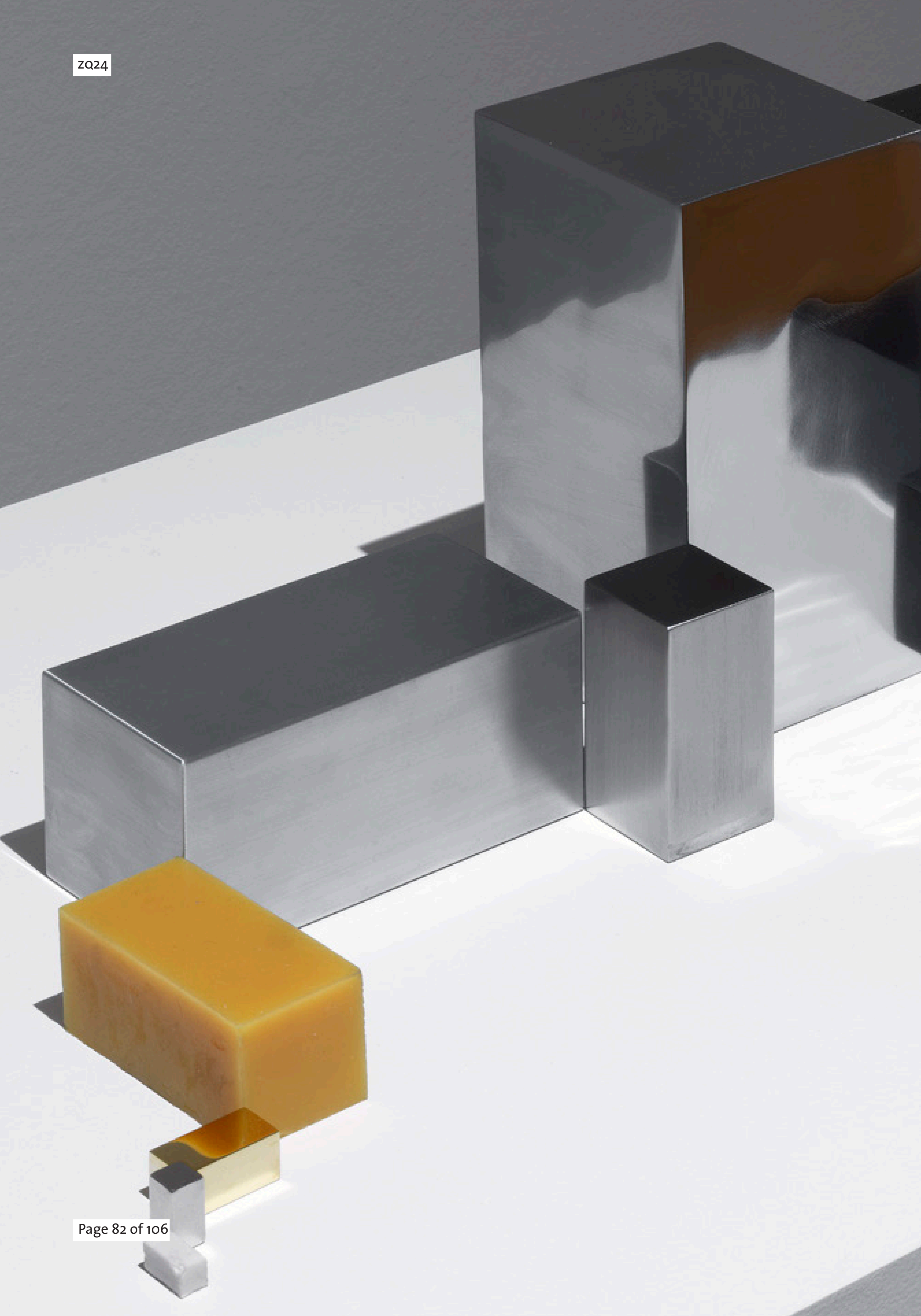


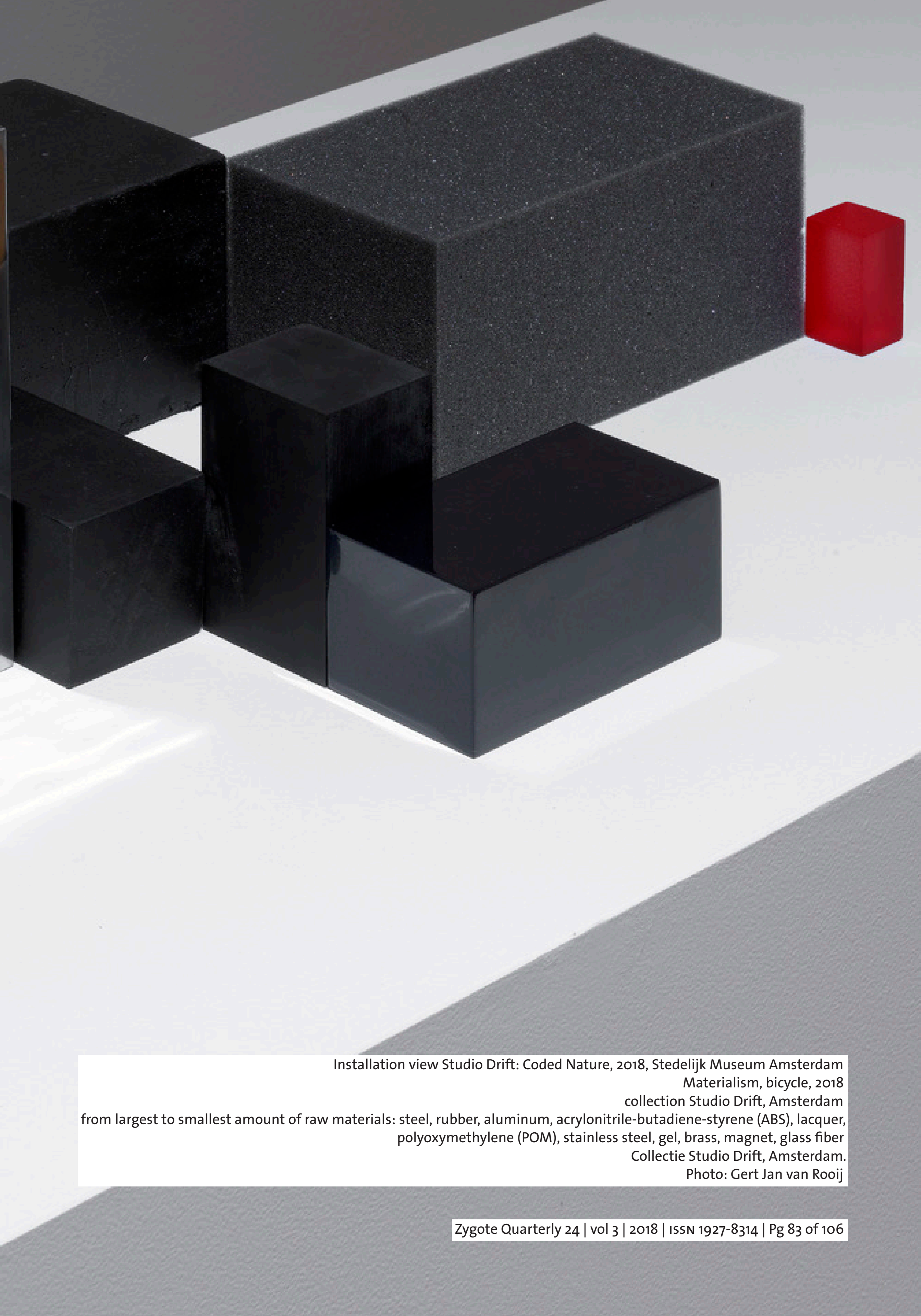
Installation view Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam. Fragile Future 3, 2009, design installation 2018, with on the left hand side of the photo Fragile Future Chandelier 3.5, phosphor bronze, dandelion seeds, LEDs, courtesy Carpenters Workshop Gallery, London. Fragile Future Chandelier 3.5, collection Stedelijk Museum Amsterdam, acquired with the generous support of the Mondriaan Fund, 2015.
Photo: Gert Jan van Rooij

Studio Drift, Fragile Future detail modules. Courtesy of Carpenters Workshop Gallery

Installation view Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam. Drifter, development 2008-2016, realization 2017,
mixed media with concrete, robotics, tracking system courtesy Pace Gallery, New York
Photo: Gert Jan van Rooij

