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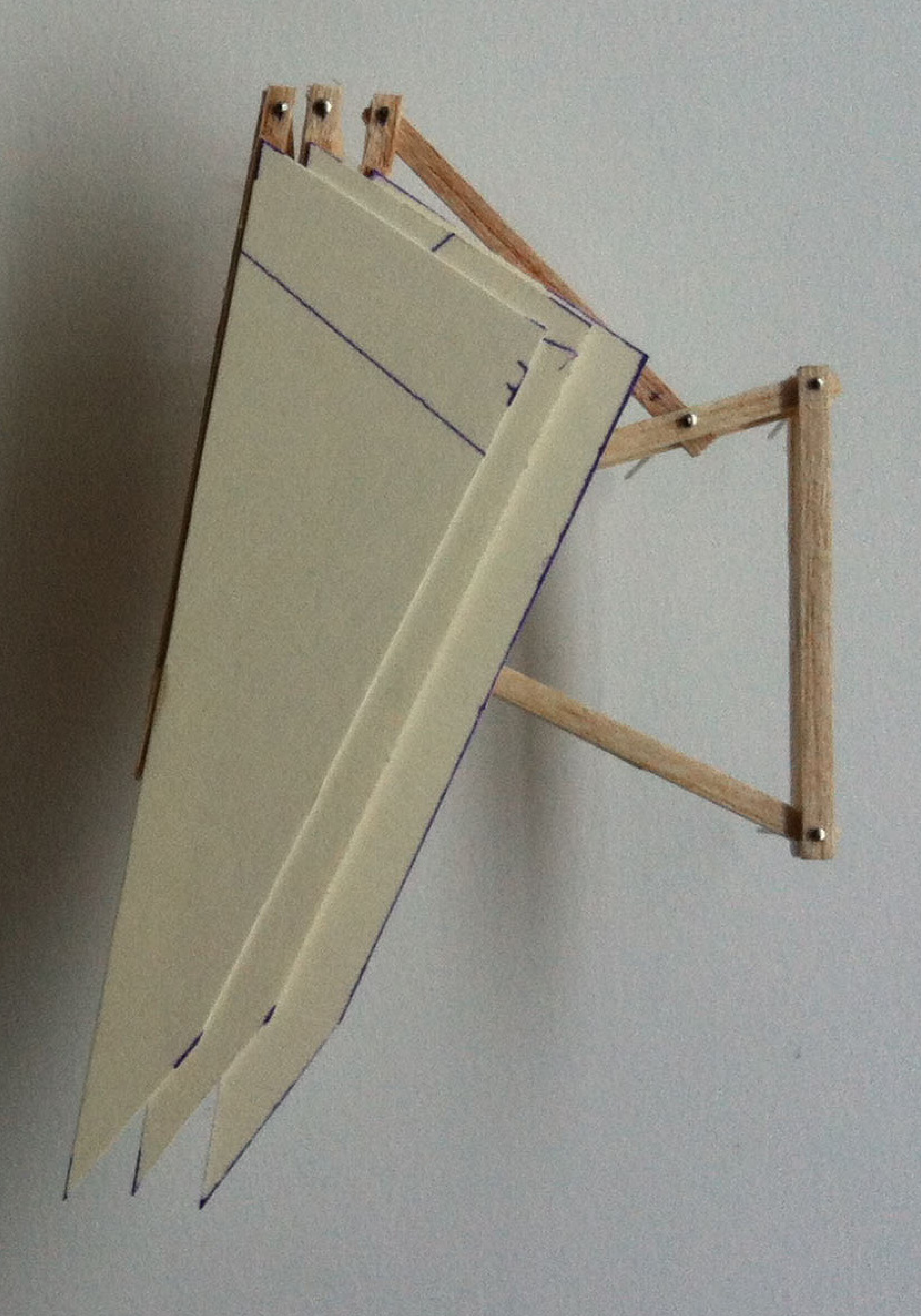

About Zygote Quarterly

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Cover art
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Editorial

Much of this issue is about bringing something new to the world, particularly the difficulties of designing, developing and selling a commercial product. For biomimics that can often contain a touch of irony as inspirations come from natural phenomena of ancient lineage; certainly “field-proven”, but not necessarily matched to a receptive market.

Sage elder of biomimetics Julian Vincent recounts engineer George Jeronimides’ development of an innovative composite material in 1980 in his article “George’s Wood”. Ryan Church, Rachel Hahs, and Norbert Hoeller outline a wide range of business case studies in the second of their three-part series “In the Trenches”. In this issue they discuss business models and market entry in the wind power, green chemistry and land planning sectors. Margo Farnsworth describes the early startup journey of REGEN Energy (Encycle) the developers of the emergent algorithm-based energy appliance sensor/controller in her elegiac tribute to founder Mark Kerbel.

Ritchie van Daal is a young Dutch artist and industrial designer who is exploring the essence of mechanical movement in his kinetic, nature-based constructions. His simple mechanisms belie a focused awareness brought to his viewing audience.

Finally, our own Heidi Fischer tromps along with another outstanding field researcher in her “Science of Seeing” series. This time it is in the primeval forest of the northern Cascades near Eugene, Oregon, tracking the northern spotted owl.

Happy Reading!

Tom Norbert Marjan

Tom McKeag, Norbert Hoeller and Marjan Eggermont

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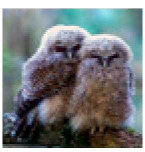
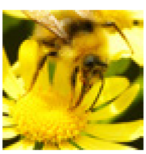




Atchafalaya Delta
Image credit: NASA Earth Observatory images by Joshua Stevens, using Landsat data from the U.S. Geological Survey and data from Ortiz, A. C., Roy, S., & Edmonds, D. A. (2017) | Flickr cc

Article

Stories from the trenches of biomimetic innovation: Business Model & Market Entry Strategy

Ryan Church, Rachel Hahs, & Norbert Hoeller

Stories From The Trenches Of Biomimetic Innovation: Business Model & Market Entry Strategy

Ryan Church, Rachel Hahs, & Norbert Hoeller

In the first article of this series (https://zqjournal.org/editions/zq21.html p. 38), we explored the ideation and proof of concept phases for four biomimetic case studies. Three observations emerged:

- Information transfer between biologists and engineers is not usually straightforward - it's important to get the science right.
- Multi-disciplinary collaboration is critical to success.
- Biomimetic practitioners can become convinced that their bio-inspired innovation will overcome any lacking in business model refinement or product-market fit.

Any innovation, whether it is nurtured through a startup or a mature company, goes through some aspects of the Valley of Death (VoD). This valley is characterized by limited financing and tight timelines, which together form the 'runway' - the amount of time the team has to generate first revenue before finances run dry. In some cases, companies can raise additional financing, but often at lower valuations than earlier rounds.

As most biomimetic innovations come from academia or 'the lab', they are subject to the startup VoD before entering the market, including sourcing and building a team to validate the technology and business case. The technology, the business case and the target market are three equally important parts of the startup triangle. Far too often, biomimetic startups neglect the business case and the target market. Marketing combined with media reports frequently emphasize sizzle over substance, as in a recent case of a promising biomimetic concrete enabling mile-high skyscrapers - as if the only thing missing from this equation was the building material. Upon serious consideration, the business case lacks a concrete foundation. This in turn markets biomimetic innovation in popular culture as a pie-in-the-sky endeavour.

The market entry strategy: what exactly you are selling, how you are selling it and to whom, are key to the success of any business. A biomimetic innovator needs to recognise the strengths of the discipline and leverage them in the strategy, while understanding and avoiding the pitfalls. This article will explore business models and market entry strategies in the context of the case studies we've been following, and hopefully spark debate about how we can chart a new course for a successful biomimetic future.

Wind turbines Scroby Sands | Photo: Martin Pettitt, 2008 | Flickr cc

Humpback Whale | Photo: rjshade, 2014 | Flickr cc

Wind Energy

Crafting the appropriate business model and market entry approach is essential to crossing the VoD. In the wind industry, there are specific market conditions that make certain business models more likely to succeed than others. The industry is dominated by a few large technology players, who assert their dominance whenever they can. They typically believe that if the technology wasn't invented in-house, it doesn't exist. The industry is currently going through a period of consolidation, as large turbine manufacturers join forces to become ever-bigger behemoths, driving down the cost of energy. But this was not the case back in the mid-late 2000s when WhalePower was trying to bring its technology to market. During that time, there were many more independent turbine manufacturers, but they all still had a *not invented here* mentality. What has also not changed is the market's risk-averse appetite. Claims of any sort are only truly believed when they are tested at full scale in the appropriate environment, many times over. Given the scale of these machines and the size of investment that goes into them, the industry does not accept technologies that are not thoroughly de-risked by reputable 3rd party engineering firms.

WhalePower

WhalePower Corporation was set up in 2005 by Dr. Frank Fish and Stephen Dewar to commercialize the tubercle technology originally developed in the early 2000s by Dr. Fish, Dr. Laurens Howle and others. Now it was time to take it out of the lab and into the commercial world. The WhalePower team needed to make a few decisions around which market they would focus on. This would determine how they would pilot test their design, and who they would partner with. They also needed to think about who their end customer would be. Choosing the wind market, they could target the turbine manufacturer and either set up a model where they manufacture the tubercles for installation at the factory, manufacture the blade with tubercles embedded as one piece, or licence the technology to the blade manufacturer or the turbine manufacturer (they are rarely the same entity). They could choose a different path and manufacture the tubercles as an add-on retrofit solution, where the end-customer is the turbine operator (targeting turbines that are out-of-warranty), or they could sub-contract that manufacturing to a 3rd party. Each option has positives and negatives in terms of effort needed, cash flow required, profit margins and market

Wind turbines Scroby Sands | Photo: Martin Pettitt, 2008 | Flickr cc

size. Entering the wind market is no small task, so these options would need to be considered carefully and dovetail seamlessly with their pilot strategy.

In July 2007, WhalePower choose to test its technology at the Wind Energy Institute of Canada (WEICan, https://whalepower.com/drupal/files/PDFs/Dr_Lauren_Howles_Analysis_of_WEICan_Report.pdf), a not-for-profit independent research and testing institute with a variety of turbine types and sizes. WhalePower decided to choose a Wenvor 25kW two-bladed turbine with a diameter of 10 meters as its test turbine. The Wenvor is a variable-speed stall-regulated wind turbine, which has fixed blades that do not pitch via mechanical motors, making them potentially more cost effective with fewer moving parts. However, most turbines as far back as 1998 were constant-speed pitch-regulated turbines, where the blades pivot around their axes to keep the turbine's RPM and power constant as the wind speed rises beyond the turbine's rated capacity. Today, all grid-scale wind turbines use blade pitch to regulate load and power output.

In choosing to perform their pilot field test on the Wenvor turbine, WhalePower made several key mistakes in their entry strategy. A two-bladed stall-regulated turbine did not reflect the current state-of-the-art technology at the time of the test, which was instead a three-bladed pitch-regulated turbine. As such, any results would be questioned by potential customers, who operated or sold a vastly different technology. A possible reason for this turbine choice is that tubercles were hypothesized to work in high angles of attack (AOA), stalling gradually as the angle was increased. Even though the AOA does not change in the Wenvor turbine, the impact of delayed stall could improve turbine performance. Also, WhalePower did not retrofit the blades of the Wenvor turbine directly, nor did they generate baseline performance data. Instead, they opted to produce specially designed tubercle blades that were significantly heavier, and compared these results to published power curve data (Howle, 2009), rather than measuring the turbine's power curve in the field. Lastly, results at the 10-meter scale cannot be extrapolated to grid-scale MW turbines with blade diameters of 100 meters or more. In short, there were many technical problems with this pilot test, leaving potential customers with many questions. WhalePower claimed a 20% improvement in annual energy production (AEP), but few believed them. Instead of addressing these problems, WhalePower decided to try and find a commercialization partner to licence the technology.

In 2008, when testing was winding down and WhalePower was looking to move to the next step and commercialize the technology, they turned to Vestas. “I remember that Vestas was on death’s door. Back in 2008, everyone was struggling”, recalls Stephen Dewar, then VP of Operations. The financial crisis was beginning to hit, and WhalePower had trouble raising financing. Vestas didn’t care about biomimicry. Instead, they just looked at the science to date, and decided to take a pass. WhalePower was not able to partner with any companies actively involved in the wind industry, either large scale original equipment manufacturers (OEMs) like Vestas, or wind farm operators like Enbridge or EDF. The technology stalled, both metaphorically and actually, while the industry was investing in larger pitch-regulated rotors. For the next eight years, the technology would lie dormant, until Tubercle Engineering Group (TEG) out of Germany secured a worldwide licence agreement for the technology (https://www.teg-group.de/en/press/press/teg-wins-over-whalepower-corporation-wcl-from-canada-as-partner-and-signs-extensive-manufacturing-and-sales-license-agreement/). Interestingly, TEG does not tout any performance gains from WhalePower, and instead has focused on improving reliability and decreasing maintenance costs for wind farm owners.

Throughout all of this, WhalePower was investigating another application: ceiling fans. This application made more sense, as the technology is a fixed-pitch variable speed system, and the heating and cooling market is very large. Prototypes could be made much cheaper, reducing the risk to prove the technology. WhalePower sold a worldwide licence to Envira-North Systems Ltd to manufacture and distribute the technology, demonstrating that there was another potential application of the underlying technology - a hallmark of biomimetic innovation.

PowerCone™

Based on the initial proof-of-concept design, Ryan Church knew that Biome Renewables (Biome) and the PowerCone would require a specialized team, a unique customer-oriented business plan, and rigorous R&D. The first person he reached out to was Stephen Davies, his professor of business model innovation, a likely place to start when building a company from the ground up. They began working on a business model using a sustainable variant of the Osterwalder Business Canvas, called the Strongly-Sustainable Business

Maple propeller | Photo: wolf4max, 2014 | Flickr cc

Model (SSBM, http://www.ssbmg.com/). Church and Davies had the same options as WhalePower: who to sell to, and what to sell. In the beginning, a fiscally conservative approach was evaluated - licensing to OEMs. In parallel, the team arranged for wind tunnel experiments at TUDelft's Open Jet Facility (OJF, https://www.tudelft.nl/en/ae/organisation/departments/flow-physics-and-technology/flight-performance-propulsion/flight-performance/propeller-aerodynamics/facilities/wind-tunnels) in The Netherlands. This world-class facility was an expensive choice for a company at this stage, but interviews with various segments of the wind industry determined that the results had to be of the highest quality, or they would be discounted. Testing an improved model at the two-meter scale proved successful, and valuable information was gathered for further iterations of the design. Notably, Biome had a solid technical foundation with which to advance customer development and involvement. Further testing at the same scale in an outdoor environment led to similar results, advancing the R&D campaign.

