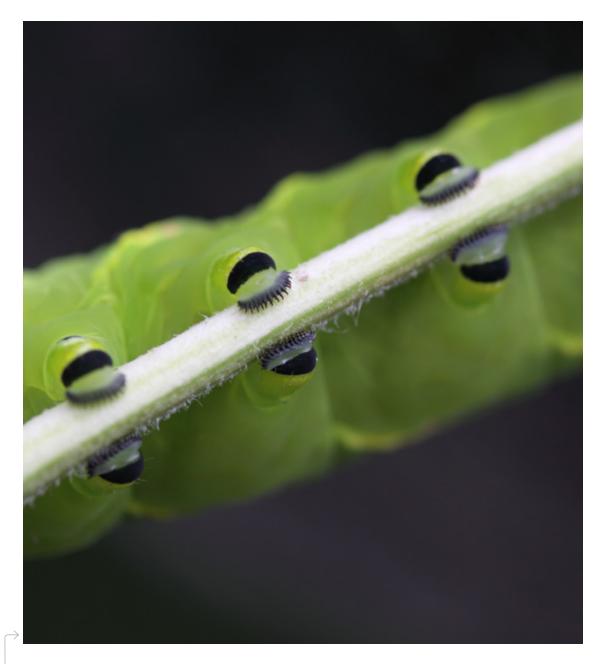






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Tomato Hornworm

Photo: RobMan170, 2009 | Flickr

We've started this journal because no one else had. That is, when we had sought a single source of intelligence for the general reader about the practice of bio-inspired design...there was none. To be sure, we found peer-reviewed journals full of academic papers and an increasing number of articles in the popular press. Between the two, however, was an informational desert. Moreover, no one source seemed to tickle both halves of our brains as designers and problem-solvers who are fascinated by the science of biology, enraptured by the heroes who make expert use of it, and enthralled by the sheer beauty of nature.

The result is this publication, and, in the course of planning it, this manifesto:

Our mission: to establish a credible platform showcasing the nexus of science, technology and creativity in the field of biologically inspired design, using case studies, news and articles that are exemplary in their impact on the field, rigorous in their methodology, and relevant to today's reader.

Our readers: are those who are curious about the converging worlds of biology, technology and design, and who are searching for ways to understand it and use it in their lives.

What's needed:

- A new intelligence source for both the informed layman and the practicing professional.
- A new model for presentation that mirrors and frames the content of a multi-disciplinary and rapidly changing field.
- A new periodical that appeals to the senses as well as the intellect.

Editorial

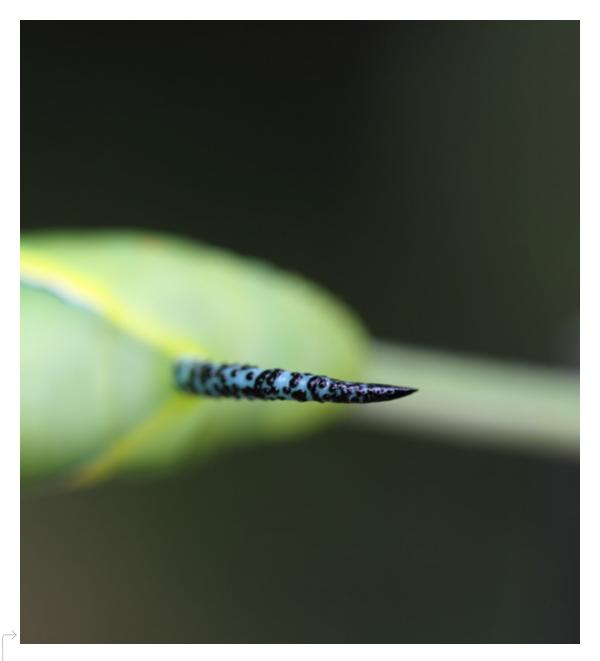
- A new venue, between the popular press and peer-reviewed journals, for a wide diversity of practicing professionals who are working at the crossroads of design and biology and would like to tell their stories.
- A new forum for a community of like-minded professionals and citizens that promotes an examination of the field itself as well as the developments within it.

What we can do: we can provide an appealing showcase for thoughtful articles about subjects we feel have significance to the field of biomimetics and our society. Life is endlessly fascinating. At a practical level, nature can encourage and guide us to develop sustainable solutions for current problems and biologically inspired solutions have become increasingly achievable and adopted. We believe that they will, in the near future, have a significant impact in how we live with both technology and nature.

We hope you enjoy our first issue and will continue to join us in our path of discovery.

Tom McKeag, Norbert Hoeller, and Marjan Eggermont

Ton Nocht



Tomato Hornworm

Photo: RobMan170, 2009 | Flickr

In this issue

We are delighted to start our inaugural issue with an article by renowned author and scientist, Dr. Steven Vogel, in which he offers his own "rogues' gallery" of good technological ideas from past societies that have never achieved commercial success. The wider issue of cultural acceptance of innovative ideas is an important one for both scientist and designer, and he illustrates this adroitly with examples of the past. Dr. Vogel is never content with the merely conceptual, however, and offers an invitation and a tool for you to test the viability of creative ideas for yourself.

The first flight of responders to our standardized interview initiate what we intend to be a continuing conversation about the state of the field of bio-inspired design. The purpose of this written survey is to gather qualitative descriptions of the work being done and the people who are doing it. Our contributors in this issue offer unique windows into their disparate worlds and are pioneers all.

You may delve more deeply into the world of industrial design as it meets the technological innovation trends of the twenty-first century in our next article, "Designed...to the Bone". The development of digital modeling directly linked to manufacturing, consumer participation in design and biomedical advances are all influences shaping the practice of Bespoke Innovations, an award-winning maker of human prosthetics.

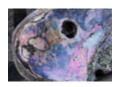
Finally, two engineers with an idea form a company despite advice from experts that swarm theory is not mature enough to be used in a commercial product. The *Power of Ants and Bees* is a story from the energy and business world that makes a compelling case for applying both the substance and spirit of nature's principles.

Thanks for reading!



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Photo: BushmanK | Flickr cc



Opinion:

When success fails

Author: Steven Vogel

When success fails

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

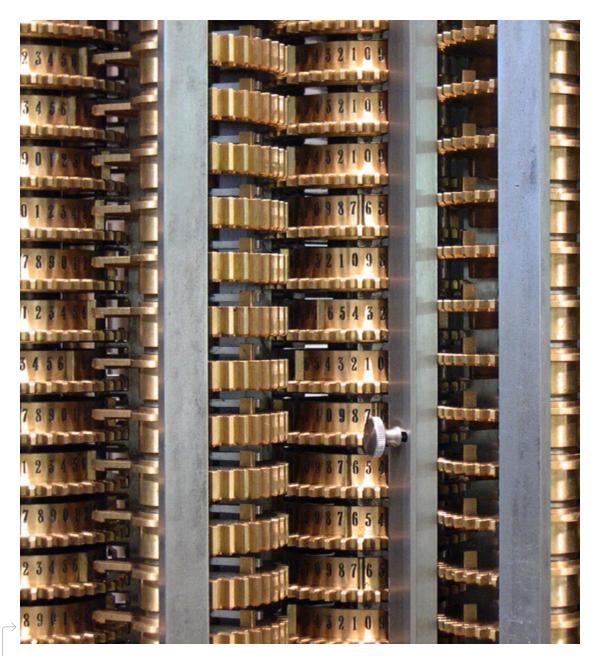
Two issues. First, is this a special case, a technology with either some intrinsic flaw or one kept from the marketplace by in insurmountable infrastructural hurdle? Second, might the case hold some lessons for current biomimetic innovation?

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

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

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

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



A close-up of the London Science Museum's replica difference engine, built from Babbage's design

Photo: Carsten Ullrich, 2005. | Wikimedia Commons

Opinion:

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Author: Steven Vogel

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

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

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

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

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



A British-made Cierva Autogiro flies over Manhattan Island.

Photo: The National Archives UK, c. 1931 | Flickr cc

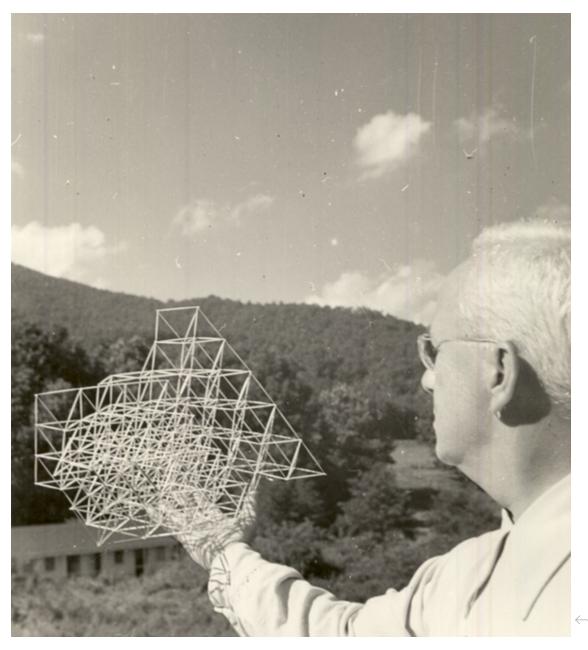
Opinion: When success fails

Author: Steven Vogel



Summer 1949 from the Black Mountain College Research Project Papers.

Photo: North Carolina State Archives, 1949 | Flickr cc



Summer 1949 from the Black Mountain College Research Project Papers.

Photo: North Carolina State Archives, 1949 | Flickr cc

Opinion: When success fails

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Autumn tulip poplar

Photo: Christine4nier, 2008 | Flickr cc

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

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

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

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

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

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

In some course in physical science, you may have encountered an expression, PV/T, which defines a constant for a given quantity of any gas: pressure times volume divided by absolute temperature will not vary—or vary enough to matter. We might borrow the expression for present use, just redefining the variables. P will now represent the probability that a device will work—both technically and commercially, if you wish. Low P, a long shot; high P, a sure thing.

Opinion:

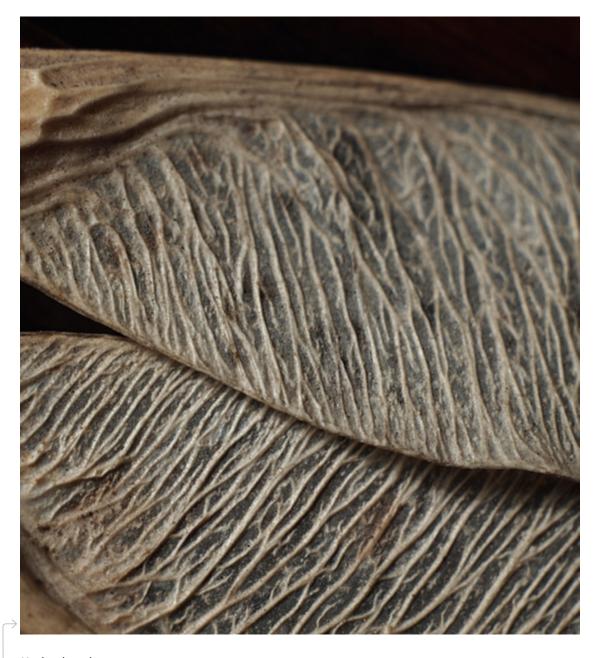
When success fails

Author: Steven Vogel

V is now the value of success—prestige, publication, tenure, or coin-of-the-realm—if the device works successfully. And T measures the time, effort, or resources needed to bring the notion to realization or to where it can be offloaded onto some other outfit. The combination, PV/T, then provides an index to the relative worthwhileness of a possible project.

