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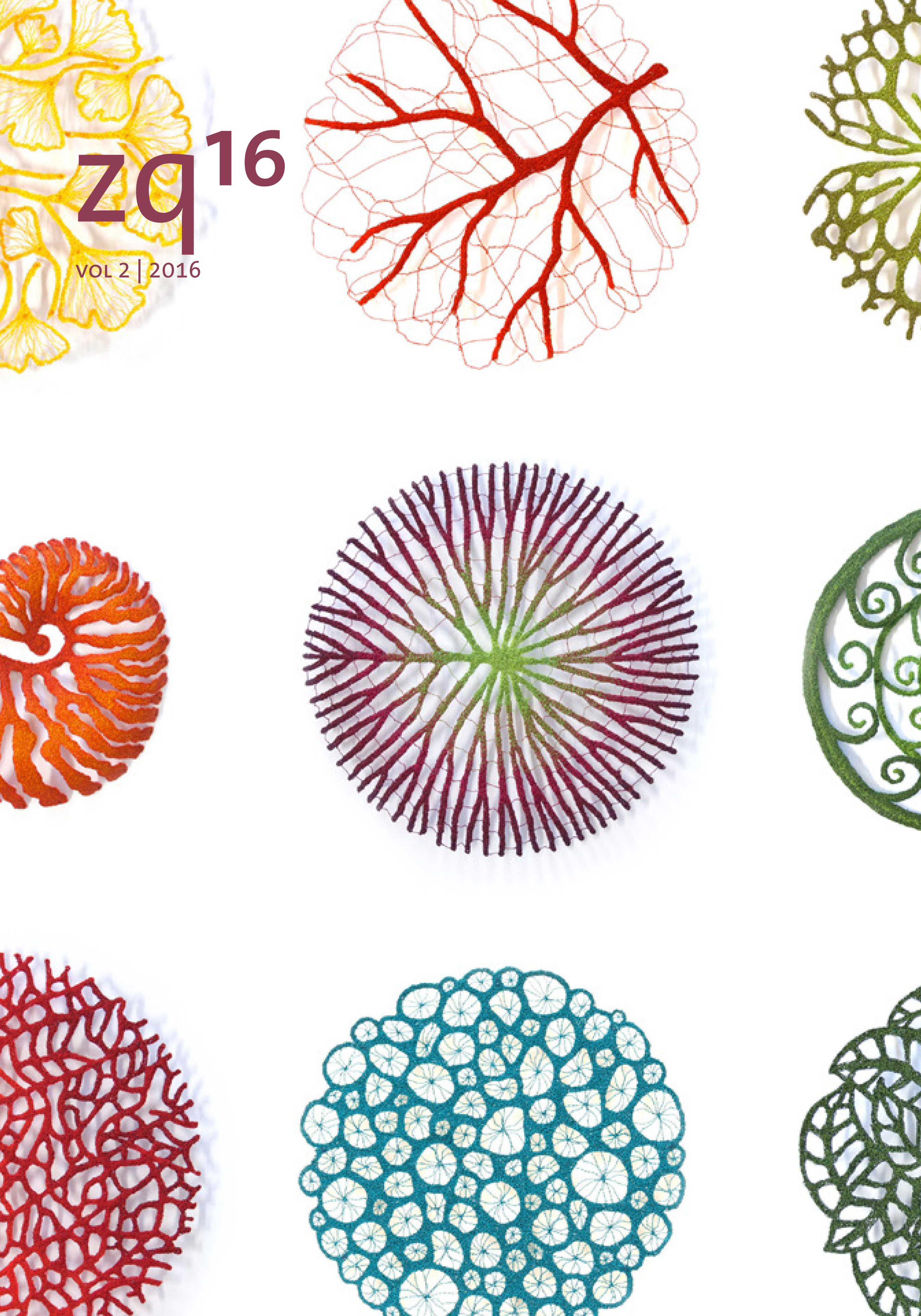




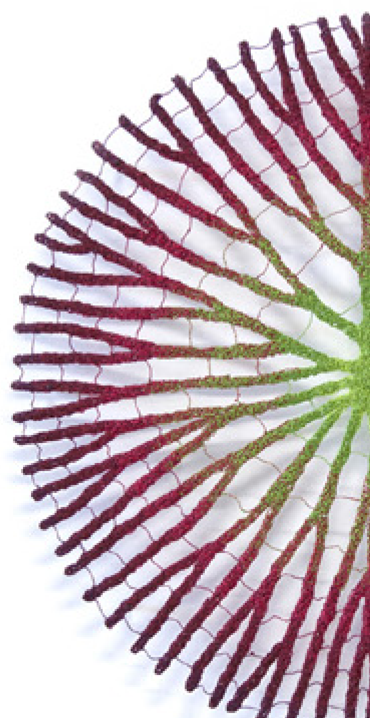

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Ginkgo biloba | Photo: . Yann 07 ., 2015 | Flickr cc

Editorial

Our Case Study this issue is about resurrection plants, how they survive the most extreme conditions and how we as humans might make use of that capability. In order to do that, the scientists who study these plants for potential applications must know how they work by reducing the very complex to the simple: an understandable list of molecular parts and relationships. This reductionist approach, however, this taking things apart, has its limits, and one often finds that it is in its complement, the building back up, that the human mind fulfills its full potential.

Destruction and Creation, with Preservation in-between, have long been the pillars of ancient religious wisdom. We will all be faced with weighty decisions about how technology will be employed and allowed to build life anew at the molecular and cellular level. A collective wisdom will be required, and full participation by a citizenry informed of science.

It is not surprising, then, to see this pattern of destruction and creation writ small in our own activities, whether scientist or artist. In this issue, artists Miebach and Woolnough go about this in individual ways; one collecting bits of data and reorganizing into a whole, and the other making the whole and stripping it down to reveal a new form. It is not so very different than the work of scientists and engineers, whether studying the feet of geckos, as Peter Niewiarowski and others do, or reimagining the role of wind turbine nosecones, like Ryan Church and Stephen Davies. Shifting from one half of the brain to the other is what makes bio-inspired work so rewarding and fun, and in our opinion piece, Shoshanah Jacobs and Dan Gillis promote their strategy for training our next generation of practitioners in this art and science.

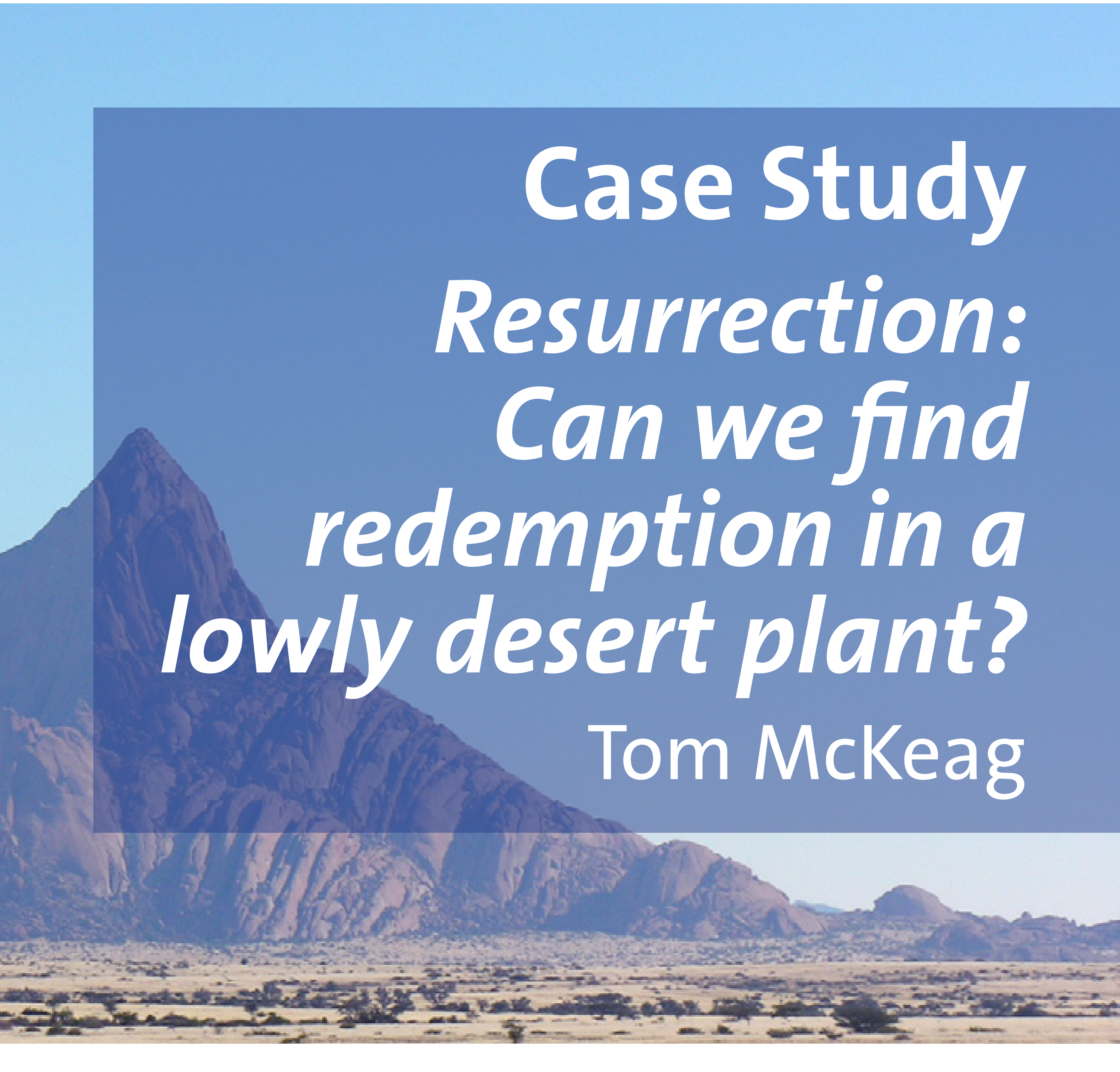
We hope this issue tickles both sides of *your* brain - happy reading!

Tom Norbert Marjan

Tom McKeag, Norbert Hoeller & Marjan Eggermont

Namibia, Spitzkoppe (Inselberg)

Photo: Hansueli Krapf, 2008 | Wikimedia Commons



Case Study

Resurrection: Can we find redemption in a lowly desert plant?

Tom McKeag

Author:
Tom McKeag

Resurrection: Can we find redemption in a lowly desert plant?

The Inspiration

In Namibia, where lone mountains burst out of the arid plain west of Windhoek, there are conditions that seem to mock any intent to live. On the bright and blasted rock faces of these inselbergs cling the straggly brown sticks of shrubs, patient in the heat and searing sun: waiting. Then the summer rains come, perhaps every two years or more, casting their brief showers like coins into a throng of indigents. The waters are as sparse as the resultant landscape and quickly disappear into the cracks and crevasses of the rocky escarpments.

The somnolent plants have not been completely idle, however, and their long root systems are soon absorbing the precious nutriment within the rocks. Within hours they are green again and producing the sugars needed for continued life. *Myrothamnus flabellifolia* is one of the approximately 1300 plants known as resurrection plants. It is a woody shrub that lives across southern Africa, in Namibia, South Africa, Zimbabwe and Mozambique.

Resurrection plants are any land plants worldwide that can dry out to a relative water content (RWC) of 5% and resume normal physiological and metabolic activities upon rehydration. They are different from the merely desiccation *resistant*. Desiccation resistant plants reduce the effects of drying by a myriad of clever strategies like smaller leaves, highly reflective coloring, moisture trapping hairs, and the intricate time management of osmosis. Resurrection plants, by contrast, become, to all appearance, dead; completely devoid of color or surface moisture, and cease many of the metabolic functions that their merely resistant neighbors may still be struggling to perform. They are desiccation *tolerant*.

A third plant strategy in a dry world is desiccation *avoidance*, the common practitioners of this we know as annuals. Within a year, the plant grows with, say, the benefit of spring rains, flowers, spreads its seed, and dies. The avoidance is in the seeds, which can be likened to DNA time capsules, waiting for the right conditions to start growth again. Germination is triggered by conditions specific to a plant's adaptation to its ecosystem over thousands of years. Water, temperature, air and sometimes light, are the main factors governing when a plant embryo breaks its seed coat and sets its metabolic machinery in action to grow into a full plant. This form, the seed, is what enabled the triumph of the flowering plants, the angiosperms, over the earth's land mass.

The seed is the most successful life form in the world, but it is a heavy and singular investment: all other phases of the plant's life cycle are merely supportive of its creation and vulnerable to the swings of temperature and moisture, par-

Myrothamnus flabellifolius, Mountain Sanctuary Park, Magaliesberg, South Africa | Photo: Marco Schmidt, 2011 | Wikimedia Commons ticularly if you are an annual, that group that evolved to die each year to avoid either cold or dry conditions.

In order for the seed or spore to germinate, it must typically imbibe water, and at the right temperature. Two main hormones are at play: abscisic acid, which inhibits germination, and gibberellin, which promotes it. Abscisic acid also inhibits plant growth and fruit ripening when conditions such as drought trigger a plant to slow down its photosynthesis or transpiration. Gibberellin regulates germination and influences growth and various developmental processes such as flowering, stem lengthening, enzyme induction and senescence.

In the Namibian desert, conditions are so extreme that *Myrothamnus flabellifolia*, a woody perennial, has evolved to practice some of the tactics more commonly performed by the seed. Shoots and leaves lapse into a similar dormancy triggered by drought-induced stress. At the cellular level, genes are triggered that begin transcripting information for the production of metabolites, a diverse and species-specific array of sugars, phenolic compounds and polyols. Some of these, most notably the sugars, pack the cells of the plant preventing damage from water loss, but also guarding against other abiotic stresses. The sugars may be forms such as sucrose, raffinose, melibose and trehalose, and they may serve several functions, acting as food reserves, osmoprotectors, or mitigators of oxidative stress. Acting in concert with the sugars are sugar alcohols and sugar acids. Collectively all may alleviate the consequences of dehydration by stabilizing proteins and other macromolecules, and protecting them from reactive oxygen species (ROS)-induced damage (Gechev et al., 2013; Oliver et al., 2011a; Yobi et al., 2012; Yobi et al., 2013). Lipids may also play multiple roles in protecting the plant against desiccation, serving as reserve energy sources, signaling molecules and protectors against structural damage.

The quickness of the plant's response at the first sensing of stress and the powerful array of chemicals it brings to bear have made this strategy very successful. Resurrection plants are found in widely diverse habitats, producing an even wider array of chemicals. For this reason, geneticists and molecular biologists from around the world have sought to mine its secrets for use in synthetic biology. Understanding the metabolic pathways in plants and other organisms enables chemical engineers to design and use cell factories to produce chemicals such as biofuels. An example is the company Amyris of Emeryville, CA, which re-engineers microbes to produce sugars at an industrial scale for a variety of products: fuels, food additives, fragrances, solvents and more.

Resurrection plants hold promise in the biomedical field as well. The brown shrub seen on the Namibian hills, *Myrothamnus flabellifolia*, is one of the most studied of these for the potential bounty of pharmaceuticals it might yield. Traditional African healers have used it for wounds, respiratory problems, mastitis, backaches, kidney and abdominal disorders, scurvy, halitosis and gingivitis.

Today scientists are looking at how the so-called secondary metabolites of resurrection plants might be isolated and extracted to produce drugs to treat bacterial and viral infection, kill cancer cells, and prevent fungal growth. Secondary metabolites are those substances that

Xerophyta viscosa, Camel Rock, Free State, South Africa | Photo: Marco Schmidt, 2006 | Wikimedia Commons do not play a role in the primary activities of life, growth, development, or reproduction. Often their function is to maintain health by preventing stresses like herbivory, or infection, hence their usefulness for pharmacologists. Plants are estimated to produce about 200,000 chemical compounds that are secondary metabolites, and only a fraction have been documented for structure, function and biosynthetic pathway. Codeine, steroids and atropine are all examples of biosynthetic drugs derived from secondary metabolites.

In general, resurrection species use their secondary metabolites for both protection against dehydration and other stresses such as UV-light and herbivore attack. *M. flabellifolia's* predominant polyphenol 3,4,5 tri-O-galloylquinic acid has been shown to inhibit M-MLV and HIV-1 reverse transcriptases (Kamng'ona et al., 2011), thus has shown promise in the treatment of leukemia and human immunodeficiency.

Dr. Jill Farrant

Photo: University of Cape Town, 2015

http://www.mcb.uct.ac.za/mcb/news/2015

The Translation

Dr. Jill Farrant is one of the many scientists who are intrigued by resurrection plants and has been studying the complex mechanisms of plant dormancy and growth for decades. Her current quest is to understand these mechanisms in resurrection plants to a degree sufficient to impart these abilities to food crops, specifically African cereals.

Human caused climate change has meant that certain parts of the world will become increasingly more drought prone, and both food and drinking water production will suffer if adaptation strategies are not developed. At the same time, the world's population is projected to increase to ten billion by 2056, according to the United Nations, an addition of nearly three billion people in 40 years. By 2050, the organization estimates, the world will have to produce 70% more food to keep up with its population. Most of the population increase will occur in Africa, and it is here that food production is the least sophisticated; farmers predominantly rely on rainfall for harvests.

Dr. Farrant and her colleagues at the Department of Molecular and Cell Biology at the University of Cape Town (UCT) with others from the U.S., Netherlands and France, have discovered that the genes that allow seeds to remain dormant until conditions are ripe for germination are the same genes as those found in the leaves of the resurrection plants. As is common in the living world, there is a myriad of genes residing in each and every organism, some turned on, and some not. If they can introduce these genes to express themselves in the mature plants of cereals like maize, then the rain-dependent harvests in Africa could become more reliable. Farrant and her colleagues would like to combine the traits or phenotypes of desiccation tolerance of certain perennials with the high productivity of annuals of commercial value, crops like wheat, corn and rice.

Farrant started her studies in seeds, but became fascinated with the similarities with desiccated plants found in her native home. Her current research focuses on how genes are switched on and off to produce these hormones and activate or suppress the metabolism of the plant. There are many genes involved in this process, and they are typically controlled by a master set of genes, the switches. The researchers at UCT are investigating three ways of breeding these characteristics into commercial crops: traditional cross-breeding, genetic modification, and gene editing.

The UCT researchers have taken a comprehensive look at the factors influencing dormancy and activation, from the molecular to the ecological. For example, they have studied the eco-physiological, physiological and biochemical functions of each target plant, as well as how proteins are expressed by genes, how these genes might be turned on by lipids in membranes, and how transcription, the turning of genes on or off, happens and where in the cell ultrastructure.

Within the chromosome of a particular plant are the DNA strands and within those strands are the genes. Within each gene are sections that contain promoters ("on" switches), the code region and terminators ("off" switches). In their experimentation, the molecular biologists are seeking to introduce a drought-induced promoter from a resurrection plant into the DNA of a commercial crop that will drive the production of anti-oxidants that will, in turn, halt the damage typically incurred by desiccation.

The Issues

If successful, crops like maize modified this way could be made tolerant of drought cycles, and perhaps even be designed to produce again and again when conditions are best. Crop yields might increase without the high capital costs of infrastructure of irrigation or soil sensors, and potentially with fewer petroleum-based fertilizers and pesticides.

How these scientists will go about this modification is not without controversy, and Farrant is careful to note that potential beneficiaries of their work must decide for themselves the relative merits of their methods. While cross-breeding and so-called mutagenic alteration of plant genes have raised few objections, genetic modification (GM) has been controversial since its inception in the 1970's.

Most GM crops in the world are grown in the U.S., Brazil, Canada and Argentina, as other regions have rejected their use outright. The European Union is the most prominent, and eight of its member countries have banned all GM crops. Several African countries have followed suit, refusing to import GM foodstuffs. Kenya, for example, bans all GM products, despite widespread malnutrition.

The EU has founded policy upon the "precautionary principle" in which important technological developments must be proven safe before widespread adoption. By contrast, U.S. policy has allowed scientific advancement to be adopted

Selaginella lepidophylla | Photo: Nicole Koehler, 2009 | Wikimedia Commons

more readily unless and until problems are documented. The American Association for the Advancement of Science, the American Medical Association and the National Academy of Sciences have all approved GM crops. The U.S. Food and Drug Administration has concluded that GM crops pose no unique health threats.

Despite these approvals, doubts remain about GM crops, particularly of what may happen when selective genes are put into complex biological environments and allowed to evolve within the natural selection cycles. Cross-species mutation, the effect of these crops on the long term health of consumers, and on insect and aquatic life, and the relationship of GMO's with increased pesticide use, such as with Monsanto's "Roundup Ready" crops are all concerns voiced by critics. Moreover, there is doubt that genetically modifying crops alone actually increases yields. In 2009, the Union of Concerned Scientists, concluded that the results of 20 years of research and 13 years of commercialization "... has done little to increase overall crop yields."