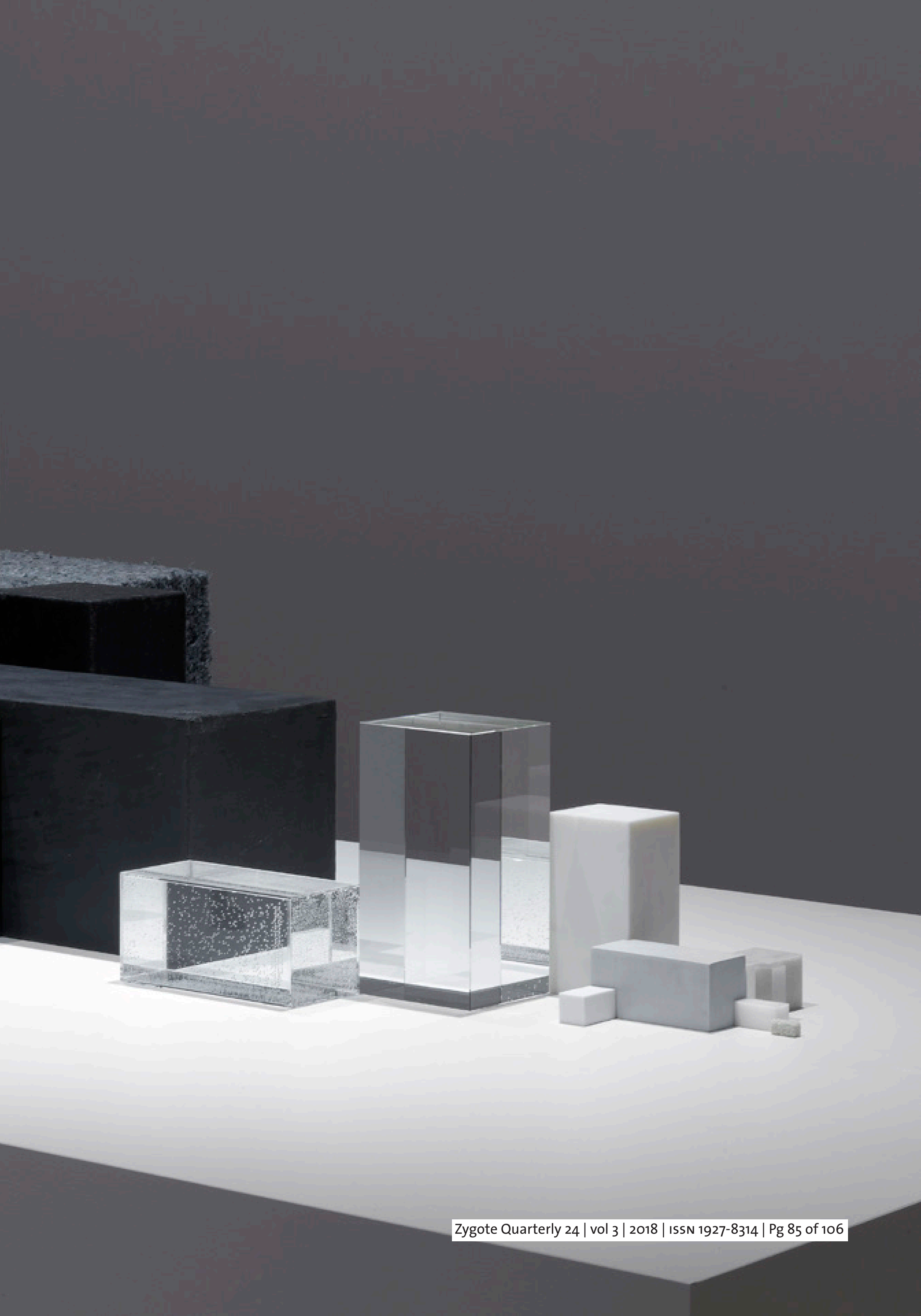
Studio Drift, Drifter, 2018, Stedelijk Museum Amsterdam. Courtesy of Pace Gallery. Photo: Tom Cornelissen