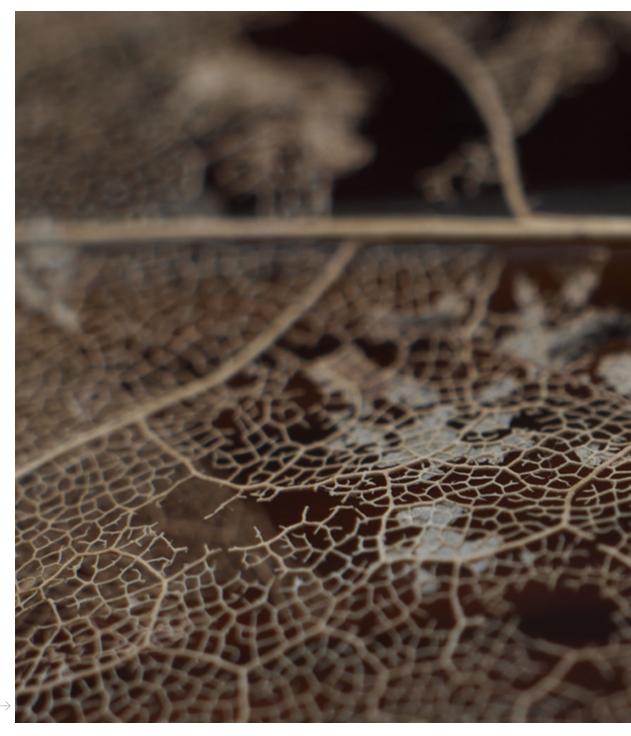
Perhaps a semi-serious example might flesh out this abstraction. We've all heard of solar heaters. What about a sky cooler, something that gets radiatively chilled in the manner of a leaf on a plant on a clear, windless night (and which leaves contrive to avoid) or an overheating camel when night falls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

It's that simple—or would be if we could fathom the unfathomable, surmount the insurmountable, and so forth. Still, someone might find that the formula at least provides some useful mental guidance. Steven Vogel is James B. Duke, Professor Emeritus in the Department of Biology at Duke University, Durham, North Carolina, USA. He is the author of several books on biomechanics including Cats Paws and Catapults, Comparative Biomechanics, Life in Moving Fluids, and Prime Mover: A Natural History of Muscle.



Maple ash seeds

Photo: Bushman.K, 2011 | Flickr cc



Maple Leaf

Photo: Bushman. K, 2010 | Flickr cc





Abalone shell fragment

Photo: Stephen Schiller, 2008 | Flickr cc



People: Interview Author: Julian Vincent

Julian Vincent MA (Cantab), PhD, DSc (Sheffield), FRES, MIM3, CEng, FIMechE is a biologist, lately Professor of Biomimetics in the Department of Mechanical Engineering at the University of Bath. He has published over 300 papers, articles and books and has been invited to give conference lectures (mostly plenary) and research seminars around the World. His interests cover TRIZ (the Russian system for creative solution of problems), aspects of mechanical design of plants and animals, complex fracture mechanics, texture of food, design of composite materials, use of natural materials in technology, advanced textiles, smart systems and structures. In 1990 he won the Prince of Wales Environmental Innovation Award. He is Associate Chief Editor of The Journal of Bionic Engineering (Elsevier) and on the Editorial Board of journals in Biomimetics, Smart Materials, Medical Biomechanics, Zoology and Food Texture. He has supervised 21 research students, all of whom were awarded the degree of PhD. In his retirement he continues to accept invitations to conferences and workshops and is working on an ontology of biomimetics. The third edition of his book with Princeton UP, Structural Biomaterials, is in press due out Spring 2012.

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

In the UK we are rather isolated these days since biomimetics is not seen (it seems) as a particularly useful set of ideas. So on the teaching side I find myself doing more with the Dutch Biomimicry group.

However, I am also getting involved with architecture at a professional level (both teaching and consulting), so perhaps there are good developments there. Also I am retained by Swedish Biomimetics 3000, so again there are positive

developments on the commercial side. It's just that there is very little targeted research going on.

What do you see as the biggest challenges?

Objective and critical approach to the science. Designers on the whole are not too worried whether the ideas they take on board are particularly practical or leading-edge. Consequently the standards are not as high as they could be. But I suppose it's good that something is happening. There are obviously problems in making the two areas of biology and technology intermingle properly, and few people seem to understand the difficulties involved. Again the architects may be leading the way.

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

Anything which raises credibility and generates general principles. At present most people seem to be content to design gizmos which hardly change the world. This is trivial. It seems fairly obvious that materials are very important, not just because biological materials perform very well, but because they are relatively easy to recycle. It's not enough to point this out, there has to be a drive to establish ways of making and recycling materials from an experimental base. We have a lot of technology available (mostly to do with assembling materials) but we need to tie the various techniques together.

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

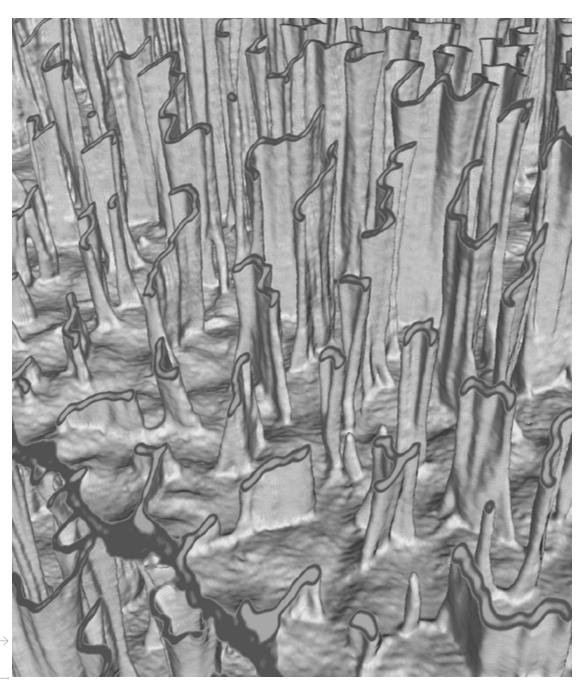


Communal silk nests of the Small Eggar moth *Eriogaster lanestris*

Photo: MarkusHagenlocher, 2007 | Wikimedia Commons

People: Interview

Author: Julian Vincent



3D visualisation of μ CT-data of a cuttlebone Photo: SecretDisc, 2011 | Wikipedia Commons

Does it matter? Most important is that I can help others to develop their own interest in the topic area

What is your best definition of what we do?

Originally my definition was "The abstraction of good design from nature", but now I prefer "The implementation of good design based on nature" or some such.

By what criteria should we judge the work? Does it work? Does it survive?

What are you working on right now?

Ontology of biomimetics, partly generating coding methods for novel solutions to problems; partly generating data to analyse problem-solving by nature and the parameters involved.

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

By default. From initial studies on the mechanical design of organisms it became obvious that models would help confirm and test the interpretation of biological mechanisms and materials. Then, since those materials and mechanisms had certain desirable attributes, the models themselves became of interest.

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

Difficult one. Any such answer has to include the way in which a biological mechanism has been implemented; also the degree of abstraction, as well as its success. I think it has to be Barthelat's

work on nacre, which suggests that the 'matrix' in biological ceramics may be more of a lubricant than a glue. This implies that many composite models of biological materials are wrong since we impose concepts of technical composites onto our understanding of bone, nacre, etc.

What is your favorite biomimetic work of all time?

Even more difficult. I tend to like counter-intuitive studies, but can't really think of any which fulfil that definition. Too much of biomimetics follows technology rather than leading it.

What is the last book you enjoyed?

Mind and Nature by Gregory Bateson. Currently reading *Thinking*, fast and slow by Daniel Kahneman.

Who do you admire?

Anyone who can make a good musical instrument

What's your favorite motto or quotation?

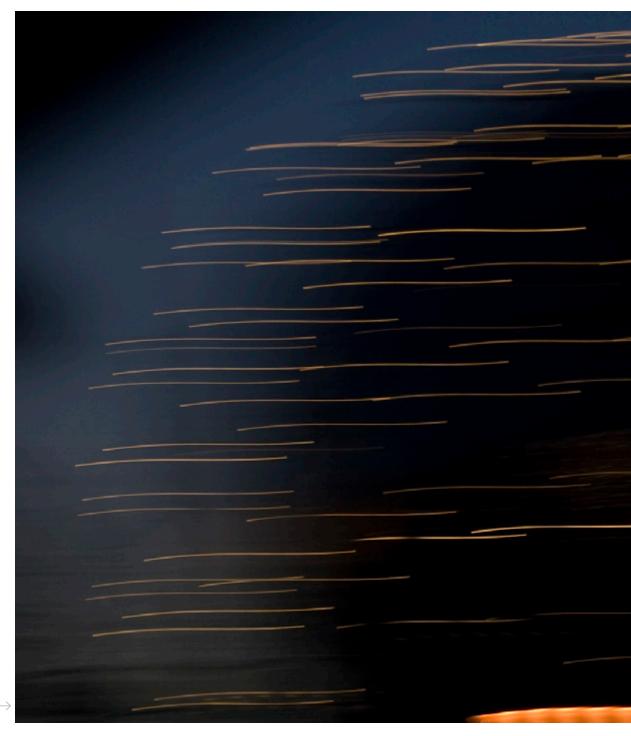
"We have little money. Therefore we must think harder" (attributed to Rutherford in Manchester).

What is your idea of perfect happiness?

Making music (of all sorts) with friends

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

Musician (it's happening now . . .) ×



Geodesic Dome Blurred

Photo: Mandy Jansen, 2008 | Flickr cc



People: Interview Author: Jay Baldwin

J. Baldwin was born the son of an engineer. Baldwin has said that, at 18, he heard Buckminster Fuller speak for 14 hours non-stop. This was in 1951 at the University of Michigan, where Baldwin had enrolled to learn automobile design because a friend of his had been killed in a car accident that Baldwin attributed to bad design. He worked with Fuller prior to graduation from U. of M. in 1955. During his student years, Baldwin worked (in a unique job sharing role) in an auto factory assembly line. He went on to do graduate work at the University of California, Berkeley.

Baldwin remained a friend of Buckminster Fuller, and reflected that "By example, he encouraged me to think for myself comprehensively, to be disciplined, to work for the good of everyone, and to have a good time doing it." [BuckyWorks, p. xi]

As a young designer in the late 1950s and early 1960s, Baldwin designed advanced camping equipment with Bill Moss Associates. Thereafter, he taught simultaneously at San Francisco State College (now called San Francisco State University), San Francisco Art Institute, and the Oakland campus of California College of Arts & Crafts for about six years.