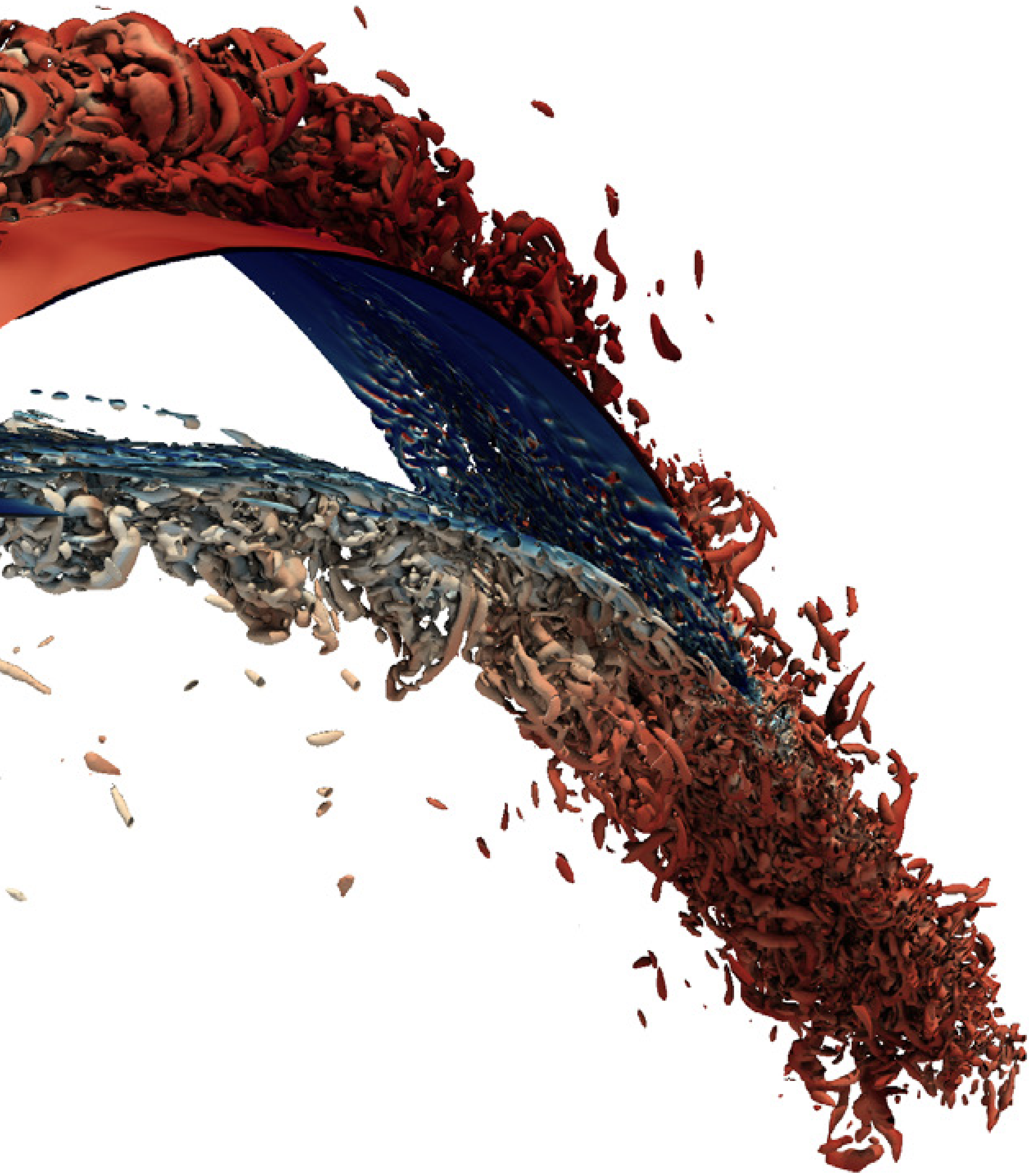
Davies and Church employed a co-creative methodology to business model iterations, getting out into the industry to speak with potential customers. The takeaways were very similar across different segments of the industry: the wind industry is very skeptical of performance claims. Further, there was a divide forming in the market between wind turbine operators and OEMs - operators were not hitting the performance metrics promised by the OEMs. This led to missed internal rate of return (IRR) targets, and a hunger for turbine operators to stop relying on OEMs to maintain their turbines. Long term maintenance and turbine performance would now be in the hands of the operator, who would be free to manage their wind assets as they saw fit. It was during this time, as Biome was completing its outdoor testing and incorporating computational fluid dynamic (CFD) simulation into its R&D program, that Biome turned to Bryan Murphy and Bachir Rabbat, owners of Quest Partners, to raise the financing needed to perform a full-scale pilot test to provide the technical proof needed to enter the market.

In raising the funds, Bryan and Bachir - supported by a growing Biome management team - took an eagle-eyed approach to crafting the business and financial plan, making sure there was alignment between what the market expected of a hardware startup, and what the business plan should be. During this process, the company decided on selling a fully-installed

PowerCone to wind farm owners. Biome would create an ecosystem of partnerships to de-risk the venture and increase the likelihood of success. In this way, Biome's business model would reflect symbiotic relationships, where every entity provided and focused on what they were best at, to deliver the outcome that benefited all. Further, Biome also championed a triple-bottom-line business model rooted in the SSBM canvas, increasing the valuation of the company to environmentally and socially conscious investors. To escape the VoD with the most momentum, Biome would need to execute on its pilot with an end customer who could successfully deploy the technology and enable the company to generate revenue. To reduce further barriers to entry in the business model, a series of conversations began with potential customers to craft a business partnership that went beyond the initial pilot. In the spring, Biome succeeded in inking partnerships with the Canadian power producer Capstone Infrastructure, a large-scale composites manufacturer, and numerous

Maple propellers
Photo: wolf4max, 2014 | Flickr cc

A frontal snapshot of a high-fidelity CFD simulation of a low pressure turbine blade showing the range of scales captured.
Photo: Engineering at Cambridge, 2017 | Flickr cc



other wind industry players to complete their business model ecosystem. Biome also received a substantial grant from the Ontario Government. The pilot process had officially begun.

Green Chemistry

Molecular Heat Eater® (Trulstech)

With the biomimetic development of the radically innovative Molecular Heat Eater (MHE®) family of flame retardant products in the late 1990s, Mats Nilsson, Founder and Chairman of Trulstech, armed with a study that demonstrated that MHE® was completely non-toxic and recipient of a prestigious innovation award, was convinced that the clear health benefits realized by the adoption of MHE® would change the industry.

MHE® represents a paradigm shift in the industry on several fronts due to a completely new approach to the underlying chemistry and raw materials. The use of MHE® results in:

- Significantly improved health outcomes throughout the product life cycle because it is non-toxic and biodegradable.
- Reduced costs through use of inexpensive and abundant raw materials sourced from food production by-products, readily available in most locations (a radical shift in the industry).
- Improved host material mechanical properties due to a reduction, sometimes significant, in the quantity of flame retardant required to meet the relevant fire safety standards of the host material in addition to a reduced need (and cost) for other chemical additives such as stabilizers and fillers.
- Reduced production complexity and capital costs due to low toxicity of feedstocks (when used in approved quantities) and reduced need for additional chemical additives.
- Reduced costs and risks associated with environmental compliance and occupational health and safety.

Trulstech's success in developing an eco-friendly solution to the industry's greatest challenges has been clear - in the decade beginning in 2003, MHE® received over ten international innovation awards. However, developing a solution is one thing - developing the right business model to successfully enter a well-established industry with entrenched interests, existing relationships, and pricing structures that create barriers to entry is another.

At the time of commercialization in the 2000s, Trulstech was entering a fast growing, established flame retardant market. According to industry reports, the global flame retardant industry, valued at approximately USD 2 billion in 2000, is expected to grow to approximately USD 12 billion in 2025. This growth is occurring in a market shifting towards more environmentally-friendly alternatives due to consumer pressure and changing government regulations driven by a growing awareness of the significant health risks posed by conventional flame retardants, risks amplified by the propensity of inert flame retardants to migrate out of products and into the environment where they persist. In addition, a shortage of raw materials needed in the production of conventional flame retardant chemicals and the associated price increases is driving companies to innovate.

The flame retardant market is dominated by few large, vertically-integrated multinational chemical companies that source and process feedstocks, manufacture chemicals and distribute a wide variety of chemical additives, including flame retardants, to materials manufacturers. Materials manufacturers then add the flame retardants and other required additives into host materials, such as plastics, foams and textiles. These materials are in turn used to manufacture the products we consume.

Nilsson's R&D decision to create a chemically bonded flame retardant that uses food-grade chemicals has implications for commercialization of MHE®. While MHE® has the potential to radically improve health outcomes while remaining price competitive, the adoption of MHE® still requires system changes, particularly for established manufacturers - shifts in investment and R&D schedules, forging of new partnerships and supply chains, and changes to production equipment and processes - which might represent significant investment and business risk. Any successful Trulstech business model would need to identify industry players within the system that both had needs which aligned with the MHE® value proposition and for which the potential for innovative growth in a changing market outweighed the risks of change, or find customers where change would be less risky. It would also need to take into account how existing market incentives might work against them.

Trulstech, an established innovation company with broad expertise, experience, and success in developing solutions for the communications industry but without any experts in the flame retardant industry, decided on an initial business model in which Trulstech would patent, contract manufacture and distribute MHE® directly

Beaver dam on the Teton (Beavers reduce fire impacts in spruce stands by creating a mosaic of habitats that act as natural firebreaks. Ask Nature)
Photo: Sam Beebe, 2009 | Flickr cc

to large materials manufacturers. Nilsson was confident that the clear potential for significantly improved health outcomes combined with its price competitiveness would persuade potential customers to make the switch to MHE®. But in pursuing this approach, Trulstech underestimated the power of existing price incentives and relationships between the established industry players. According to Nilsson, only after a few years of scant success using this approach did he learn that although flame retardants represent a small percentage of the overall number of chemical products purchased by these large materials manufacturers, materials manufacturers, while impressed with the eco-friendly product, were unwilling to switch because they received a discount by purchasing all their chemicals from one large chemical supplier.

The established industry incentives and relationships created a barrier to entry that the Trulstech business development approach did not anticipate, nor did market pressures present scenarios in which the eco-friendly health benefits of MHE® outweighed the costs of change. Having an industry expert on their team could have helped them better evaluate market trends and identify and target industry players with needs better aligned with the value proposition of MHE®. Trulstech had to pivot and change their approach.

Recognizing that Trulstech was first and foremost a research and development innovation company and not a chemical manufacturer or distributor, and taking his lessons learned from large materials manufacturers, Nilsson refocused his efforts on selling the MHE® patents, along with research and development support, to chemical manufacturers looking to expand their eco-friendly product offerings in regions around the globe. MHE® is currently marketed under the name Apyrum sold by Deflamo in Europe and the former Republics of the Soviet Union. Trulstech is now working to solidify business partnerships with chemical manufacturers in North America, Australia and China to bring MHE® to new markets in an industry that is experiencing an increase in government regulations and business and consumer pressures for eco-friendly products.

In any line of business, selling IP in well-established industries where large companies dominate is difficult. The industry's resistance to change has frustrated Nilsson, but he continues to seek out win-win opportunities to establish MHE® in fast-growing markets. The next article in this series will discuss the evolving strategies of Trulstech partners around the globe.

Stories From The Trenches Of Biomimetic Innovation: Business Model & Market Entry Strategy

Ryan Church, Rachel Hahs, & Norbert Hoeller

Spain
Photo: NASA Johnson, 2015 | Flickr cc

Built Environment
This article explores the wider applicability of the broader "Building with Nature" concept. Can the "Building with Nature" concept deliver effective and cost-efficient results in a broad range of situations? Although these projects are tied to "place", a specific combination of ecological/social/ economic factors, are there transferable patterns?

Pamplona's Aranzadi Park
The Arga River in northern Spain has been prone to flooding in recent years, particularly in a two-hectare area around a meander in Pamplona where the rich soils from past flooding supported some of the oldest biodynamic farming in Spain. Flash floods exacerbated by canalization have driven out all but a few local farmers. In 2008, architects Iñaki Alday and Margarita Jover Biboum won a competition to design and implement the Aranzadi Park. In September 2013, the park successfully coped with the largest volume of flood waters in recorded history, even though construction was not yet finished (https://archello.com/project/aranzadi-park).

View over the Arga River, Pamplona
Photo: Adam Jones, 2014 | Flickr cc

A "river landscape" has been created by widening the river and incorporating low bushes to filter water while maintaining visual access. A secondary channel through a 'floodable forest' absorbs periodic flood waters, protecting surrounding fields and orchards (https://www.metalocus.es/en/news/aranzadis-meander-park-aldayjover-architecture-and-landscape).

Alday and Jover see landscape architecture as a transformative socio-economic-ecological system that adapts to the complexity and uncertainty of change. Rivers are constantly in motion and can dramatically reshape the landscape. Rather than being perceived as a threat, to be constrained by dikes and dams, the Arga River is now an integral part of the park, sharing space with citizens, orchards, and agriculture.

Alday and Jover's designs recognise the role of humans in shaping the world (both positive and negative), and the importance of embedding ourselves in nature. The Aranzadi Park dynamically rebalances natural forces and human needs, and reconnects the public with the river, farms, orchards, and natural spaces, helping the public appreciate the living system and encouraging stewardship (García García, 2016).

The Delfland Sand Engine

About 120 km of the Netherlands' North Sea coast is a sandy shore backed by extensive dune systems. In the past, the emphasis was on separating the land from the sea and resisting the forces of the sea using fixed infrastructure. These dikes blocked access to the beaches and dunes on the seaward side and in some areas required expensive foundations to prevent undermining by currents and waves.

In 1990, changes in policy recognized the dynamic nature of the shoreline. Dikes were replaced by local 'nourishment' with about 1 million m^3 of dredged sand in locations wherever the shoreline was receding. Although this approach helped preserve the natural environment and created recreational opportunities, the process needed to be repeated every five years, disrupting both offshore and onshore ecosystems, and increasing the steepness of the lower shoreface (Slobbe et al., 2013, table 1).

The Delfland Sand Engine (http://www.dezandmotor.nl/en/) pilot project was launched in 2009. It is an offshore "mega-nourishment" of 20 million m^3 near Den Haag, allowing winds, currents, and waves to naturally regenerate about 18 km of coastline and dunes over a 20-year predicted lifespan. This proactive approach is expected to reduce environmental impacts, strengthen ecosystem services, expand recreational opportunities, and increase freshwater storage under the dunes. Early results have been positive: in addition to attracting kite surfers, basking seals (uncommon in the area) have been observed, along with pioneer species and even a rare plant. An extensive interdisciplinary research project is underway involving 15 PhDs and 6 postdoc students from hydrologists to ecologists (Luijendijk, 2016).

The Sand Engine cost €70 million, compared to €60 million/year (2011) for the entire coast. At this point, it is not clear which solution is more cost-effective, due to the large up-front costs and difficulties in measuring ancillary benefits. However, the amount of sand required by current local "nourishment" has been rising, while the cost of the Sand Engine approach is expected to decline if it is implemented along the entire coast.

The "hard" and "soft" interventions before the Sand Engine were technical, within the scope of coastal engineering and local government. The size and long lifespan of the Sand Engine required active engagement of a broad range of public

Untitled (kompaskwal | Compass Jellyfish | *Chrysaora hysoscella*)
Photo: Zandmotor, 2015 | Flickr cc

Zandmotor overzicht vanuit noord (Sand Engine view from the north) | Photo: Zandmotor, 2017 | Flickr cc

Planten noordkant duinmeer (Plants north of the ‘dune lake’) | Photo: Zandmotor, 2016 | Flickr cc

stakeholders, both supporters and detractors. It was essential to develop consensus on broadly shared goals and accept uncertainty: models of the full system were limited, there were many unknowns, and nature is inherently dynamic. The Netherlands is fortunate in having a design-making approach supporting investment spanning decades, flexible funding methods that consider multiple benefits, a willingness of the public to try novel approaches, and a culture of working together to solve problems. Nevertheless, one commentator mentioned that change required lots of cups of coffee over many kitchen tables to explain the project and address concerns.

The success of the project required accepting that engineering, nature, and society are all interrelated. According to de Vriend et al. (2015), these projects require different ways of

- Thinking: design a solution based on the natural system and stakeholder interests, rather than a design based on narrow requirements
- Acting: non-traditional designs and full lifecycle management, rather than delivering an engineering project
- Interacting: co-creation among problem owners, experts, and stakeholders.

Zandmotor recreanten (Sand Engine recreational use) | Photo: Zandmotor, 2016 | Flickr cc

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The Sand Engine attracted international attention - Peru reportedly wanted three of them. Although every implementation has a different geography, hydrology, ecology, local dynamics, mix of stakeholders, and potential benefits, the process is transferable. To assist implementation, the EcoShape website (https://www.ecoshape.org/en/) is an evolving repository of pragmatic guidelines, tools, models, components, and a library of projects.