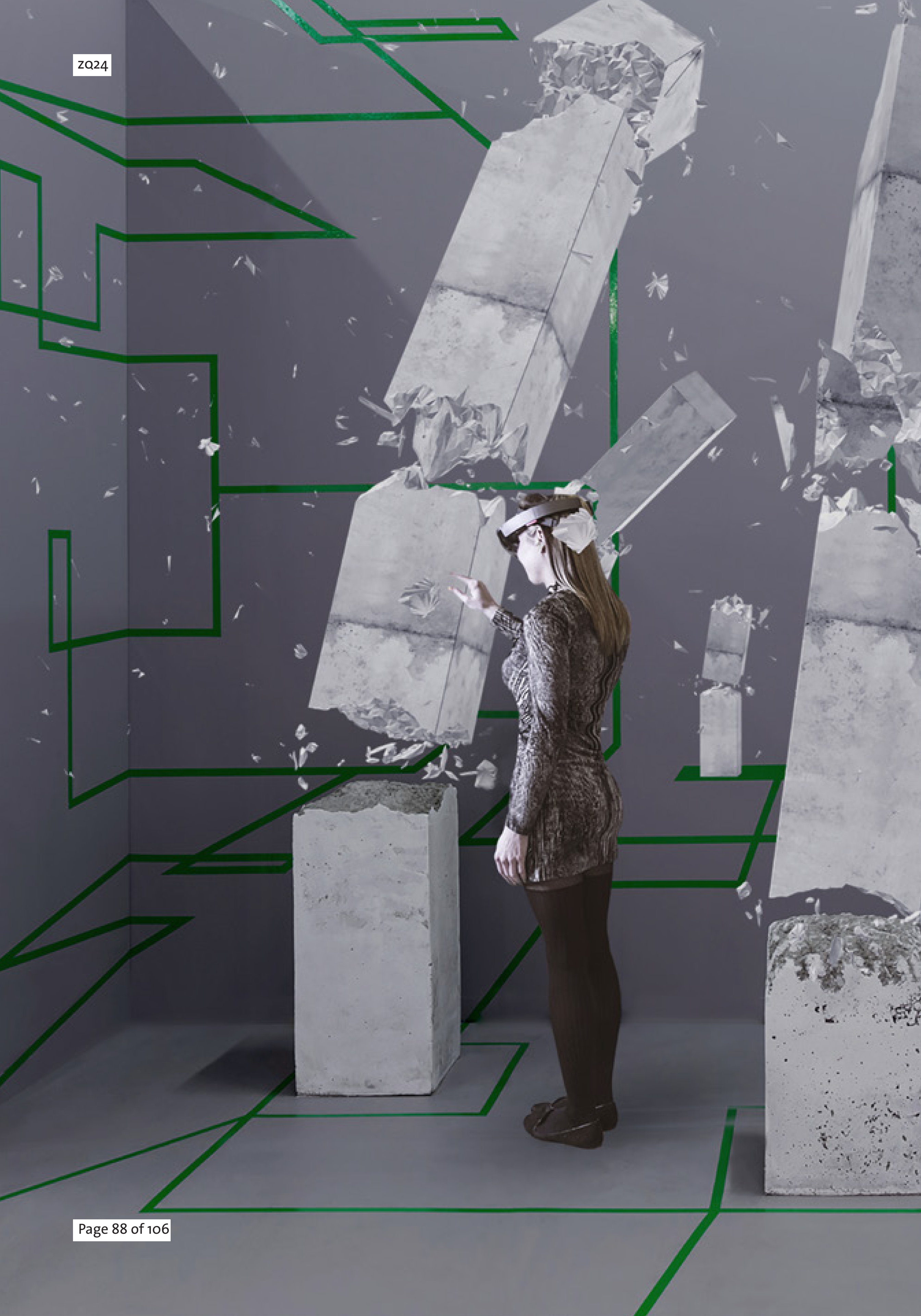


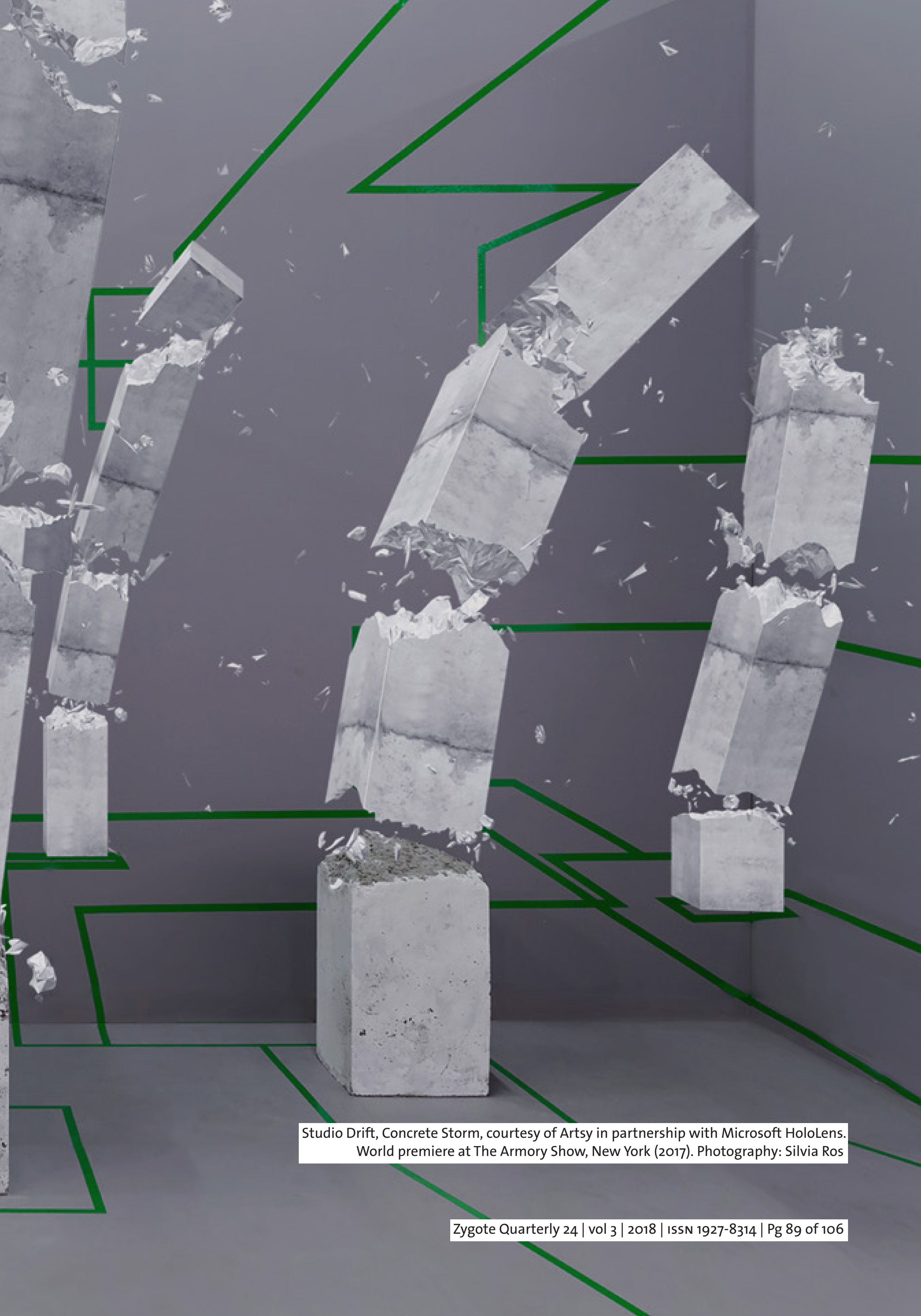
Installation view Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam
Materialism, bicycle, 2018
collection Studio Drift, Amsterdam
from largest to smallest amount of raw materials: steel, rubber, aluminum, acrylonitrile-butadiene-styrene (ABS), lacquer, polyoxymethylene (POM), stainless steel, gel, brass, magnet, glass fiber
Collectie Studio Drift, Amsterdam.
Photo: Gert Jan van Rooij