The period 1968-69 found him both a visiting lecturer at Southern Illinois University and the design editor of the innovative Whole Earth Catalog. (The Catalog came out in many editions between 1968 and 1998, and Baldwin continued to edit and write for both the Catalog and an offshoot publication, CoEvolution Quarterly, later renamed Whole Earth Review.) In the early 1970s, Baldwin taught at Pacific High School. Baldwin was at the center of experimentation with geodesic domes (an unconventional building-design approach, explored by Fuller, which

maximizes strength and covered area in relation to materials used). He also dove enthusiastically into the application of renewable energy sources in homes and in food-production facilities, working with Integrated Life Support Systems Laboratories (ILS, in New Mexico) and with Dr John Todd and the other New Alchemists involved with the "Ark" project. Baldwin's initial involvement with solar energy was during that very experimental, ad-lib phase when much was moving from principles or theory into actual development. In the 1970s, at ILS, he was the co-developer of what has been touted as the world's first building to be heated and otherwise powered by solar and wind power exclusively.

Baldwin referred to his own rural home as "a three-dimensional sketchpad."

During the Jerry Brown administration, Baldwin worked in the California Office of Appropriate Technology. Since the 1970s, Baldwin has continued to work as a designer in association with numerous organizations and projects. He organized for himself a mobile design studio and machine workshop (in a van pulling an Airstream trailer) to drive to various projects across America.

With the ears of a wider audience in the 1980s, Baldwin developed an incisive critique of the American automobile industry, which he viewed as over-focused on superficial marketing concerns and farcically under-concerned with real innovation and improvement. He was also a constructive critic of the emerging industries manufacturing "soft technology" equipment like wind turbines.



Bucky Fuller (center) inside the New Alchemy Pillow Dome in 1982 with Jay Baldwin.

People: Interview **Author:** Jay Baldwin

In the 1990s, Baldwin wrote a book about Buckminster Fuller, his ideas, experiments, and influence, *Bucky Works: Buckminster Fuller's Ideas for Today*.

In the late 1990s, he worked with the Rocky Mountain Institute (Snowmass, Colorado) in the research, design, and development of the ultralight, ultra-efficient "Hypercar" — a prototype by way of which independent designers hope to show the way for the world's auto manufacturers. With conceptual development having begun in 1991, the current version of the Hypercar uses a small generator to power an electric motor in each wheel.

Given his long-term role as a "technology" editor, something should be mentioned about the scope of Baldwin's focus on technology. His interests remained broader than that represented in the shifting media and popular focus of the mid 1980s and later, which inclined to highlight the micro chip and electronic devices based on it. Baldwin has continued to point out the value of (and need for evaluation of) technologies within a larger perimeter. Certainly shelter and transportation technologies have always interested him. So have tools, and whether a device or tool or process was freshly innovative or age-old in concept, if it enabled a person to "do the job" with wood, metal, fiberglass panels, soil, trees, or whatever, it remained worthy of Baldwin's attention. Whereas the personal computer often (though not necessarily) inclines its operator toward imagination, almost in the sense of entertainment, Baldwin has remained equally interested in doing, in application. And while he has never ceased to be interested in the products of the factory, Baldwin has always wanted to empower individuals and small teams of people to accomplish something. Baldwin, as one of the notable designer technologists whose cross-disciplinary approaches

have opened new territory, was featured in the 1994 documentary film Ecological Design: Inventing the Future. The film viewed these designers as "outlaws" whose careers have necessarily developed "outside the box" of their time, largely unsupported by mainstream industry and often beyond the pale of mainstream academia, as well.

J. Baldwin invented (and has built) a permanent, transparent, insulated structure — of aluminum and Teflon — he calls a "Pillow Dome," said to have withstood 135-mph winds and tons of snow. The Pillow Dome weighs just one-half pound per square foot. The basic approach has since been applied in large-scale applications such as the Eden Project in Cornwall, England. Baldwin continues to practice design (as exemplified in the unique and aerodynamic 'mobile-room' Quick-Up camper he has put on the market) and to teach design at the college level. In recent years, he has taught at Sonoma State University, San Francisco Institute of Architecture and at California College of Arts & Crafts. (Source: as suggested by J. Baldwin: http://en.wikipedia.org/wiki/J__Baldwin)

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

Just getting started, and not well -known as a necessary discipline. Not well understood, either.

What do you see as the biggest challenges?

Persuading and teaching the volk that biomimicry is necessary and desirable (and even profitable).

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

Efficient energy and materials use; non-toxic chemistry; cold manufacturing processes; optimization; synergy.

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

My effort to always design to be "comprehensive" and "anticipatory" as Buckminster Fuller advised.

What is your best definition of what we do?

Observe, explore, and attempt to demonstrate and teach the principles and examples of biomimicry.

By what criteria should we judge the work?

Measuring the results and comparing them to the best you can find in Nature.

What are you working on right now?

A new book, (my 5th), addresses the dark side inherent in any technology.

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

Buckminster Fuller was my Professor at U. Mich. in the 50's.

What is your favorite biomimetic work of all time?

The Boeing 747.

It's lift/drag ratio (le finesse) was modeled on the wonderfully efficient hummingbird. Both beings burn 0.4 of their takeoff weight per hour!

What is the last book you enjoyed?

Finite and Infinite Games by James Carse.

Who do you admire?

Why...Allan Savory. He's an unconventional thinker, and his radical, counterintuitive ideas actually work. He fulfills Bucky's admonition, "Philosophy, to be effective, must be mechanically applied."

What's your favorite motto or quotation?

"In the end, only integrity is going to count." Buckminster Fuller (again).

What is your idea of perfect happiness?

Working with good people trying to discover how Nature works., and recruiting others to the cause.

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

A fence - tester. ×



Dragonfly Wing

Photo: Stephen Begin, 2011 | Flickr cc



People: Interview Author: Maria Mingallon

Maria Mingallon is a chartered structural engineer with a degree in architecture. Her main research interests are focused in complex geometries, emergent technologies, form finding and biomimicry.

She graduated in 2005 in Civil Engineering in Spain at UCLM and obtained a scholarship to complete her studies at Imperial College. She has worked at Arup since graduating as a Structural Engineer. Among other projects, she has designed two footbridges leading to the Aquatics Centre by Zaha Hadid Architects at the London 2012 Olympic Park.

In 2008 Arup sponsored her master degree in Emergent Technologies and Design at the Architectural Association from which she graduated with Distinction. She is currently teaching the courses 'Advanced Construction' and 'Community Design Workshop' to the professional MArch class at McGill School of Architecture. She has previously taught at the Architectural Association as a visiting tutor.

She is also part of the reviewing committee for the Symposium in Simulation for Architecture and Urban Design (SimAud).

Maria has recently published her first book: Fiber Composite Adaptive Systems: A manifesto into self-actuating potentials of fiber composite structures embedded with shape memory alloy actuators, Dec 2010.

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

It is still quite limited when one looks at the number of industries where biomimicry is being considered in the design process. Currently it is applied in very specific industries, where innovation is the key differentiator. This is however not the case in more conservative industries: such as the construction industry. While this could be one of the main candidates that could best benefit from bio-inspired building strategies, it is rare to find people who even know the term biomimicry.

What do you see as the biggest challenges?

Convincing people that investing in research in biomimicry at early stages of a project can pay off. Also that the majority of the times, we are already looking for inspiration in the natural systems when we design, for example, the drainage system in a highway.

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

Natural building strategies (including natural structural typologies) and material science are two main ones. If we could ever build like nature does, we would certainly be close to perfection! And worldwide waste will not be an issue anymore. Another interesting area is finding sustainable strategies for producing and saving energy, i.e. not only its production per se but also its efficient management.

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

I consider Nature as the best professor in structural engineering. Nature is just a free encyclopedia where we can find answers to pretty much all design challenges. Nature would have already dealt with the issue and tested it over millions of years through evolution. Natural structural

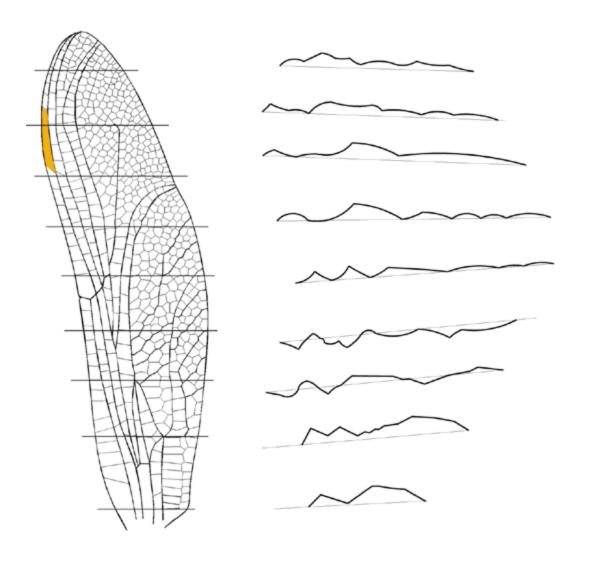
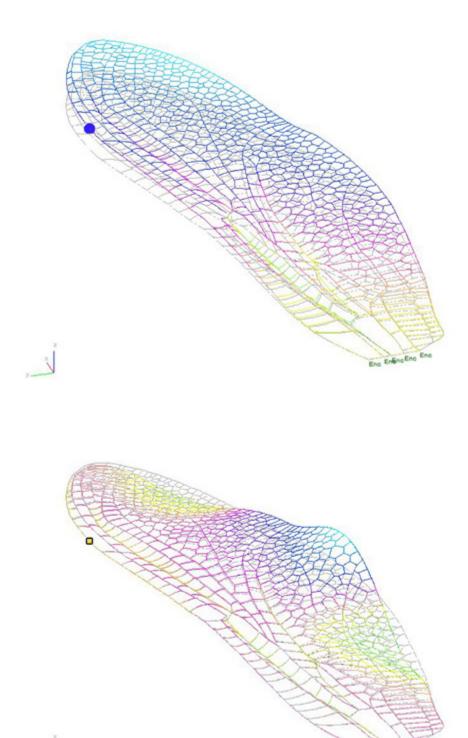
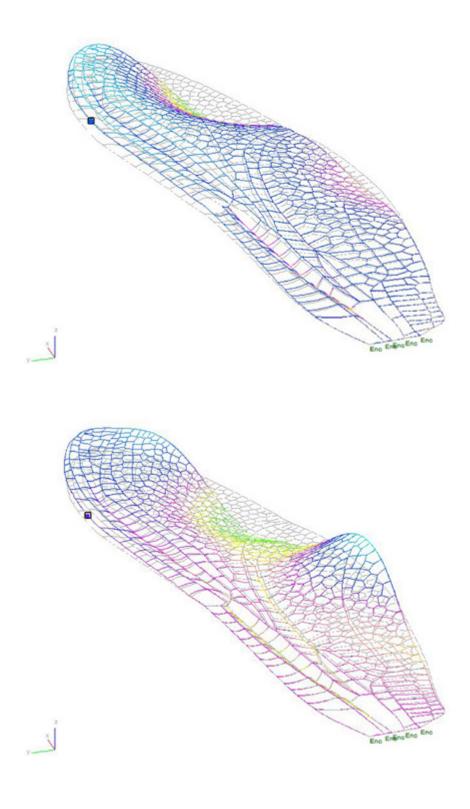


Illustration courtesy of Maria Mingallon \vdash







People: Interview Author: Maria Mingallon

typologies, processes of formation, and natural building strategies are my main interests in biomimicry.