Clearly, solving the current and coming world food crisis will require a range of methods across many disciplines including better governance and distribution methods, stricter environmental safeguards, regenerative agricultural practices, and water conservation, as well as improved crop varieties. It remains to be seen how the secrets of the miraculous resurrection plants will be used in agriculture and pharmaceuticals, but the promise is there if we are wise enough to make healthy use of it. ×

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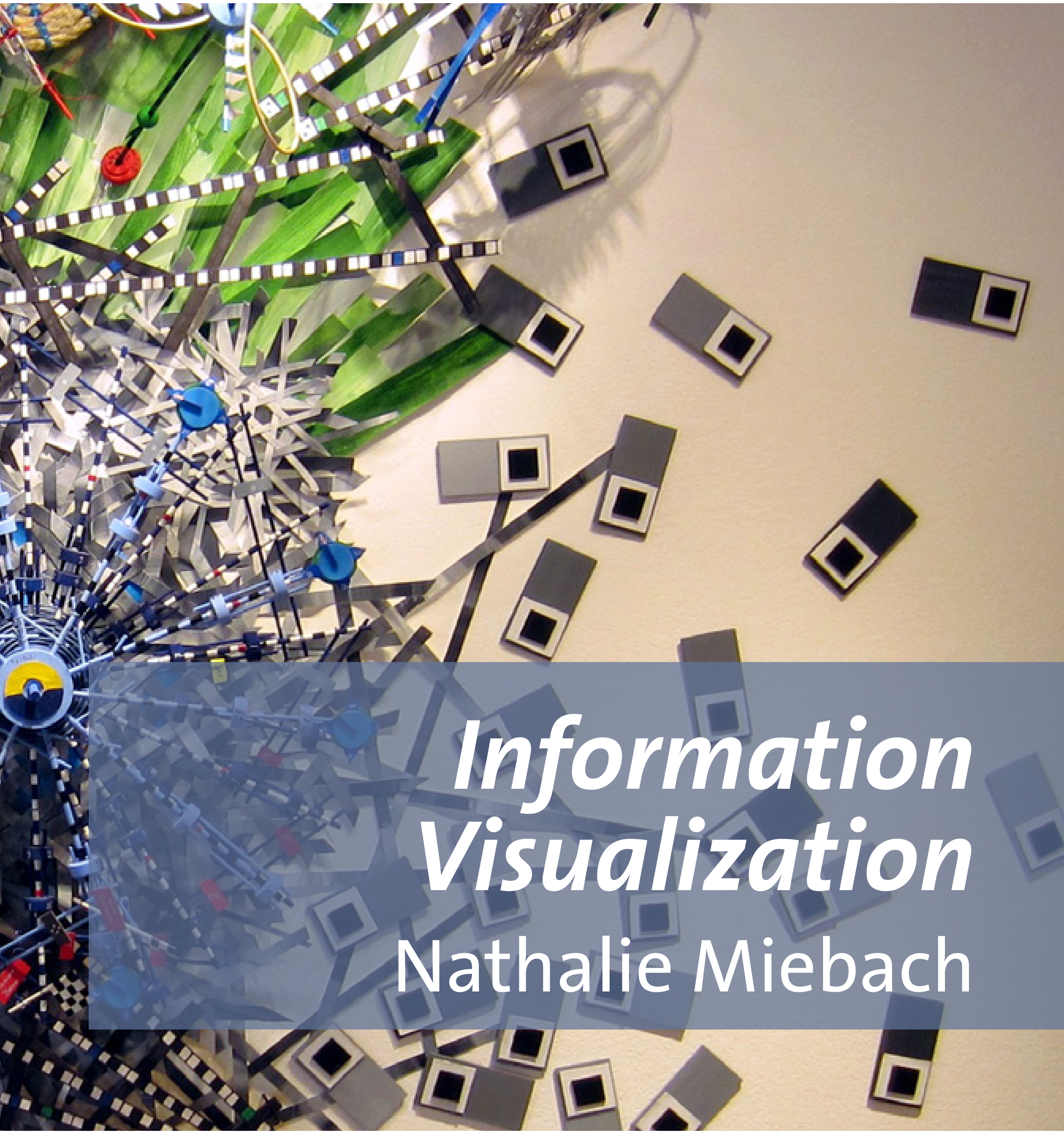
Myrothamnus flabellifolius, Mountain Sanctuary Park, Magaliesberg, South Africa | Photo: Marco Schmidt, 2011 | Wikimedia Commons

Retiring Bob Cafam 1 (detail)

Nathalie Miebach



Information Visualization

Nathalie Miebach

Could you tell us about your background and how you got started?

This merging of basket and astronomy began in 2000, when I attended astronomy classes at Harvard University and studied basket weaving with a local craft artist. Serendipitously, both classes fell on the same day, so that I would bring all my buckets, reed and half-finished baskets with me into the lecture hall. Astronomy was fascinating, but frustrating. I never seemed to be able to get a real sense of the time and space dimension we talked about in class, because everything we ever looked at was on the two-dimensional plane of the projector wall. At some point the light bulb went off in my head that I could actually use basket weaving as a three-dimensional grid through which to translate astronomical data with to get a more tactile, physical sense of what I was learning about in astronomy. For my "final paper", I turned in a sculptural translation of the Hertzsprung-Russell diagram, looking at the evolutionary stages of stars. Professor Chaisson was very open-minded, loved it and promptly invited me to share the sculpture at science conference organized by the Wright Center for Science Education.

In 2004, I began focusing my sculptural data translation on weather, because I wanted to find a more tactile, physical way of understanding the complexity of climate change. Utterly confused by all the charts and figures online and the endless policy debates about climate change, I found myself wanting to bring all this information into my own world – the physical world all around me. Rather than diving right into climate change, I decided that I would begin by studying weather and its systems. My theory was that if I could understand how weather interacts in my own backyard, then maybe I could, one day, truly appreciate the complex interactions of natural and manmade factors that make up climate change.

To me, the key is to make weather tactile, to have it emerge from the flatness of the computer screen and the abstraction of the graph – to physically realize the complexity of weather. I have built my own weather station and gather data every day. I use the Internet to collect local, historical and global data to put my findings into a broader context. From all these numbers, I begin a translation process into the third dimension, using basket weaving as a simple spatial grid through which to translate the data. By staying true to the numbers, the forms I create are not only tactile data visualizations, but are also sculptures and installations through which viewers can approach the information from all sides. The premise is simple: if I can touch the information, perhaps then the complexity of climate change or weather can become more real and understandable.

What kind of techniques do you use for your work?

There are really two parts to my process: data-collecting and the visual translation of data. The first part, data-collecting, takes place in various forms. If I am looking at a specific environment close-by, I build very low-tech data-collecting devices that I bring to a particular place on a daily basis. I record both the numbers the devices are measuring as well as everything else that is happening all around me. My own observations and recordings are then compared to sites on the Internet that record similar data nearby. For exam-

The Halloween Grace | Nathalie Miebach


100 FT
70 MPH
31.5N/63.2W
70 MPH
← GLOUCESTER
56 MPH
29.8N/66.4W
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7:00

ple, if I am recording weather data, I will always compare what I have recorded that day with what a nearby weather station has recorded, as well as look at weather satellite imagery of that day to place my observations in a more global context. If I am looking at an environment that is too far away or too impossible for me to get to, such as the Antarctic, I turn to the Internet and use data from various research stations, university or governmental agencies. As a rule, I always double and triple check data I use from the Internet, even if it is from reputable sites, because there is, unfortunately, a lot of junk on the web.

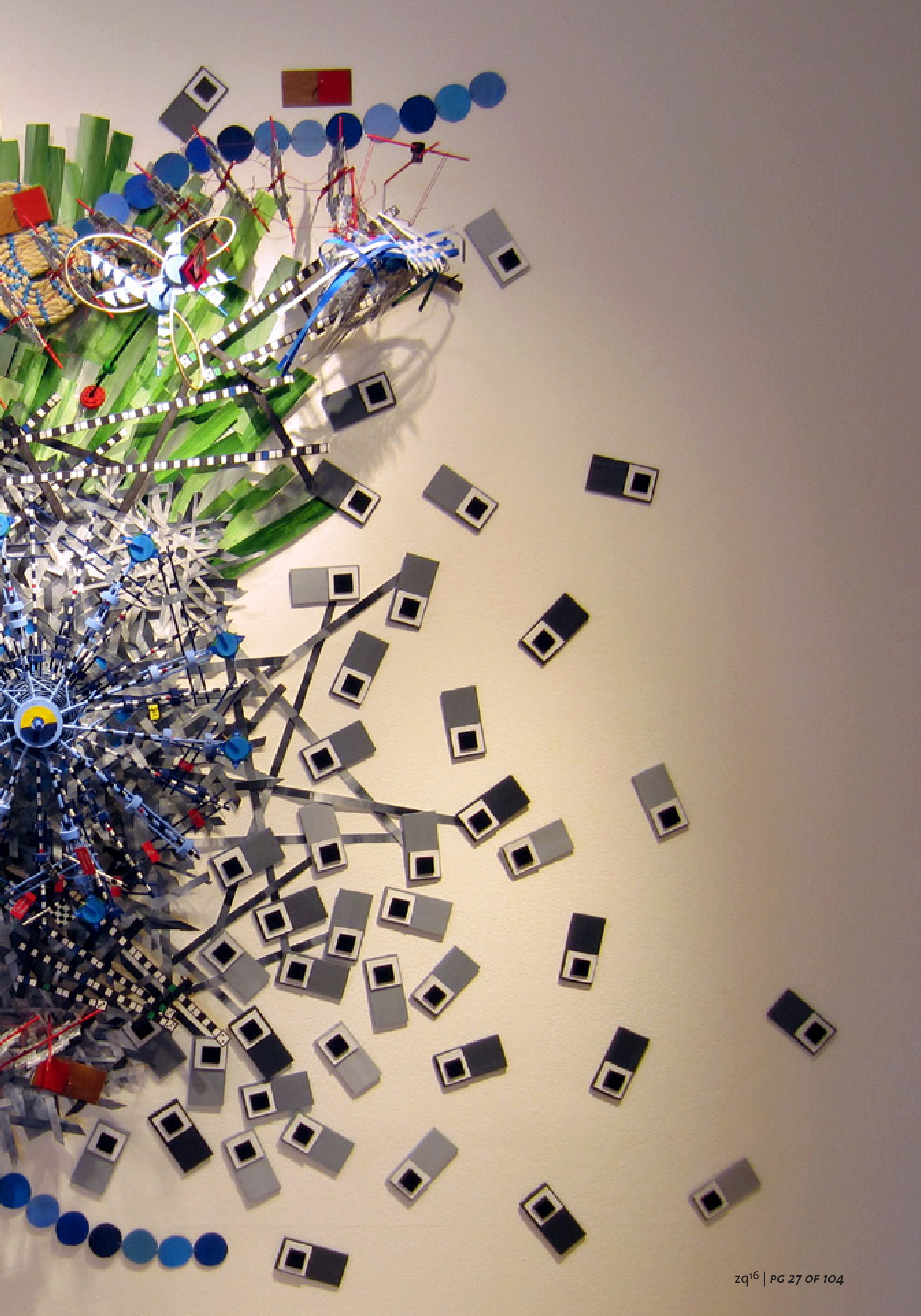
I much prefer doing my own observations because the key to understanding dynamic, complex relationships between different systems within an environment is actually in what you observe peripherally. It is what I observe all around me (the cloud cover, bird behavior, water current, the way the ground feels, the way the air smells, etc) while I wait for my instruments to record data that helps me see the behavioral complexity of hundreds, even thousands, of systems that make up weather. I keep describing this as a type of visual 'listening' with my peripheral vision, though I am still learning myself what that actually means.

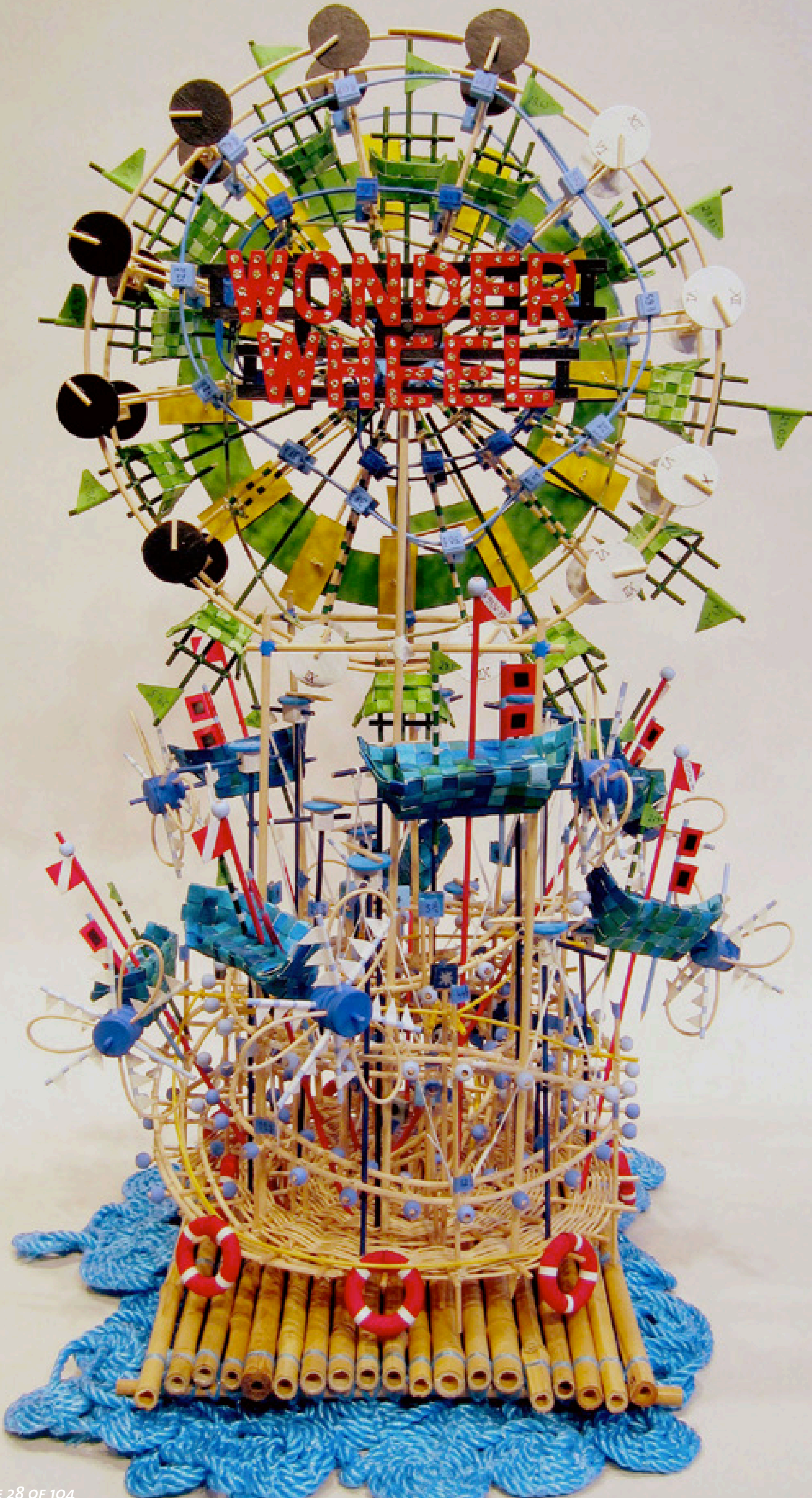
After I have a good chunk of data recorded, I become a sort of detective, in which I look for patterns, inconsistencies, cause-and-effect type behaviors that suggest linkages between certain variables. With a huge cup of coffee and some Steve Reich playing through my headphones, I stare at these stacks of graphs, numbers and diagrams to find something worth investigating further. What I begin to translate depends partially on the format of the data. For example, data that is presented in forms of maps are the worst, because for me to get to the actual value of a piece of information, I have to decode it and extract it from the map itself. It's like I am peeling away the visual in order to see the number, so I can retranslate it into something visual. Much too complicated! The more numerical and drier it looks, the better. Numbers function a bit like Lego pieces, in that I assign each value a physicality that gets integrated into the basket. I never change the value of the numbers to conform to some sort of aesthetic preference. This allows the sculptures to exist both as sculptures in space, but also as actual devices that could be used to read data from a specific environment.

From the many variables I have collected, I will choose two or three to begin the initial translation process. The basket is my method of translation because it provides me with a simple, yet effective 3D grid through which to translate data with. The sculpture is a collaboration between the material, the numbers and myself. The material I use to translate is reed, which has an inherent tension that does not allow me to completely control it. If I push it too hard, it will simply break. The changing nature of the numbers over time as well as the inherent tension of the reed is what create the shape of the basket. I try to let the changing tension of the reed dictate the shape; only in certain instances do I step in and exert pressure when I sense the piece falling physically apart. I never know what the shape will be beforehand, which often leaves me scratching my head – some shapes are easier to work with than others.

Once the basket sculpture is done, I have a temporal landscape on which I can plot more data on top that is related to the initial relationship I was looking at. In some ways, this is when I

Retiring Bob Cafam 1 | Nathalie Miebach




WONDER
WHEEL

start to ‘visually listen’ again, for how and what I will translate further on this shape will depend on what conceptual aspect I want to further explore, as well as how it will aesthetically fit together. Colors and shapes are assigned to various variables (e.g. red for temperature, blue beads for wind strength, etc.), with legends next to the sculpture letting the viewer know what each of them means. These choices are directed through a combination of referencing commonly associated shapes or colors with certain variables (e.g., temperature is almost always either red or blue), as well as the availability of materials I happen to have in the studio.

On a surface level, my current work is about translating science data related to weather or polar regions undergoing drastic changes due to climate change. But on a deeper level, this work is also about thinking. Assigning colors and shapes to certain variables is very much like assigning a concept to a particular word. Like an anthropological linguist, I try to create my own sense of meaning through these colors and shapes that articulate the nuances, patterns and inconsistencies I see as developing a visual language that enables me to articulate relationships I see or sense within the environment I am observing.

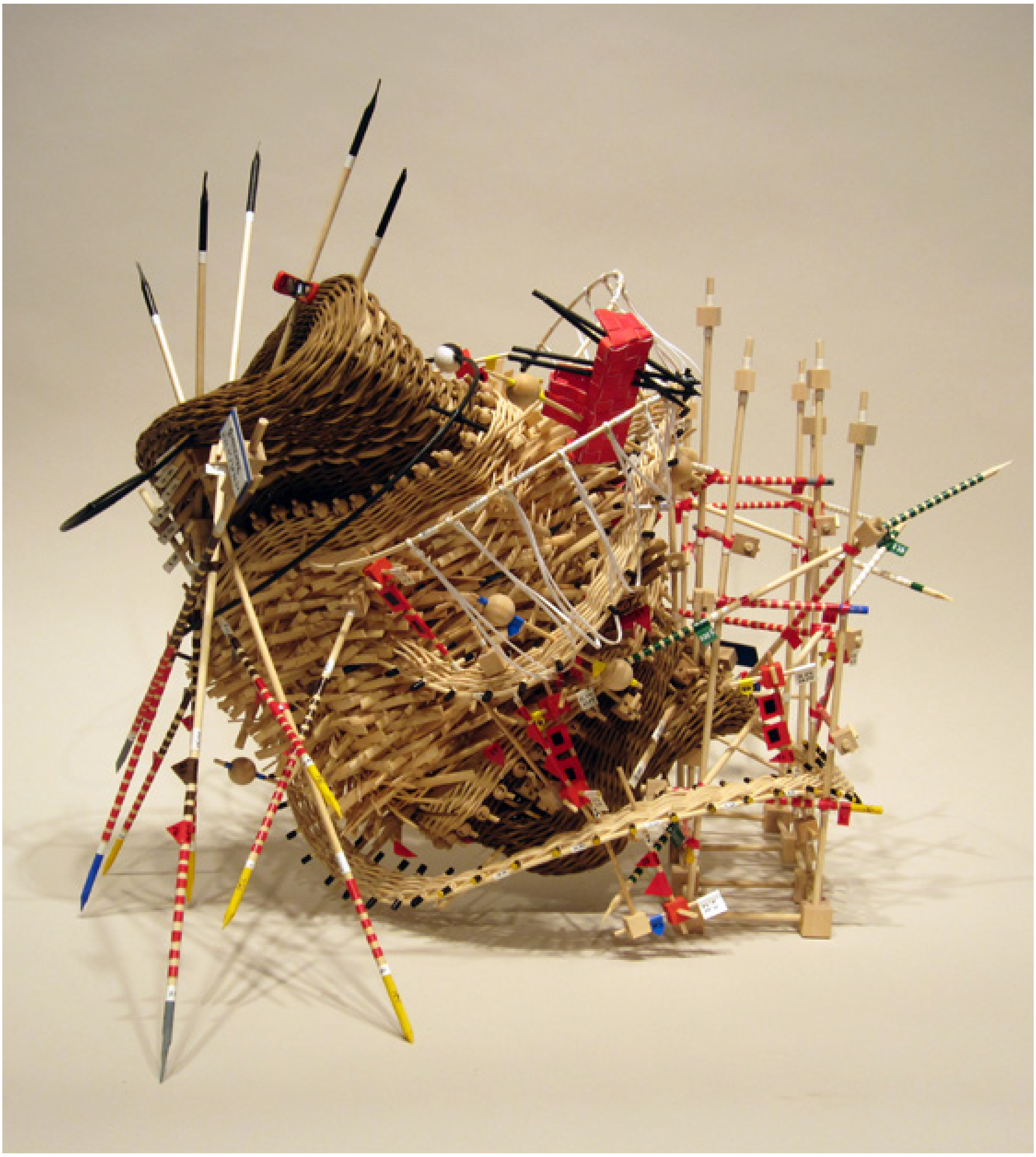
As an artist who has been focusing on translating data into 3D woven structures for over 12 years, I am keenly aware that the predominant way we engage with information today is through the digital realm – tablets, computers and smart phones. My sculptures, on the other hand, are tactile 3D representations of meteorological and climate data. Using basket weaving as my primary medium of translation, my interest is in exploring how our understanding of information is shaped through the media we employ to articulate the information we gather. How would our understanding of climate change differ, if we could walk around the information, touch it and possibly even hear it? Would the complexity of climate change and the networks of systems both natural and man-made become somehow more urgent and real if we could learn about this complexity directly through our senses, as opposed to through an LED screen?