Installation view Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam
Materialism, Volkswagen Beetle, 2018
from largest to smallest amount of raw materials: cotton, polyurethane, horse hair, steel, rubber, tar, aluminum, wood powder, Tectyl, glass, polyoxymethylene (POM), lacquer paint, polyvinylchloride (PVC), acid, aluminum magnesium alloy, paper, grease, motor oil, gear oil, polyamide, acrylonitrile-butadiene-styrene (ABS), brake fluid, lead, polymethyl methacrylate (PMMA), stainless steel, copper, bakelite, high-density polyethylene (HDPE), cork, brass, glasswool, porcelaine, plexiglass, polybutylene terephthalate (PBT), magnet, kit, graphite, Vitrite, tin, chrome, wolfram
Collectie Studio Drift, Amsterdam.
Photo: Gert Jan van Rooij



Installation view Studio Drift: Coded Nature, 2018, Stedelijk Museum Amsterdam
Collection Studio Drift, Amsterdam.
Photo: Gert Jan van Rooij





Studio Drift, Concrete Storm, courtesy of Artsy in partnership with Microsoft HoloLens. World premiere at The Armory Show, New York (2017). Photography: Silvia Ros

Starling Murmuration - RSPB Minsmere
Photo: Airwolfhound, 2015 | Flickr cc

Book review

Regenerative Urban Design and Ecosystem Biomimicry by Maibritt Pedersen Zari

Reviewed by Alexandra Ralevski, Colleen Mahoney, and Jamie Miller

Regenerative Urban Design and Ecosystem Biomimicry by Maibritt Pedersen Zari
Reviewed by Alexandra Ralevski, Colleen Mahoney, and Jamie Miller

Dr. Maibritt Pedersen Zari is a Senior Lecturer at Victoria University of Wellington's School of Architecture. She has written extensively on the role of biomimicry and ecology in architecture to encourage regenerative development. *Regenerative Urban Design and Ecosystem Biomimicry* is intended for "students, professionals and researchers of architecture, urban design, ecology and environmental studies, as well as those interested in the interdisciplinary study of sustainability, ecology and urbanism." The book uses biomimicry "to translate ecological knowledge into practical methodologies for architectural and urban design" to support "creation and evolution of cities that are radically more sustainable and potentially regenerative." (p. i)

Structure

Chapter 1 assesses the roles urban environments play in contributing to climate change and loss of biodiversity driven by the continued growth of cities. Despite the relatively slow renewal rate of buildings, cities have the potential to be a positive force for change through regenerative design.

Chapter 2 provides an overview of biomimicry, exploring levels of emulation (organism, behaviour, ecosystem) and dimensions (form, material, construction, process, function). The sustainability of bio-inspired buildings tends to be associated with emulating at the process/function level of ecosystems, thereby helping buildings reinforce rather than degrade key natural cycles and ecosystem services.

Chapter 3 explores how biomimicry can reduce greenhouse gas emissions and also increase the adaptability of the built environment to climate change. The long lifetime of buildings limits the impact of new materials with a lower greenhouse gas footprint, but improvements can be introduced through retrofits and additions. Emulating ecosystem functions rather than their processes is more likely to result in regenerative designs, especially if targets are based on ecosystem health metrics.