What is your best definition of what we do?

Provide for a forum where specialists in biomimicry and individuals interested on learning from it can share ideas, projects and other initiatives. Essentially becoming a 'bank' of data in biomimicry case studies and examples, i.e. a source of inspiration. It will also contribute to help spreading the word on how biomimicry can push the boundaries of current design and construction strategies.

What are you working on right now?

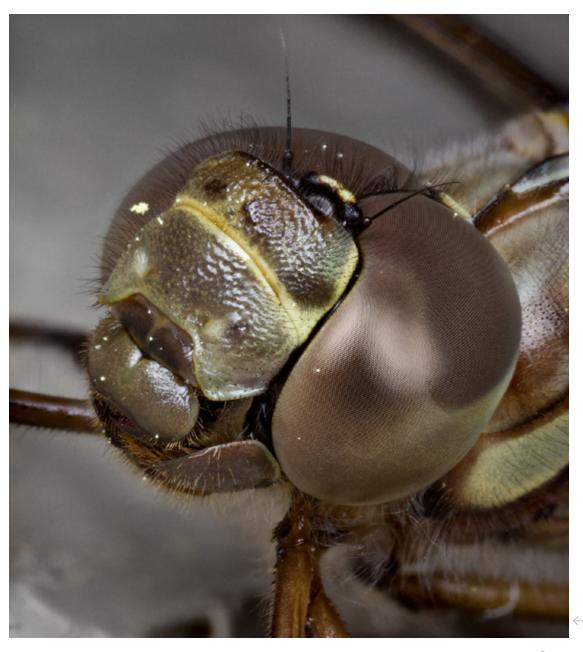
"The Architecture of the Dragonfly Wing: A Study of the Structural and Fluid Dynamic Capabilities of the Anisoptera's Forewing". The work presented here is part of a technical paper co-authored by Maria Mingallon (Arup, Senior Structural Engineer) and Sakthivel Ramaswamy (KRR Engineering, Director), published and presented at ASME 2011. The paper outlines the main findings of a broader biomimetics research study undertaken at the Architectural Association as part of the master program in Emergent Technologies and Design. The aim of the research was to derive the adaptable and performative logics of the dragonfly wing. Digital simulations in GSA by Oasys were necessary to understand multiple-pattern and corrugated geometries, which proved to render a unique structural behavior which is responsible for the high performance of dragonflies in passive flight.

The morphology of the dragonfly wing is an optimal natural construction built by a complex pat-

terning process, developed through evolution as a response to force flows and material organisation. The seemingly random variations of quadrangular and polygonal patterns follow multihierarchical organizational logics enabling it to alter between rigid and flexible configurations. Being the dragonfly wing has a highly dynamic structure, vibration studies were necessary to obtain realistic deformation patterns and thus, understand its structural behaviour. Ten vibration modes were extracted from the modal analysis performed in GSA. Our eyes have difficulties distinguishing the third, fourth and fifth vibration modes (which occur almost simultaneously), due to the high frequencies exhibited. In our case, slow motion pictures featuring the real flight of the dragonfly, allowed us to identify up to the third mode of vibration by comparison with that calculated in the analysis.

The outcome images featuring the different modes of vibration of the wing illustrate the correlation described earlier between the geometrical patterns and the different degrees of flexibility. The rectangular pattern found at the uppermost zone of the wing is designed to withstand load perpendicular to the leading edge taken by the wing during flight, while corrugations help with resisting loads perpendicular to the plane of the wing.

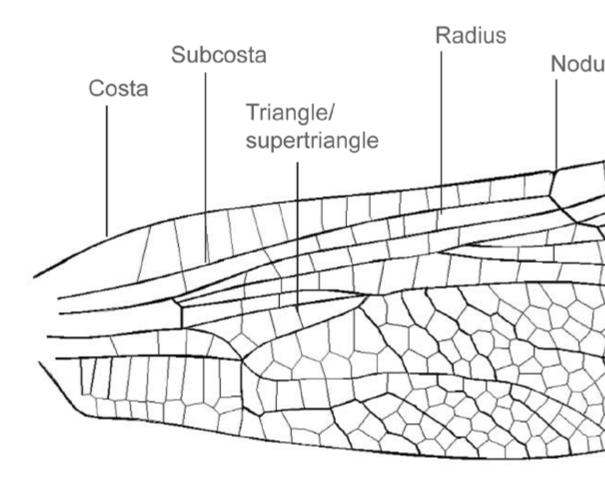
A torsional wave at the trailing edge can be observed throughout the different modes; this occurs due to the tendency of the elements closer to the wing's tip, to twist ahead of those nearer to the base, creating a torsional wave. Located at the leading edge the nodus acts as the reinforcement and the shock absorber. The nodus copes with combined torsion and bending stress concentrations at the junction of the rigid concave



Dragonfly Eye 🕨

Photo: Stephen Begin, 2011 | Flickr cc

Basal Wing Section



Distal Wing Section

pterostigma (sort of counterweight to control wing flapping)

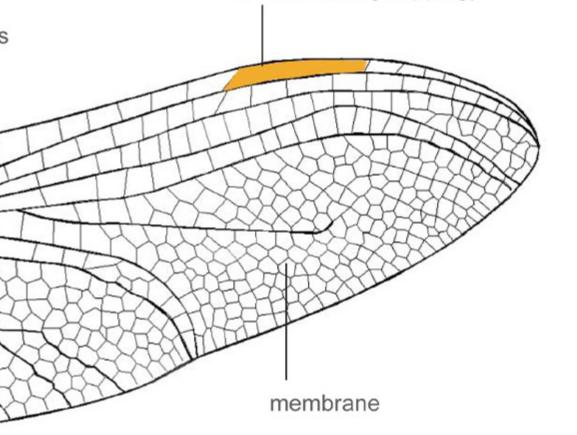


Illustration courtesy of Maria Mingallon -

People: Interview

Author: Maria Mingallon

ante-nodal and the torsionally compliant postnodal spars. The concentration of stresses and bending moments must have imposed strong selection pressure in the development of the nodus, which combines a stress absorbing strip of soft cuticle with strong, three dimensional cross bars across the entire spar between the costal margin and the leading edge.

The deformed modal shapes demonstrate that the pentagonal-hexagonal pattern is designed to deform and thus, provide the thrust necessary to maintain the dragonfly in the air. The 120° angle present in these geometries, allows for the polygons to reorganise from being in a single plane to form a concave surface, utilising much less energy than that of the rectangular pattern.

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

It was through a course in Biomimetics at the Architectural Association, London, UK by George Jeronimidis (Reading University, UK) and Michael Weinstock (Director of the master program in Emergent Technologies and Design at the Architectural Association, London, UK).

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

http://www.asknature.org/media/image/19041 (see image p. 44)

What is your favorite biomimetic work of all time?

Lotus Paint products: Lotusan® paint.

But also: Self-healing Autonomous Material, from the Department of Mechanical and Aerospace Engineering at Arizona State University (http://www.asknature.org/product/78db777befc7ao725fo317274337of8o).

What is the last book you enjoyed?

The Tinkerer's Accomplice: How Design Emerges from Life Itself by J. Scott Turner.

Who do you admire? Why...

D'Arcy Thompson, his book On Growth and Form reveals secrets in natural engineering that are not taught at schools of structural engineering.

What's your favorite motto or quotation?

"Strain, the result of stress is a direct stimulus to growth itself" by D'Arcy Thompson, *On Growth and Form*.

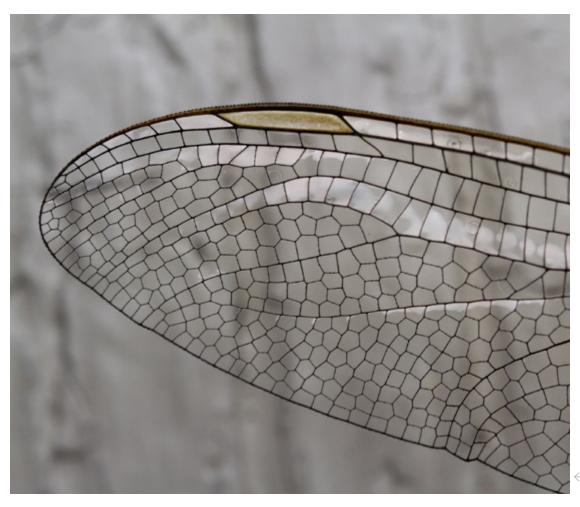
Also: "Form follows function", Bauhaus School of Architecture.

What is your idea of perfect happiness?

Working on projects where the client is interested on bio-inspired opportunities and being able to research on them and apply them to the project; it provides a sense of harmony difficult to explain but I guess it comes from thinking that at least you are learning from the best teacher... nature!

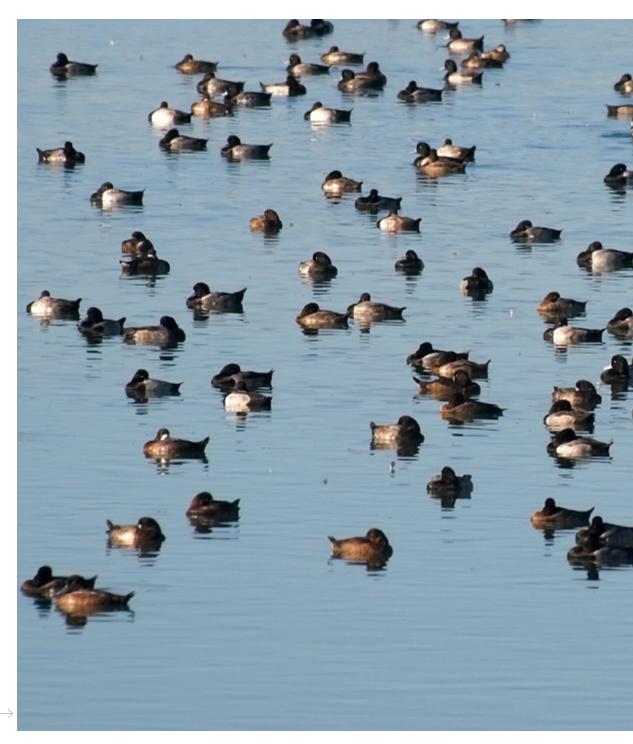
If not a scientist/designer/educator, who/what would you be?

I once wanted to be a gymnast but my bones and tendons stopped being so flexible when I started my engineering degree. I think being a structural engineer/architect/researcher/professor is all I want to be!



Dragonfly Wing

Photo: Stephen Begin, 2011 | Flickr cc



Ducks are back

Photo: Ingrid Taylar , 2009 | Wikimedia Commons



People: Interview **Author:**Jane Fulton Suri

Jane Fulton Suri is a Partner and Executive Creative Director at IDEO. She's responsible for evolving content and craft, insight, and design thinking in service of clients worldwide. Jane came to IDEO from psychology and architecture with the ambition to bring social science-based perspectives to the design practice. Working on diverse challenges for clients in multiple industries, she pioneered human-centered approaches and fostered a collaborative community. She evolved techniques for empathic observation and experience prototyping that are now employed widely in the design and innovation of products, services, and environments, as well as systems, organizations, and strategies. Now, as designers face increasingly complex and systemic challenges, she has begun to look beyond human behavior to explore how patterns in nature and living systems may inform and inspire more elegant and sustainable solutions.