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

When I started this work, art was very much in the service of science and the work was very didactic and meant to explain something. Every piece began with a specific question I had about either the science I was studying or about the environment from which I was extracting the information from. It was important that the work was deeply rooted in the precision, accuracy and methodology of science.

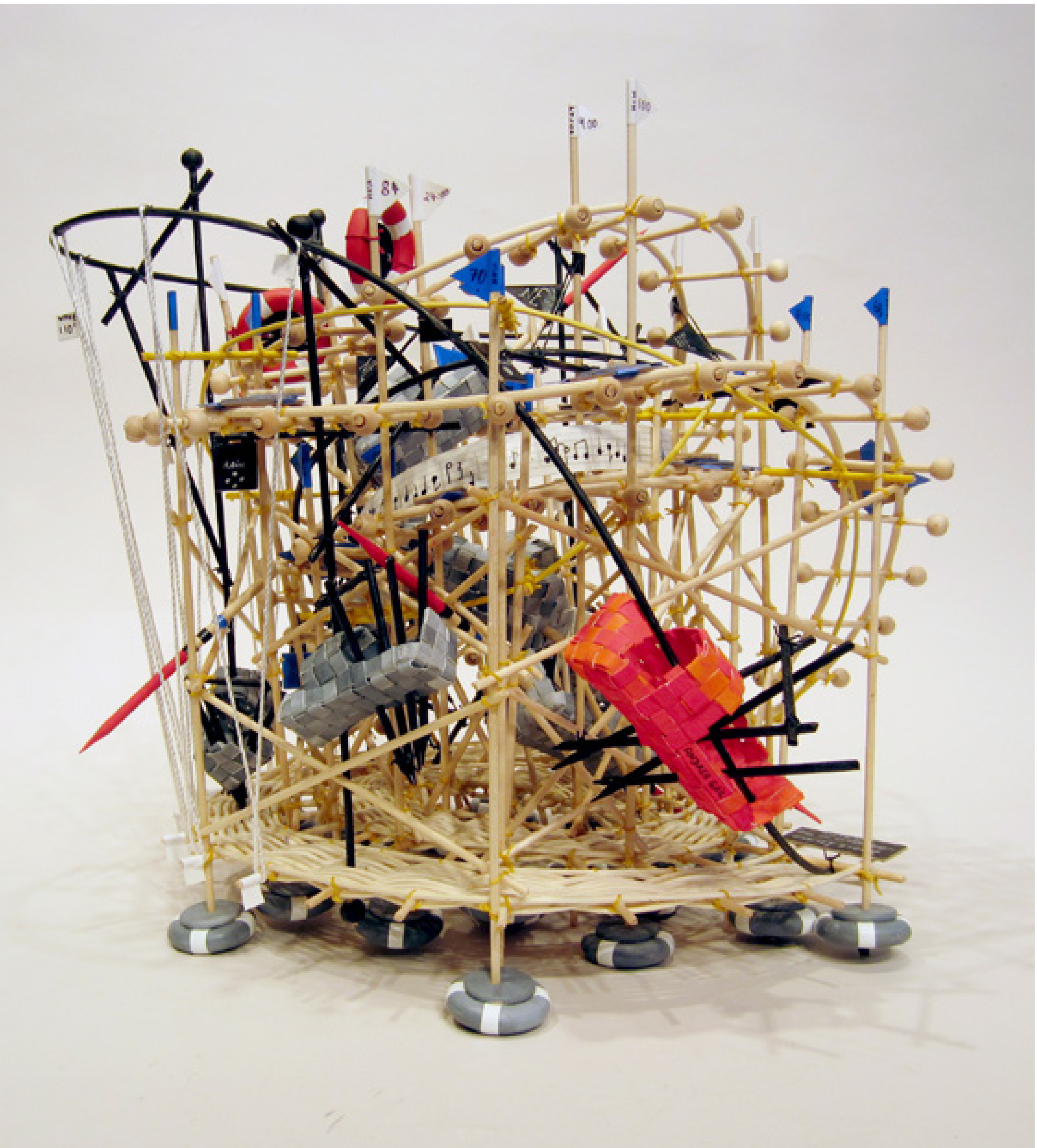
After focusing on weather data for several years, I began to become increasingly interested in the discrepancy between how weather instruments record weather and how we as human beings actually interact with and interpret weather. Most of the time, weather falls into the background and we only notice it when we forgot our umbrella or the windshield wipers need replacement. But, human beings are actually great weather stations because we register a lot more information about our environment than we are aware of most of the time – both physically and emotionally. A thermometer won’t ever get the flu, a wind meter won’t ever lose a loved one and

Artist:
Nathalie Miebach



The Winds Kept Roaring

Nathalie Miebach



The Perfect Ride

Nathalie Miebach

a barometric pressure device won't ever fall in love. We do, and these human experiences can influence the way we read, understand and remember weather. Once in a while, weather seeps to the foreground such as when we get married, when we lose a loved one, when we hear about attacks like 9/11 – we remember the weather on those days. And then there are weather events that affect us personally, when we see the rage and fury of a blizzard come through and shut down a city for a few days.

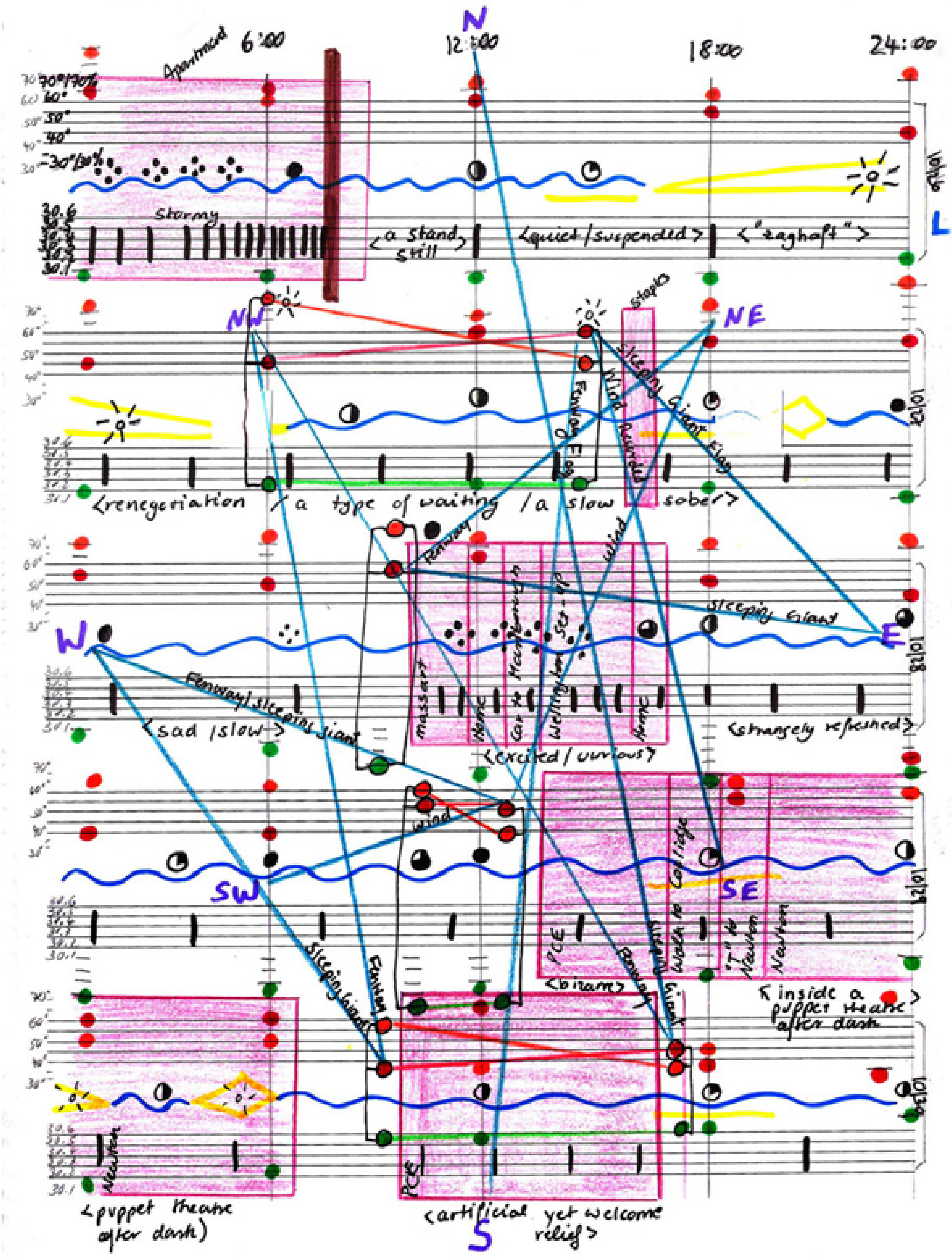
In order to tap into those more nuanced readings of weather, I began to translate weather data into musical scores, in which the notation system became a filter that would allow me to bring in subtler readings of the information without actually changing the data. The scores are built entirely of weather observations – both from weather instruments and weather observations recorded in a notebook. I use these scores in collaborative performances with musicians, who are asked to interpret the data within very specific parameters. The goal isn't to make expressive music about weather, but to reveal a kind of nuance in the data through sound, which is harder for me to reach through sculpture. I, in turn, use those same musical scores as blue prints and build sculptures that function as data visualizations of the weather event as well as 3D musical scores.

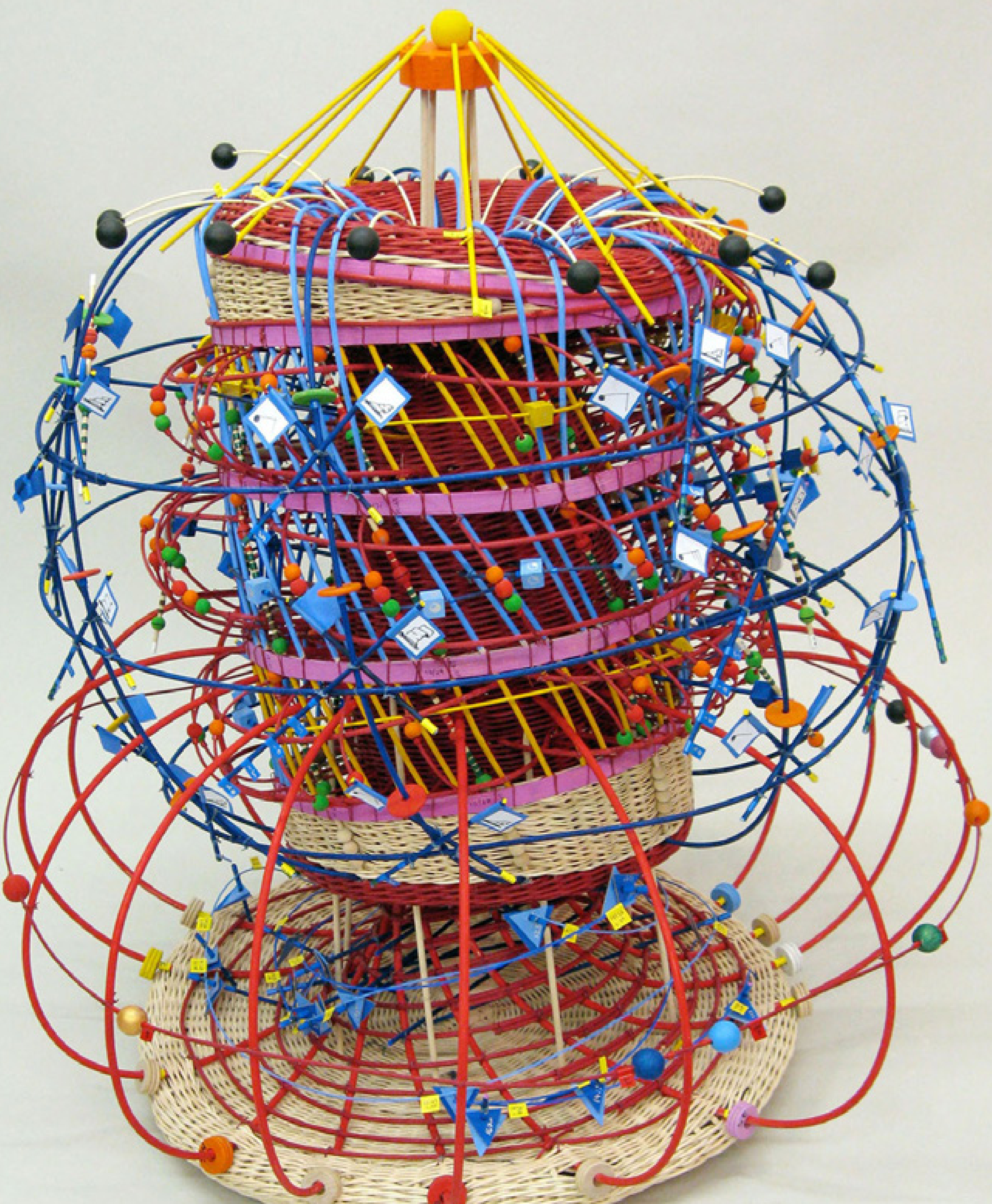
The unexpected, and possibly most wonderful, aspect of showing my work to the larger public, is that it triggers all sorts of stories people have about weather that they generously share with me. Even though I'll only meet them for a moment, often not even getting their name, they leave me with a story – a story of riding out a storm on a boat in the ocean, a suggestion of where the best place is to see thunderstorms coming in from the Prairie, a great weather website they check before their morning coffee. I'm then left with these wonderful gifts that combine not only a lot of meteorological observations, but also a human experience and memory that was shaped by this event. These weather stories from strangers I hardly know become my entry point into exploring deeper the actual meteorological science of the event or place they remember. It allows me to bring in a more nuanced way of exploring science data, in that the objectiveness of weather data has to be juxtaposed with the subjective description of the experience, while still telling their story of weather. Weather is a great equalizer in that everyone, regardless of socio-economic background, race or gender, experiences it on a daily basis. It is a companion we carry with us throughout our lives.

The latest development of my work was triggered by personal stories connected to major storms or disasters. I've been doing a series on Hurricane Sandy, based on stories I heard from people who survived the storm in both Seaside Heights and Coney Island. I find that to make huge disasters such as Hurricane Sandy relevant to the general public, you can't just bombard them with statistics and data. It's the human stories that are linked to these events that become important lenses through which to view and interpret the raw data in order to make sense of it.

Navigating Into a New Night

Weather Score for Sculptor and Musician





Navigating Into A New Night | Nathalie Miebach

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

I think when one is genuinely curious about something, the categorizing by disciplines become irrelevant. I don't think of either art or science when I am in the studio – I think of weather, of behaviors, of trying to visualize that which I cannot see, but not whether what I do is art or science. While it is easier for me to define and perhaps thus distinguish the boundaries of what is and isn't science, the parameters of art are much more fluid, open and up for debate. Does the practice of one necessarily exclude the practice of the other? I suppose the distinction between these two fields become particularly tricky when I come across persons, particularly scientists, who have never lifted a brush in their life, but whose approach to thinking about a particular problem feel very akin to those of an artist. What is that particular quality that makes it so? I'm not entirely sure myself, but I do think that a healthy respect for intuition, contradiction, nuance, reason as well as a knack for being able to disregard the very parameters of mental thought any discipline imposes on itself, are all in there. Rooted in that perspective is a firm belief that art is fundamentally a language of thought, before it is one of visual means. It is also where I think the still unexplored, and huge potential for art lies – in that recognition and exploration of art as a mediator between thinking and the visualization of that thinking.

And yet I can't deny that some of the very conceptual boundaries that define art and science are what attracts me to them. A question articulated through science begins with a very different premise, confined by its own language, expectations and rules, than if I address that same question within the context of art. What I love and deeply respect about science is that its very premise, its very raison d'etre rests on doubt. Art is an enormously versatile language through which to express nuances, contradictions and peripheral specificity, even absurdity – all through the logic of visual means. In that sense, both disciplines provide the perfect ingredients to dig deeper into any question. Like an opportunistic leech, I take from both disciplines what I deem as essential in helping me explore what I am curious about.

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

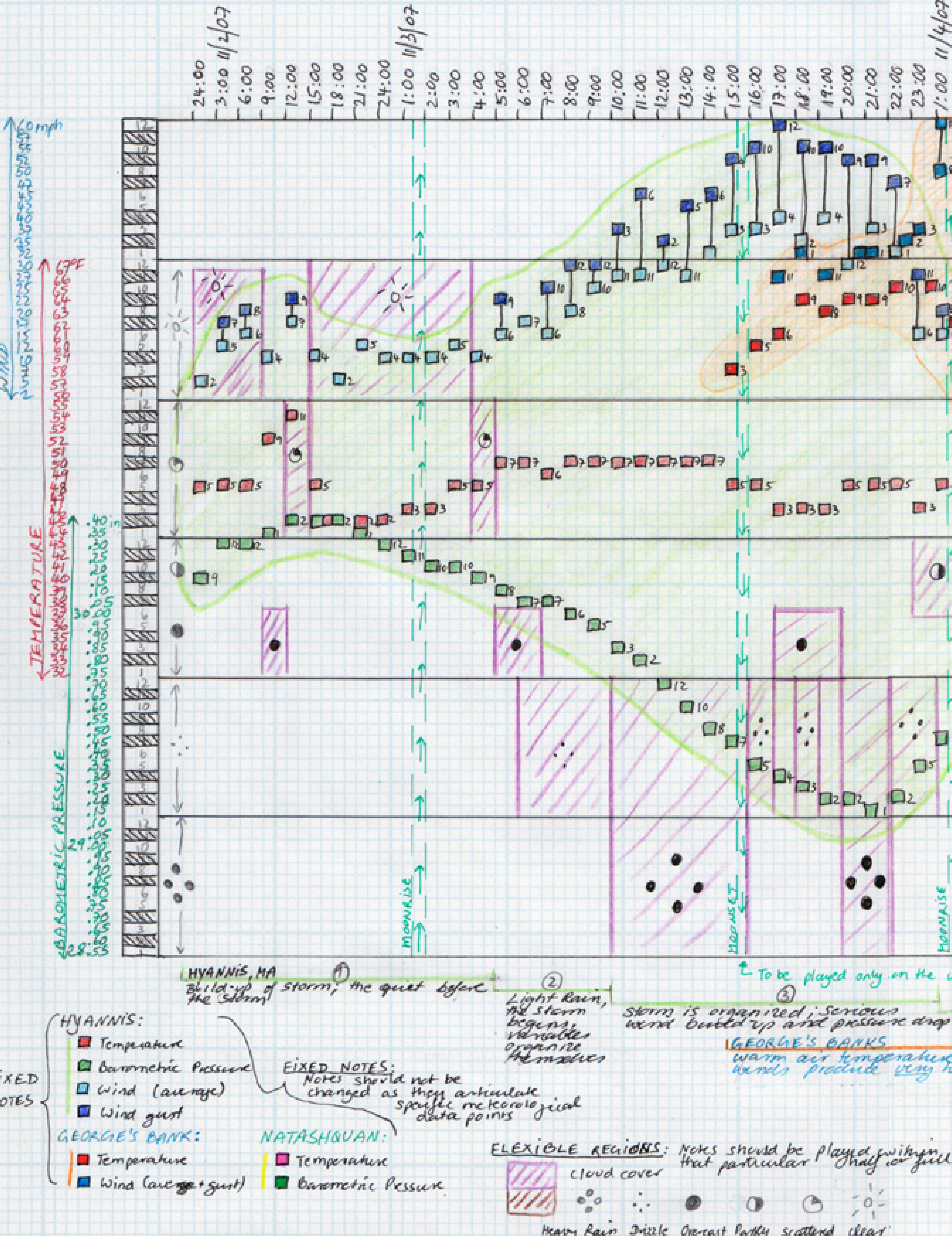
One of my most important influences in terms of thinking about systems in a visual and time-linear way has been music, particularly the works of Steve Reich, John Luther Adams, and Arvo Paert.