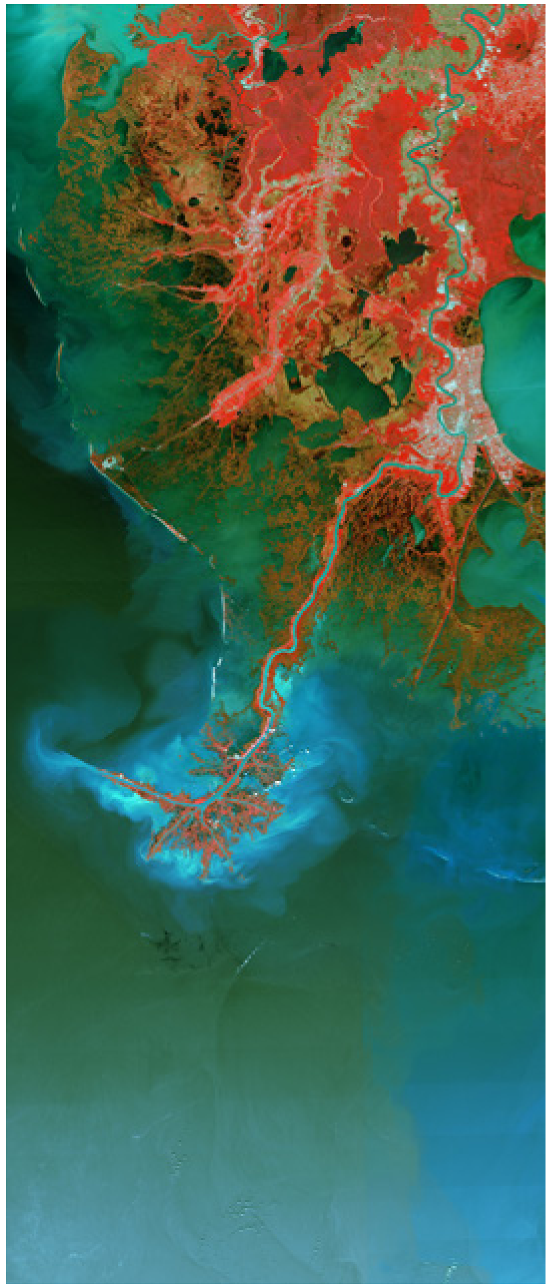
Proeverij van Zandmotorplanten (A tasting of Sand Engine Plants)
Photo: Zandmotor, 2016 | Flickr cc

Mississippi Delta Case Study

River deltas are complex ecosystems balancing sedimentation with erosion and subsidence. Healthy deltas support diverse ecosystems while acting as buffers from flooding and storm surges. Galloway studied deltas extensively in the 1970s and published a classification of deltas based on whether they were primarily influenced by fluvial, wave, or tidal forces. Human activities are increasingly affecting river deltas, with numerous stakeholders often having conflicting goals. Hillen et al. (2008) extended Galloway's classification to include human influences, and recommended an integrated approach to delta development that incorporated natural, ecological and social factors.

The Mississippi River delta is one of the largest in the world, and is under pressure from agriculture, transportation, and industry. Canalization to protect New Orleans and agriculture from flooding has led to loss of delta marshes at a rate of about 115 km^2 per year, affecting stakeholders such as fisheries, recreation/tourism, and biodiversity. The loss of protective delta plains is putting New Orleans and surrounding areas at increased risk.

The Mississippi River is also constantly wandering. It was predicted that the



Mississippi River Delta, USA / Landsat-8, USGS/ESA (part of Art and Science Exhibition Part III)
Photo: Ars Electronica, 2015 | Flickr cc

Marsh restoration projects in the Mississippi River delta. Pass A Loutre Wildlife Management Area and Delta National Wildlife Refuge. | Photo: Lauren Sullivan/Unleveed, 2014 | Flickr cc

Mississippi flow would shift westward into the Atchafalaya River by the 1970s-1980s, bypassing Baton Rouge and New Orleans. The Old River Control Structure built in the 1960s ensured that 70% of the Mississippi River's flow would continue in its present channel, but sedimentation below the control structure has raised the riverbed by 30 feet since 1992, reducing the river's carrying capacity. Research suggests extreme rainfall could cause flooding sufficient to overwhelm the Old River Control Structure, catastrophically altering the course of the Mississippi (Hardy, 2018).

Hillen estimated that key areas of the Mississippi delta need an additional 10 mm/year of sediment deposition to maintain ground levels, with 1-2 mm/year due to sea level rise and 8-9 mm/year due to subsidence (mainly from oil and gas extraction). Modelling of diversions suggested that marshes to the east and west of the Mississippi could be regenerated by diverting one third to half the Mississippi river discharge, depending on the time scale of the project. Timing diversions during periods of maximum flow increases the amount of sediment deposited while reducing the impact on shipping. The results were supported by a physical model of the lower 122 km of the Mississippi which compressed two years of sedimentation into 33 minutes.

The research suggested that controlled diversions could allow natural processes to restore the marshes, balancing human and natural influences on the delta. Some stakeholders would see short-term impacts, but the diversions would preserve the delta and provide long-term benefits for all stakeholders, including reducing the impact of storm surges. Realistic diversion rates will gradually build out delta marshes over a 50 years period, requiring a long-term commitment from all stakeholders. Although Hillen identified the range of stakeholders and addressed concerns from the shipping industry, the effort to engage the stakeholders and build a consensus has not been assessed. The next article in this series will describe the challenges of trying to implement more resilient development in New Orleans.

Observations

1) A solid business model and market entry strategy is just as important as developing a viable biomimetic solution. What initially appears to be a clear market opportunity based on the biomimetic benefits may turn out not to be associated with a compelling need. An established market with a glaring problem that needs solving will always be a better starting point, rather than choosing

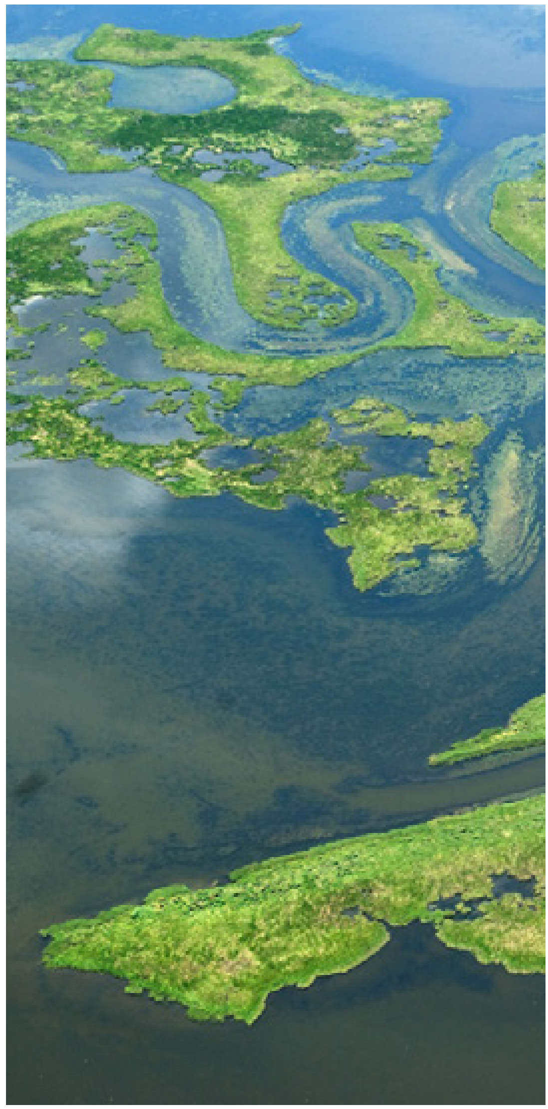
a cool emerging sector, like the Internet of Things, Big Data or Artificial Intelligence.

2) When entering the market, don't focus heavily on the biomimetic function - you won't be able to relate to many of your potential clients. Hammer away at the problem the customer is facing and why your innovation can solve it, or solve it better than the competition. Entrepreneurs tend to get too excited with biomimetic concepts, and forget they operate in the business world.

3) Continually re-evaluate the effectiveness of your market strategy and be prepared to pivot if clients are not receptive or new opportunities present themselves. This is true for any startup, but biomimetic entrepreneurs can sometimes become fixated on the obvious benefits of their solution. Time is not on the side of the entrepreneur, particularly a biomimetic entrepreneur who often must deal with new technologies that are hard to explain to clients.

4) Find or plan to build a supportive ecosystem of strategic partners to fill gaps in the underlying research and business models. Biomimetic startups can find themselves outside of traditional supply chains, increasing the risk both for the entrepreneur as well as their clients.

The next article will explore the challenges of commercializing and scaling up biomimetic innovations. ×



Verdant wetlands southeast of New Orleans in the Missisippi River delta
Photo: James Davidson, 2010 | Flickr cc

References

de Vriend, H. J., van Koningsveld, M., Aarninkhof, S. G. J., de Vries, M. B., & Baptist, M. J. (2015). Sustainable hydraulic engineering through building with nature. *Journal of Hydro-Environment Research, 9*(2), 159–171. https://doi.org/10.1016/j.jher.2014.06.004. Retrieved August 8, 2017, from https://www.researchgate.net/publication/268221283_Sustainable_hydraulic_engineering_through_Building_with_Nature

García García, M. (2016). Fluidez disciplinar: Conversación con Iñaki Alday | Disciplinary fluidity: Conversation with Iñaki Alday. *ZARCH*, (7). https://doi.org/10.26754/ojs_zarch/zarch.201671530/. Retrieved February 26, 2018, from https://papiro.unizar.es/ojs/index.php/zarch/article/view/1530/1756

Hardy, S. (2018, February 3). Could Mississippi River change course? New research raises question, but Corps says plan working. Retrieved February 27, 2018, from http://www.theadvocate.com/baton_rouge/news/environment/article_d5a29f26-06a9-11e8-abde-8b9660c81021.html

Hillen, M., Kuilboer, J., Nordbeck, P., & Treffers, R. (2008). Building with nature - Finding a balance between natural and human processes in deltas. *Innovative Solutions for the Delta*, 77-92. Retrieved August 8, 2017, from http://www.unisdr.org/files/12330_inovativesolutions.pdf#page=77

Howle, L. E. (2009). WhalePower Wenvor Blade. Belleqant, LLC. Retrieved from http://www.whalepower.com/drupal/files/PDFs/Dr_Lauren_Howles_Analysis_of_WEICan_Report.pdf

Luijendijk, A. (2016). The Sand Engine - a “Building with Nature” pilot. TUDelft. Retrieved February 5, 2018, from https://www.fzk.uni-hannover.de/fileadmin/institut/Veranstaltungen/FZK-Kolloquium/Kolloquium_2016/Praesetationen/11.FZK-Kolloquium-2016_Vortrag_Luijendijk.pdf

Slobbe, E. van, Vriend, H. J. de, Aarninkhof, S., Lulofs, K., Vries, M. de, & Dircke, P. (2013). Building with Nature: in search of resilient storm surge protection strategies. *Natural Hazards, 66*(3), 1461–1480. https://doi.org/10.1007/s11069-013-0612-3. Retrieved August 8, 2017, from https://www.researchgate.net/publication/257632773_Building_with_Nature_In_search_of_resilient_storm_surge_protection_strategies

Ryan A. Church is the Founder and CEO/CTO at BiomeRenewables Inc., where they are developing biologically-inspired renewable energy technologies. They are launching in the wind industry with the PowerCone, an enhancement technology that enables nine world-firsts in the wind industry with initial indications suggesting that this technology could break the Betz Limit while decreasing turbine loading. He has given university lectures and advised governments in both Canada and Europe as a thought-leader in the field of renewable energy and biomimicry. Recently, Church was nominated as a Forbes 30 under 30 in Energy.

Rachel Hahs is Certified Biomimicry Professional and sustainability expert working to expand the sustainability discussion to business strategy, innovation, product development and systems where significant sustainability and competitive advantage gains await. Building on ten years' experience at URS Corporation focusing on sustainability in business operations where inefficiencies are largely the result of poor design upstream, she is interested in how the use of biomimicry in innovation can result in disruptive cascading sustainable system innovations that can accelerate our transition to a sustainable future.

Driftwood Beach
Photo: Kevin Lawver, 2014 | Flickr cc

Article

George’s Wood

Julian Vincent

George's Wood

Julian Vincent

I've always called it "George's wood" because George invented it. But it's made from glass-fibre reinforced plastic (GFRP) or carbon-fibre (CFRP) or Kevlar or plant fibres.

Around 1970, George Jeronimidis came to the Engineering Department in Reading to work with Jim Gordon, who wrote *The New Science of Strong Materials* (still in print from Princeton University Press. Strongly recommended). His project was to understand why wood is tougher than it should have been according to the then current understanding, based on the friction generated as the wood fibres are pulled apart.

When a fibrous composite breaks, a crack can travel up and down the fibres if the fibres are not stuck too strongly to the surrounding matrix, loosening them from the matrix and causing them to break some distance away from the main crack surface. As the two halves of the piece of material are pulled apart, the fibres are pulled out of their holes, losing energy (appearing as work of fracture) due to friction between the fibres and their surrounding matrix. It is certainly easy to see fibres pulled out from wood when it breaks - the wood cells appear as splinters - although one does not see many ends of the cells. The cell walls are torn apart. But "pull-out" accounts for only a tenth of the work of fracture observed when wood breaks, and it says nothing about what might go on inside the fibres. In contrast, fibres in artificial composites are solid and so do not deform other than stretch a little.

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From his work with wood, George discovered a new mechanism for toughening composite materials and, in making models of the mechanism, probably produced the first effective biomimetic material, with properties better than those of the model material (Table 1). It was truly George's Wood.

The test samples were plates about 30 cm square of the same weight per unit area. The figures in the second column (resistance to deflection) are divided by the figures in the first column to give stiffness per unit weight. Similarly, the work of fracture is divided by the figures of the first column to give a specific toughness.

Where should we start? The following are common knowledge:

- Wood is made of tubes arranged in parallel up and down the stem.
- Wood has cellulose nanofibres, largely arranged helically (why? tensile stiffness must be compromised) in the cell walls of the xylem tissue.
- The nanofibrils wind in the same direction - with the same 'handedness' - throughout the tree (Why?).
- The direction of winding of the nanofibrils averages out at about 15 degrees to the long axis of the cell (Why 15?)
- The nanofibrils are glued together and waterproofed by the surrounding lignin, making a two-phase fibrous composite.
- When you break wood in tension along the length of the wood cells you get splinters.

Let's break off for a model system: a paper art straw, helically wound, is rather like an individual wood cell. Holding the two ends of the straw in your hands, stretch the straw slowly and carefully. As you pull, the fibres in the paper rotate closer to the longitudinal axis of the straw; this causes large shear deformation resulting in helical fractures running around the straw; the straw buckles inwards and it eventually breaks. George made some models of wood cells by winding glass fibres helically around a rod some

Specific gravity	Stiffness (GPa)	Specific Stiffness	Toughness (kJ/m^2)	Specific Toughness	Material
1.6	140	87.5	1	0.6	CFRP
0.68	10	15	7	10	Oak
0.61	11	18	10	33	G's W (corrugated)
2.7	70	26	400	150	Tough Aluminium
7.8	206	26	1220	156	Tough steel
0.65	11	17	500	820	G's W (tubes)

Table 1. Comparison of different materials in a drop-weight fracture test.
CFRP - Carbon Fibre Reinforced Plastic; Oak - oak wood; G's W (corrugated) - as Fig. 6; Tough Aluminium - High strength structural alloy; Tough steel - Carbon steel quenched and tempered; G's W (tubes) - Plate made as Fig. 4.