Jane created Thoughtless Acts? Observations on Intuitive Design (Chronicle Books, 2005), a collection of snapshots that depict the subtle and creative ways in which people interact with the world. Jane believes that everyone is creative and resourceful at heart and finds great rewards when tapping into that capacity.

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

It's a way to widen the lens through which designers look at the world for inspiration and guidance. It's evolving from an emphasis on materials and mechanisms to also provide good models and metaphors for some of the challenges we face.

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

How design happens, how designers think, how designers learn.

By what criteria should we judge the work? Elegance, resonance, making sense.



What are you working on right now?

Capturing what we have learned in one of IDEO's studios about a 3 month experiment in integrating a biologist with our design teams—and building some tools to try to sustain some of those perspectives.

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

Thinking about people as part of natural systems, not just human culture.

Decoys carved by Amiel "Ame" Garibaldi in the first half of the 20th Century. Many of his decoys were made from redwood stairway posts, reclaimed from demolished Victorian houses. He didn't use patterns, saying that "all ducks in a flock are different—makes the rig look more natural." J. F. Suri

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

Movies by 81 year-old master of the documentary genre, Frederick Wiseman. Actually what was really inspiring was the opportunity to hear him talk about his craft and process which he characterizes as creating "a dramatic narrative from basically found events." I think of this as close to design: found matter and models as the raw material for things we create, and that subsequently themselves create new meaning.

What is your favorite biomimetic work of all time?

It's not here yet—I think it's still gestating.

What is the last book you enjoyed?

Thomas Hanna's Somatics: Reawakening The Mind's Control Of Movement, Flexibility, And Health.

What is your idea of perfect happiness?

Enjoying being here, not thinking about perfect happiness!

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

A cat: enjoying being here, not thinking about perfect happiness! ×



Nasturtium | Entrance for Bees | Photo: Philip Bouchard, 2009 | Flickr cc



Bone

Photo: Patrix, 2010 | Flickr cc



Article: Designed to the Bone

Author: Tom McKeag

Designed...to the Bone

The Trends

These are exciting times for designers: new tools are bridging the gap between the inspirational and the practical. This is an especially golden opportunity for those who make things inspired by the intricate and dynamic world of nature.

In our opinion, three trends have combined to create a revolution that will have broad and lasting consequences for our society. The explosion in information technology and networking, the disruption of the current mass production model of manufacturing, and the integration of machines and humans will be the phenomena that drive this sea change.

Complex forms can be analyzed, designed, prototyped and manufactured in ways that would have been impossible just five years ago. A natural form can now be scanned, modeled in software, digitally tested for stress loads and then made in a variety of materials directly from the designer's plans in a fraction of the time and cost required previously.

These new capabilities in analysis and design have mingled with progress in miniaturization and biomaterials to contribute to the continued refinement and commonality of the human/machine interface. It was among the important scientific trends cited in a 2009, National Academy of Sciences report, "A New Biology for the 21st Century".

This article is about how these three trends have converged at a small company in San Francisco, Bespoke Innovations. Bespoke makes artificial limbs, providing an improved relationship between an amputee and the synthetic device that has been made using these new and powerful tools. We chose this product design as a case study because it illustrates a combination of science, technology and design, and because these techniques hold such promise for the general practice of bio-inspired design and the betterment of our society.

The Arena

Prosthetic devices have been made since the age of the ancient Egyptians. While there have been marked improvements in the industry, most experts would agree that we are a long way from truly mimicking the natural model. Historically, artificial limbs have been uncomfortable, mechanical, and impersonal. Moreover, they have not often afforded the wearer a feeling of wholeness, but rather a feeling of burden. While articulation has been adequate, it has not been refined, and certainly not responsive in real time to the conditions of the environment. For example, the average lifespan for an artificial limb is three years because of the changing size and shape of the residual limb. Finally, most prostheses have lacked any individuality that reflected the user. The typical lower leg prosthesis comprises a custom socket made of polypropylene that fits

Prosthetics

Several advances in prosthetics have pushed the field towards the more responsive, and, perhaps, biologically-inspired. Here are a handful of the techniques that are blurring the line between machine and human.

Myoelectric devices, are controlled by tiny voltages generated on the surface of the skin by the activity of residual muscles. These voltages are amplified and processed so that when the user flexes a muscle, motors on the prosthesis move in a predictable way. Typically applied to upper body applications, each device is likely to cost in the tens of thousands of dollars.

Similarly, a "smart" foot, with pressure transducers that sends signals to implanted electrodes in the stump allows the user to feel the ground (and therefore adjust his gait) but is expensive.

Neural interfacing, or neuroprosthetics, is still in the development stage, although advancing at a rapid pace. Here, the brain controls nerve impulses that are rerouted to surrogate muscles. These muscles, in turn, send amplified electrical charges to synthetic sensors connected to the artificial device.

Trials on human subjects have been started by a team led by scientists



Bespoke Innovations

Black polymer and chrome

Article: Designed to the Bone

Author: Tom McKeag



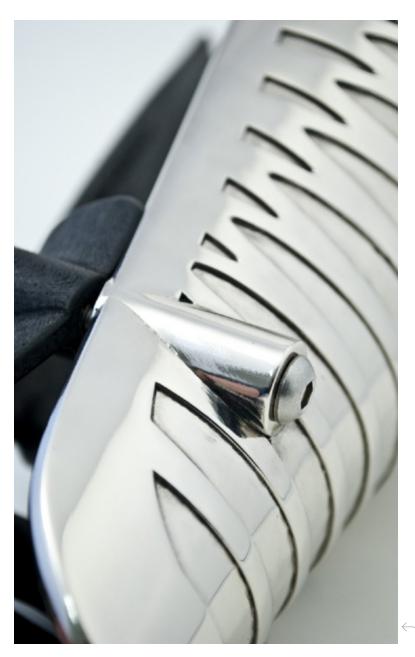
Bespoke Innovations

Black polymer and chrome

from Johns Hopkins. Microarrays in the test subjects' brains will record and transmit signals to a ninepound arm with 22 degrees of freedom of movement, individual finger control and sensors for virtual touch sensation. In 2003, monkeys had been conditioned to use the arm type and, in 2008, to control the walking movements of an entire robot through brain activity.

The joining of living tissue to synthetic devices is also being vigorously pursued and medical implants designed for acceptance. A 3D printed titanium jaw was successfully implanted in an 83-yearold woman in the Netherlands in June, 2011. The research that formed the basis for the pioneering operation was carried out by a team from the Biomedical Research Institute at Hasselt University in Belgium.

The event was singular: the first patient-specific implant of a replacement lower jaw, with all the attendant complexities of articulated jointing and tissue regrowth. The metal jaw had been sprayed with a bioceramic coating by use of a high-temperature plasma spray. New bone growth has been demonstrated using a similarly coated porous titanium scaffolding by researchers at Washington State University in the United States.



Bespoke Innovations

Chrome

Article: Designed to the Bone

Author: Tom McKeag

around the residual limb; a solid core or pylon made of titanium, aluminum or carbon fiber; a foot of urethane foam with a wood core; cuffs and belts for attachment; and prosthetic socks for shock absorption and fit. The pylon is usually encased in a soft polyurethane foam cover shaped like the leg and covered with a sock colored to match the patient's skin tone.

Hugh Herr, head of the biomechatronics group at MIT's Media Lab (biomech.media.mit.edu) estimates that there are over 1 million amputees in the United States, with about 150,000 prostheses sold every year. Clear advances have been made towards making a more organic limb, but many of the new products and procedures are costly (see sidebar).

The Challenge

The particular challenge we describe here is one of design of form and the making of physical shapes for structure, appearance and biomechanical performance. Given the current drawbacks of prosthetic devices, how does one make an artificial limb that is strong, lightweight, durable, and cheap? Can one make it comfortable, beautiful and individual without it being a crude imitation of the leg that was lost?

Our players are an industrial designer and a surgeon, with a supporting cast of software engineers, and manufacturers of scanning and printing devices. Not to be forgotten are medical researchers, patients, prosthetists, physical therapists and biomechanical experts.

The Company: Bespoke Innovations

Our case study is Bespoke Innovations of San Francisco, California. Bespoke makes prostheses

or artificial limbs for people and was founded in 2009 by Scott Summit, an industrial designer, and Dr. Kenneth Trauner, an orthopedic surgeon. It is run by CEO Paul C. Lego. The company employs 8 people and is currently in a second round of venture capital investment. They have garnered several awards for their designs recently, including a 2011 Good Design Award and a 2011 Gold IDEA Award from the Industrial Design Society of America.

Summit is the Chief Technology Officer and creative leader of the company. His background is in consumer electronics and he has contributed to several award-winning designs for companies like Apple, Nike, and Palm. He has a wide view of the field of technology and industrial design, having taught at Stanford, Carnegie Mellon and Singularity University. While he is proud of this past work, it is clearly eclipsed by his current passion for Bespoke's mission:

"Industrial Design can be used as a tool for improving the quality of people's lives and solving real human needs. The new digital tools make it far easier for an innovator to explore these opportunities than ever before."

He explained how he believes advances in technology will usher in a new age of "mass customization". Three processes will form the basis of this and are used by Bespoke every day in their work:

- Precise and affordable 3D scanning and imaging
- Computer Aided Design using parametric modeling
- Digital Fabrication

The printing of living tissue has been carried out for some time; in some cases entire organs have been made this way. The challenge of keeping these organs functioning has involved, among other things, the provision of blood vessels. Scientists of the BioRap Project at Fraunhofer Institute for interfacial **Engineering and Biotechnology IGB** in Stuttgart, Germany have recently manufactured synthetic capillaries by combining additive manufacturing with multiphoton polymerization. Intense lasers were focused at a tiny space to stimulate molecules of a tissue culture making an elastic solid able to interact with tissue in the human body. The solid was then coated with modified biomolecules to avoid rejection by the host. Findings were shown at the Biotechnia Fair in Germany in October, 2011.



Bespoke Innovations

Chrome



Bespoke Innovations | Sara Lace #1 pattern | Ivory polymer and chrome



Article: Designed to the Bone

Author: Tom McKeag

The company's "Fairings" product work illustrates this process. These are special coverings surrounding the mechanical core of an artificial leg, and at Bespoke they can be as wildly creative in appearance as the customer wants. Leather, wood, carbon fiber, or any of the synthetic fabrics used in auto interiors or fashion can be used to make a unique personal statement.

In a typical case, the company will take 2-3 days to design an artificial lower leg. It starts with the living or "sound" leg being scanned three-dimensionally. This image is mirrored in CAD software and superimposed over the prosthetic. The customer picks options with the designer, and then the basic piece is made in a 3D printer and special detailing added on.

In Summit's opinion, the current capabilities in digital fabrication represent a revolution in manufacturing, where "complexity is free". In other words, given the powerful tools mentioned above, it does not take any more manpower or money to produce a complex shape than it does to make a simple one. Moreover, the ability of 3D printers to reproduce themselves represents a completely new level of capability that is just now being explored.