Music has always felt very three-dimensional to me. When I hear certain pieces of music, I see shapes and colors in my mind. When I have a particular sculptural problem I can't resolve, I will often listen to certain types of music. The melodic structures I hear, somehow provide audible alternatives that often lead to sculptural solutions.

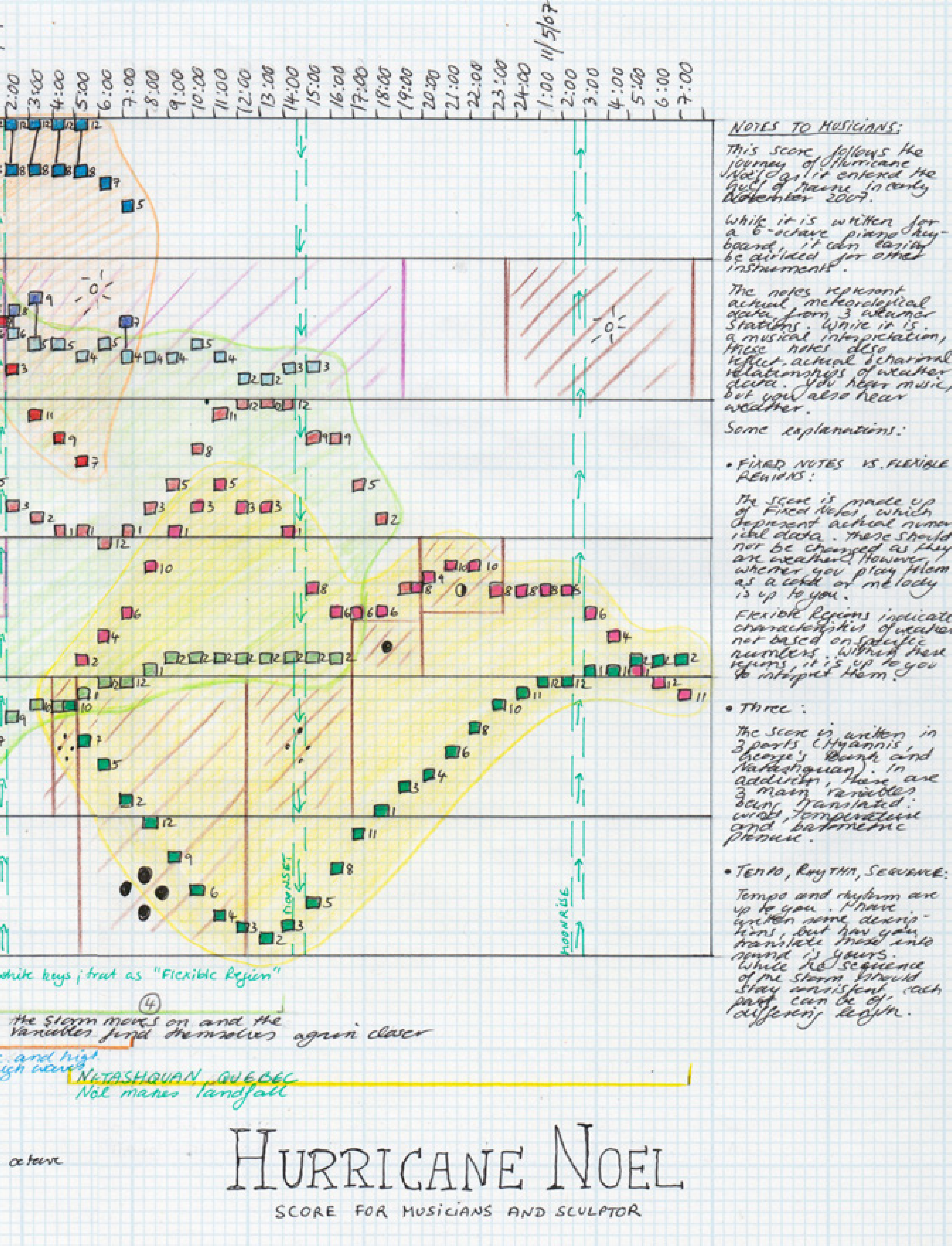
What are you working on right now? Any exciting projects you want to tell us about?

My plate seems to always be overflowing, which I suppose is good. I'm usually working towards exhibitions or commissions. I also always try to


Jet Star



Hurricane Noel Whole | Nathalie Miebach


11/5/07
NOTES TO MUSICIANS:
This score follows the journey of Hurricane Noel as it entered the Gulf of Maine in early November 2007.
While it is written for a 6-octave piano keyboard, it can easily be divided for other instruments.
The notes represent actual meteorological data from 3 weather stations. While it is a musical interpretation, these notes also reflect actual relationships of weather data. You hear music, but you also hear weather.
Some explanations:
• FIXED NOTES VS. FLEXIBLE REGIONS:
The score is made up of Fixed Notes which represent actual numerical data. These should not be changed as they are weather. However whether you play them as a chord or melody is up to you.
Flexible Regions indicate characteristics of weather not based on specific numbers. Within these regions, it's up to you to interpret them.
• Three:
The score is written in 3 parts (Hyannis, George's Bank and Natashquan). In addition, there are 3 main variables being translated: wind, temperature and barometric pressure.
• TEMPO, RHYTHM, SEQUENCE:
Tempo and rhythm are up to you. I have written some descriptions, but how you translate these into sound is yours. While the sequence of the storm should stay consistent, each part can be of differing length.
MOONSET
MOONRISE
white keys; treat as "Flexible Region"
the storm moves on and the variables find themselves again closer
NATASHQUAN, QUEBEC
Noel makes landfall
octave
HURRICANE NOEL
SCORE FOR MUSICIANS AND SCULPTOR

have at least one project that pushes me out of my comfort zone and those usually entail collaborations.

There are two projects I'm particularly excited about. The first is my collaboration with Cuban-American filmmaker Allison Maria Rodriguez. We are making a video piece called "Shelter" that explores the current migration crisis in the Mediterranean. Allison's approach to narrative is completely different from mine, but we share the same fascination for stories that seem very childlike on the surface, but reveal a much darker essence on second reading. Our piece will be on display at the Boston Convention Center Marquee for the duration of the summer. The second project I'm looking forward to is a group exhibition called "Intersections", which will be at the Akron Art Museum, from Oct 1, 2016 - Jan 15, 2017. It features six contemporary sculptors for whom working in 2D is an important element in their process. For this show, I'm building a large wall piece (25' x 12') on Hurricane Katrina.

What is the last book you enjoyed?

There are so many books I've enjoyed reading. I'm currently rereading the Harry Potter series, which is a guilty pleasure I indulge in every two years or so.

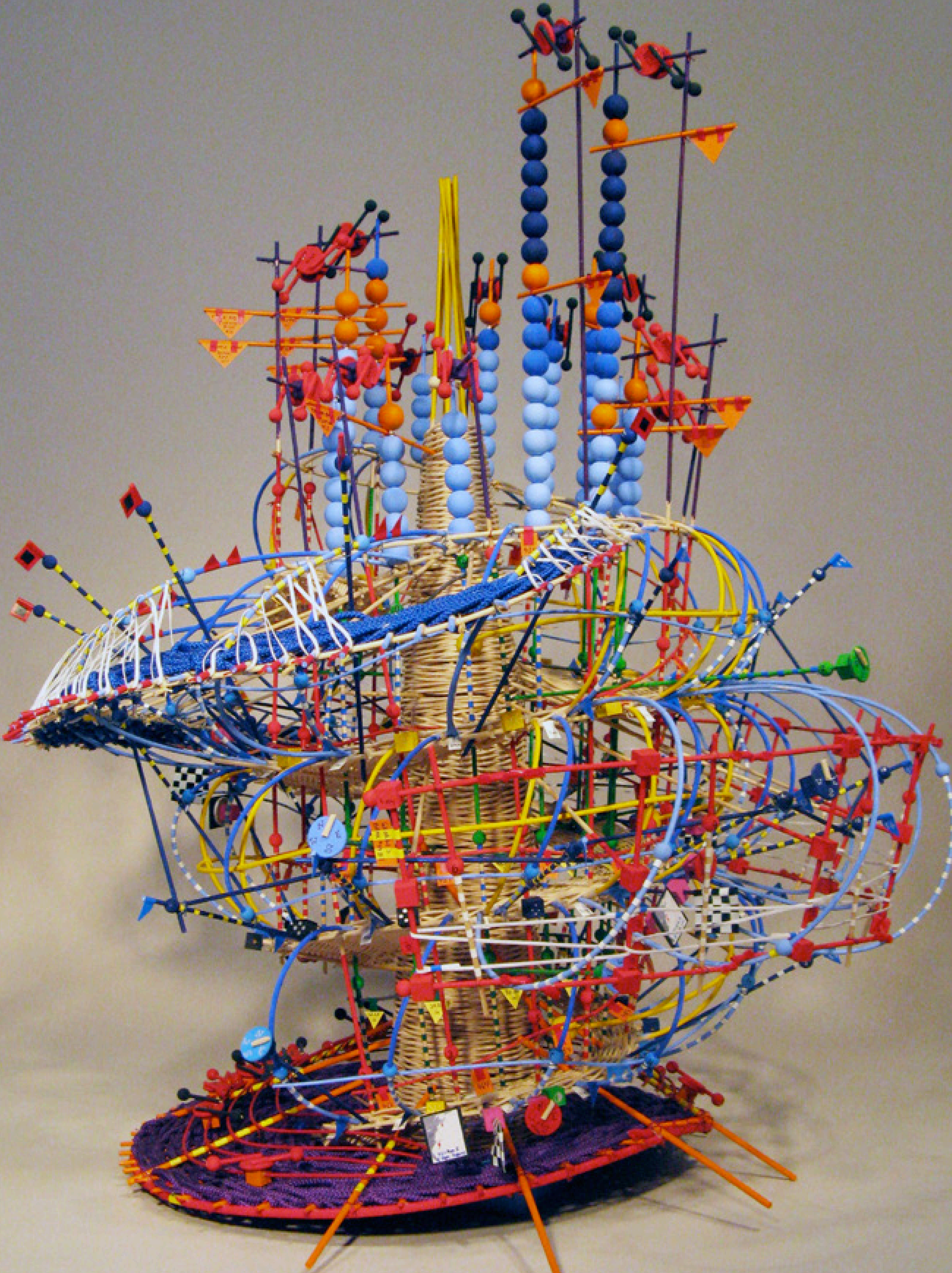
Ray Bradbury has been very influential in my work, especially his book Something *Wicked This Way Comes*. In that same theme, *The Night Circus* by Erin Morgenstern is also a great read.

My first language is German, which I think is an incredibly beautiful language. Some of my favorite German language authors are Michael Ende, Erich Kaestner and Siegfrid Lenz.

What's your favorite motto or quotation?

Play as an elastic sense of logic. I came up with this phrase in my studio. I take play very seriously because I think it's the key in being able to move creatively and uninhibitedly between disciplines. Creating the mental environment in which play can exist is not always easy. About a year ago I began to integrate a "play day" in my studio practice. I go to the studio 6 days a week, one of those became my "play day". On that day I don't think at all about data or concept. I just focus on form, color and space and I have to finish what I build that day. I began to really look forward to my "play day" every week, because it became filled with unexpected discoveries about sculpture. These discoveries are now coming into my data translations. ×

Hurricane Noel | Nathalie Miebach



Leaf Pair (Ginkgo Biloba)
Photo: PYHOOYA, 2008 | Flickr cc

People
Interviews with
Peter Niewiarowski and Ryan Church

Gecko

Photo: Pancholp, 2016 | Flickr cc

Interview

Peter Niewiarowski

vol 2 | 2016

People:
Interview

Author:
Peter Niewiarowski

Dr. Peter Niewiarowski (https://www.uakron.edu/biology/faculty-staff/detail.dot?identity=1201909), Professor of Integrated Biosciences (IB) and Biology at the University of Akron (UA), is a Biomimicry Research and Innovation Center (BRIC) Principal Investigator. His appointments include Post-Doctoral Researcher, Savannah River Ecology Lab, University of Georgia, 1993-1995; UA Professor since 1995; and, Interim Director, UA Integrated Bioscience PhD Program, 2009-2012. His research includes projects in amphibian population biology, life history evolution and physiological ecology of lizards and gecko ecology and evolution, especially as it relates to adhesion. Gecko adhesion research, in collaboration with the lab of Ali Dhinojwala, a UA polymer scientist and BRIC principal investigator, is the main focus of his current work, including biomimetic applications.

Peter Niewiarowski

Photo of Peter Niewiarowski

Peter teaches introductory and advanced levels within UA's Biology and IB programs. He developed courses including Advanced Ecology, Herpetology, Principles of Biology, Vertebrate Zoology, Tropical Vertebrate Biology, Communicating in Integrated Bioscience, Research in Integrated Bioscience, Theory and Foundations of Biomimicry, and Biomimicry Design.

Peter holds a BS in Biology, Marlboro College, Marlboro VT, 1984, and a PhD in Ecology and Evolutionary Biology, University of Pennsylvania, Philadelphia PA, 1992.

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

In my view, it is in a very exciting, generative phase. There is no shortage of activities and initiatives, formal and informal, academic and non-academic, which are popping up globally. Many are connected or are getting connected through dynamic knowledge and social networks that amplify potential impacts beyond local frames. I am daily struck by the intellectual and creative dissonance that emerges from so many diverse and widely distributed efforts in both the application and process of biomimicry. The dissonance is driven by enormous messiness, which is disconcerting to many people, but which is also a fundamental source of surprise and success. For a biologist, it is like going to a new place for the first time … the excitement around the un-

Gecko | Photo: kevin1024, 2007 | Flickr cc

Gecko | Photo: Pancholp, 2016 | Flickr cc known and of discovery is visceral. It is great to be a part of this time in the development of the ideas and application of biomimicry.

What do you see as the biggest challenges?

I think the biggest challenges include finding ways to connect, sustain and deepen the diverse groups developing biomimicry across the globe. From my vantage point, I think we need more work across disciplinary lines in academic settings, and this will require courage, experiments and patience. There are many programs where two disciplines are brought together, like biomechanics and bioinformatics. Much rarer are platforms where the cultures, methods, and perspectives of 3 or 4 fields can be brought to bear collaboratively on problem definition, discovery, design and the application of biomimicry. In my view, expanding what is possible with biomimicry will require such exploration, integration and synthesis. Similarly, we should look for new ways to create paths that cross and become well-worn between academia, business and communities. Universities can lead both of these kinds of changes, but it is not work that universities are necessarily used to. Our collective here in northeast Ohio was built by partners that cross many of the lines noted above and we find the work difficult yet rewarding. Biomimicry as a practice would benefit from more experiments crossing these boundaries.

How did the University of Akron Biomimicry Training Platform Get Started?

Doug Paige (Associate Professor of Industrial Design at the Cleveland Institute of Art, https://www.cia.edu/faculty-and-staff/douglas-paige/) and I started collaborating in 2010 on combining biology and design as part of the University of Akron's Integrated Biosciences PhD program. Holly Harlan, founder of the Cleveland Entrepreneurs for Sustainability (E4S) network, encouraged us to attend a Biomimicry 3.8 Educators Workshop in San Francisco. When challenged to set ourselves a Big Hairy Audacious Goal, we decided to launch a sustainable PhD platform around biomimicry and collaboration that cuts across fields and programs. It was an idea that would have gone exactly nowhere without the collaboration of Tom Tyrell and Don Knechtges, two entrepreneurs who created Great Lakes Biomimicry (GLBio, https://glbiomimicry.org/), an organization focused on using biomimicry for regional economic development. GLBio connected us to industry, making the funding for biomimicry fellowships possible. The virtual Biomimicry Research and Innovation Center (BRIC, https://www.uakron.edu/bric/) was launched in 2012 and recognized as a key initiative of the University of Akron's Achieving Distinction Strategic Investment Program (http://www.uakron.edu/provost/achieving-distinction/2012-recipients.dot). BRIC's success in winning university support depended on our corporate connections and economic development focus through collaboration with GLBio. Moreover, the focus of GLBio was to define a large scale sustainable platform for regional economic development through biomimicry. That vision was and continues to be a force driving biomimicry well beyond academic boundaries.

What are the unique features of Biomimicry Training Platform?

Although other institutions support PhD fellowships, they are typically associated with a single professor or grant initiative. The Biomimicry Training Platform is a research area of the University of Akron's Integrated Biosciences (IB, http://www.uakron.edu/ib/) interdisciplinary PhD program that draws students from a wide range of colleges, such as Arts and Sciences, Engineering, Polymer Science, School of Nursing, Arts and Sciences, Engineering, and Fine Arts. The platform started with three biomimicry Fellows in the fall of 2012 (http://bioinspired.sinet.ca/content/uakron-phd-training-biomimicry-peter-h-niewiarowski) and has since grown to 15 Biomimicry Fellows (https://www.uakron.edu/bric/fellowships/index.dot). In the same time, IB has grown to 50 PhD students in five research areas.

We admit students with a Bachelor's or Master's degree from any program. The current Fellows have backgrounds not only in biology but also arts, industrial design, engineering, mathematics, and computer science. They are supported by BRIC that draws faculty members from all colleges. BRIC is a fluid and dynamic organization – although focused on biomimicry, the members continue to work closely with colleagues in their individual faculties. Additional partners include the Cleveland Institute of Art, GLBio, and the professional design firms Balance Inc. (http://www.balanceinc.com/) and Nottingham Spirk (http://nottinghamspirk.com/).

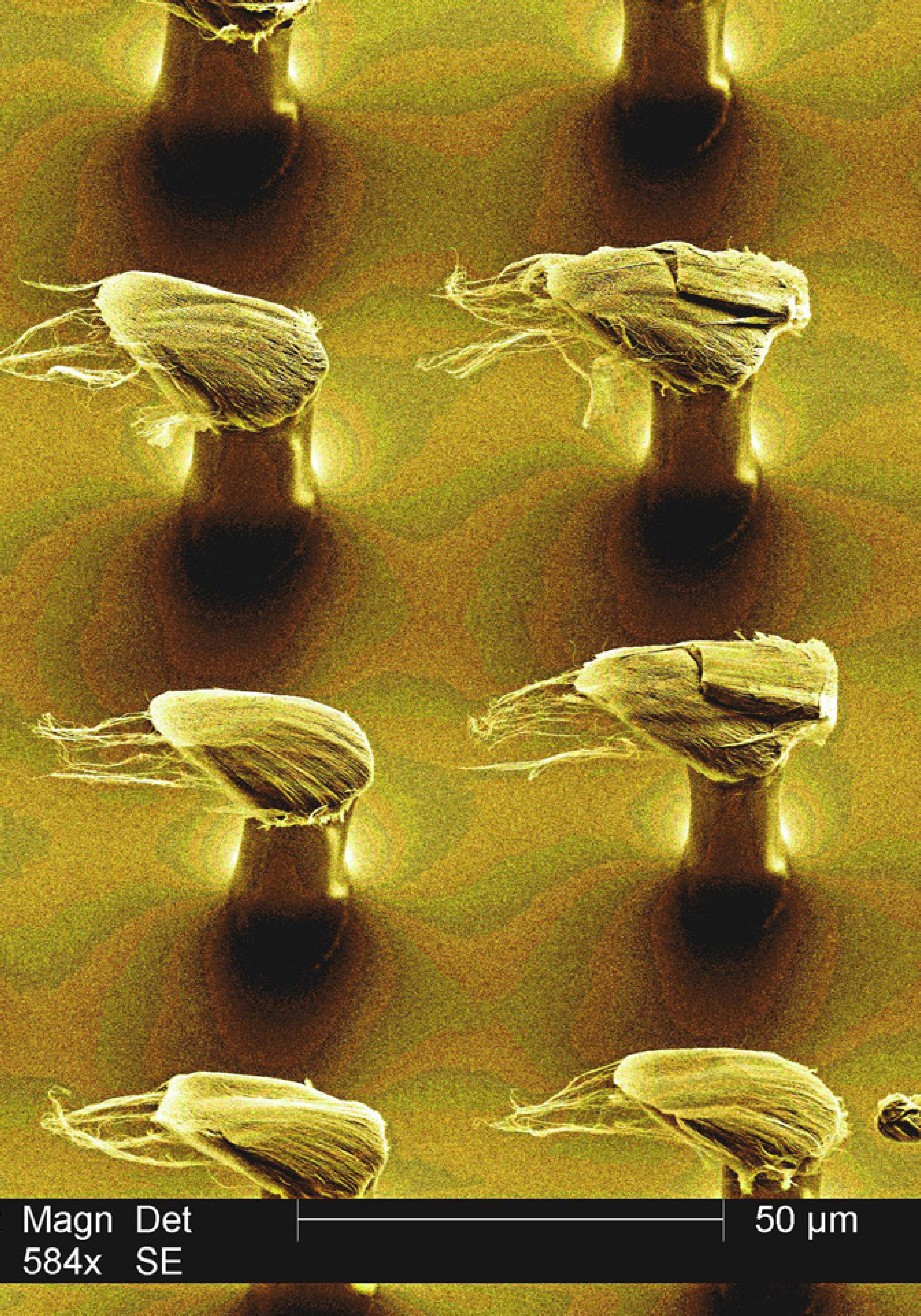
Lastly, Biomimicry Fellows are embedded in industry or schools, supported by five-year industry or foundation stipends of about $130K arranged by BRIC and GLBio. Fellows funded by industry usually work with the company's R&D department, providing training in biomimicry as a tool, exploring specific initiatives, developing intellectual property, and in some cases working on new products and services. Six of the current Fellows are funded by foundations such as the Cleveland Zoological Society, Avon Lake Regional Waters and the Nord Family Foundation – they work with non-profits or help K-12 schools to develop curricula that broaden the STEM (Science, Technology, Engineering and Math) experience to include new approaches to innovation.