Chapter 4 introduces the importance of hierarchies as a way of dealing with complexity and allowing change to occur at multiple levels by enabling emergence, self-organisation, and decentralised action. Research suggests that it is the diversity and strength of relationships that underlies resilience, rather than the number of organisms or species. Change often occurs

European Paper Wasp (*Polistes dominula*) | Photo: Goshzilla - Dann, 2009 | Flickr cc

Cliff Swallows (*Petrochelidon pyrrhonota*) and colony of dried mud nests | Photo: BLMOregon, 2017 | Flickr cc

Regenerative Urban Design and Ecosystem Biomimicry by Maibritt Pedersen Zari
Reviewed by Alexandra Ralevski, Colleen Mahoney, and Jamie Miller

through using existing resources and information in novel ways. Table 4.2 includes an extensive list of ecosystem process strategies organized in four tiers with the associated implications for ecosystem health. Emulating the outcomes (functions) of ecosystems may be more useful than focusing on the inner workings (behavior) of ecosystems since they tend to be easier to understand and measure.

Chapter 5 emphasizes the importance of setting goals related to ecological imperatives, rather than just human goals. The author highlights the importance of sourcing energy, providing fresh water, purifying water/air/soil, and regulating climate, based on three ranking criteria:

1. Integration or emulation of the ecological service within the built environment.
2. Importance of the ecological service on ecosystem health.
3. Impact of urban development on the ecosystem service.

Ecosystem services of medium importance in the built environment include cycling of nutrients, creating habitats, and providing food.

Chapter 6 examines the possibilities of applying ecosystem services in the three cities of Wellington (New Zealand), Havana (Cuba), and Curitiba (Brazil). It focuses on carbon sequestration, air purification, habitat provision, nutrient cycling, fresh water, fuel/energy and food. Although it provides a good summary of the statistics for each of these categories both pre- and post-development, it leaves much to be desired in the way of novel design implications of these services. Although the role of the built and surrounding environments are discussed when considering design goals, the 'ecomimicry' connections between the services could be more thoroughly examined.

Chapter 7 promotes setting performance goals based on metrics derived from healthy ecosystems and using our growing understanding of ecosystems to explore synergies among current technologies and design approaches, rather than relying on future technologies that may have unintended consequences. Given the ecological challenges that we face and the inherently long lifespan of our built environments, we need solutions that can be integrated into our existing urban environments.

Discussion

A Novel Design Lens

'Regenerative urban design' is a phrase fraught with difficulties. While it often focuses on new innovations in greening spaces, designing new buildings to meet various sustainability requirements, or design challenges focused on buildings of the future, the fact remains that most of the built environment that will exist in developed countries for the next 50 to 90 years has already been built. This means that the majority of regenerative urban design does not address the pressing needs associated with improving the current built environment.

Often, the 'sustainability' of a building is judged on an individual basis, with the building's performance measured as if in a vacuum, separate from the surrounding buildings and environment. Altering this view to consider a building as just one part of a much larger ecosystem of an entire city allows for a change in mentality that shifts the focus away from individual performance goals and towards an integrated urban ecosystem. Biomimicry offers an excellent platform for this type of design because the success of every biological organism is dependent on the larger ecosystem within which it exists. This process of an ecosystem approach using biomimicry principles is known as "ecomimicry".

Zari's book offers a framework for rethinking the concept of regenerative urban design as an ecomimicry process. Although this will require a major shift in how we currently approach sustainability, it should be noted that up until now, the drive towards more a sustainably-conscious built environment was driven less by design and more by societal pressures, which were born out of an awareness of the seriousness of climate change. A similar shift must occur again, from taking sustainability on a case-by-case basis to considering the built environment as part of a much larger integrated urban ecosystem. This change in mentality will be aided by books such as Zari's, which provide a new framework to encourage cities to be a positive force for change through regenerative urban design.

The Practitioner's Perspective

Regenerative Urban Design and Ecosystem Biomimicry by Malbritt Zari is an interesting book that will appeal to academics and researchers of architecture and urban design. The book is less accessible for practicing architects or policy makers in city governance. Design professionals and urban

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A female *Argiope mascordi* is well camouflaged in the centre of its circular shaped stabilimentum. It has recently moulted leaving the exuvia (remains of an exoskeleton) above the web. This specimen was seen at Emu creek north Queensland in a small colony of *Argiope mascordi* spiders.
Photo: Graham Winterflood, 2018 | Flickr cc

planners know that cities need to become more resilient, but how can this be accomplished by looking to nature for inspiration?

There are many sections of the book that challenge a professional to see where we can make change – specifically in cities. Zari points out that "the majority of urban settlements are dependent on fossil fuels to heat, feed and transport people in a linear system which creates pollution, leading to climate change and the decline of biodiversity health. This system also causes the degradation of waterways, air, soils and human health while using non-renewable resources in wasteful ways such that they cannot be reused." Many architects would agree that we must not continue to design buildings like we have been for the past 100 years. We understand that we can't continue building more and bigger cities without making serious changes in response to numerous challenges including those presented by climate change. But how do we design so that cities function like an ecosystem?