The company has put the benefits of technological advances in scanning and fabrication to use in improving the lives of those who have lost limbs. The process gives the client a satisfying natural contour to the prosthetic, a chance to be part of the design process and to express a positive individual style. A disability has been turned into an opportunity for very personal and beautiful design.

The Inspiration

The company is investigating a deeper application of their successful methods, and looking more closely at nature in order to do it. The new goal is to improve the performance of the prosthetic device, specifically its strength to weight ratio, by improving its structure.

The human body continues to provide their inspiration in the structure of bone. Bone can be considered a system, rather than a single material, and its interrelated parts are fascinating. Indeed, bone could be described as the ultimate smart composite. Made up of specialized cells and protein fibers, it is as strong as steel and as light as aluminum. It also reacts to external forces, constantly changing to resist stress or repair injury (see sidebar).

Summit is not the first designer to look at bone. D'Archy W. Thompson, author of the monumental text, *On Growth and Form*, was quite inspired by bone and wrote at some length about its structural properties and the cause of their formation.

He relates the story of the Swiss engineer, Carl Culmann and his 1866 visit to his friend, the doctor Hermann von Meyer. The doctor had just cut a longitudinal section through a human bone and the orthogonal intercrossing of the trabeculae clearly showed the lines of stress, both compressive and tensile, that would be predicted from the activity of the bone.

"That's my crane!", Culmann cried, as he realized the solution to a thorny design problem for a lifting device he had been working on. Thompson goes on to explain why such trabeculae would be self-organized to orient that way because of



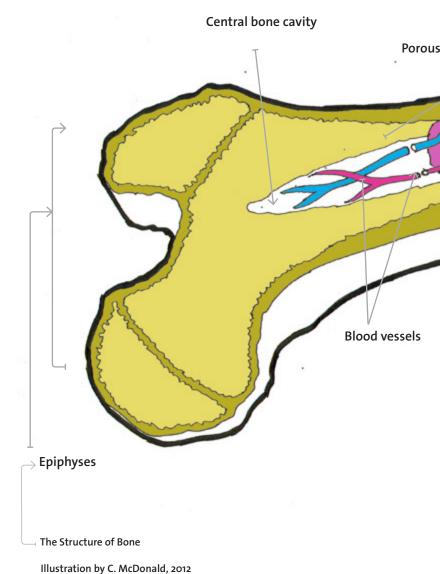
Article: Designed to the Bone Author: Tom McKeag

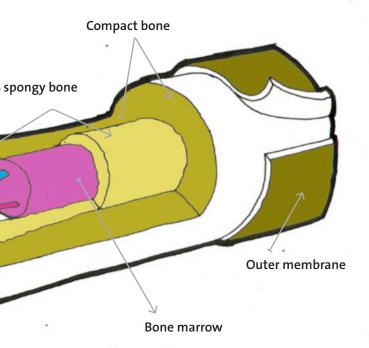
The Structure of Bone

Just as many of us forget that our skin is an organ (our largest), so too, do we forget that our bones are alive. Blood, oil, and nutrients flow through healthy bone continuously; new cells are being produced while old cells are eliminated. It is within bone marrow, a long bone's inner core, where you manufacture blood cells for your entire body.

All bone is not created equal. While its recipe of specialized cells, protein fibers (mostly collagen), carbohydrates, mineral crystals (calcium phosphate) and water is basic, it can be adjusted in proportions and array. A typical leg bone, therefore, might be better thought of as a system of inter-working parts than as a single entity. Surrounding the marrow core, or medullary canal, is a layer of spongy or cancellous bone. The open matrix of this material also contains marrow, and the bony struts or trabeculae within evolve to orient along the stress lines imposed on the overall structure. Outboard of this cancellous bone is a layer of compact bone: hard, strong and shell-like because of its greater density of crystals.

Like all structures in the cellularbased living world, this material has been built up from the very small into a larger, complex struc-





ture. Osteons are the rod-shaped building blocks of this material, each formed, in turn, of concentric rings of lamellae, each surrounding tiny blood vessels and nerves and each with allowed gaps to service cells. Like the wires in a steel cable, these osteons are bundled together for a strength much greater than the individual components. Surrounding this cortical bone is the periosteum, a thin, fibrous membrane that serves to anchor tendons and ligaments, nourish the bone and aid in repair. It is connected to the marrow core by tiny, blood vessel-filled canals.

The familiar bulges on each end of long bones, the epiphyses, are made largely of spongy bone. They absorb shock and form the bending joints between bones. The epiphyses are joined to the shaft of the bone by the epiphyseal plate, a cartilaginous area where new bone is grown. As R. McNeill Alexander points out in his worthy book, Bones, evolution has solved a knotty problem here: How to keep the joints working and still grow a shaft longer? The answer is to do your growing behind the relatively unchanged butt ends. When you no longer need to grow taller, around age 18 for most of us, this plate solidifies into the hardened bone typical in the shaft and bulges on either side. ·

Article: Designed to the Bone

Author: Tom McKeag

the nature of shear stress and where it would be experienced within the fields of compression and tension.

The Translation

Summit, too, is interested in the trabeculae of bone, those stress-respondent struts that fill the spongy part of the system. This latticework network is a wonderful model for lightweight strength, a textbook example of growing shape to strength, given their orientation and growth in response to lines of stress.

He explained his design rationale:

"Some of my first load-bearing leg concepts comprised tibial components which were mostly hollow, yet the contoured walls were connected with internal counter-rotating double-helical structures at a 60-degree pitch. A three-dimensional triangular lattice structure resulted from the intersecting spirals, creating a lattice of three-dimensional triangles with edge angles of roughly 60 degrees throughout. This enhanced the overall strength of the parts while using minimal material."

In addition to reducing weight the helical lattice design created a central axial void and it allowed excess powder from the additive manufacturing to escape via special ports at the ankle.

Summit is excited about taking these geometries to a finer level and cites the availability of software that allows the user to create a single 'voxel' or 3D cell, which can propagate three-dimensionally so that the resulting mesh populates a volume.

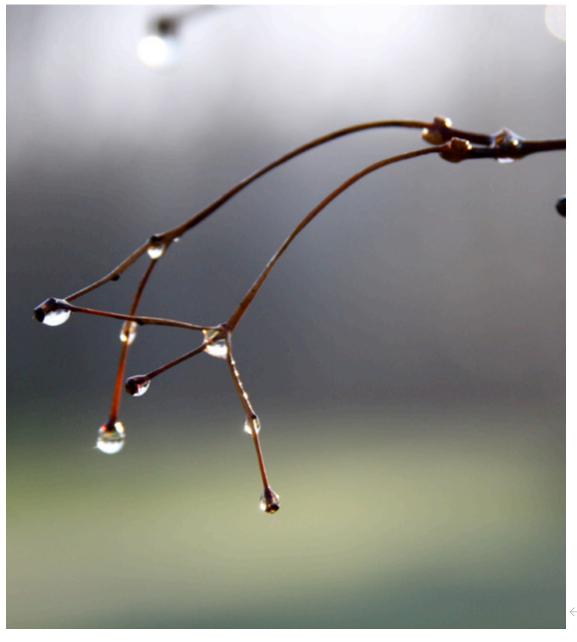
"The advantage is that the designer has the flexibility to design that voxel to meet either isotropic or anisotropic needs, depending on the mechanical demands of the part. For example, a lattice that can expect more compressive pressure than rotational will look rather different from one that is designed to resist or promote torque. A creative designer can fine-tune the voxel—or the blending of voxels throughout the structure - so that the resulting lattice accurately addresses the demands of a highly specialized environment."

While our current technologies do not allow the kind of real-time response to environmental stress that determines the growth of living bone, Summit points out that we can anticipate, predict and test these stresses and design and test the made structures accordingly.

"Through Finite Element Modeling, we can see the effects of structural loading on a designed part while it exists only in its virtual CAD stage. Through a recursive simulation process, however, the part can be designed to 'learn' where it fails, strengthen itself in such a way that it minimizes that failure condition, and test again. This generative cycle may be repeated until it is suitably strong for its demands."

The potential to address quality-of-life issues for many forms of disability is clear.

"This approach to product creation invites a custom solution to be created on a per-person basis, entirely unlike anything achievable by mass production. Unique or special needs may soon be addressed with all of the consideration that is currently given only to the larger market products"



Branch ₋

Photo: Muffet, 2006 | Flickr cc

Article: Designed to the Bone

Author: Tom McKeag

The Concepts

Nature builds from the bottom up. The very small module is arrayed into increasingly complex shapes. Rather than produce a gross shape and then cut away parts of it and then fasten pieces together (as man has done typically), nature has always done "additive manufacturing". Nature forms to shape. Nature tends to grow its material in response to environmental forces (stress). A thickened tree branch or the shape of trabeculae in bone are examples.

Shape is strength. Material and the energy to make it are expensive in the biological world, so if you can get the most out of the structural geometry of your form you are far ahead in the natural selection game. Bone trabeculae are a perfect example.

Little things multiply up. Bone is a system of interrelated parts grown from the cellular level, and arranged in an increasingly complex array. The ultimate form is much stronger than the sum of the individual parts.

Nature tends to solve problems across a hierarchy of scales. Within this complex form, materials and their arrangement are working at different scales to achieve the overall performance required.

The Impact

The short-term implications of these developments present themselves differently in the three fields of design, manufacturing, and use. It is the blending of all these fields into one sphere of control that makes all of this so revolutionary.

Ultimately, the designer will also be the manufacturer and the user. Great societal changes will likely occur because of it.

The designer can combine the expanding power of rapid processing and artificial intelligence with more sophisticated and engaging user interfaces to blur the line between human and machine. Mundane tasks, as a result, can become more intuitive and can free the problem solver for more creative activities. This is particularly marked in the fields of engineering, industrial design and architecture.

The manufacturer can produce things more efficiently and therefore expand functional capabilities and reduce cost. Indeed, because of increasingly affordable 3D printing tools, the role of manufacturing may change, as designers acquire more means of production.

The new design software tools span the gulf between design and manufacturing in two ways: the designer can test a product's performance without actually making it, and can make it directly from design software to 3D print manufacturing without the expense and time of tool and die making. Finally, the sophisticated modeling software allows design exploration without years of specialized training in the making and updating of the tool itself. It is quite probable that a 3D printer will become as ubiquitous a personal appliance as a 2D color printer is today. The efficient customization of responsive aids to living will herald a new physical reality for the patient, customer or user and Scott Summit of Bespoke is optimistic about the future:

"I can envision a day fairly soon where the individual end user is not simply a passive purchaser of a product that addresses their needs. Instead, this user may become in some ways the very "DNA" of the product itself, infusing that product with a quality as unique as their fingerprint."

The Tools and Methods Used

Software: 3DS Max, Pro/Engineer, GeoMagic, Rhino, 123D Catch, FlexScan

Hardware: structured light scanning devices, stereophotogrammetric scanning, 3D Systems

Sinterstation Pro

The Contact

Scott Summit Founder/CTO Bespoke Innovations 321 Pacific Avenue, San Francisco, CA, 94111 415-546-6919 www.bespokeinnovations.com



CAD model

Courtesy of Bespoke Innovations



Honey Bee Swarm

Photo: kaibara87, 2010 | Flickr cc



Article: REGEN Energy

Author:Mark Kerber with Norbert
Hoeller and Tom McKeag

The Power of Ants and Bees

Can research into the behavior of social insects such as ants and bees save us money and at the same time reduce greenhouse gas emissions? REGEN Energy (Toronto) is a new business venture founded on this premise, and is on track to both commercial and environmental success.