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5 mm in diameter. He then coated them in epoxy resin, cured the resin and removed the rod. Just as with the paper straw, when these tubes were stretched, the fibres tended to rotate, setting up shear forces in the wall of the tube. The resin between the glass fibres cracked, leaving the glass fibres unbroken (Fig. 1). This allowed the fibres to reorientate more and the tube to stretch a little further. The remarkable result is that although the structure of the material is degrading, the glass fibres are still intact and the tube can continue to resist the tension - just like wood.

When you hear wood creaking under load, it's these little cracks appearing. More and more cracks appeared between the fibres, each time causing a drop in the force the tube could take, but each time allowing the tube to extend a little further as the fibres came more into line with the long axis of the tube. Eventually the tube broke when the fibres could no longer change their orientation significantly. The equivalent happens in wood (Fig. 2). When wood stops creaking under load, it is about to fail totally since this mechanism of "graceful failure" can no longer occur - all the failure sites have been activated. The tube thus showed an almost ductile behaviour (Fig. 3) with an initial elastic portion (a rising straight line), a yield point at the top of this section where the force drops indicating the first fracture, and post yield deformation with multiple small cracks, each crack stopping and the tube still supporting a rising load - an overall behaviour that is typical of mild steel. This is remarkable, since cellulose and lignin are both brittle materials - they break at low deformation. But by controlling their structure, as George did in his models, brittle materials (including glass) can generate a tough material. Nature doesn't always need metals for structural purposes. It can make better cheaper.

George put all these facts together, plus some observations and maths, and made similar models of wood cells from tubes

Figure 1. A tube made from helically wound glass fibre in a resin matrix. It has been stretched and has failed by the resin cracking between the fibres

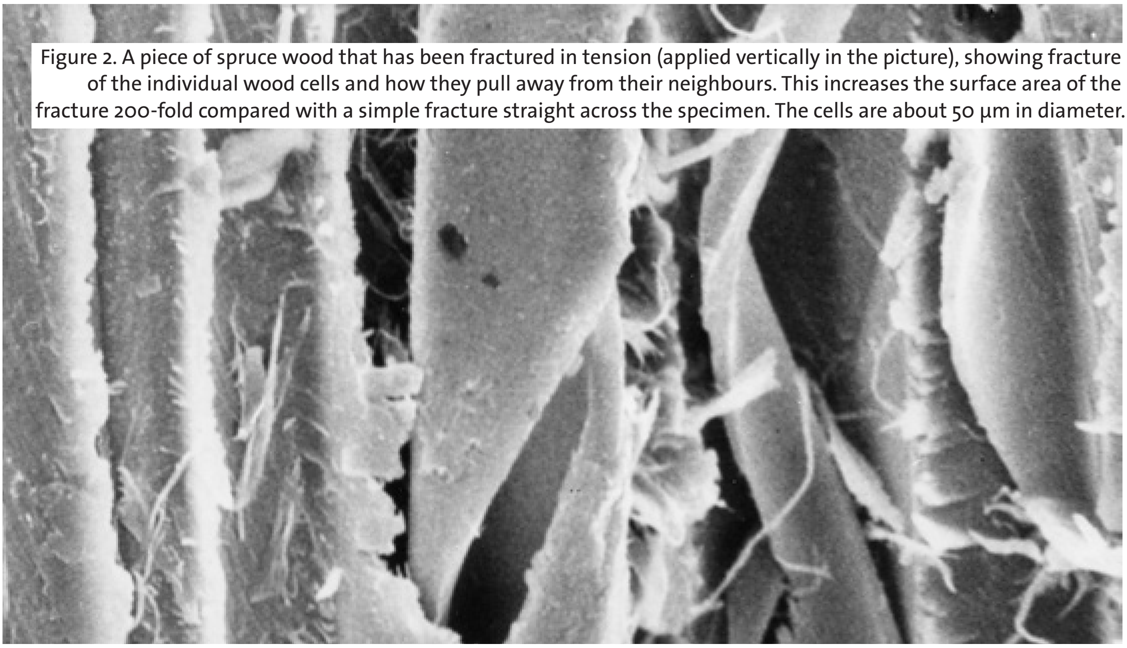

Figure 2. A piece of spruce wood that has been fractured in tension (applied vertically in the picture), showing fracture of the individual wood cells and how they pull away from their neighbours. This increases the surface area of the fracture 200-fold compared with a simple fracture straight across the specimen. The cells are about 50 μm in diameter.

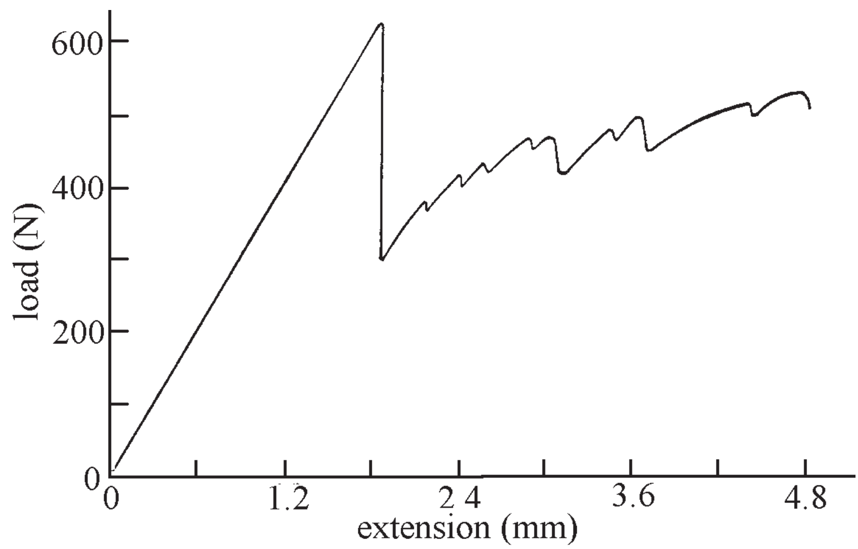

Figure 3. Force deflection curve of a single helically wound tube. The initial failure, followed by a number of minor failures, gives a curve rather like a ductile metal, showing yield and post-yield ductility. But the components from which the tube is made are both brittle.

Weathered wood | Photo: PatM, 2007-2013 | Flickr cc

George's Wood
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of glass fibres, gluing tubes with the same winding angle into beams for testing. He then broke the beams in bending, producing a fracture surface very much like wood (Fig. 4). The experiment showed that when the glass fibres were wound at an angle of 15˚ to the long axis of the tube, the material was very tough indeed, requiring a lot of energy to break it (Fig. 5).

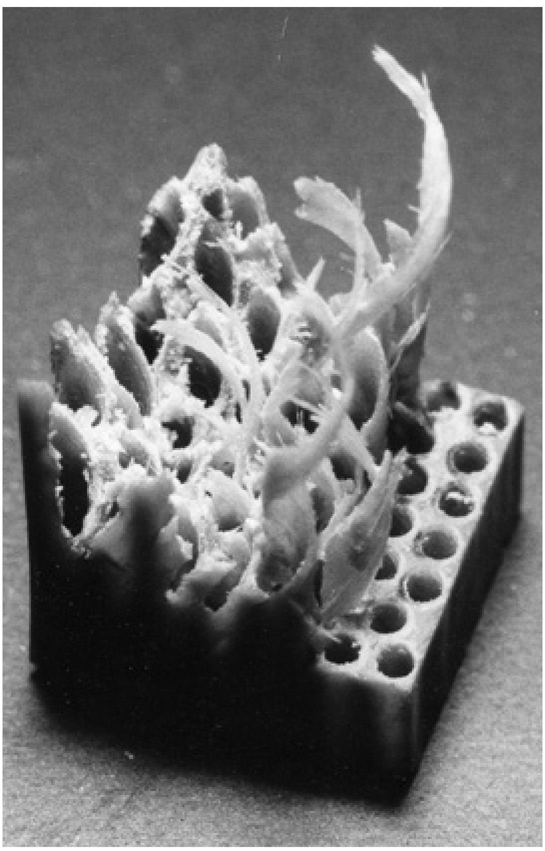

Figure 4. Fractured sample of George's Wood showing sections of the tubes (right) and the way in which they break (left) producing curling segments of the tube walls which resemble the splinters from wood.

In a separate series of experiments, George, Jim, and a colleague, Richard Chaplin, developed another method based on corrugating sheets of preferred orientation pre-preg, which are sheets of soft, uncured, fibreglass with the fibres oriented parallel to each other (https://www.fibreglast.com/product/about-prepregs/Learning_Center). The sheets were assembled with the angle of fibres between adjacent sheets at about 12˚ to each other (Fig. 6). Although this resists fracture in a slightly different manner from the model wood made from tubes, it is still light and tough.

The two wood analogues were then tested in impact (a falling weight) compared with specially toughened aluminium and steel, oak and plywood. Under these conditions, George's Wood was 5 times tougher, weight-for-weight, than the toughest steel (Table 1).

Here are some of the uses suggested and experimented with, mostly using the wood analogue of Fig 6:

- A bullet fired at a 1 cm thick plate is stopped; the bullet penetrates part way and is held within the material. We have light-weight bullet proof armour replacing the current ceramic plates (heavy) or Kevlar vest (stops the bullet, but deflects and allows bruising of the body). Possibly

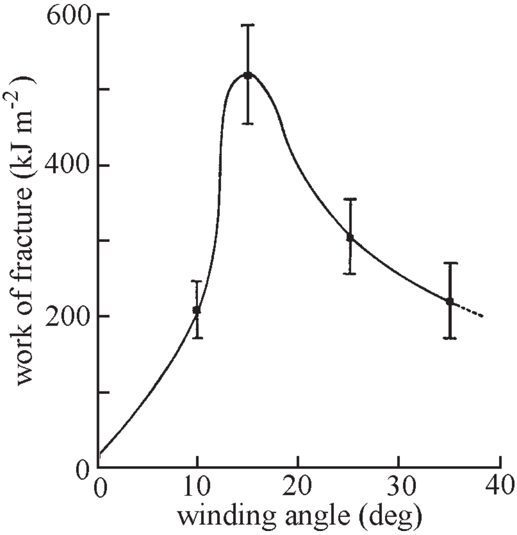

Figure 5. Curve showing the work to fracture of samples like those in Fig. 4 and the way it varies with the winding angle of the glass fibres.

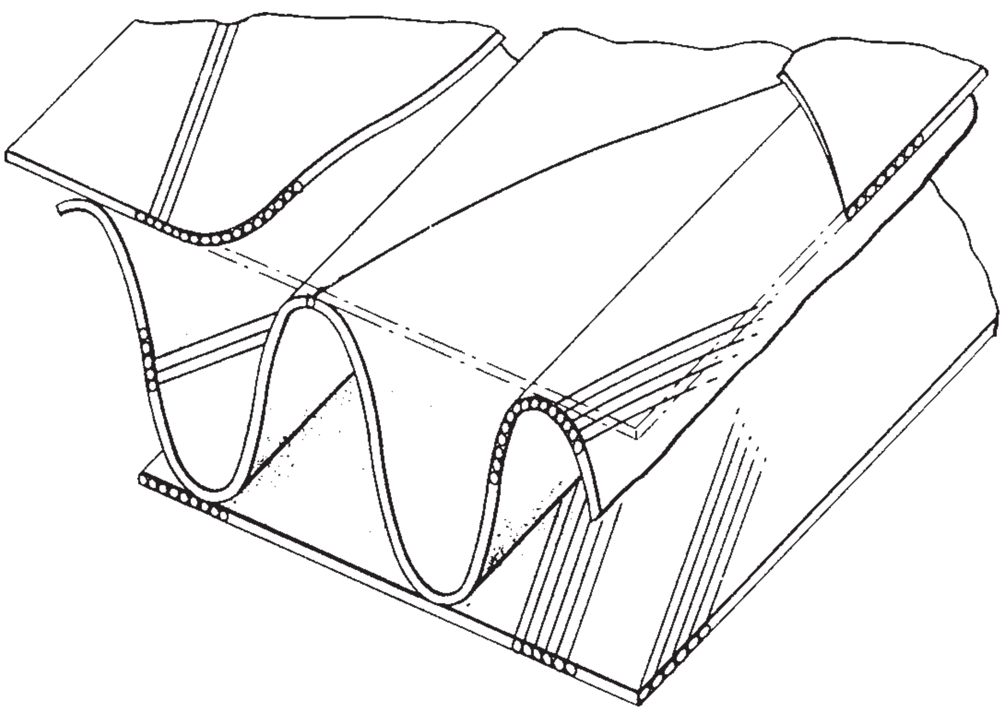

Figure 6. Another version of George's Wood using the technology of corrugated cardboard. The groups of parallel lines indicate the orientation of the fibres in the sheets of pre-preg.

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more important, the material retains its strength. A ceramic plate will spall and shatter and be less effective.

- In a series of tests for designing armoured protection for the seat of the pilot of a helicopter, George's Wood was found to retain 80-90% residual strength after being fired at, compared with a thick (and heavy) carbon fibre plate, which was instantly rendered useless.
- George's Wood allows a knife to penetrate part way, but because the glass fibres don't break, they move aside to accommodate the knife. The knife is then held by friction against the parted fibres in much the same way that a nail is held in wood. The attacker cannot remove the knife for a repeated attack, which allows the victim time to respond.
- The ability of George's Wood to retain an attacking object makes it ideal for shielding machinery such as a jet engine, where if a component breaks away it is liable to be thrown off at speed and cause further damage. Or possibly worse, bounce back into the engine and cause it to break up completely.
- Because the secret of George's Wood is in its structure, it can be made in a variety of sizes, depending on the size of threat, using a range of fibres with different properties. The material made from individual tubes shows good resistance to delamination, a common problem with layered composites

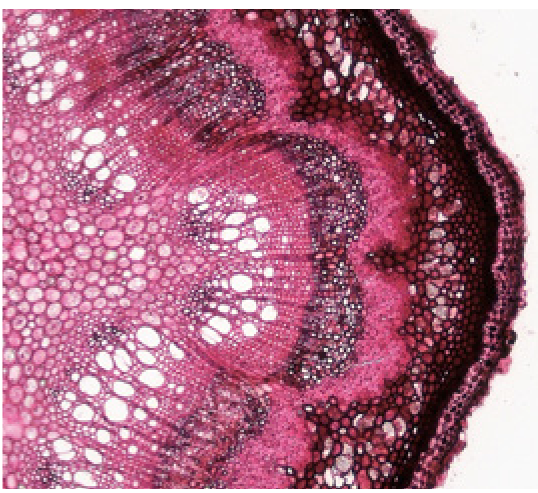
The question is why, if this is such a wonder material, is it not used widely? During the latter stages of development of George's Wood (the version made from tubes), another inventor filed a patent that covered a totally different (and, of course, less effective) toughening mechanism. The patent had been written in such a way that it was interpreted as covering George's Wood as well. Rumour had it that the patent office did not understand the difference between the two mechanisms. The corrugated version was successfully patented, but despite its performance (it was used in the work on helicopter seats) it was never commercialised.

There is still much to be done to develop George's Wood, much of it patentable. The toughening mechanism is independent of scale; thus it can be optimised to resist a variety of threats. A structure made of smaller tubes would be needed to stop a flechette. One of nature's favourite tricks is a density gradient (plant stems commonly have smaller cells with thicker walls on the outside): an armour to stop a variety of threats would have larger tubes on the outer surface, smaller on the inner. The cockpit door on a commercial aircraft is an obvious application, as is a riot shield, which we have shown can provide the same amount of protection as the current shield but at half the weight. Since the secret of George's Wood lies in its geometry, it can be effective even when made from a variety of materials. Only two fibres have been used - carbon (strong but brittle) and e-glass (https://www.azom.com/article.aspx?ArticleID=764, less strong but more extensible). The criteria for choice are primarily stiffness, so Kevlar and many plant fibres are obvious candidates. We don't know what the advantages of mixing fibres would be, or how this could lead to a further range of optimisations.