What factors helped the initiative be successful?

It is still too early to assess success, given the relative youth of the initiative compared to established PhD programs. We were fortunate to have strong support from U/Akron leadership from the beginning of the project. The partnership among U/Akron faculty, the Cleveland Institute of Art, GLBio and industry has been essential in building a collaborative that actively engages and nurtures networks.

U/Akron brought academics who understand the challenges of developing PhD programs as well as existing research connections with industry R&D departments. The Cleveland Institute of Art provides a focus on arts and design that complements the U/Akron capabilities. GLBio was started by two entrepreneurs who had a long history in running both small startups and large companies. GLBio had built extensive networks of regional corporate leaders interested in economic development, innovation and sustainability – invaluable in identifying suitable targets for the initial proof of concept. The full im-

This image is a colored versions of an SEM image of submicron hierarchical structures comprised of polymer pillars with transferred vertical carbon nanotubes fabricated using several lithographic steps. These are further tested and employed as novel and advanced nano-structures to mimic super adhesive properties of the gecko-foot. | Photo: Engineering at Cambridge, 2012 | Flickr cc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584x SE
50 µm

pact of BRIC, especially beyond the boundaries of the University, cannot be appreciated outside of its deep collaboration with GLBio. Industry partners such as Partner Hannifin, Sherwin Williams, GOJO Industries, Lubrizol, Bendix, Goodyear, Kimberly-Clark, and Nottingham Spirk help ground the Fellows' research.

Lastly, BRIC has been able to build a critical mass of local expertise that also has global reach. In spite of the importance of digital communications, face-to-face interactions are still essential for effective interdisciplinary collaboration.

What insights have you developed since founding BRIC?

Interdisciplinary collaboration sounds easy but requires considerable and constant effort if it is going to be repeatable and scalable. Like any complex system, it involves building a network that enables information flows, interactions and creating new capacity.

All parties need to feel that they are getting value from the interaction. BRIC allows industry personnel to learn biomimicry concepts, explore how they can incorporate biomimicry at different scales into different departments, and experiment on specific projects. The value for Fellows tends to be more diverse. Some want to make an impact beyond building knowledge in their field or are attracted by the creative aspects of making ideas real. Others see collaboration as a way to identify gaps in current knowledge, increasing the breadth and depth of their understanding. The process of developing practical applications by creating and then testing models is consistent with how academics work.

Lastly, biomimicry is more than knowledge transfer – often the knowledge is either not available or hard to apply. Success frequently involves negotiating a common understanding across fields. Soft skills in social interaction and confidence combined with humility are as important as specific expertise – key relationships are tested regularly. It is crucial to create a 'space' that encompasses the important knowledge fields and ideally enhances all of them.

What results have you seen so far?

The first cohort of three Fellows (Daphne Fecheyr-Lippens, Bor-Kai Hsiung, and Emily Kennedy) are now in their fourth year. All have vastly different backgrounds but are deeply committed to biomimicry. They are truly the heroes and pioneers, dealing with the enormous challenges of dealing with the cultures of a university graduate program and industry R&D. They take great pride in how the initiative has grown around them. They have shown the value of taking ownership and being empowered to drive change by engaging in the real world.

Industry results depend heavily on company leadership, expectations and dynamics. Emily Kennedy has worked with multiple R&D departments at GOJO (https://www.gojo.com/) to improve sustainability, reduce carbon footprint and develop new ways of delivering products, leading to the filing of six patents. I expect that six or so Fellows will be delivering similar results over the next few years.

Gecko

Photo: Pancholp, 2012 | Flickr cc

What opportunities do you see in the future?

Opportunities: really, imagination is the only limit. Most exciting, in my opinion, are opportunities for diverse partnerships to drive formal R&D of methods for the field of biomimicry, and for getting biomimicry thinking into school curriculums at early ages.

What is your favorite interdisciplinary work of all time?

A book: *On Growth and Form* by D'Arcy W. Thompson. Cliché, I know.

What is the last book you enjoyed?

The systems view of life: A unifying vision by Fritjof Capra

Whom do you admire? Why...

People that pursue their dreams with passion, but never at the expense of others. Because that's a big part of what improves our world.

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

Never even think about that; seems like a distraction to consider it.

What is your idea of perfect happiness?

It seems like an odd question. What I can say is I would be happier if I had a little more time for play, family and friends and a little more money to travel to faraway places I have yet to see. ×

Double-Crested Cormorant's Eye

Photo: jpmatth, 2009 | Flickr cc

Interview
Ryan Church

Ryan A. Church is an entrepreneur, designer, biologist and inventor with over 10 filed patents to his name in a variety of disciplines from fluid mechanics, to healthcare, multi-scaler additive manufacturing and biologically-inspired materials. In 2014, he was named a Dean's entrance and SSHRC scholar in the Strategic Foresight and Innovation (SFI) Graduate program at the Ontario College of Art and Design University (OCADU) in Toronto. His thesis combined knowledge of biomimicry, policy innovation and foresight methodology to produce *Canada's Greenprint*, a future roadmap for Canadian renewable energy abundance by 2050. Presently, Mr. Church is the founder and CEO of BiomeDesign (https://www.biomerenewables.com) and its family of companies, which includes BiomeRenewables, BiomeMarine, BiomeAerospace, BiomeHealthcare and BiomeSocial, all of which incorporate biomimetic design.

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

The practice of biomimicry is in an exciting growth phase. More and more engineers, manufacturers and industrial companies, the people who make our world, are turning to nature to discover how to build smarter, lighter, leaner and 'greener'. Biomimicry has come a long way since its inception 500 years ago with Leonardo da Vinci. Of course, back then it was not called 'biomimicry,' it was just Leonardo's natural intuitive process for invention. As he famously said, "those who are inspired by a model other than Nature, a mistress above all masters, are labouring in vain."

What do you see as the biggest challenges?

The biggest challenges in biomimicry today are probably in the manufacturing industry. Understanding nature's recipes of green chemistry, let alone mastering them in the manufacturing plants of the future, will be the final step in going 'green'. When you understand how to manufacture the products of the future using only organic building blocks, you automatically build products, devices and structures into a circular economy - one where 'waste' becomes obsolete. In nature, there is no such thing as 'waste' because everything is composed of the same basic building blocks. The grand challenge lies first in understanding nature's method, and second in transitioning from one way of making to another.

A second, somewhat related challenge is how to give multi-functionality to materials at a variety of scales. Nature is a master at this - everything is lean, and has a multitude of functionality. Present day manufacturing typically associates one function to one material class, and layers multiple parts that do one job each. The challenge will be to create, for example, materials that combine structural and electrically-conducting properties.

What is your best definition of what we do?

Over the course of the last few years, I have been asked many times what the definition of *biomimicry* is. This happens mostly with friends, who are generally non-experts in the fields of biology and design, but who are interested and drawn in by that word. The Oxford English Dictionary defines biomimicry as: "The design and

A Different Sort of Technicolor Yawn | Photo: kukkurovaca, 2008 | Flickr cc production of materials, structures, and systems that are modelled on biological entities and processes."

This, however, is not the definition I give. For me, biomimicry is an active verb. It is a call to action: to produce materials, objects, and systems that are based on the processes of the natural world. There is nothing passive about it. I tend to focus on the *process* as much as the end products. Biomimicry, or biologically-inspired design, can occur at all levels, from the cell to the biosphere. At each level, nature has something slightly different to say, yet the principals are maintained throughout. This self-similarity of form and process at different scales is a hallmark of biology. The circular mechanisms and feedback loops of the cell, through material and nutrient cycling, are also found in the biosphere at larger scales, and across larger timeframes.

Using this metaphor, it is not hard to see how businesses, in addition to products, can be created using this circular and sustainable mindset. The innovative ontology developed by Antony Upward and the Strongly Sustainable Business Model Group (SSBMG, https://sustainablebusinessmodel.org) provides the foundation for a rigorous set of strongly sustainable business requirements. SSBMG is part of OCADU's Strategic Innovation Lab, where I studied. We employed SSBMG's Flourishing Business Canvas (FBC, http://www.flourishingbusiness.org/) to describe the business model for our venture and received an honourable mention with a perfect 16/16 score in the 2014 Design Management Europe (DME) award for corporate sustainability.

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

In short, education and conservation work. The field of biomimicry is driven by inquisitive minds with a multidisciplinary background - namely design or engineering combined with biology or another natural science. These inquisitive minds have one thing in common, and that is creativity with the ability to think laterally and arrive at analogous solutions. An education system that champions well-rounded students with the freedom to ask, 'how does nature...' would really push the field of biomimicry along. I think the rise in conservation work around the world has increased the level of interest in how the natural world operates - the more we probe, the more we find unique strategies that organisms have evolved. These niche strategies are often a boon for biomimetic practitioners.

By what criteria should we judge the work?

For the discipline of biomimicry to have substance, real-world solutions need to come out that are markedly better than non-biologically derived ones. We need standards to help verify claims and ensure that products are not incorrectly marketed as biomimetic when they are not.

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

I am a graduate of the SFI Master's Program at OCADU. This degree blends design, foresight and business into one package, and prepares students for a creative life in their area of interest

Double Crests | Photo: jpmatth, 2012 | Flickr cc while maintaining a solid background in business. When I explain this degree to my peers, I say it is like an MBA in design: something that could prepare the creative among us towards business ventures, while taking the long view. At the beginning of my degree, I had planned to start my own business, but I wasn't sure in what field. The one thing I was sure about was that it would be biomimetic, both in its organizational structure and in the products and services that it delivered.

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

I routinely scour the web and journals like *Nature* or the *Journal of Experimental Biology* for examples of amazing discoveries by scientists. Usually the sentence goes something like 'researchers have discovered that ___ does ___ by ___.' I am endlessly amazed at the unique adaptations that organisms, plants and animals have made to adjust to their environment. I also enjoy being in the natural world and taking the time to observe and probe detailed questions about what I am seeing.

What are you working on right now?

The energy industry is a foundational sector - something that we will always need. My environmental awareness and love for biology further directed me towards renewable energy, and my interest in aerodynamics landed me in wind energy. The wind industry is booming, growing by 44% in 2014 alone. The climate crisis is a main concern for me, so I was more than keen to help the situation while building an interesting and fulfilling career.

In 2014 I founded BiomeRenewables, a start-up enterprise to push the development of biomimetic technology in the area of renewable energy. By focusing on circular and self-sustaining business practices, BiomeRenewables makes renewable energy products that are intelligently designed and inspired by the natural world. My goal is to produce the most efficient wind turbine I can using the principles of biomimicry and attracting a strong and diverse team to see it through. The article "Putting the Nosecone to Work" in this issue describes our journey.

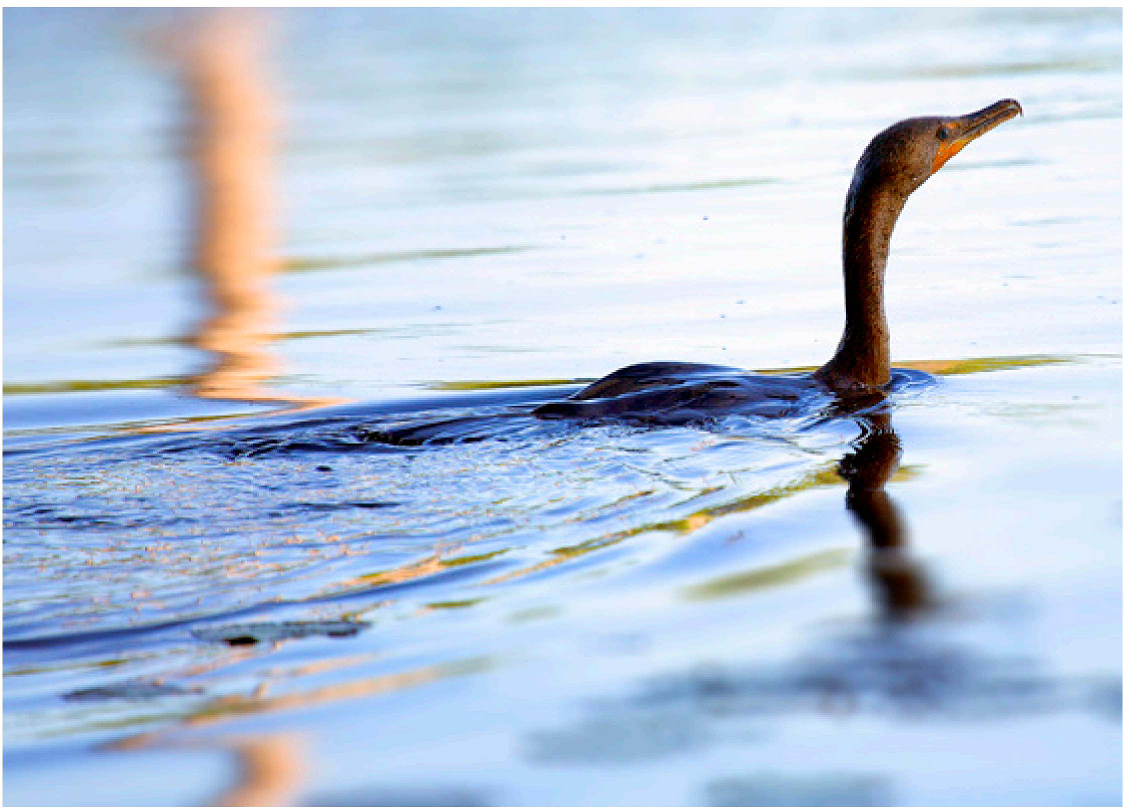
At present, I am also working with our partners Autodesk and 3D4MD (http://www.3d4md.com/), a Canadian company headed by Dr. Julielynn Wong who is a pioneer in 3D printing medical devices in challenging environments. Dr. Wong and I are working towards using our PowerCone technology as a stand-alone power source in remote locations and disaster-affected areas to power small communities and 3D print medical supplies on site. We are also investigating the benefits of incorporating the PowerCone into NASA's research on wind power for Mars missions (http://mragheb.com/NPRE%20475%20Wind%20Power%20Systems/Wind%20Power%20for%20a%20Mars%20Mission.pdf).

Who do you admire? Why...

I was first introduced to the subject in a TED talk given by Janine Benyus, who is a source of inspiration for me. She speaks so eloquently about the natural world, and is a powerful advocate for the field. Another powerful advocate is Prof. Neri Oxman at the MIT Media Lab, who I had the pleasure of meeting. I love her approach to bio-inspired design, and hope to collaborate with her in the future. I also admire Dr. Craig Venter and his company JCVI and Prof. George Church (no relation) at Harvard for their entrepreneurial spirit and quest to push the boundaries of biology. We can learn much from their work.

What do you like to do in your spare time?

When I'm not relaxing with family and friends, I enjoy classical piano, carving in the Northwest Coast Haida style, oil painting and writing works of historical fiction. My first due out soon is *A Cormorant's Tale*. Other works due this spring include a chapter in *The Future of Business*, on energy futures and policy innovation and a book of general science entitled *Universalis*. I also enjoy outdoor activities and adventure travel. At the moment, I'm a resident of the Little Italy district of Toronto, eating as much pasta as I can. ×



Cormorant

Photo: Mark Giuliucci, 2014 | Flickr cc

Radiating growth (2016) Polyester thread and pins on paper, 40 x 40cm

Meredith Woolnough

Portfolio

Meredith Woolnough

Could you tell us about your background and how you got started?

I have always loved making things. As a child I was happiest (and according to my mother, scarily quiet) when I was scribbling with pencils or squelching play dough. This love for creating with my hands never went away and it felt very natural for me to study fine art following high school. Once at University I majored in the field of textiles and for my final project I focused exclusively on embroidery. For this project I spent a year bent over a very old, clunky sewing machine, experimenting with embroidery as a form of drawing.

What kind of techniques do you use for your work?

I use a freehand machine embroidery technique, which is basically a fancy way of saying that I draw with a sewing machine.

To create my pieces I stitch numerous layers of threads onto a water-soluble substrate to build up a drawn design. Once my thread drawing is complete I simply wash away the base fabric, leaving the skeleton of stitches behind. After dissolving the base fabric I can manipulate and mold the piece to take on certain shapes and forms. It is this sculptural element that I love the most about this particular embroidery technique.

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

In that first year with the clunky old machine at university I created a series of large scale hanging artworks. It was a huge project and after that year I was pretty burnt out and didn't think I would ever go back to the sewing machine again. However not long after I was invited to take part in a group exhibition and I found myself back into it. For this early show I created a series of small coral pieces, inspired by a recent trip to the Great Barrier Reef. This was the first time that coral made an appearance in my work and I have been coral crazy ever since.

This fascination with natural forms has since grown to include various leaf structures, mollusks, annelids and even microscopic cells. In the last few years research has become an important part of my practice and I get a little kick out of correctly identifying any plant or coral that I find. My research starts with direct observation of nature through fieldwork in the form of hiking, scuba diving/snorkeling and photography. I then develop many drawings: some in the field, others back in the studio before I settle on a design that will translate well to a stitched drawing. I feel like I make a better connection with the organism through research and the ensuing artworks are stronger as a result.

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

I find that I look at things very closely now, almost on a micro level. I get lost in the small details. Every time I pick up a leaf I zoom in on its vein structure and map the paths of the tiny lines. When I go diving I often end up following some poor fish around because I get caught up staring at the scale patterns on its side. I have been told that I am a real pain to go on a bush-

Golden Ginkgo Square (2015), polyester thread and pins on paper, 70 x 70cm

Meredith Woolnough

walk with because I am always stopping to look at this leaf or that toadstool. For this reason when I do my preliminary fieldwork for an artwork I usually go alone so I can wander, explore and sketch at my own pace. I think we often race through life too quickly and it's really important to slow down and take the time to really look at things. There is so much to learn by simply observing.

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

The natural world is obviously my main source of inspiration. I know it sounds terribly corny but I never tire of the beauty that can be found in nature. Nature fascinates me and I can get completely lost in an environment when I start examining it closely.

One of the most memorable, and humbling moments of my life was the very first time I went scuba diving on a coral reef. The beauty, the colour, the complexity and the sheer alienness of that environment just grabbed me. It was so different to anything I had experienced on land and the weird weightless, isolated feeling of scuba diving only added to the complete all-encompassing experience. Coral reefs continue to delight and inspire me. If the reef is creative food then I feel very well fed after every dive.

I try to get out of the studio regularly to immerse myself in nature. This process helps to keep me inspired and motivated, but it also has an equally import role in getting me out of the studio and away from the sewing machine for a while. My work is very repetitive and laborious and I can easily spend the day sewing without coming up for air – which is probably not very healthy. So by going out into nature not only do I recharge the creative batteries but I also get to stretch my sewing legs.

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

Right now I am working on some pieces inspired by fungi, which is a new direction for me. The interest in this area came from a field trip where I was working alongside a very knowledgeable lady, Maree Elliott, who was collecting fungi for her PhD research. She was kind enough to let me help her with the collection and documentation of the various samples she collected and tolerated me picking her brain about every little mushroom I found along the way. Inspired by one of the species I documented during this fungi filled weekend (*Coprinellus disseminates*) I am currently stitching and molding hundreds of tiny little toadstool caps. I am not really sure what form the final artwork will take just yet, but I am having lots of fun making it.

What is the last book you enjoyed?

On a recent holiday I got a change to sit down with the novel *The Signature of All Things* and found myself really getting into it. I think I related to the main characters love of botany and her desire to spend her days with her nose buried in moss.

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

Pinterest, facebook and Instagram are my big three that I visit daily. All of these sites I use in equal parts for promotion of my work and also personal procrastination – which I have identified as a necessary part of the creative process (or at least that is what I tell myself). I also find these types of social media sites are a great way to connect with other artists and to find new inspiration.

What's your favorite motto or quotation?