The distribution of electricity usage is as important to utility companies as the amount of usage. Peak usage that is significantly higher than the 'base load' forces utilities to maintain excess generating capacity that is only required for limited periods during the year, or purchase power from other utilities at a time when overall demand and price is high. In either case, peak power is often generated from coal- or gas-fired generators: these can quickly adjust to electrical demand, in contrast to hydro-electric, nuclear, solar or wind-powered generators. Cutting peak power usage can therefore have a significant impact on greenhouse gases by reducing the need to fire up fossil fuel plants.

Utilities pass on the high cost of peak power to larger customers by charging more for electricity during high usage periods or basing part of the monthly bill on the customers' peak demand for that month. It is advantageous for these customers to smooth out their energy consumption and avoid large spikes. In the past, the primary tools available were centralized energy management systems that were often expensive, require ongoing management, and could impact users if the systems took drastic action to control energy demand. The complexity of these systems rises

dramatically with size, further driving up costs and increasing 'brittleness': the possibility of failure under unexpected conditions.

In early 2005, Mark Kerbel and Roman Kulyk were looking for a new business opportunity and identified ten real-world problems. Based on their extensive knowledge of building control systems, utility operating models and the regulatory environment, they knew that commercial facilities operators have an incentive to reduce their peak electricity consumption but existing 'command and control' solutions were expensive and clumsy. An alternative was a system in which intelligence was distributed. Mark had read Steven Johnson's Emergence: The Connected Lives of Ants, Brains, Cities, and Software. Instead of relying on a central controlling authority, social insect communities follow a different model where agents make independent decisions based on simple 'rules of behavior' while communicating with each other using a simple language. Under the right conditions, this can result in systems that demonstrate complex, emergent behavior. A growing body of research in 'swarm theory' is gradually uncovering the underlying principles behind such self-organizing systems found in a number of species.

Although they were unsure if they could apply Johnson's fundamental principles of emergence, they decided to explore swarm theory, reading technical papers, following conferences and identifying key experts in the field. Unfortunately, the experts they contacted all felt

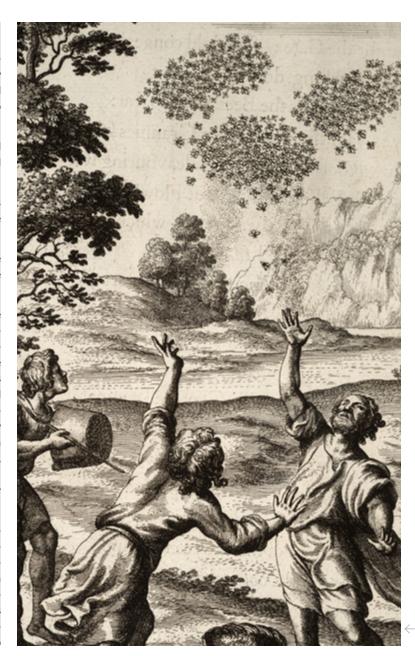
Eusocial Insects

Termites, bees, ants and wasps belong to the so-called eusocial ("truly social") insects. To be a truly social society in the biologist's sense is to possess three basic traits:

- •adult members must be divided into those who reproduce and those who do not:
- these adults must coexist across two or more generations in the same nest;
- •and non-reproducers (or those that reproduce less) must care for the young.

As you might guess, all of these attributes have survived the natural selection numbers game because they perpetuate the gene pool so well. These communities are the "superorganisms," a word coined by William Morton Wheeler in the 1920s, and discussed by the eminent biologist E.O. Wilson in his book with Bert Holldobler, The Superorganism: the Beauty, Elegance and Strangeness of Insect Societies.

It is an apt description of these colonies of creatures, for they dominate our terrestrial world, accounting for more than 1,000 trillion individuals. Indeed, Wilson estimates that their global weight is roughly equal to that other overachiever, Homo sapiens. More to



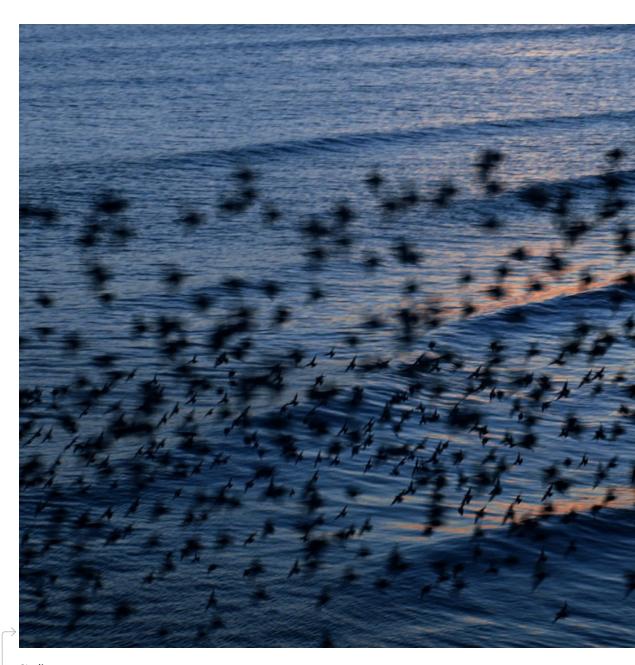
Swarming of bees. State 1.

Wenzel Hollar (1607–1677) | Wikimedia Commons

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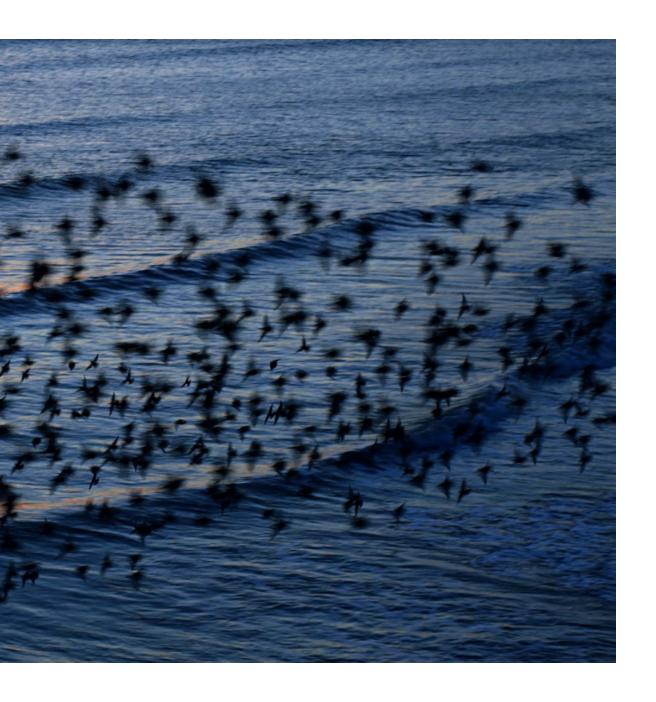
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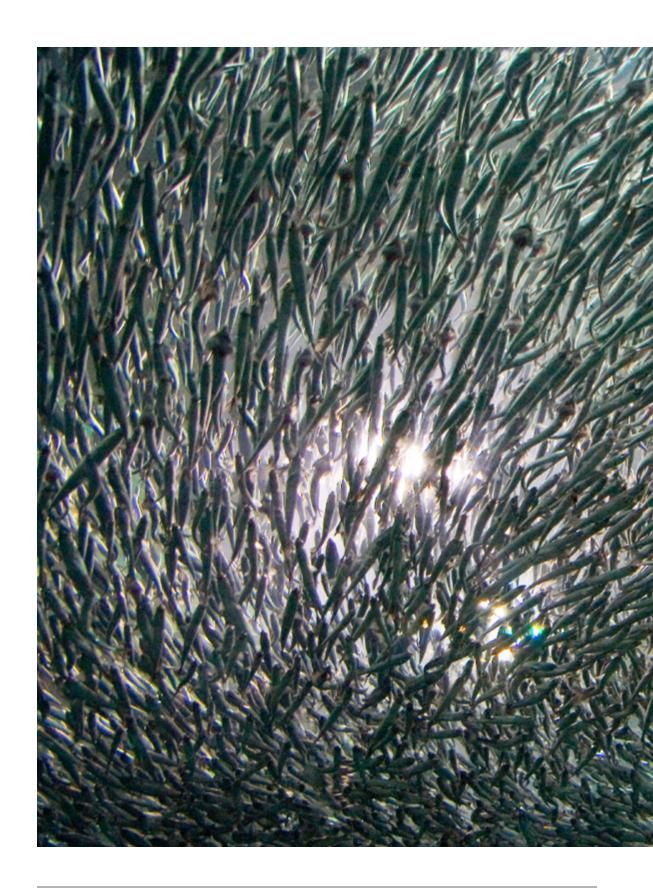
Author:Mark Kerber with Norbert
Hoeller and Tom McKeag



Starlings swarm

Photo: auspices, 2010 | Flickr cc







Fish School | Photo: Lance McCord, 2005 | Flickr cc

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that practical applications were premature and more research was required. Fortunately for Roman and Mark, their background in engineering, computer science and math allowed them to develop their own algorithms. The result was an autonomous, wireless power controller designed for cyclical electrical loads that communicates power usage patterns with its peers. Each power controller manages its connected electrical load such that the peak power consumption of the system is minimized, without any impact on users. Initial real-world installations have showed peak energy reductions around 30% (see Centennial College data analysis report for more details). Overall consumption could also be reduced by adjusted duty cycles for nights and weekends when buildings were not occupied.

Two years after the launch of the EnviroGrid™ controller, a chance conversation with a customer led to the broader problem of demand

that would allow the controllers to modify their own settings based on environmental inputs.

The greater demand for electricity combined with the growth of smaller renewable energy providers will drive a need for wide-scale deployment of appliances and other power loads that manage their usage to optimize the overall ef-

response management. Central building con-

trol systems can be programmed to respond to

alerts from utilities when the electrical grid be-

comes overloaded. However, the response often affects users by shutting off discretionary loads

across the board. At the end of the demand re-

sponse period, these controllers may bring multiple loads back online, resulting in a spike that

affects peak electrical consumption. REGEN

Energy added the ability to remotely modify

the EnviroGrid™ controller, allowing gradual and

granular control of device duty cycles during and

after the demand response window. Recently

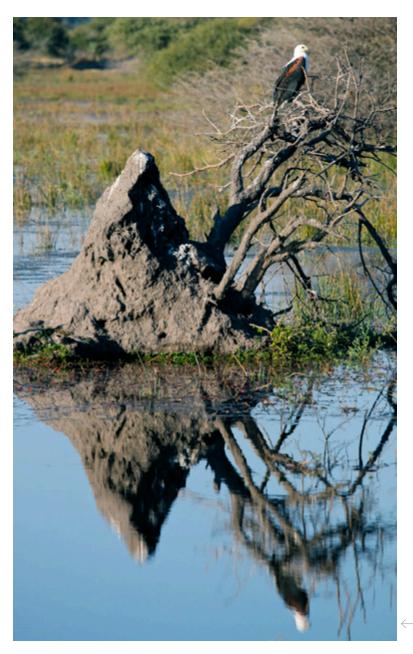
REGEN energy released a set of enhancements

Before and after power usage at a 'big box' retail store showing reduced peak consumption after installation of EnviroGrid™ controllers.

the point, the name also indicates a more systemic characteristic. The colony, rather than the individual, is what functions as a unit, adapts to change, and is maintained and perpetuated. As such, argues Wilson, these societies are the perfect window into "the emergence of one level of biological organization into another."