Just as the fibres in George's Wood can be brittle, so can the matrix. Cured epoxy resin is a very viscous polymer, but under high strain rates such as those imposed by a bullet, is more like a glass. We didn't have the equipment to test specimens with glassy matrices, but the indications are that the geometry would still provide impact protection with the right balance of matrix with fibres.

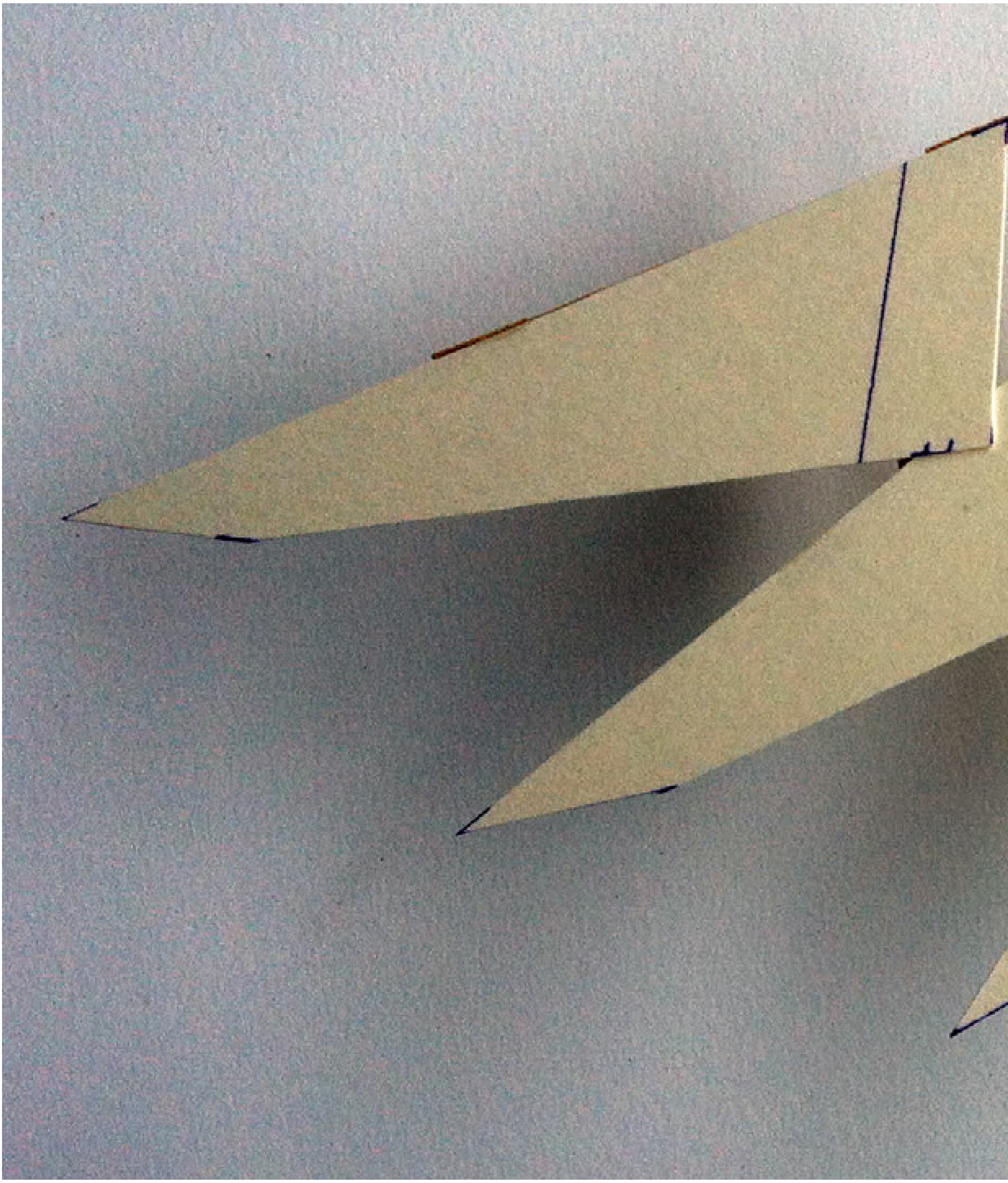
There is a third resource to be used - the holes. They make connections throughout the material and can be used as a distributive system. An obvious use is repair. After a knife attack, the fibres may not be broken but the matrix will be. If the matrix monomer is supplied as an aerosol under pressure, it will accumulate at sites of damage where the pressure dissipates. With its fibres again stabilised, George's Wood is good to go.

George published the secrets of his Wood in 1980. Nearly 40 years later, there is still much to play for. ×



Woody Dicot Stem - One Year Quercus
Photo: BCC Bioscience Image Library, 2014 | Flickr cc

Julian Vincent has always been intrigued by the exposed mechanics of insects. Largely in response to broken promises of promotion, he became a semi-professional musician and branched out into areas of science and technology bounded by biology and materials science. Since retiring he has had no laboratory and has had to resort to thinking.



Wing system 3.2 (3)
Ritchie van Daal

Portfolio

Ritchie van Daal

Portfolio
Ritchie Van Daal

Could you tell us about your background and how you got started in the field of art and design?

My name is Ritchie van Daal, I'm 25 years old. I live in a small town in the south of the Netherlands. I've set up a company specialized in mechanical art sculptures about 2 years ago, where I design, develop, produce and sell my own creations. Next to that I'm also an instructor in the area of engineering concepts and industrial design, where I teach practical skills such as wood or metal working to students and help students with the realization of their projects.

My workshop is based in Roermond, relatively close to where I live. I started my company in 2016 a year after I graduated.

VANDAAL

I graduated from the Maastricht Academy of Fine Arts & Design in 2015, department product design. But in all honesty, I only started at the academy because I got rejected as a marine; I wanted to be an engineer/technician on submarines like my great-uncle was. After I got rejected, I figured that I'd do art instead, as my back-up, since that was something I considered myself good at.

My major, which was a 3 year course, was in the field of product design. But on top of that I also took courses in jewelry design and dabbled in Fine Arts a bit, which allowed me to explore my affinity with engineering on a very creative level.

What kind of techniques do you use for your work?

Mostly it's a mix between conventional techniques such as woodworking, artisan goldsmithing or conventional machining (milling/lathework), that in combination with a lot of model making and additive manufacturing as well as other CNC techniques.

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

My ‘style’ has always been a ‘result of’; I liked industrial constructions, architectonic shapes, mathematical shapes and equations, I liked machines, I liked metal, wood and rough materials like concrete and that all came together at one point or another in the study.

I can’t really say I have a definitive style, but I have a way of solving problems, or coming up with constructions which is very natural to me and shapes result from that.

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

Any project will influence my way of looking at the world. When I’m researching movement, I will subconsciously see movement everywhere, because that’s where my focus is at.

I think I’ve always had a bit of a different view on the world. As a kid I had to grow up pretty fast, even though I never realized that myself. Don’t get me wrong, I had a very good childhood, only different from most children. My parents divorced when I was young, about 9. Mom didn’t have great income, but she made it work, we didn’t have much but I had all I needed.

I think that because of this I appreciated the little things in life and learned I had to work hard to make something of myself. In turn this created a certain tenacity and a drive to excel in stuff I have affinity with.

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

In *The Artificial Selection Project* my inspiration mainly comes from nature in combination with a deep fascination for mechanisms and construction.

I also really appreciate the work of designers like Studio Mieke Meijer, Paul Heijnen or Jeroen Wand. They all have been mentors of me at one point.

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

Currently I’m working on a few things. I’m continuing *The Artificial Selection Project* - I’m researching the movement of fish this time. Three new sculptures are nearing completion. These will be the first in a series of 7 pieces total and they’re the most complex sculptures I’ve made to date. I’m also developing 2 types of large 3D printers, but that’s really more of a shop

Portfolio
Ritchie Van Daal

improvement/hobby project, not really a commercial/art project.

What is the last book you enjoyed?

A friend of mine has given me a list of 125 really good audiobooks he got from one of his mentors and gave me the tip to turn on the audiobook when I'm reading the actual book, that way you'll read faster and more efficiently. The list is comprised of all kinds of books ranging from books by Neill deGrasse Tyson, to books about finance or how to train yourself to be a more mindful person. I'm actually pretty excited to get started.

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

Aliexpress, definitely Aliexpress. My company is built on Swiss precision and Chinese prosperity. It's the biggest online warehouse you can find and ridiculously cheap too. They literally have everything.

Secondly of course there is Youtube. I follow all kinds of channels that have to do with making or backyard science, like Adam Savage's Tested, SciShow, Cody's Lab, AvE or AWE just to name a few.

Then there is Instructables, a knowledge bank of all kinds of people doing and building cool things and sharing what they've done too. Also Instructables has teamed up with Autodesk to provide a lot of free tutorials. Sharing is caring!

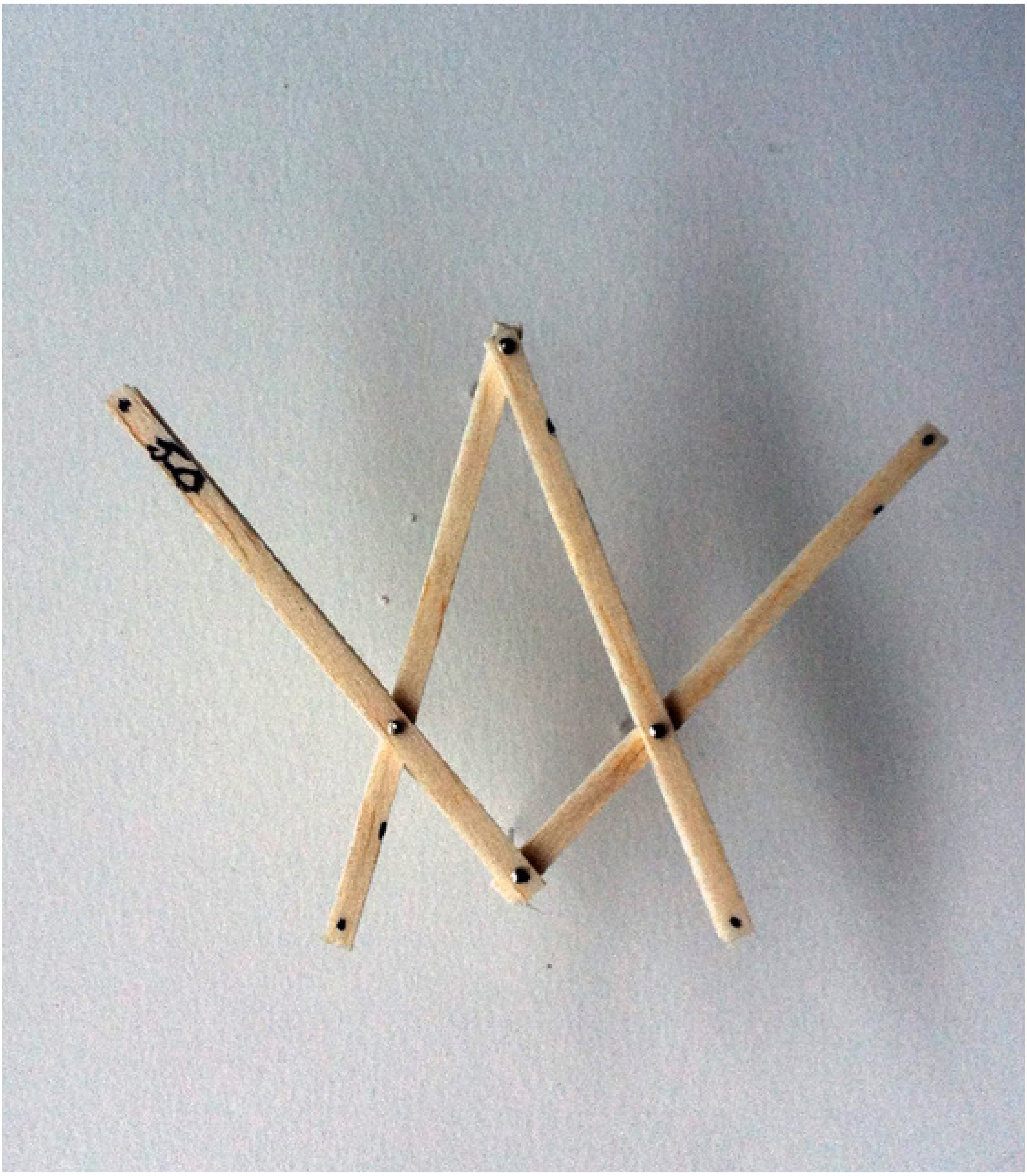
Fourthly I would have to say Google: any of my designs begin with the question "How to … " and then Google provides me with the answer.

I also use generator websites for gears, websites which have databases filled to the brim with mechanisms and mechanical principles.

What's your favorite motto or quotation?

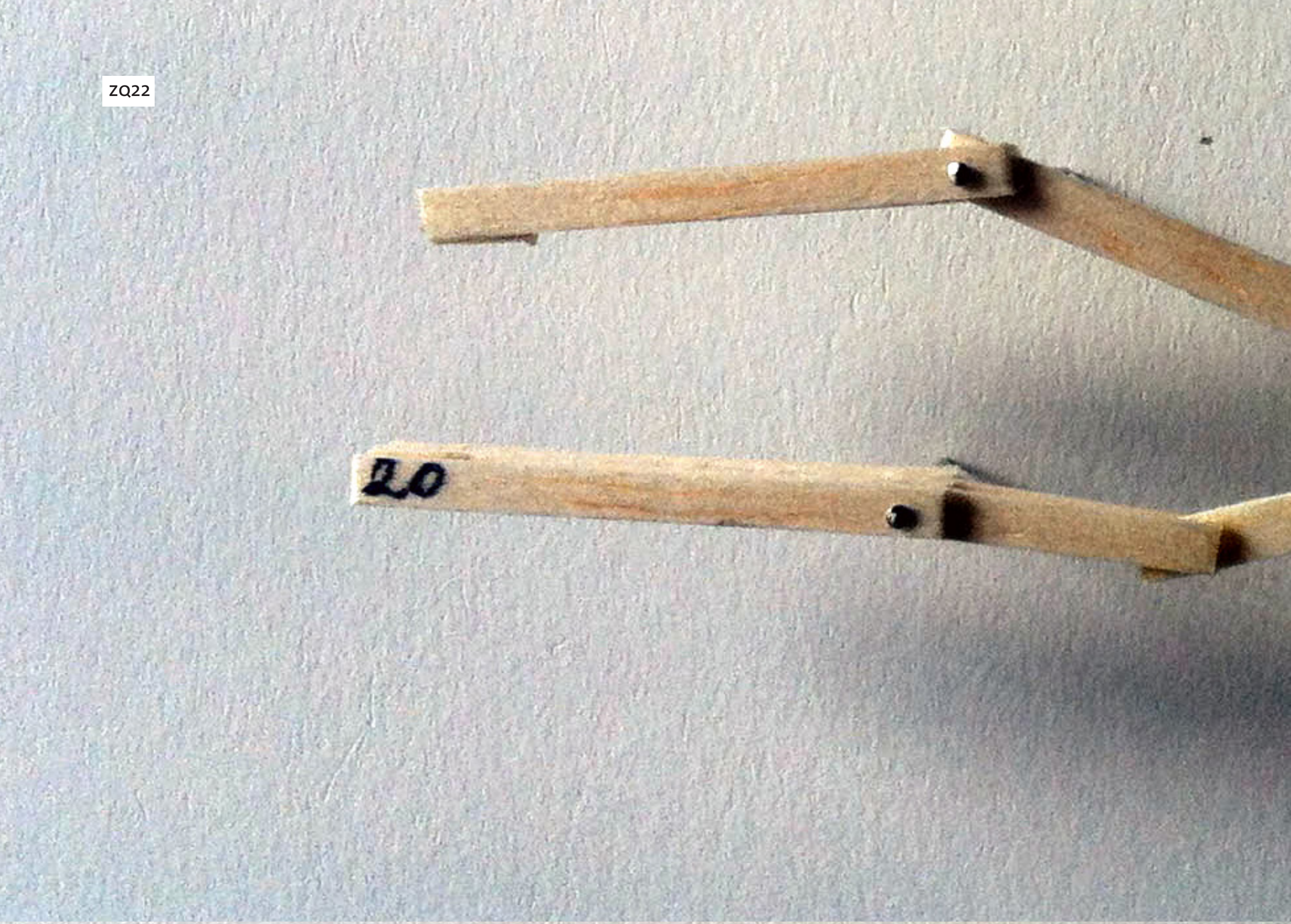
Impossible is nothing, just do it, challenge everything. ×

The Artificial Selection Project features a man-made 'evolutionary' chain resulting from research on the movement of animals, recreated and further developed by creating numerous models and testing in a very trial-and-error way, ultimately manifesting and exhibiting that movement in a series of kinetic and mechanical sculptures.