Life without art is just 'eh'. ×

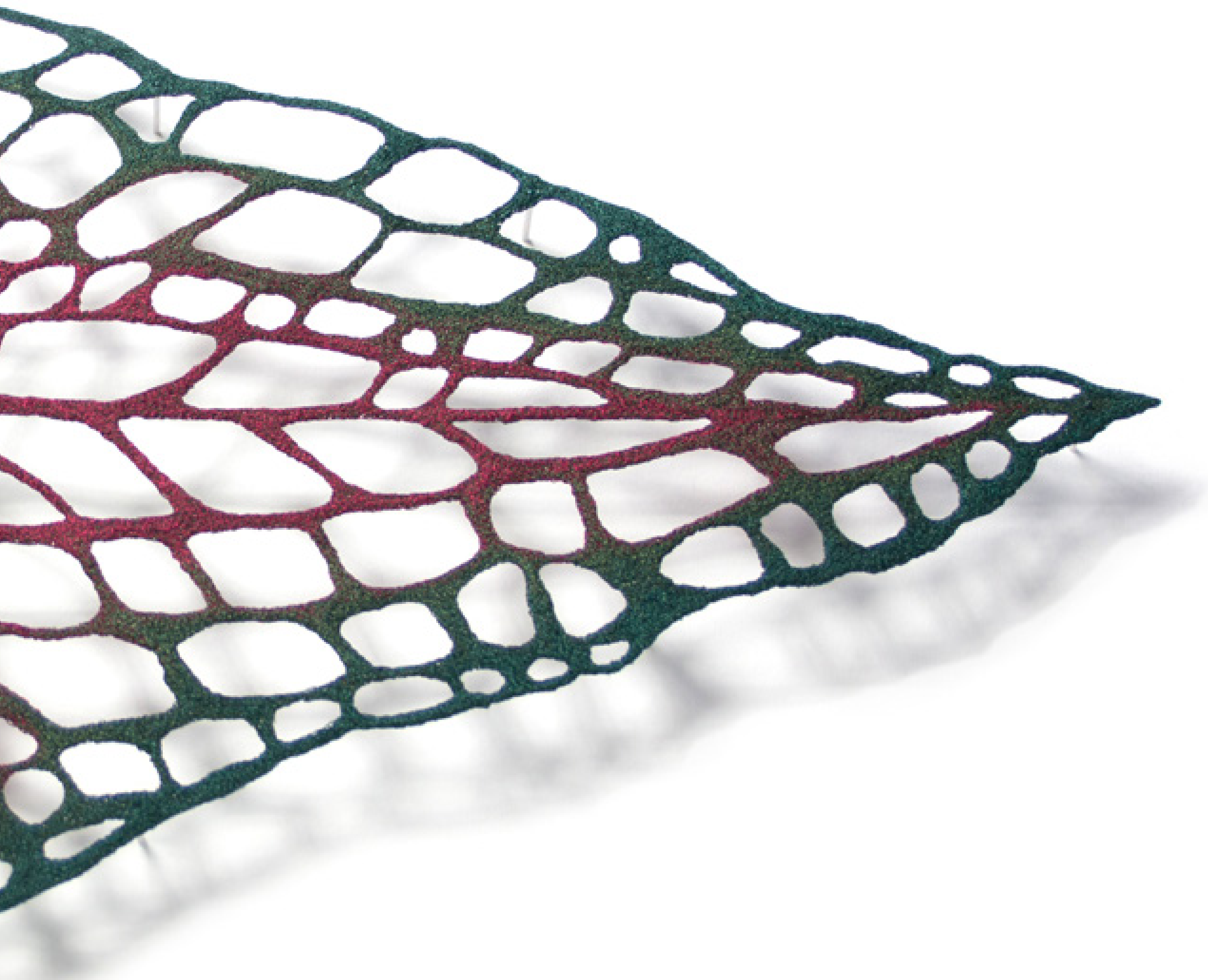
For more of Meredith Woolnough's work please visit www.meredithwoolnough.com.au

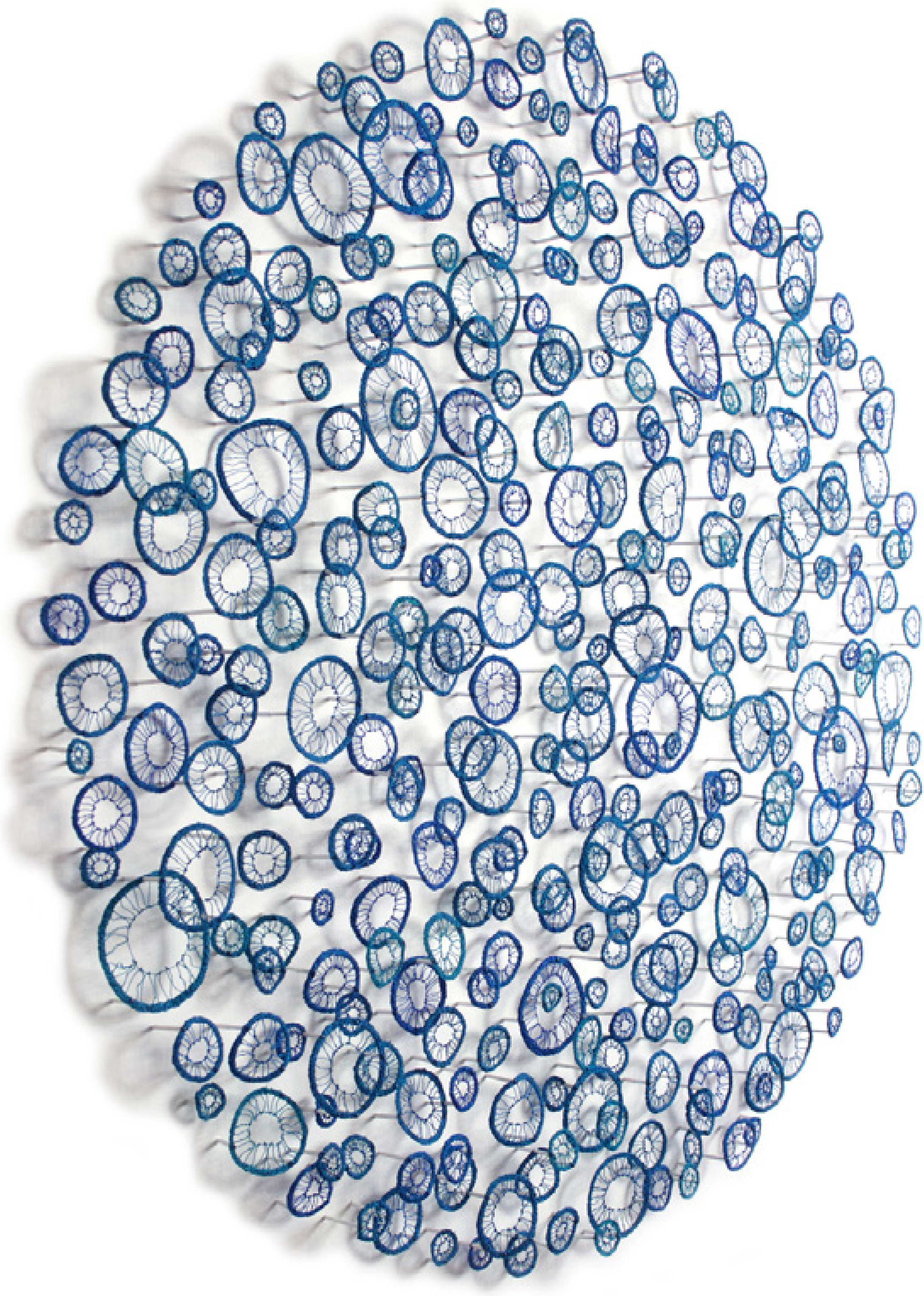
Meredith installing Scribbly gum leaf

Scribbly Gum Leaf (2014) Polyester thread, Wall installation, 100cm diameter | Meredith Woolnough

Ammonite (2015) Polyester thread and pins on paper, 94 x 99cm | Meredith Woolnough

Caladium (2016) Polyester thread and pins on paper, 66 x 81.5cm | Meredith Woolnough



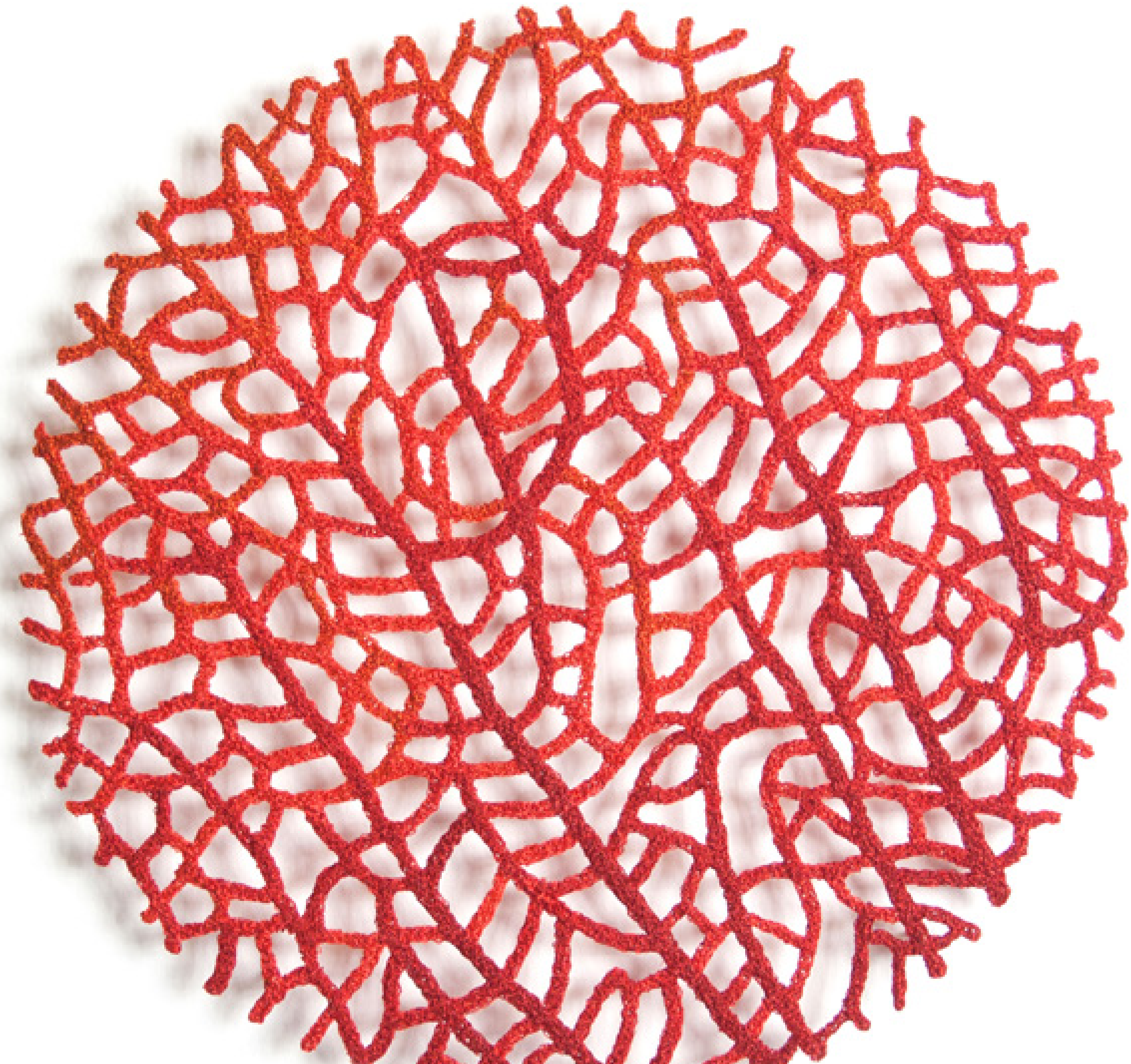


Under the Microscope (2015) Polyester thread and pins on paper, 93 x 93cm | Meredith Woolnough

Mushroom coral mandala (2015), Polyester thread and pins on paper, 93 x 93cm | Meredith Woolnough

Hydrangea petal (2015) Polyester thread and pins on paper, 93 x 82cm | Meredith Woolnough

Evergreen leaves (2016), Polyester thread and pins on paper, 40 x 40cm | Meredith Woolnough



Fan coral circle (2015) Polyester thread and pins on paper, 40 x 40cm | Meredith Woolnough

Northern Gannets

Photo: Akulatraxas, 2015 | Flickr cc

Opinion

Innovation Through Transdisciplinary Training

Shoshanah Jacobs and Daniel Gillis

Innovation Through Transdisciplinary Training

Dr. Shoshanah Jacobs is an Assistant Professor and member of the College of Biological Sciences Office of Educational Scholarship and Practice (CoESP) at the University of Guelph. She is co-creator of the ICON Transdisciplinary Classroom. Her research focuses on science education, knowledge translation and transfer, in addition to seabird foraging ecology in the department of Integrative Biology.

Dr. Daniel Gillis is an Assistant Professor and Statistician in the School of Computer Science, co-founder of Farm To Fork, and co-creator of the ICON Transdisciplinary Classroom. His research spans public health and ecological risk assessment, methods for alternative data collection, and community-engaged and transdisciplinary pedagogy.

Over 55 years ago a champion of bionic research, Dr. Jack Steele, voiced his concern about the lack of opportunity for transdisciplinary discourse in the academic institution. He argued that although the need for interdisciplinary effort was appreciated and the product of bionics was valued, "the half breed is often socially acceptable to neither parent group." This was, he said, "the fundamental challenge of biomimetic research."

This challenge can be addressed in two ways. We could encourage the training of 'half breeds' and promote interdisciplinary courses of study in post-secondary education, offering more double majors, or general studies, cross appointments for faculty and researchers, or the establishment of interdisciplinary institutions. Alternately, we could teach everyone the principles of Knowledge Translation and Transfer (KTT, http://www.omafra.gov.on.ca/english/research/ktt/indexktt.html), making each individually responsible for representing their discipline when seated around a transdisciplinary design table while creating new knowledge spaces that transcend individual disciplines.

The first option, the *Homo Universalis* approach, has its limitations. Disruptive innovations come from emergent procedures, not from those ascribed to existing fields of study. *Intra*disciplinary teams, those composed of members from the same discipline, make disciplinary widgets using disciplinary methods. *Inter*disciplinary teams, those composed of members from several disciplines, make an interdisciplinary widget whose parts are derived from disciplinary methods. But a *trans*disciplinary team works in a totally different way, an emergent way, to make new, and often disruptive widgets. And sometimes it isn't even a widget. A transdisciplinary process requires all members of the team to devise a common procedure for solving the challenge, a procedure that cannot be attributed to a single discipline. The outcome is one that cannot be readily associated with any one discipline.

Imagine that the current set of knowledge for a particular domain, say Arts & Social Scienc-

Puffins | Photo: eric robb niven, 2014 | Flickr cc

Blue-footed Boobies | Photo: Vince Smith, 2010 | Wikimedia Commons es, could be contained within a single book. An *intra*disciplinary team with domain specific training would identify a problem and build solutions using the knowledge contained on a page or pages within that single book. Their work might result in the addition of a page due to the creation of new domain knowledge, but this would be done independently of the current knowledge contained in other books. An *inter*disciplinary team might identify a problem that is specific to a single domain, but that requires a solution that uses the knowledge contained in multiple books (e.g. a biologist requires a statistician to develop a new statistical method to evaluate biological data they have collected). In some sense, the *inter*disciplinary team develops a process from problem to solution by lining up pages from each of the books. Each page provides the necessary information to develop an interdisciplinary solution. Again, the work of the team might result in the addition of new pages to each of the books, but the books would remain as separate from each other.

*Trans*disciplinary teams work differently by rethinking the books and the pages of knowledge within. Instead of lining up pages from each of the books, a *trans*disciplinary team folds and bends them into origami; creating spaces and shapes that allow team members to see knowledge from their domains in new and innovative ways. Where *inter*disciplinary teams share discipline-specific knowledge and tools, *trans*disciplinary teams go beyond this – creating a new space for knowledge creation.

What is necessary for this to happen? Clearly, great skill is necessary to work effectively on a transdisciplinary team. This requires that each team member learn how to become part of that team; a skill that is as, or more valuable as those discipline-specific skills we learn in post-secondary institutions. To that end, we developed the Knowledge Translation and Transfer (KTT) approach as a solution.

Universities and colleges can play a major role in shifting the focus from educating 'half-breeds' to educating experts in specific disciplines who are capable of translating their discipline for meaningful transfer and effective use. Two things are required 1) education in KTT, and 2) opportunity to practice and receive feedback. While this list is short, the challenges are significant. In the spring of 2014, we were awarded a $25,000 grant from the University of Guelph's Learning Enhancement Fund to develop a framework by which we could achieve these two objectives. It was ready for a pilot run in the winter semester of 2015.

We were naïve regarding the challenges associated with teaching the principles of KTT. We had no idea how little 'content' is available to develop a curriculum but we were relieved to find a few valuable resources, including some of our colleagues on campus. The pilot run of our program, ICON (Ideas Congress) offered a simple curriculum in KTT: audience analysis, facilitation of decision making, problem identification, and problem analysis. We used an active learning pedagogical model (no lecturing), to ensure that our students interacted with each other and worked together. Students were assessed using 7 deliverables (4 assignments, a final report, a final presentation, and a reflection paper) and they were allowed and encouraged to submit assignments using non-traditional formats (e.g. video) as it was believed that this would foster KTT skills.

Our second challenge was providing undergraduate students from a variety of disciplines the opportunity to work together in a meaningful way. Creating an elective course is unlikely to attract the required academic diversity. We arranged with the central administration of the University of Guelph to allow us to offer participation in ICON as an alternative to an upper level independent study course with credit going towards the student's degree program. That is, students were permitted to enroll in a single-semester independent study course relevant to their discipline in order to participate in the ICON classroom. With this minor modification to the traditional framework, we managed to make all students across campus eligible to participate in ICON during the course of their studies. While the overwhelming majority of departments were supportive of this arrangement (in some cases providing more than one independent study course code for use), a small number of units closed their independent study courses to participation in ICON, citing concerns related to their belief that ICON would not satisfy the learning outcomes set out for their degree program. In this case, several students opted to enroll in ICON through other units, or by auditing without credit. The pilot ICON class was truly transdisciplinary, including 24 students from the social, biological, physical, and engineering sciences, as well as the arts and humanities domains. This ensured that ICON students had the opportunity to learn about and practice their KTT skills in a transdisciplinary setting.

After completing the KTT curriculum, ICON students were asked to solve a social challenge that would require their new KTT skills, their discipline-specific training and expertise, and a fresh look from a variety of perspectives. Specifically, students worked with Reid's Heritage Homes (http://www.reidsheritagehomes.com/), a leading Ontario developer involved in the Natural Resources Canada Net-Zero demonstration project. The industry partner tasked them with developing solutions that would reduce energy usage in the home using some form of human behaviour modification. The challenge was purposefully broad to provide students with the opportunity to explore solutions outside of their discipline-specific experience, through the exploration of problem solving tools of their classmates. Through open discussion and debate, students organically formed groups based on where they felt their discipline-specific expertise would be most useful and where they felt most engaged. Team formation had only one restriction; that each team have at least two distinct colleges represented. For the remainder of the semester, student teams met weekly to develop their solutions using the KTT skills previously learned. During this period, we facilitated team discussions, helped groups formalize and focus their solutions, and maintained a direct line of communication with Reid's Heritage Homes.

We observed, anecdotally, that students transitioned from quiet, reserved, and somewhat nervous in the role of discipline experts at the beginning of the semester to engaged and active contributors of ICON. Moreover, students actively began using the tools provided during the KTT training when they were presented with the Industry Partner's behaviour modification challenge. For example, the importance of understanding terminology was explored early on when students were assigned a seemingly simple task: define "a lot of money." It became clear that their experience, discipline-specific training, and assumed context influenced their understanding of the phrase, and acted as a barrier to KTT. The need to understand terminology differences between disciplines occurred multiple times throughout the course, and provided students with a better understanding of the various definitions of (for example) *population, independent, persona, conditioning and regression*. This allowed the students to better explore potential solutions since they were able to understand the various ideas being discussed. Students also spent much time discussing how they might use discipline-specific skills to address the issue of modifying human behaviour. This fostered new ideas, and refinements to their respective solutions. For example, one team approached the classroom challenge using tools of *conditioning* from psychology, *feedback* and *gamification* from computer science, and *indirect reciprocity* from evolutionary biology to develop a new curriculum for elementary school students that sought to change behaviours by targeting the children that lived in the homes.

By semester end the students had developed multiple solutions that included 1) the aforementioned educational program for elementary aged school children, 2) an online community that branded a sustainable lifestyle while also lobbying the government for tax incentives for household energy conservation, and 3) an Internet-of-Things connected smartphone application that alerted household occupants whenever real-time energy usage approached a user-determined energy budget threshold. These solutions required student teams to communicate effectively while considering the issue of energy consumption from multiple angles, and using tools from each of their respective disciplines. More importantly, their solutions seemed to emerge when they moved beyond the linear pathway from one discipline box to another, and began to rethink how the boxes could be connected. The result, we believe, was the beginning of a new space for knowledge creation and potential solutions. That is, the students were beginning to work in a truly transdisciplinary manner. In this case, students were not required to become 'half breeds' by learning the theory of tools outside of their discipline, nor were they required to become experts of those tools. Instead, students had to practice KTT skills to demonstrate why and how a tool from their discipline could be effectively modified to become part of the team solution, and then work together to develop a new space for solving the challenge.