The author states that "ecosystems provide designers with examples of how life can function effectively on a given site and climate, and offer insights into how urban landscapes and the built environment could function more like a system or set of relationships, rather than as a set of individual unconnected object-like buildings." Most architects design one building at a time for unique owners and users - it will take new ordinances at land use and planning levels for the author's suggested change to occur. This simply can't scale with one building at a time. We can't simply state that encouraging greater interdependence and the sharing or exchange of resources will make a difference – planners and architects will need clear directives for guidance and practice. Building developers and city governance will need to define and conform to new guidelines if they are going to begin to function more like an ecosystem. Public works, planning, fire protection, building departments and code enforcement all exist in silos. In order for a city to be designed to function with cooperative links/relationships, the very process of planning and approvals will need to change, an issue not addressed in this book.

The only nature inspired example given in the book is the keystone species the beaver. In order to be true to the title and reference to biomimicry, the author needs to have many more examples of flourishing ecosystems. Each ecosystem needs to have its attributes broken out so that the reader can see simple and clear concrete examples. These examples could then be used to communicate patterns in ecosystem

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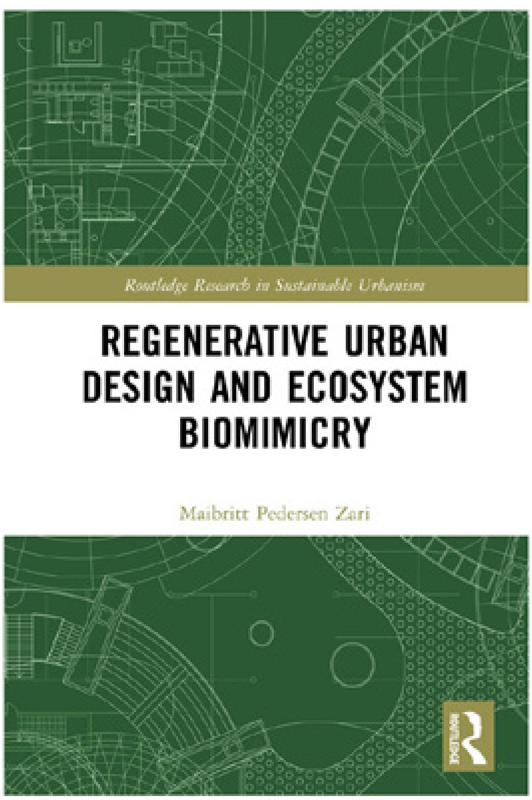
services that design professionals can emulate.

Practitioners would benefit from a version of this book that specifically focused on how ecosystems work and how nature's genius can be emulated, including clear and measurable ways for us to create conditions conducive to life in our cities.



A "Call to Action"

Whereas the sexiest examples of biomimicry are typically those showcasing innovations inspired by the forms or patterns in nature, the ones that focus on systems-level application may have the greatest overall impact. In *Regenerative Urban Design and Ecosystem Biomimicry*, the author provides a good overall description of the key tenets of what we understand biomimicry to be and potential principles of application at a system's level. Her work allows us to reframe urban design through a biological lens and critically reflect how we could integrate biomimicry at multiple levels in our attempt to reduce human impact on ecological systems, specifically climate change.

What the author tackles in this book is the difficult challenge of communicating systems-based application of biomimicry. Zari uses a more academic approach, providing good philosophical foundation for moving forward - even drawing on practical examples to help solidify the theory. But the biggest concern in reading this book is that the over analysis of "proper" applications may lead to perpetuating its lack of application. That is, biomimicry may be at risk of "paralysis by analysis".

Zari, M. P. (2018). *Regenerative Urban Design and Ecosystem Biomimicry*. Routledge. Retrieved from https://www.routledge.com/Regenerative-Urban-Design-and-Ecosystem-Biomimicry/Pedersen-Zari/p/book/9781138079489.

The complexity of large systems can overwhelm us and prevent us from seeing opportunities to intervene. Thus, in order to keep pushing the biomimicry forward, we could use systems-level understanding to provide the philosophical backing of our biomimetic perspective but focus more on leveraging emerging technologies like additive manufacturing, 4D printing, green chemistry and material ecology, big data, and computational architecture to create small-scale disruptions that could lead to larger-scale transformations. That is, emulate the pathway of a company like Tesla, that focuses on a single application that's guided by a longer-term and larger goal.

This is, however, easier said than done.