Wing system 2.1 (2)
Ritchie van Daal

Betelgeuse Kinematic Model | Ritchie van Daal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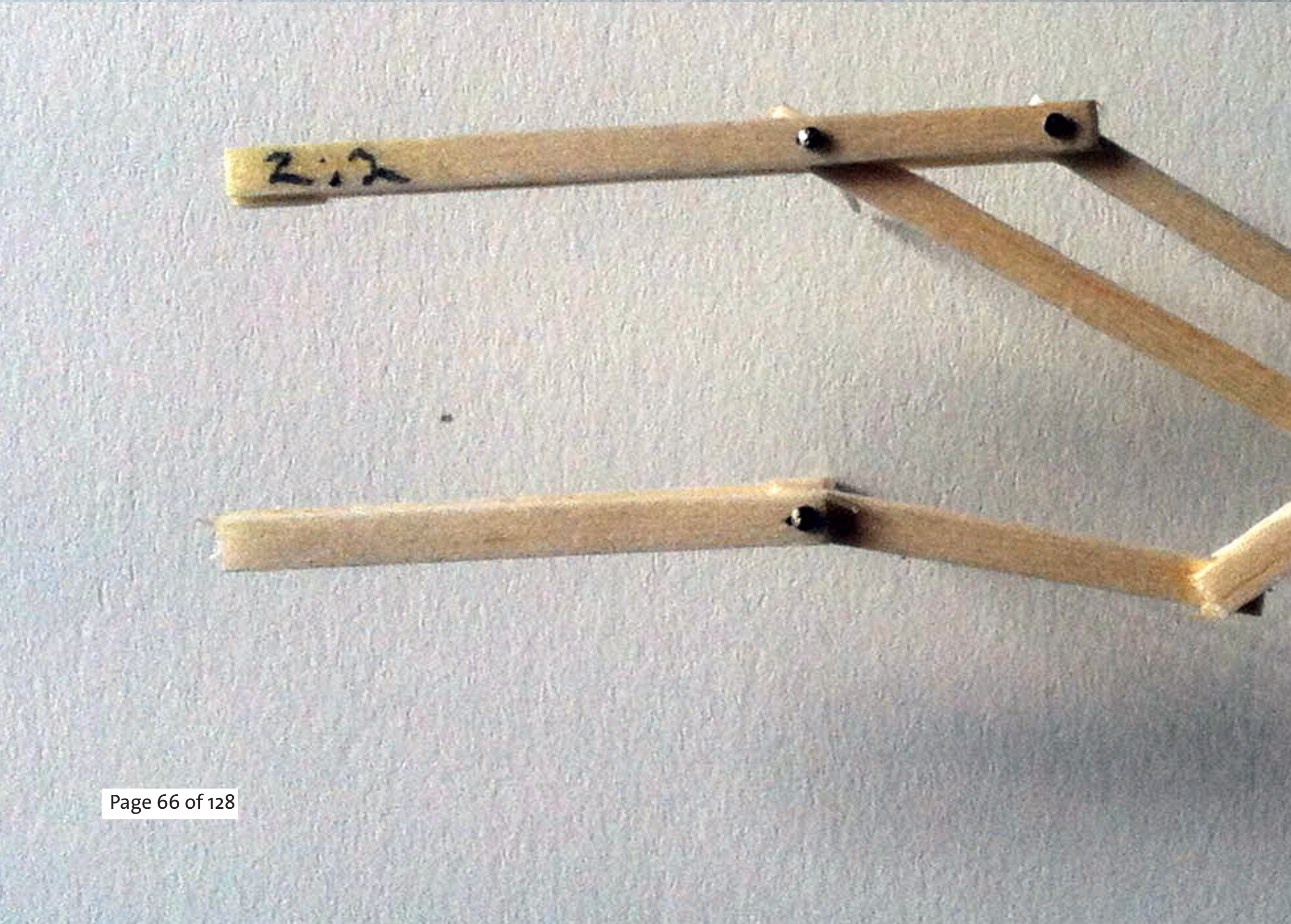
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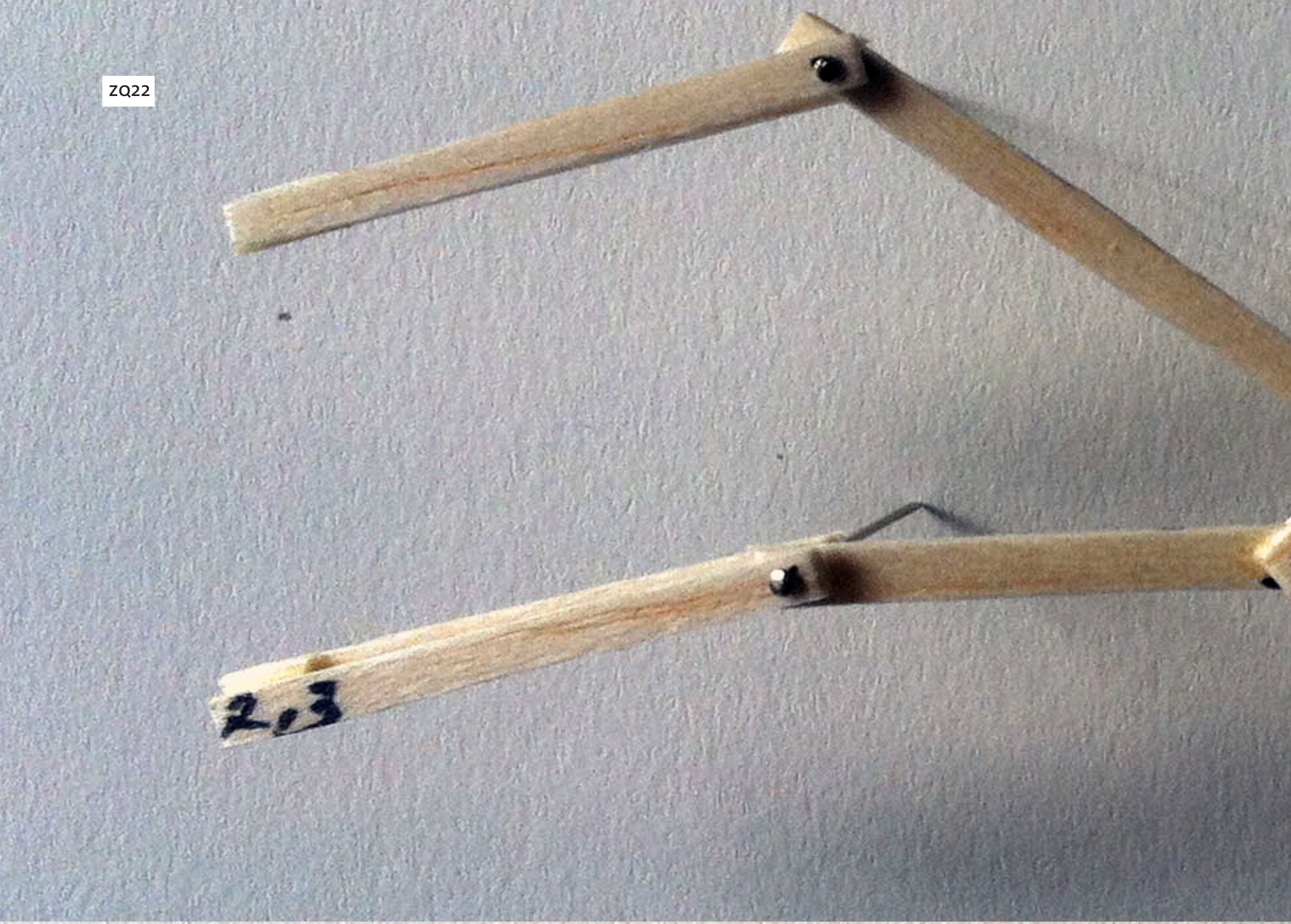
Betelgeuse 2.0 and 2.2 | Ritchie van Daal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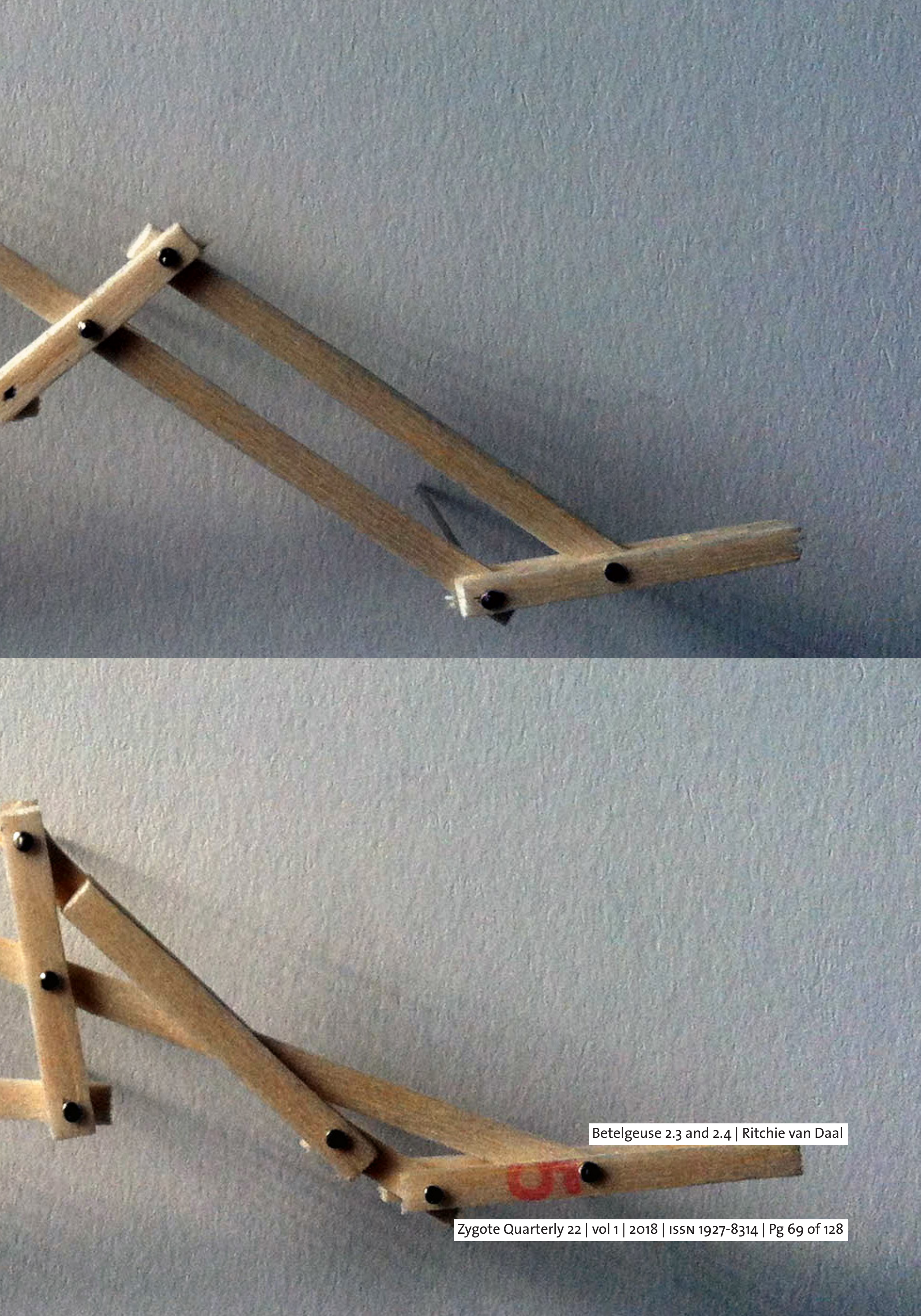
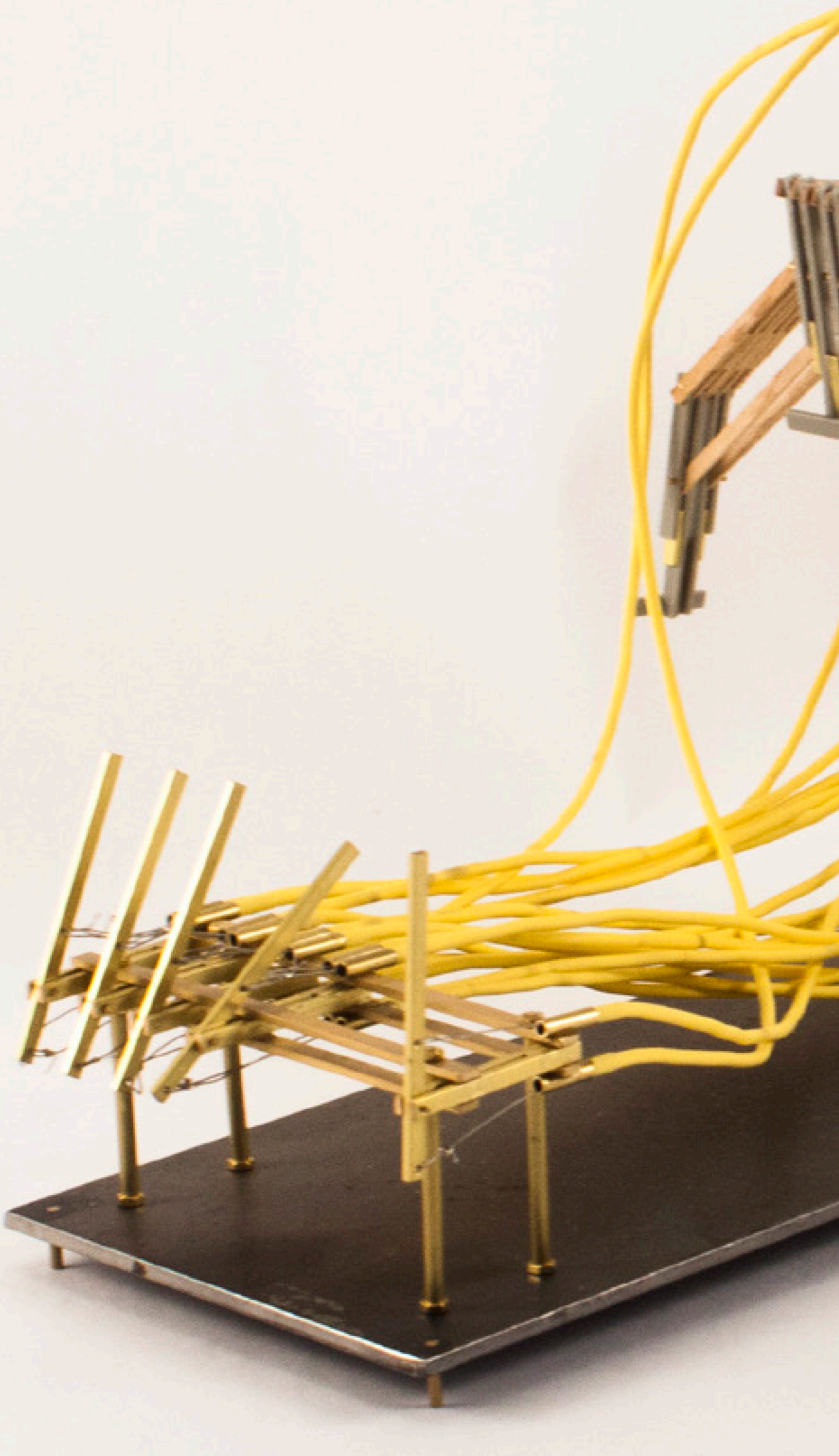