As a final deliverable the students were required to present their solutions to executive members of Reid's Heritage Homes without discipline-specific jargon. This necessarily meant that the students had to fully understand their industry partner so that they could present in a manner that was effective and clear. According to one executive, the benefits of ICON were deemed extraordinary, and provided outcomes that "truly show the opportunity to which this program created a baseline for innovation and inspiration."

Based on the quality of the solutions developed by the ICON students, teams were encouraged to submit their projects to innovation-based competitions. One project was awarded first place at the Pitch for Progress Competition (http://www.uoguelph.ca/cbase/events/pitch-for-progress/, a university initiative that was part of the 10th Annual Summit of Universities Fighting World Hunger), while another placed top three in the Scotiabank's Ecoliving Award challenge (http://www.enactus.ca/resources/resource-library/scotiabank-ecoliving-challenge/, a Canadian-wide competition). Most importantly, we were subsequently contacted by Reid's Heritage Homes inquiring about two of the student projects and request follow up information and to express their interest in supporting the expansion of ICON as a tool for innovation.

We also asked ICON and non-ICON students to provide feedback on the course. Students in ICON indicated that they had a larger contact network and greater writing skills compared to non-ICON students, while half of the non-ICON students surveyed indicated that they would have enrolled in ICON if they had known about it during course selection. Further, ICON students indicated that they had acquired new skills that could be used after graduation that went beyond those learned in their traditional classrooms. The most obvious of these included team-working and communication skills, but they also identified skills specific to the KTT training, such as understanding their audience, understanding their own discipline-specific biases, and problem evaluation and analysis.

We are presently reviewing and analyzing data collected throughout the semester to better understand the types of students who might enroll in ICON, its pedagogical outcomes, innovation outcomes, and its long-term effect on student success post-graduation. This also includes a short and long-term evaluation of the program from the point of view of student and faculty satisfaction, and learning outcomes. There remain several outstanding challenges associated with ICON, including the sustainability of the program within the existing university structure. Regardless, the ICON classroom represents a potential framework for KTT education and innovation at the undergraduate level that aims to provide students with a set of skills that are currently in demand by employers. These include the ability to communicate effectively within and outside the organisation, to solve problems, to think critically and to work in teams.

ICON represents an innovative and effective way of addressing Steele's "fundamental challenge of biomimetic research." Rather than teaching 'biomimicry', or developing interdisciplinary programs, we believe that the most useful training for a designer seeking to tap into the innovation of biology is that of knowledge translation and transfer. This ensures that the designer is able to communicate her/his need, access the required information, and apply it to the problem. It means that she/he will be able to collaborate with people from a diversity of academic backgrounds as she/he develops new tools and procedures for answering new questions. Training in KTT is a means of giving the designer a lifelong skill, rather than only a simple tool. ×

Additional Reading

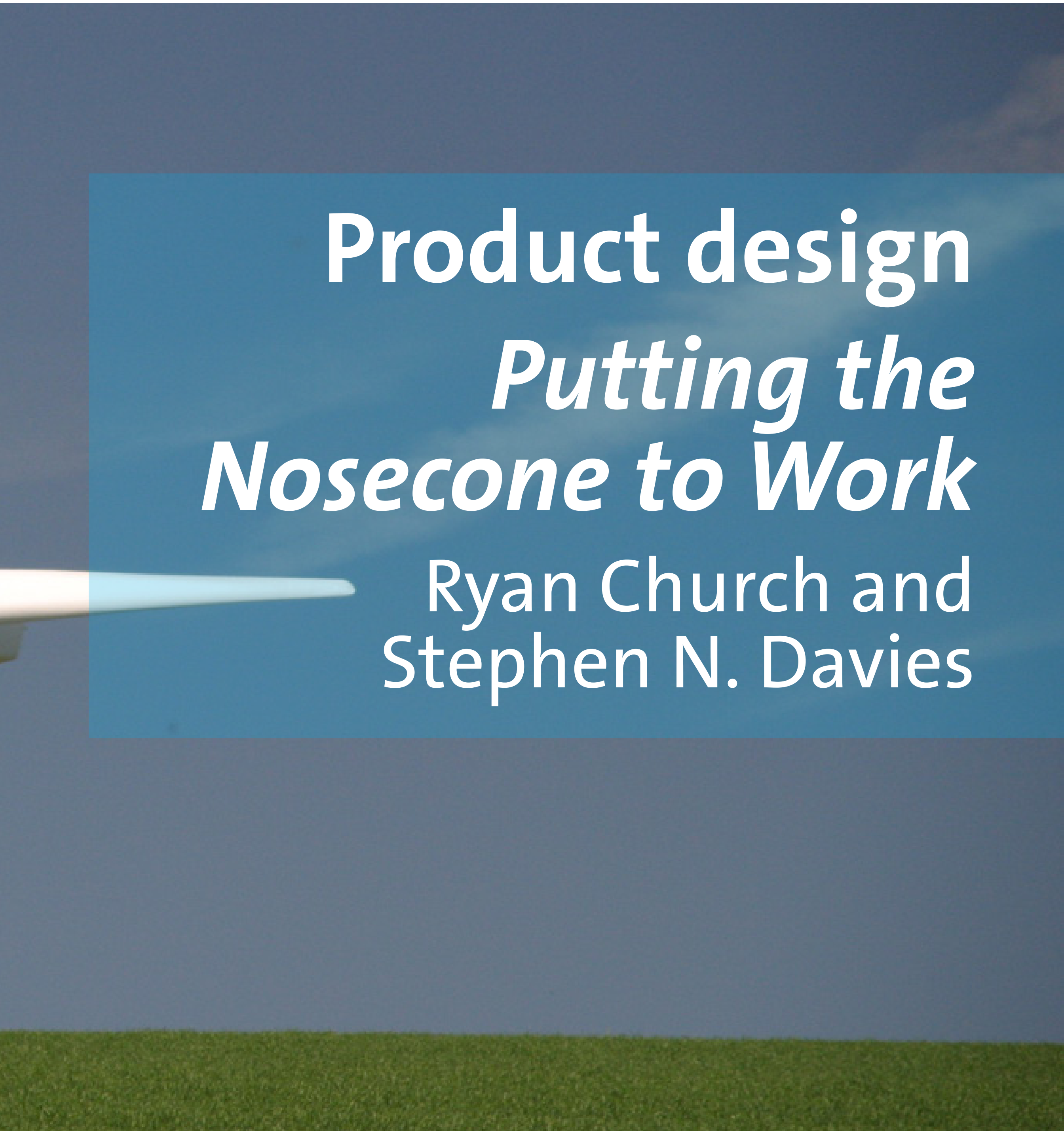
University of Guelph KTT Resources: http://www.uoguelph.ca/omafra_partnership/ktt/en/kttinaction/Knowledge-Translation-and-Transfer-Resources.asp

Integrating Renewables and Conservation Measures in a Net-Zero Energy Low-Rise Residential Subdivision: http://www.nrcan.gc.ca/energy/funding/current-funding-programs/eii/16140

Gannets | Photo: midlander1231+, 2015 | Flickr cc

Windturbine

Photo: äquinoktium, 2007 | Flickr cc



Product design

Putting the Nosecone to Work

Ryan Church and
Stephen N. Davies

Biomimetic Design of BiomeRenewables' PowerCone Technology

Ryan Church is an entrepreneur, designer, biologist and inventor with over 10 patents to his name. He is the founder and CEO of BiomeDesign and BiomeRenewables (https://www.biomerenewables.com). He currently resides in Toronto, Canada.

Stephen N. Davies is Managing Director of Transformation by Design (http://transformationbydesign.com/), a business design consultancy and a Certified Management Consultant (CMC). He is also an Assistant Professor at OCAD University where he teaches Strategy Development, and Business Model Innovation in the Strategic Foresight and Innovation program (Master of Design).

The Challenge

In the early 1990s, the tri-blade wind turbine was pioneered in Denmark and has been the gold standard for wind turbine design ever since. This design makes sense for a number of reasons, such as limiting tip-speeds below transsonic velocities and balancing the gravitational load (there are never two blades at 12 and 6 o'clock). This design allows for the construction of large machines, which have exploded in size in recent years, consisting of a tower supporting a nacelle (generator housing) and central hub, with three blades attached to the hub. From the point of view of a wind turbine operator, the goal is to extract as much energy out of the wind as possible and keep the turbine spinning, lessening downtime and unreliability of power supply. At present, the hub and the root of the rotor blades play no part in extracting energy from the wind - a significant loss of potential energy production for wind turbine operators.

In 2012, media coverage of wind development in Southwestern Ontario made Ryan Church aware of wind turbines and their inherent problems. Noise emissions from the turbines were causing a great deal of concern to local citizens, and the province was acting quickly to review noise regulations. Irritations aside, if you are producing noise, you are not producing energy. There are other sources of energy loss such as yaw error, the inability of the wind turbine to face directly into the on-coming wind. This in turn produces undue stresses and loads on the machine, leading to wear and tear on parts, and ultimately premature failure. Other problems include something called *rotor-root suction*, a phenomenon whereby air is sucked into the area of low pressure around the hub, actually pulling wind away from the rotor blades and reducing efficiency.

To tackle these challenges, Church launched the start-up BiomeRenewables (https://www.biomerenewables.com) in 2014 while a graduate student at OCADU (http://www.ocadu.ca/). He was later joined by William Georg, an engineer by training and fellow classmate; Stephen Davies, a professor of strategy and business in-

Windturbine | Photo: Beige Alert, 2010 | Flickr cc novation; Phil Lefko, a corporate lawyer with vast experience in the wind industry; Hassan Jaferi of MaRS Innovation, a technology transfer leader; and Jay Wilgar, a wind developer and fellow entrepreneur.

Wind turbines are complex machines with many moving parts; an amazing amount of engineering goes into them. If BiomeRenewables was going to apply biomimetic innovation to wind turbines, making them more efficient, quieter, and generally run smoother, then the design team needed to do two things: the first was to step back and remove all creative limitations, and the second was to re-define the problem. As with any complex system, whether biological or man-made, the perceived problem may in fact not be the actual problem. This means, back to the basics.

The Betz Limit and the Navier-Stokes Equation: The Physics of Turbulence

It is reported that when Werner Heisenberg was asked what he would ask God, he replied “When I meet God, I am going to ask him two questions: Why relativity? And why turbulence? I really believe he will have an answer for the first.” Similarly, Richard Feynman, the eminent Noble prize-winning physicist, said that turbulence is the last great unsolved puzzle of classical physics. Our best guesses to date are the Euler and Navier-Stokes equations, developed in the late 19th century ... they have yet to be proven. Our understanding of turbulence and turbulent flow remains limited. There are a few things that we *can* say for certain about turbulence, such as ‘fluids always flow in the path of least resistance’ and ‘turbulence is random and chaotic.’ It is this inherent randomness that has prevented us from understanding it, yet the natural world has developed methods of working with, diminishing and altering turbulence to its benefit.

Turbulence can be thought of as a *battle of the forces* between gravity, the kinetic energy of momentum, and inertia. Above a certain threshold, the system of fluid molecules becomes turbulent and tears itself apart. Below a certain threshold, this system is laminar and smooth. Using another biological analogy, this represents a tipping point in the system, and is determined by the inherent properties of the fluid - its viscosity for example, which determines the degree or tendency for it to become turbulent - and the forces involved.

One further parameter has since made itself evident: time. The timescale over which events happen has a direct effect on the nature of their being. Taking a biological example, the kingfisher’s ability to dive from one liquid into another that is 800 times denser without creating a splash is down to that amazing beak. But why and how? What principle of physics allows it to maintain laminar flow? Key factors are the timescale over which the kingfisher dissipates the energy of its dive in combination with the shape of its beak, which induces a particular pressure wave to form. The analogy here would be moving your hand gently through a pool of water from point A to B, or smacking it suddenly. Smacking the water reduces the timescale to such a degree that turbulence occurs. This principle, as utilized in nature, can be applied to wind turbines.

Turbulence, and the drag that results from its formation, is a key limitation to the efficiency and quiet smooth operation of wind turbines. Understanding turbulence - what causes it and what could prevent it - would allow BiomeRenewables to create a more efficient wind turbine. The maximum efficiency that is currently thought feasible for a wind turbine is 59.3%, and is known as the Betz Limit. This limit is based on the given volume of air coming at the rotor blades, its velocity and density, and thus the energy that is in the wind. Out of this maximum available energy in the wind, only 59.3% can be harvested, because a 100% harvest rate would mean that the wind speed immediately behind the rotor blades would be zero, and would break the laws of physics - notably, Newton's Second Law and the Continuity Equation. The limit also assumes a few other characteristics, such as a strictly axial flow through the rotor blades and a continuous rotor blade throughout the entire diameter.

Today's wind turbines do not have a continuous rotor blade. Most have a blade root that is circular, and a hub that, while in front of the generator, does not act to capture any energy from the wind. This area around the hub - the central axis - is the location of the rotor-root suction phenomena noted earlier. Recalling the basic law above - that fluids flow to areas of least resistance - this phenomenon makes sense. The best wind turbines today out at sea get about 47.5% efficiency. While this is still a significant amount, there is still another 11.8% to squeeze out - and that is if you play within the limitations of the Betz Limit. The area around the nose cone, despite this phenomenon, has received little R&D attention – most research has focused on the rotor blades. When Church asked a senior consultant in Germany why no attention was being paid to the nosecone, his response was blunt: "Why would anybody want to innovate there? It's just a cap for the nacelle." Based on a systems approach, the key to innovation in wind appeared to be at the center. In 2011, General Electric recognised this problem and launched their ecoROTR project that used a large hemisphere to redirect airflow from the nosecone towards the blades (see *References*).

The Design Clock - How We Developed the PowerCone

Many innovations in history have come into the minds of several inventors at the same time, and it is usually the first to publish or the first to market that succeeds. Since bio-inspired design innovation is the core value proposition from BiomeRenewables, it is essential that speed be

Figure 1: The Design Clock

Source: BiomeDesign

realized early on. Iterating fast and being nimble in the design process is at the core of what the BiomeRenewables team calls the Design Clock.

This clock is a series of six steps (Fig. 1). Each step can be run through multiple times while the clock circulates back on itself. The Design Clock is a way of organizing the design process, which can at times seem like a chaotic and messy space (Fig. 2). While there is room for creativity, this energy is channeled into certain objectives that must be achieved before moving on to the next 'hour' of innovation.

Step 1: Human-Centered Design - Know Your Customer

At BiomeRenewables, the user is at the front end of design. Understanding customer pain-points is the first step in the Design Clock. This mindset, called Human-Centered Design (HCD), requires

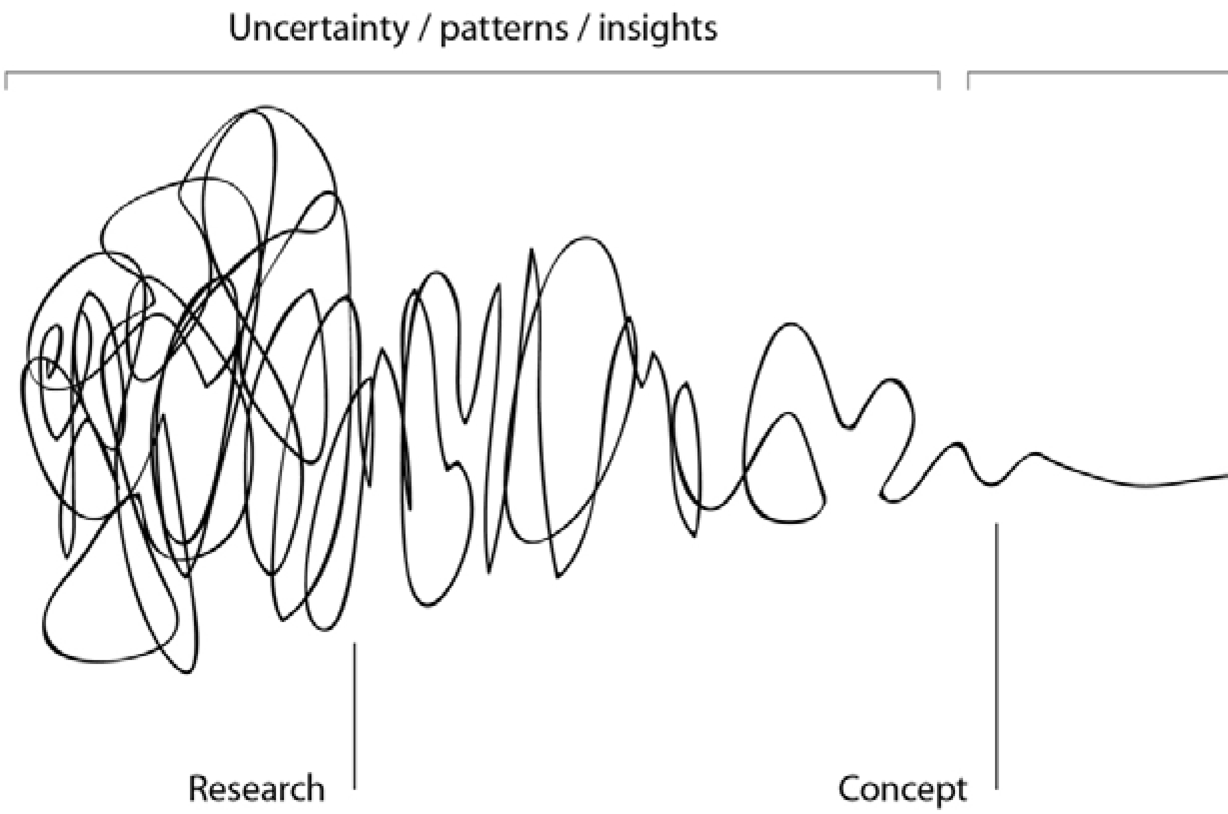


Figure 2: The design squiggle

Courtesy of Daniel Newman

creating and designing for someone. This means taking a step back, talking to your primary customers, and discovering their pain-points. With regards to the PowerCone, this meant travelling to trade-shows and conferences and listening for problems beyond the noise of the media. Rotor-root suction, yaw error, efficiency losses, blade erosion, transportation and many other problems became apparent through these discussions using HCD.

Step 2: Uncovering Actual Problems

With an understanding of the current pain-points from the customers themselves, the design team moved to define the actual problem versus the perceived problem, the second hour of the Design Clock. Defining *actual* problems is only possible when the industry is properly and fully understood. It's important to remove barriers, because these barriers may be artificial - and the very reason why a certain solution hasn't arisen yet.

Key to this step is the ability to grasp the big picture as it extends into the future. Foresight techniques are used to assess drivers and trends in the industry, and if the identified problem area makes sense. By assessing trends and drivers, where the industry may be going can be predicted with some degree of accuracy and rigour, enabling innovation for the future.

Modelling the future may seem like science-fiction to some, but companies like Shell have been doing this successfully for decades. An analysis of wind industry suggested that class III (low wind) turbines were increasing dramatically to over 60% of the market. This makes sense, because most of the *ideal* locations have already been taken, and if wind power is going to grow, it's going to grow in sub-optimal locations. Further, if the wind industry is going to expand its power output ability, how will this be achieved given the various technological, geographical, and political demands? The biggest trend is the increasing size of the rotor blades (Fig. 3).

In the future, wind turbines may have a rotor diameter of 250 meters or more, but it is unclear whether this trend can continue forever. This trend in size drives research into composite materials and blade profiles that are increasingly fluidic in shape and adaptive to conditions, or 'smart'. However, with this trend also comes an increasing hole in the middle of the turbines that is not being used to extract energy, because the root or base of the rotor blade is proportionally larger. This means that rotor-root suction is a problem that is only going to get worse with time.

Here, in the region of the nose cone, the problems of rotor-root suction, yaw error, efficiency losses, vibration, unequal blade loading and increased maintenance intervals were all related and coming together in a big mess - a good sign that a re-design is necessary. From that, the problem area was clear - innovate at the center of the turbine. With the actual (versus perceived) problem area identified, and the future industry landscape mapped, one more level of the problem needed to be defined: the design parameters of the intended solution. For Biome-Renewables, the defined problem was now to create a unique shape at the center of the turbine that would direct the incoming air flow towards the rotor blades, and thus limit or prevent rotor-root suction and the host of other problems mentioned.