Emergence is a key trait of biological organization. Within the nested scales of hierarchy from the atom to the biosphere, life exhibits this principle: whole systems cannot be explained by an examination of their parts because they are the product, rather than the sum, of these parts. The final formula and product, therefore, include the complexities of the array, relationships and interactions of those parts. Emergent properties are everywhere in nature, from DNA to ecosystems.

The mound building of termite colonies is a good example of emergence. A complex, many-part structure rises 2,500 times the height of any one of its individual builders, full of arched tunnels, nurseries, growing chambers and ventilation shafts. Over time, the efforts of individual termites combine to build an immense and complex structure without the need for any central control.



Termite Terraforming

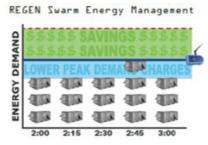
Photo: jurvetson, 2011 | Flickr cc

ENERGY DEMAND

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Article: REGEN Energy Author: Mark Kerber with Norbert Hoeller and Tom McKeag







ficiency of the grid. Such 'smart appliances' can automatically reduce consumption during periods when the local power grid is overloaded and allow customers who are billed based on 'time of use' billing to shift consumption to periods when electricity is cheaper. The scalability, lowcost, flexibility and self-management capabilities of the REGEN Energy power controllers, combined with the potential for granular usage reporting, make them ideal components for the 'intelligent grid' of the future. In addition, the EnviroGrid™ controllers can report usage to a central collection point, allowing timely preventative maintenance and further optimization of the system.

The founders of REGEN Energy combine a passion for social and environmental issues, deep expertise in the electrical sector, business experience and strong entrepreneurial capabilities. Using a disruptive innovation approach, they were able to identify an opportunity that could be developed rapidly, from initial idea to first customer implementation in 18 months. Although Mark and Roman did not become aware of the wider field of bio-inspired design until later in the development of the EnviroGrid™ controller, their work is an example of applying

Two modes of power management by Enviro-Grid™ controllers: flattening of peaks as well as reduction in overall consumption during demand-response periods.

"deep patterns" or principles from nature to deliver environmental and economic benefits in an elegant and cost-effective manner. Their idea was inspired by the growing body of knowledge about swarm theory, emergence and self-organizing systems. The process and the final service also share characteristics with natural systems, including the delivery of multiple benefits, fast and direct payback, efficient use of resources, self-management, and a reliance on information rather than energy to solve problems. The solution is robust, adaptive, requires no centralized control and shows potential for further spin-off applications.

REGEN Energy has been able to overcome the skepticism of engineers about the feasibility and reliability of emergent systems by leading with a problem, explaining the theory and backing up claims with numerous case studies. The company's development process has also been an excellent example of the growing collaboration between industry, academia and government. REGEN Energy was able to bridge the different cultures, objectives and timelines of industry and academia, translating theory into practice,

Different castes tend to young, reproduce, farm fungus, maintain ventilation, build, repair and defend the nest. Despite a daily fluctuation from 40 degrees C to less than o degrees C, the termites are able to maintain a constant inside temperature of 30 degrees Celsius. Within thick, insulating walls they accomplish this by creating and constantly maintaining a draft of air from low openings to top holes. They make use of the so-called stack effect, convective airflow from cool to warm. The termites are constantly tweaking these openings for optimum performance, sometimes adding wet mud that aids cooling with its evaporative effects.

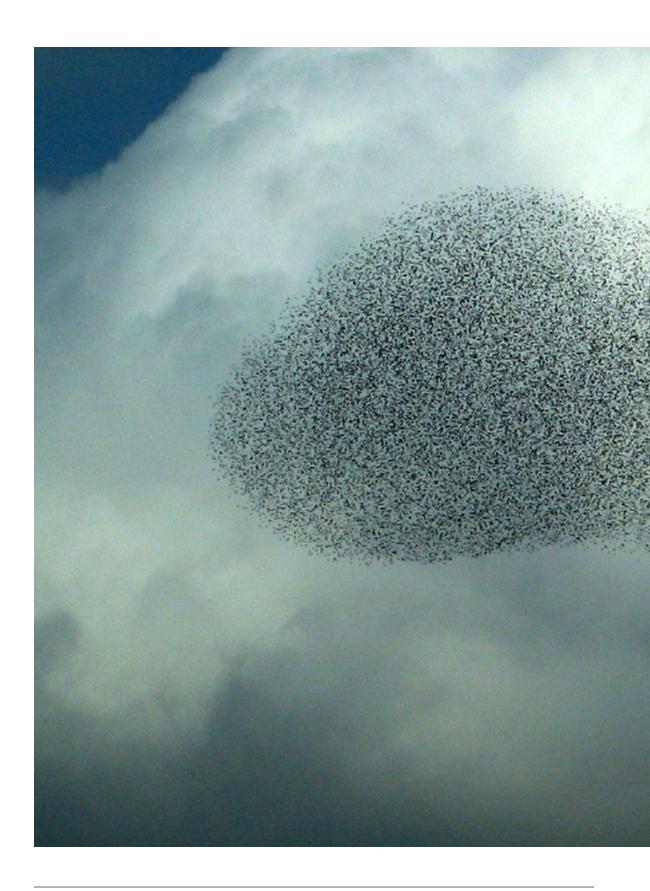
This is self organization and in the insect societies it happens because of two things: developmental algorithms that determine the castes with their specialized skills, and behavioral algorithms that determine how individuals will act toward each other and respond to a few environmental possibilities. Moment to moment communication occurs via pheromones, the chemical messages of the insect world. At a higher level, the algorithms themselves evolve through the process of natural selection, just as the traits of individual animals do.

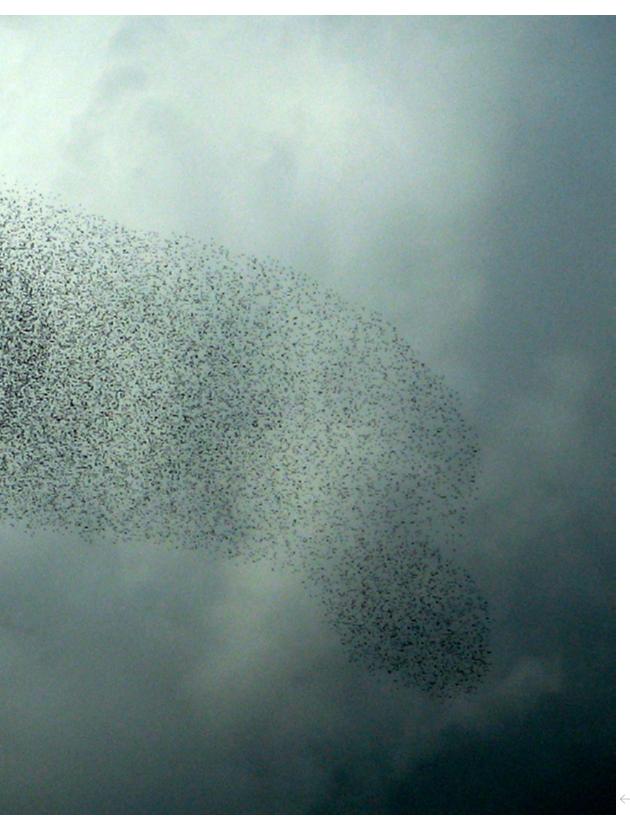
It is a successful strategy indeed. While these types of societies



Starlings

Photo: Kitty Terwolbeck, 2011 | Flickr cc





Murmuration:Starlings near Athens | Photo: muffinn, 2008 | Flickr cc

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providing business relevance and delivering over 60 successful site implementations throughout North America.

Additional information:

- •"Bubbling under: Canada's top 10 cleantechs" (Clean Break, October 27/2007)
- •"Cleantech First Annual Corporate Knights Ranking" (Corporate Knights, October 25/2007)
- •"Lots of buzz surrounding this company" (The Star, September 3/2007)
- "Reducing Peak Demand using Self-Organizing Systems – Follow Nature's Lead" (REGEN Energy, May/2007)
- •"Smart Grid: Taking our Cue From Nature" (REGEN Energy, 2009)

Mark Kerbel manages REGEN's U.S. West Coast office based in San Diego, CA, serving customer, channel partners, and utilities in California, Arizona, New Mexico, and west Texas. Mark is co-author of REGEN Energy's swarm logic patent, and involved in the development, funding, and commercialization activities of the firm, particularly with its key U.S. customers and strategic partners, He is a frequent speaker on the topic of emergent systems theory and its application to Smart Grid and Smart Buildings technologies. Prior to forming REGEN, Mr. Kerbel has served as a board member and executive as a founding partner of the SPi Group, one of Canada's leading software solutions providers for the retail energy sector. Mr. Kerbel has chaired and/

or been invited to participate on a number of committees in the energy sector including the Electronic Business Transaction Standards Working Group of the Ontario Energy Board, the Technology Joint Sector Committee of the Ontario Energy Association, the Smart Meter Initiative of the Ontario Energy Board and the Regulated Price Plan Initiative of the Ontario Energy Board. More recently, Mark has become a member of the OpenADR alliance. He obtained his B.Math in Computer Science from the University of Waterloo.

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REGEN is now https://www.encycle.com

represent only two percent of the world's insect species, they account for over half of the biomass. These insect societies "...illustrate, through thousands of examples, how the division of labor can be crafted with flexible behavior patterns to achieve an optimal efficiency of a working group."

Over the past several decades, "bottom-up" or "swarm" logic has been gaining momentum in the fields of artificial intelligence, cybernetics, telecommunications, physiology, management and logistics. Internet searches, market predictions, customer preferences, vehicle routing and manpower management have all benefited from the eusocial insect organizational model. The reason is that it works: its simplicity, adaptability and robustness outperform our traditional "top-down" methods in many cases, particularly in complex systems.

Icosystem of Cambridge, Mass., has used so-called evolutionary computation to organize field crews for oil and gas drilling. In reviewing schedules, the consultants employed algorithms based on the foraging behavior of ants, and rated routes based on similar feedback mechanisms. Similarly, Southwest Airlines wanted to improve the efficiency of assigning arriving aircraft to gates at airports. It used an ant-based simulation model where planes 're-

intelligence is also being explored by Volvo in developing its injuryproof car by 2020. In this case, locusts, rather than ants, are being studied for their ability to avoid collisions while flying in groups of millions. They do it by neural circuitry that connects visual input directly to their wings for near-instantaneous adjustment of flight. Volvo is hoping that this "sensory input routing methodology" can be adapted to our current manufacturing technologies and commercialized.

Courtesy of REGEN Energy

REGEN Controller

membered' only the gates that had

the shortest delays, like the phero-

mone trails that ants leave. Swarm