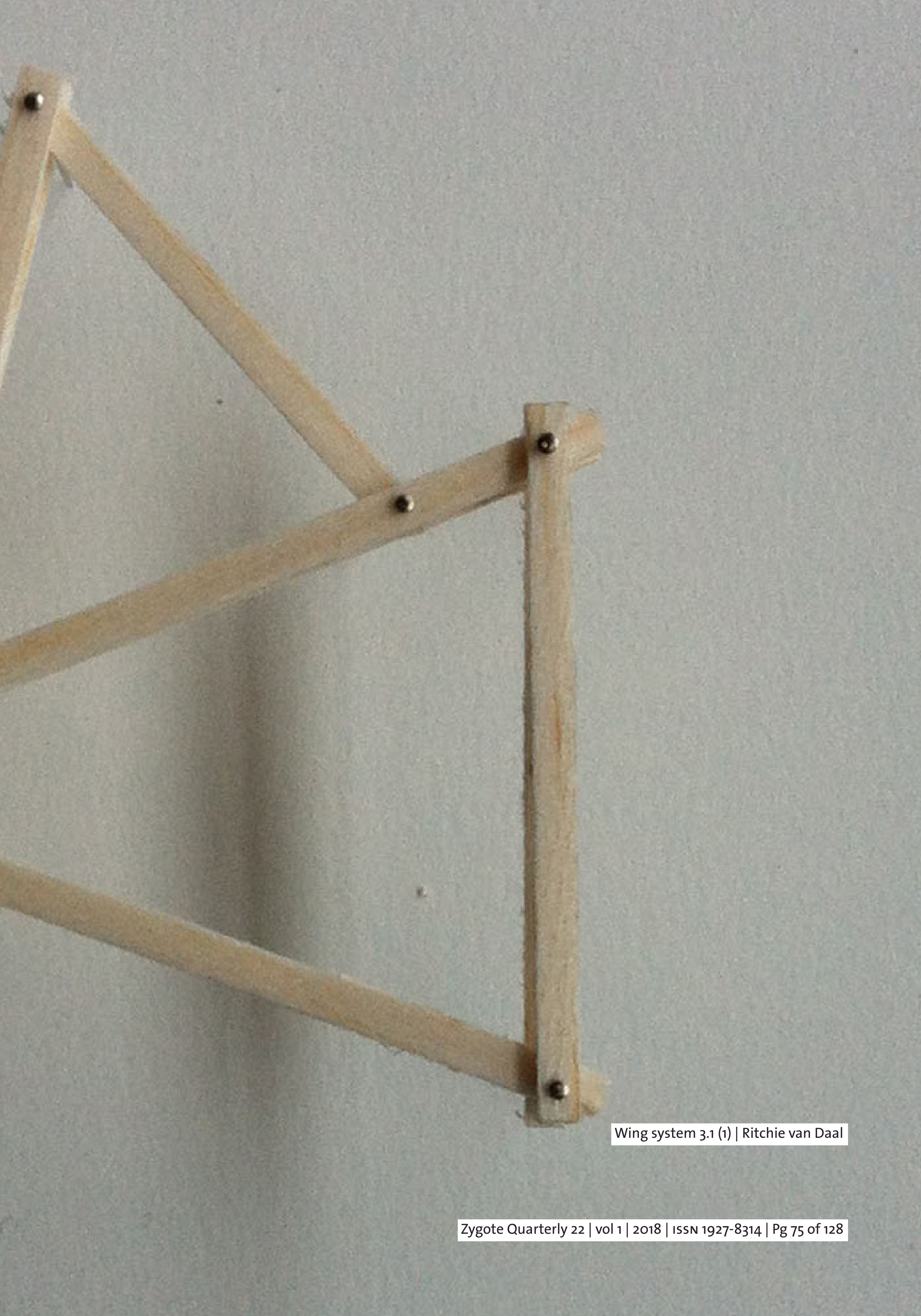
Betelgeuse 2.3 and 2.4 | Ritchie van Daal