Step 2 (Second Iteration)

Turbulence is known to be a bigger problem for objects moving at slower speeds than it is at faster speeds because the separation of boundary layers occurs when smaller forces are involved. This means that turbulence is happening to a greater extent at the center of the turbine than

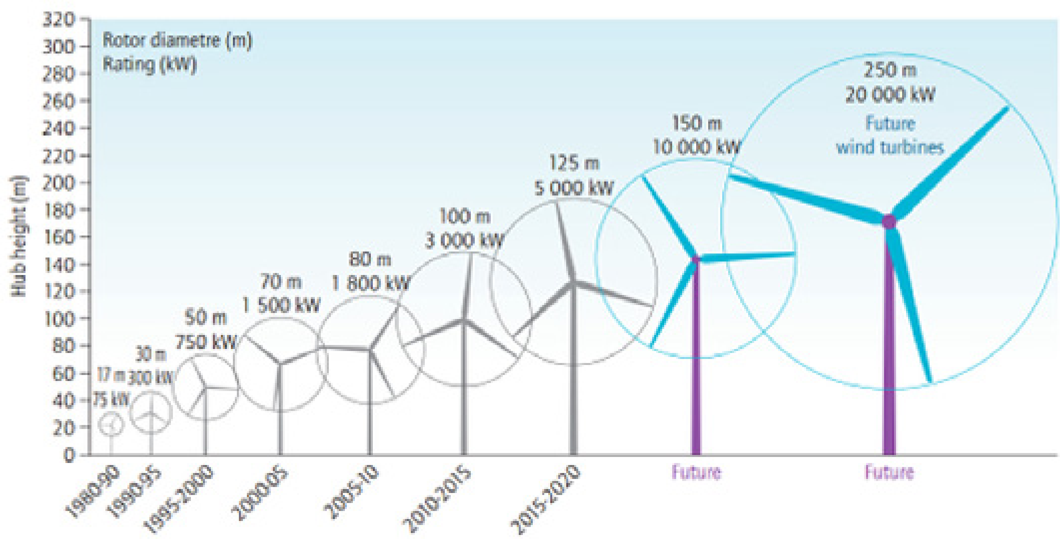


Figure 3: The future of wind?

Source: IEA 2013

it is at the blade tips. So a design objective would be reducing turbulence, particularly because at the center - but how?

The Golden Ratio of 1.618, discovered by Leonardo Fibonacci in the 12th century, is found throughout nature, and has some amazing characteristics that manifest themselves in the natural world, from sunflowers to nautilus shells (Fig. 4). It also makes an appearance in fluids, such as the spiral that forms when you pull the plug in your sink. This pattern is even seen in space (Fig. 5), where two massive black holes approaching on a collision course follow the same fluidic laws of least resistance.

If this ratio describes the most efficient rate of energy dissipation seen in nature (as fluids flow to areas of least resistance), it should also work in reverse - this ratio, in combination with the appropriate time spectrum (i.e. length), could describe a maximally efficient shape for extracting energy out of a fluid. With a realization that turbulence, and its inherent properties, are closely linked to a rate, the team focused on how time might influence the design parameters that favour laminar flow, and not turbulent flow. The defined question now became: 'how do we create a unique shape at the center of the turbine that would direct the incoming airflow towards the rotor blades, (and thus prevent rotor-root suction) on a timescale that favoured laminar flow?'

Step 3: Inspiration

Step Three of the Design Clock asks 'how might nature...?' This is where biomimicry and lateral creative thinking become involved - 'how does

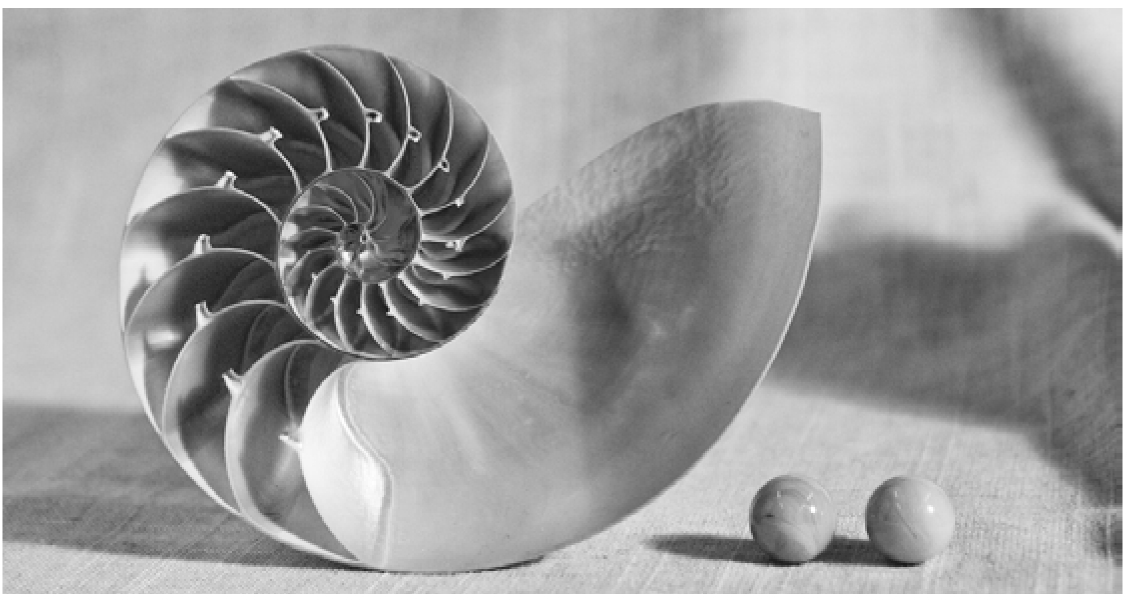


Figure 4: Nautilus

Photo: Fred Dawson, 2010 | Flickr cc

nature use timescales to reduce turbulence on bodies moving through fluids?' Context is key. Environmental surroundings and considerations of context are always highly important in discovering analogous processes in nature that will work to solve your agreed-to problems. Biomimicry, done properly, is not a quick process. It is something that takes multiple iterations.

The kingfisher - and particularly its graceful dive into water - stood out as a primary starting point, but modifications would need to be made. As the kingfisher dives from air to water, turbulence is reduced through shape and fluidic channeling over a large timescale. The kingfisher's long slender beak spreads the pressure wave that develops over a large surface area and timescale. Further, its beak is not perfectly linear, but curved slightly from tip to head. This means that the energy is dissipated in a non-linear fashion, gradually increasing in intensity as its beak enters further into the water and potentially a powerful starting point for inspiration.

But how would this relate to the nosecone of a wind turbine? The deck of Church's family cabin overlooks Shuswap Lake in British Columbia and is situated behind a maple tree. One day Church saw one of these seeds helicopter its way down and land on the deck. The motion was certainly following the path of least resistance. The ratio, or degree of spiral that this seed made in three-dimensional space while falling, seemed similar to the Fibonacci sequence. Church began to think about the bulb of the seed as the nosecone, and the wing as the rotor blade (Fig. 6). Using lateral thinking, Church realized that combining the principles of the Fibonacci sequence with that of the kingfisher might create a unique organic shape that would direct the incoming airflow towards the rotor blades (and thus prevent rotor-root suction) on a timescale that favoured laminar flow.

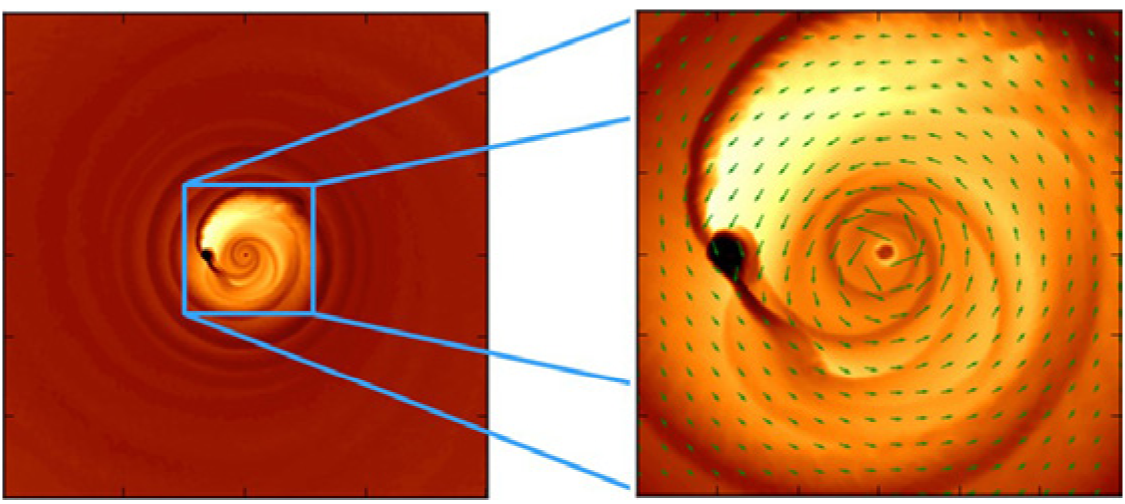


Figure 5: Intricate dance of black holes

Photo: Zoltan Haiman, Columbia University, 2015 | nasa.gov

Step 4: Discuss

Step four in the Design Clock involves a collaborative discussion. Using the maple seed and the kingfisher as inspiration and first principles of physics to work from in the area of turbulent flow. The design team discussed the concepts and the problem area to verify that they seemed to be reasonable. Using the first principle of removing all creative limitations, the team began sketching with these two ideas in mind and developed many iterative solutions.

Steps 5 and 6: Creating/Testing the Prototype

Step Five of the Design Clock is a tactile process of iterative prototyping, involving many materials from the local arts and crafts store. Test models of the PowerCone were built as cheaply and quickly as possible, with the one criteria being that the physics of what was happening be correct and consistent with the natural world. This process continued through successive iterations until a design was achieved that would satisfy the customer's core requirements. This step was combined with Step Six, which involves testing these ideas, and returning to Step Five in multiple iterations.

Using an inexpensive model, three wind turbine blades were constructed from micro-crystalline wax, and set up on a test model in a home-made wind tunnel made from plywood. The nosecone was constructed from a pliable gum medium, and set on the wind turbine. Through a simple power test using a digital multimeter, results were recorded with various PowerCone prototypes that maintained the proportions of the Fibonacci spiral, but varied in length and width, until one shape resulted. This was then set against the current nosecone as you would find on a wind turbine. The results warranted further testing and prototyping.

Figure 6: Maple seeds

Photo: upupandabear, 2013 | Flickr cc

Returning to the top of the Design Clock, the team further defined the problems and probed new ones, such as 'how do we concentrate the flow in the spiral?' This second pass in the prototyping and testing stage involved the Waag Society in Amsterdam (http://waag.org/en/about-us), who witnessed a test of the second iteration. This test included modifications to concentrate the flow in the spiral, which was achieved by curling the lip of the spiral back on itself to contain the flow. These tests warranted further slight modifications and further testing, which was recently completed at the Open Jet Facility (OJF), (http://www.lr.tudelft.nl/en/research/blinde-paginas/open-jet-facility/) at TUDelft in August 2015. Each test has built on the previous tests.

Each pass around the Design Clock leads to a more refined innovation that better addresses the core challenges of customers in the wind industry. With multiple patents filed and in the works, BiomeRenewables is driving innovation through biomimetic solutions to real-world problems.

Results

The PowerCone (Fig. 7) is the final result of two years of research into fluid dynamics, wind turbines and biologically-inspired design. By going around the Design Clock multiple times, the BiomeRenewables team honed in on a few major problem areas, namely: reducing yaw error, increasing efficiencies, reducing turbulence, reducing rotor-root suction, balancing the load on the machine and lowering the start-up or *cut-in* speed. Exploring further iterations to the proposed design unlocked multiple value propositions. The net effect of these solutions would be a wind turbine that is able to extract more energy out of less wind in areas that are less well-suited to development, while reducing wear and component failure on the machine. By looking at how the kingfisher achieves its remarkable diving feats and how the Fibonacci sequence is harnessed by the seed of a maple tree, an integrated solution was achieved for the nosecone of a wind turbine.

Wind tunnel tests conducted at the OJF at TUDelft in the Netherlands showed a reduction in turbulent flow and rotor-root suction as compared to a standard wind turbine with a standard nosecone as a baseline. The PowerCone reduced the cut-in speed by 0.75 m/s and increased efficiency by an average of +25% over all flow velocities tested. When this data was applied to the data from a real-world wind farm in the U.S., the annual energy production (AEP) increase was estimated in excess of +7%, and this excludes potential gains from correcting the yaw-error or increasing the cut-out speed. Based on preliminary

Figure 7: Artist's rendering of a PowerCone on a horizontal-axis wind turbine

Source: BiomeRenewables, 2016

tests, the PowerCone was not only lighter than the GE ecoROTR but also delivered significantly better AEP. These results were achieved by reducing wake vortices and inducing both axial flow through the rotor and radial flow away from the central hub towards the tips of the rotor blades, in effect compressing the airflow and channeling it to the areas where it can be most useful for power generation. This effect is not considered in the calculation of the current Betz limit, but perhaps it should be. The PowerCone re-directs airflow by 90 degrees in an open environment, slowing it down and extract more energy from it by decreasing its momentum.

BiomeRenewables expects that the PowerCone can be retrofitted in just 2 days without removing any additional hardware, resulting in a payback between 9-14 months on a turbine with an estimated 20-year lifespan. Conversations with industrial partners helped refine the design from a feasibility and marketability standpoint - new technologies need to be easy to install, without upsetting the workflow or industry standards. This was done by going around the Design Clock a further time. As such, the Design Clock is not just used for innovation, but also for real-world feasibility testing, and discovering the easiest path to market.

Next Steps

While the PowerCone has come a long way, BiomeRenewables' work is not done. With the results seen at TUDelft, a full-scale pilot test is in the works, and we are in talks with multiple large-scale wind turbine manufacturers in the U.S. and Europe. In addition, a plethora of other adaptations is also being explored, including tidal turbines and other stand-alone power-harvesting devices. With minor modifications, the PowerCone concept could also be used in machines and devices that put energy into a flow, such as propellers and turbochargers. In this way, the PowerCone is a platform technology that has the potential to transform multiple industries.

Returning to the mantra that began this article, biomimicry at BiomeRenewables is a verb. It is about action, so the inquiry into nature at the beginning of the journey must lead to a tangible deliverable at the end. This is how biomimicry can have a positive impact on the world, by delivering on the promise. The goal at BiomeRenewables is that biomimicry should touch you and your life in a positive way - and if it's doing its job, you won't even notice. ×

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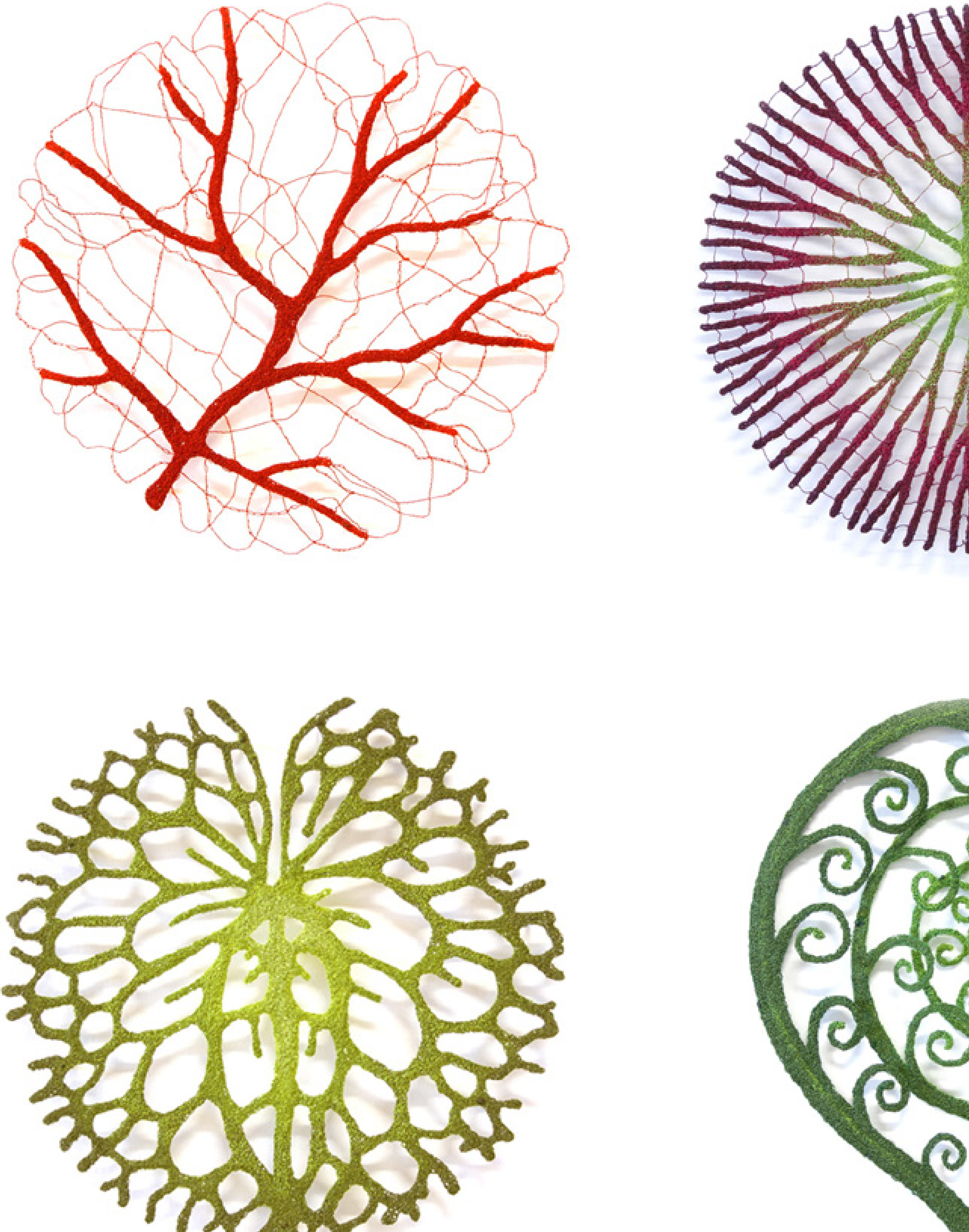

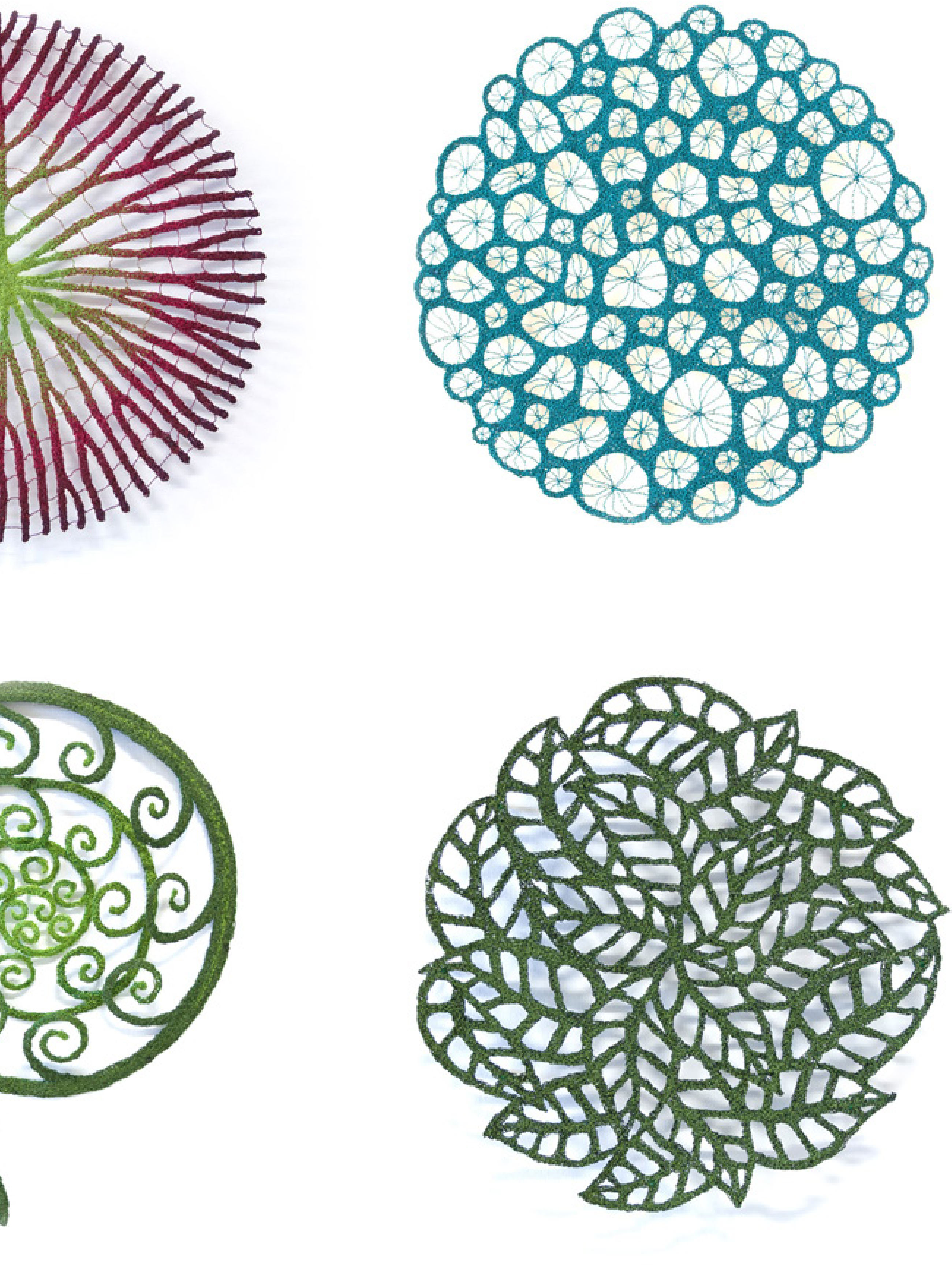


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