Moving forward, let's embrace the systems perspective but focus on inspiring a new ecosystem one application at a time. To do this, our success will lie in our creativity, both in the ideas we abstract from nature but more so in how we exploit emerging technologies and collaborate to manifest the designs that can transform our interpretations of design and nature and ultimately, the systems that we build and inhabit. ×

We would appreciate your feedback on this article:

Colletes hederae (Ivy Bees)
Photo: Kate Russell, 2017 | Flickr cc

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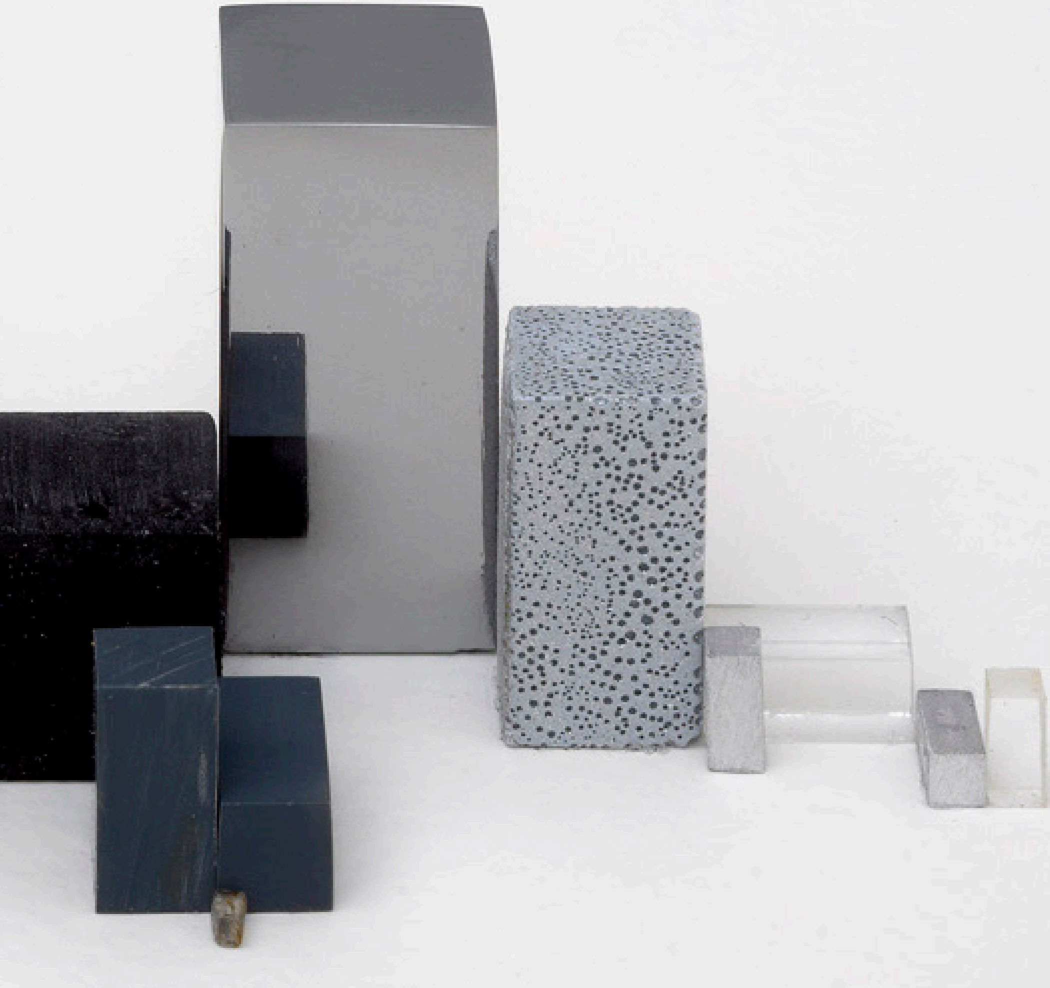
Alexandra Ralevski is a postdoctoral associate in the Department of Comparative Medicine at Yale University, engaged in translational research in the fields of neuroscience and plant biology. She is interested in the application of biological design to other fields, including biomimicry, architecture, engineering, and systems design. She also works as a biomimicry consultant and content manager for AskNature.org.

Colleen Mahoney is an architect, a biomimicry specialist, an amateur nature and portrait photographer, a volunteer in environmental education, nature lover, and life-long learner. Colleen got her undergraduate degree in Architecture at the University of California, (Berkeley), holds a Master's of Science in Biomimicry, and a Master's for Sustainability Leadership from Arizona State. In her 40-year career as an architect, Colleen has been a leader in green building and her firm's projects have been recognized as outstanding examples of innovative design, energy efficiency and sustainability.

Jamie Miller is an engineer and the President of Biomimicry Frontiers - a consultancy that applies biomimicry principles and technologies to the built environment. He was lecturer of OCAD University's biomimicry programs from 2012 to 2017, received a PhD in engineering that focused on systems-level biomimicry, and has most recently founded the Biomimicry Commons, which is a tech incubator and disrupter space in Guelph, Ontario, Canada.

Paper Wasp Nest
Photo: Ben Grantham, 2010 | Flickr cc



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