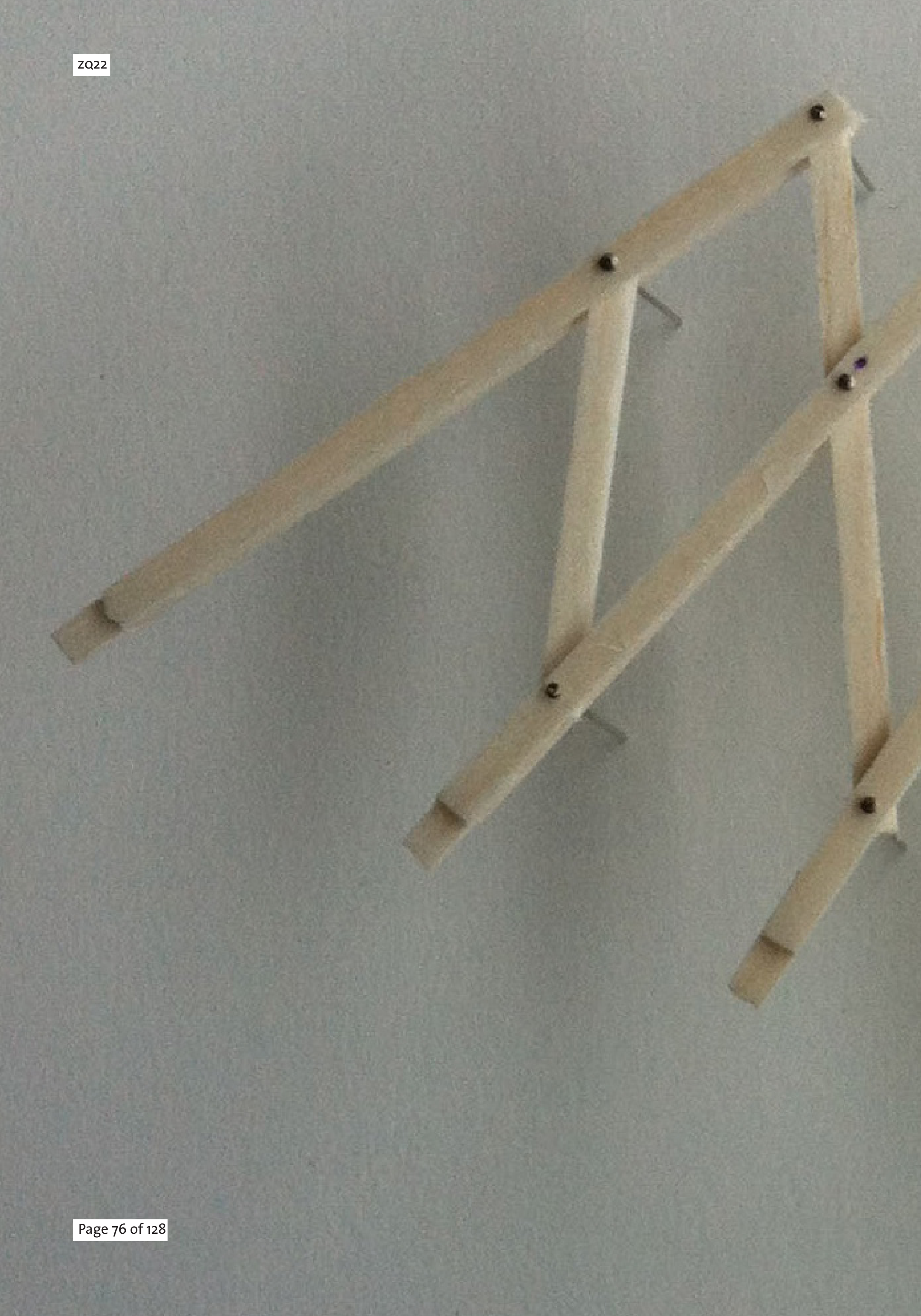
Betelgeuse | Ritchie van Daal

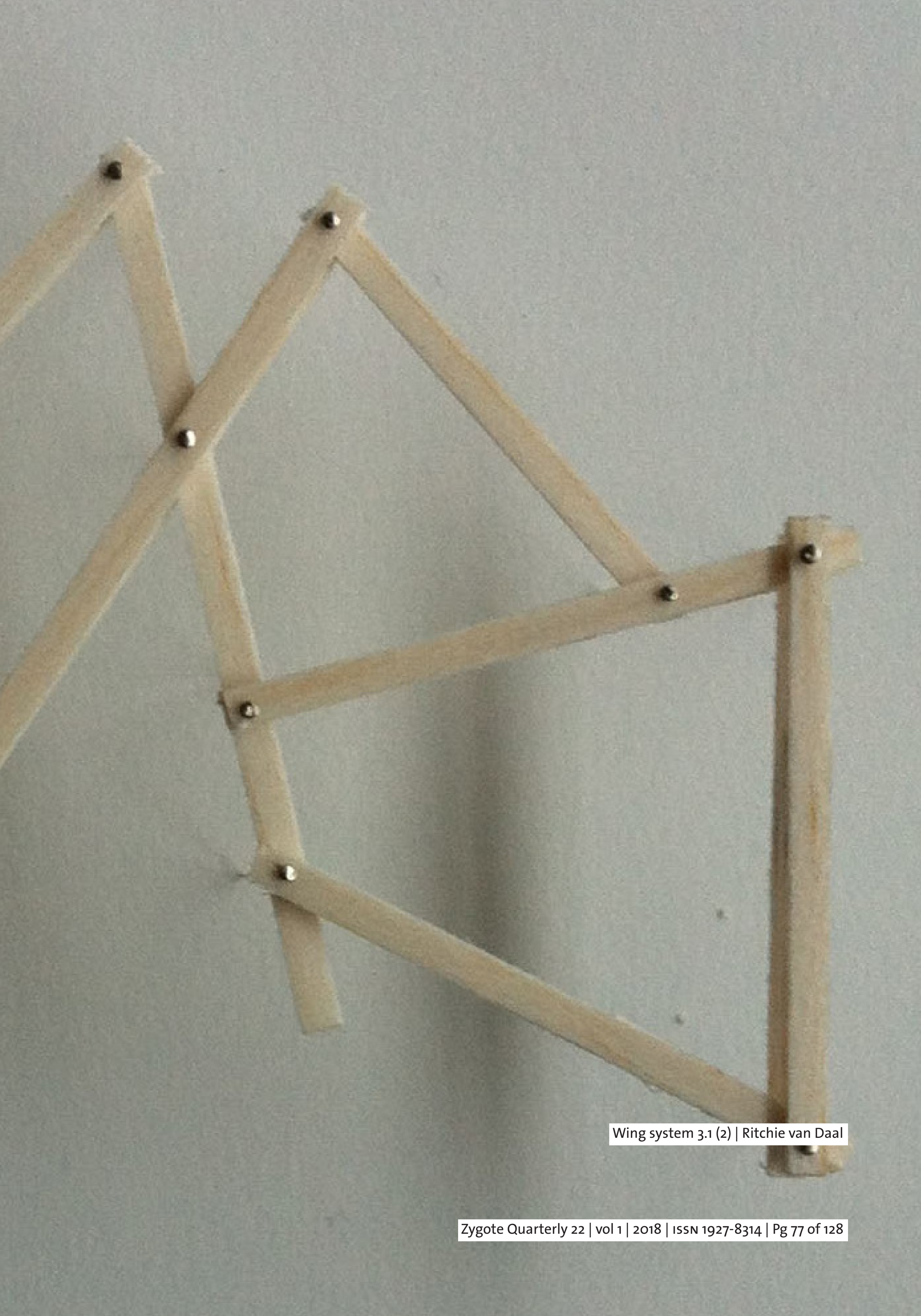
Arcturus front | Ritchie van Daal

Arcturus overview | Ritchie van Daal

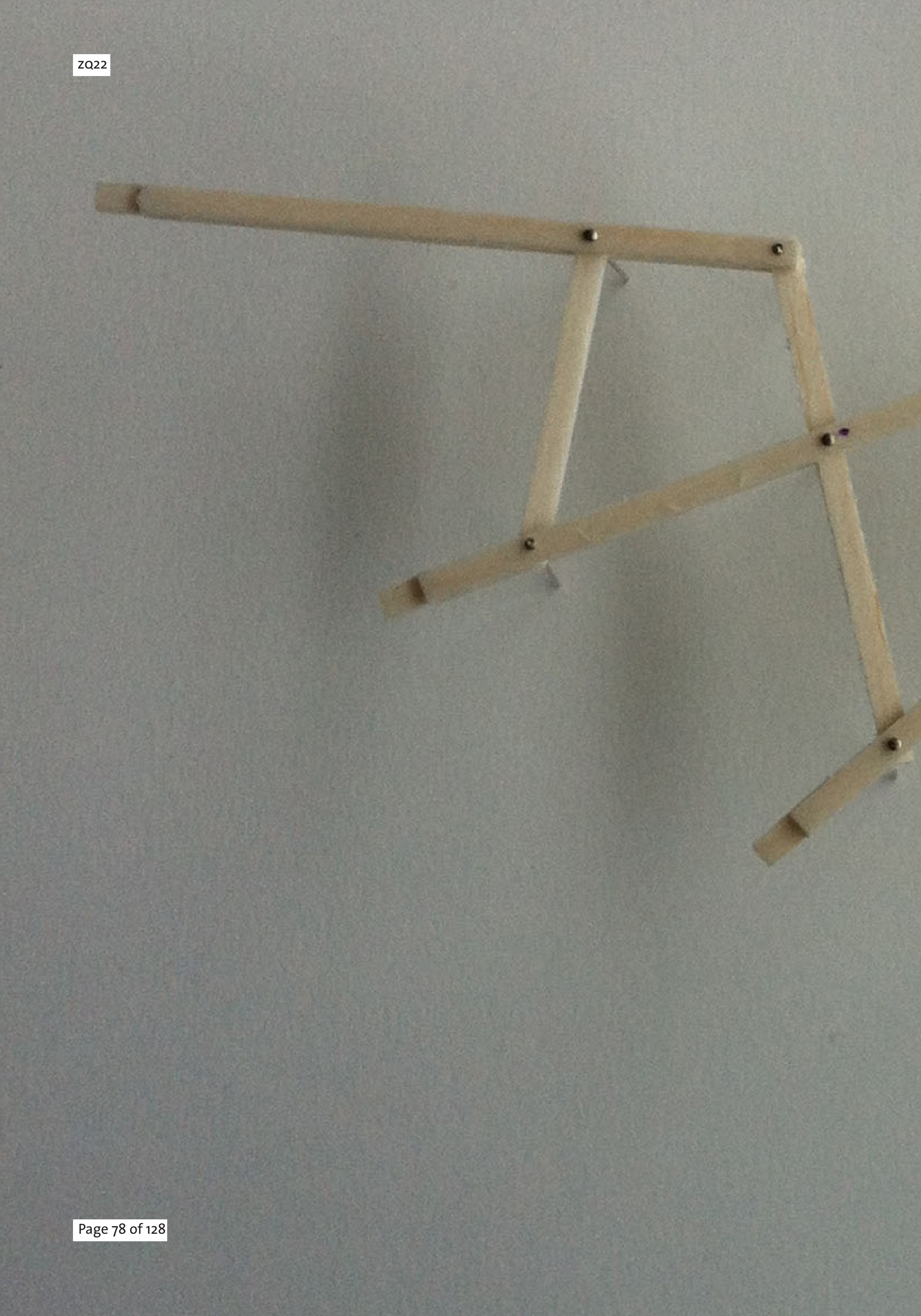


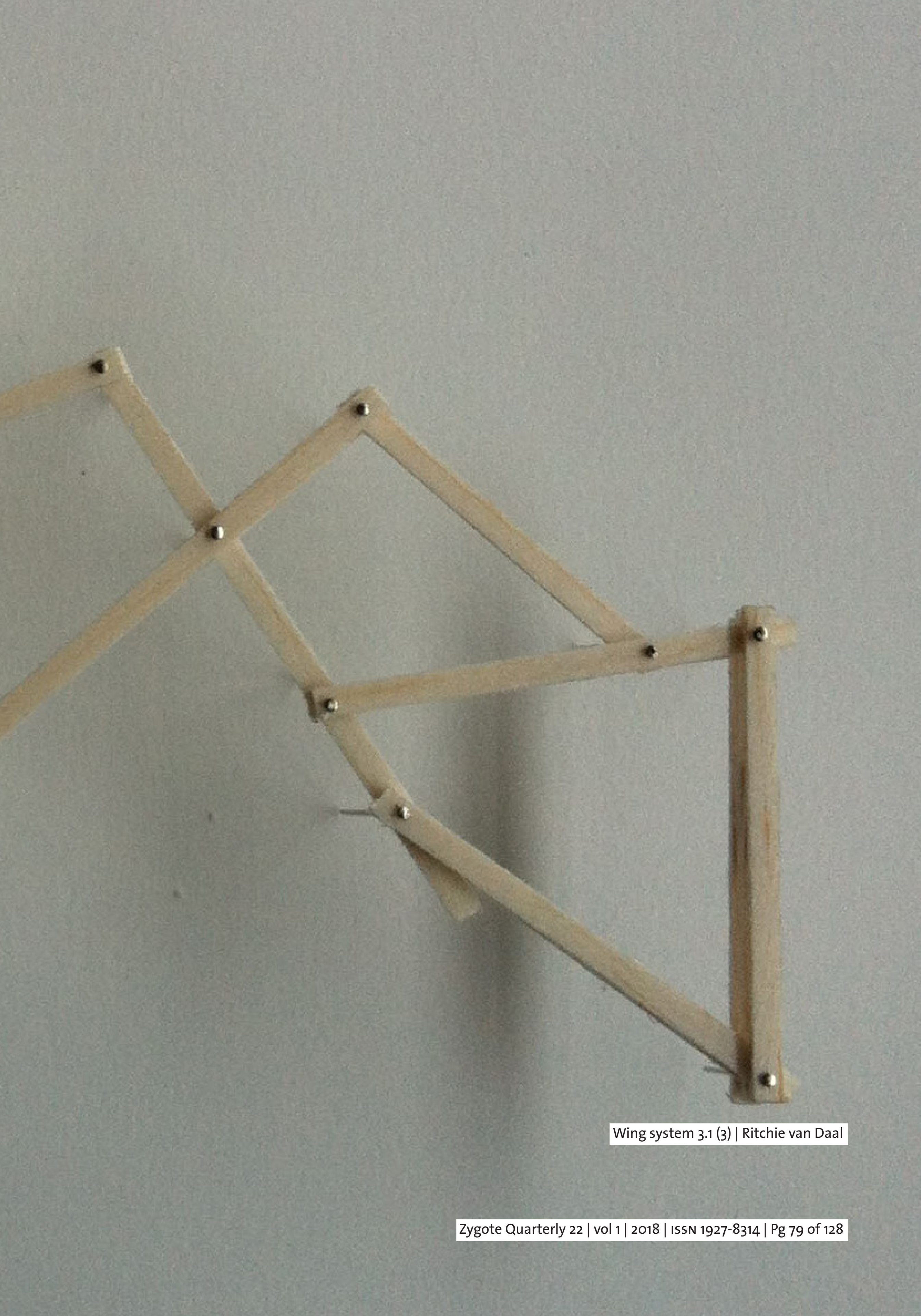
Wing system 3.1 (1) | Ritchie van Daal





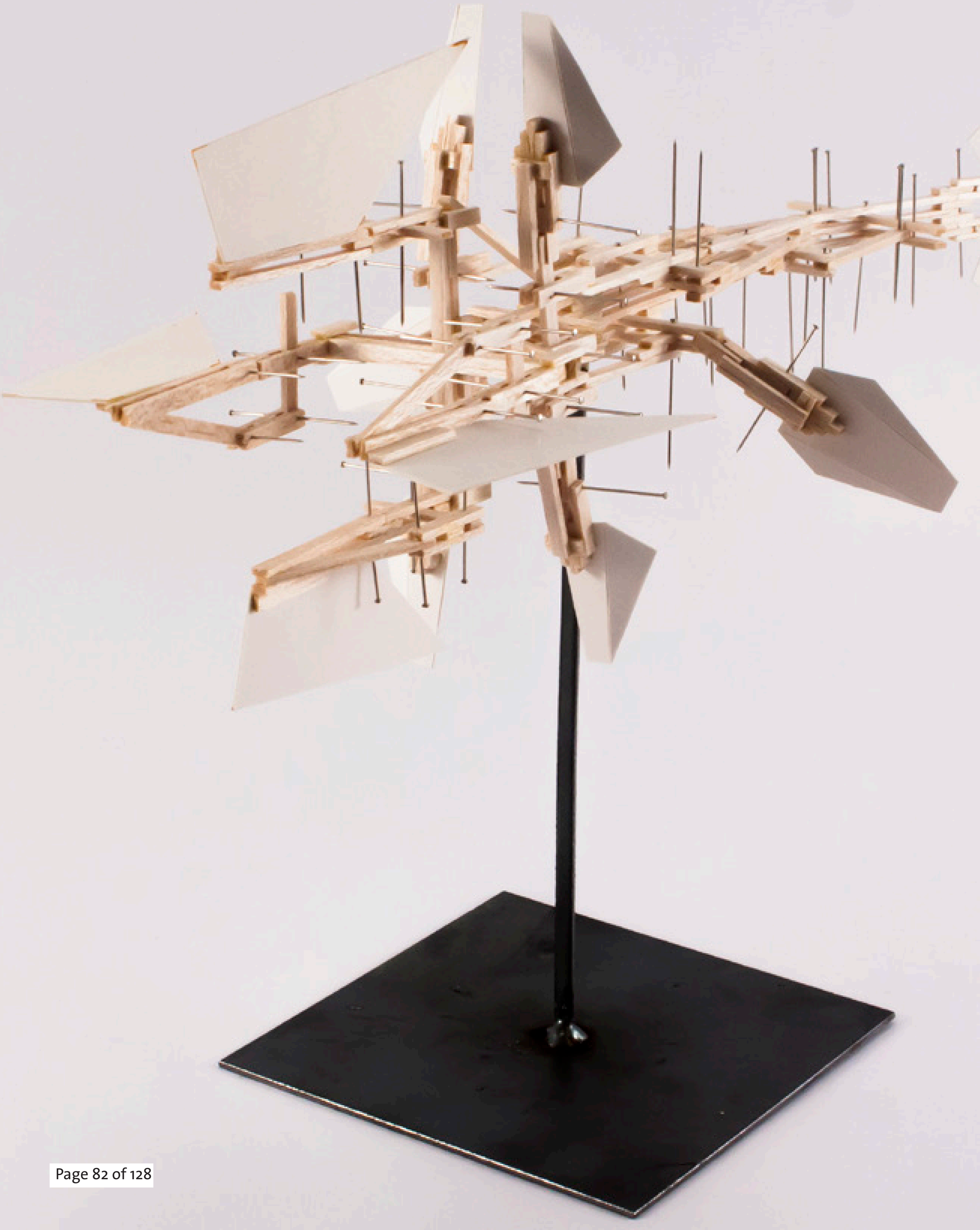
Wing system 3.1 (2) | Ritchie van Daal





Wing system 3.1 (3) | Ritchie van Daal

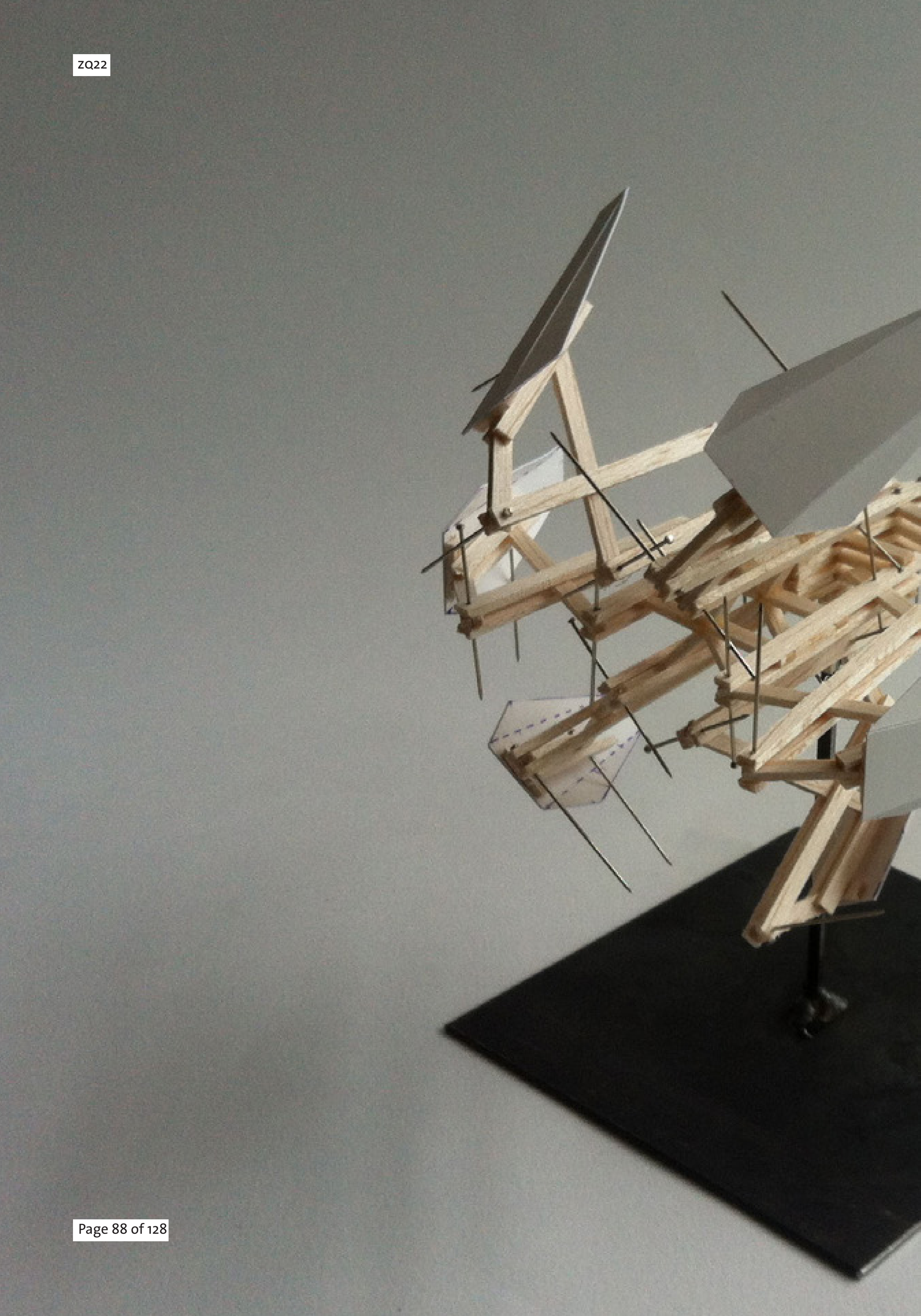
Arcturus | Ritchie van Daal

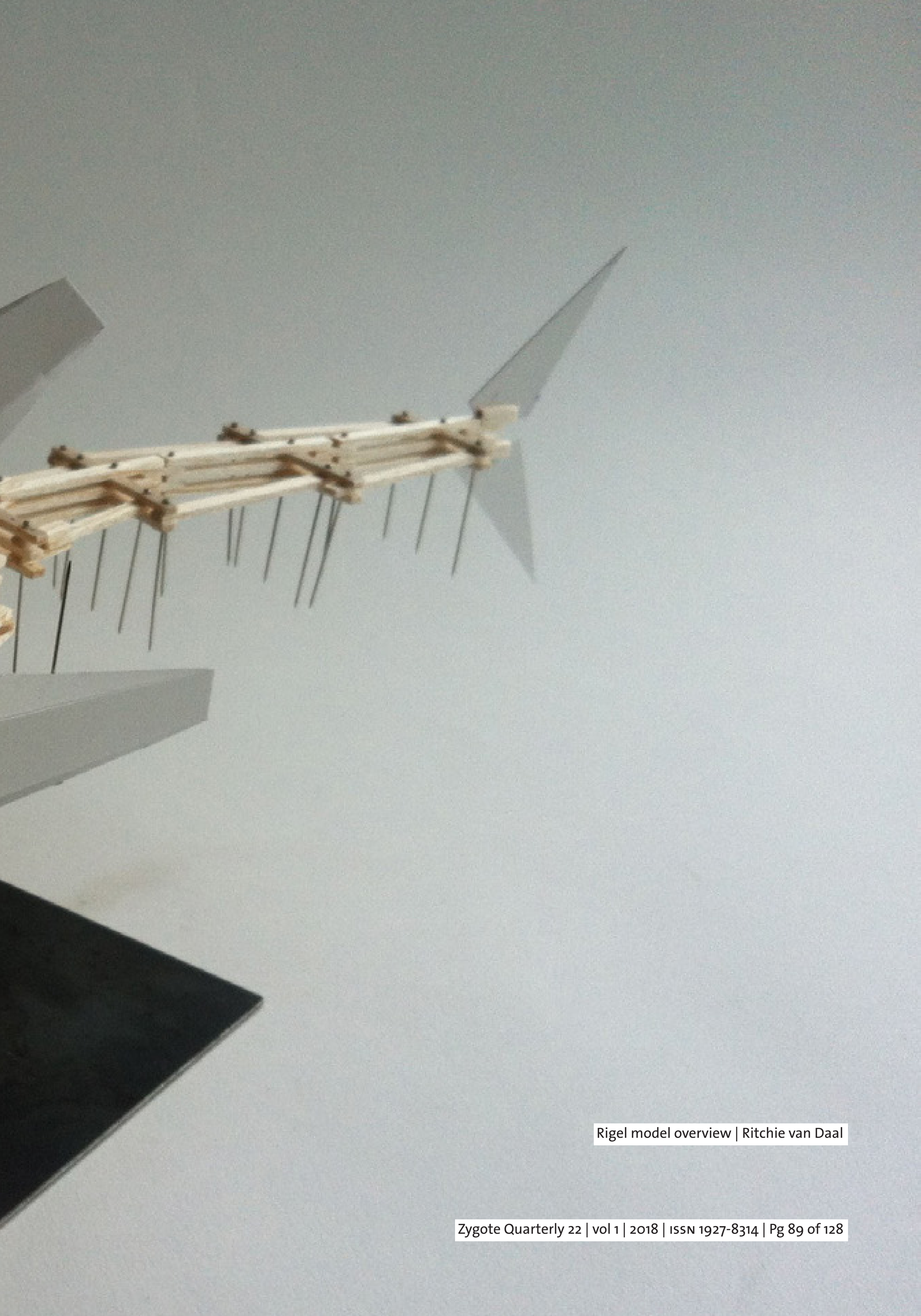


Shark | Ritchie van Daal

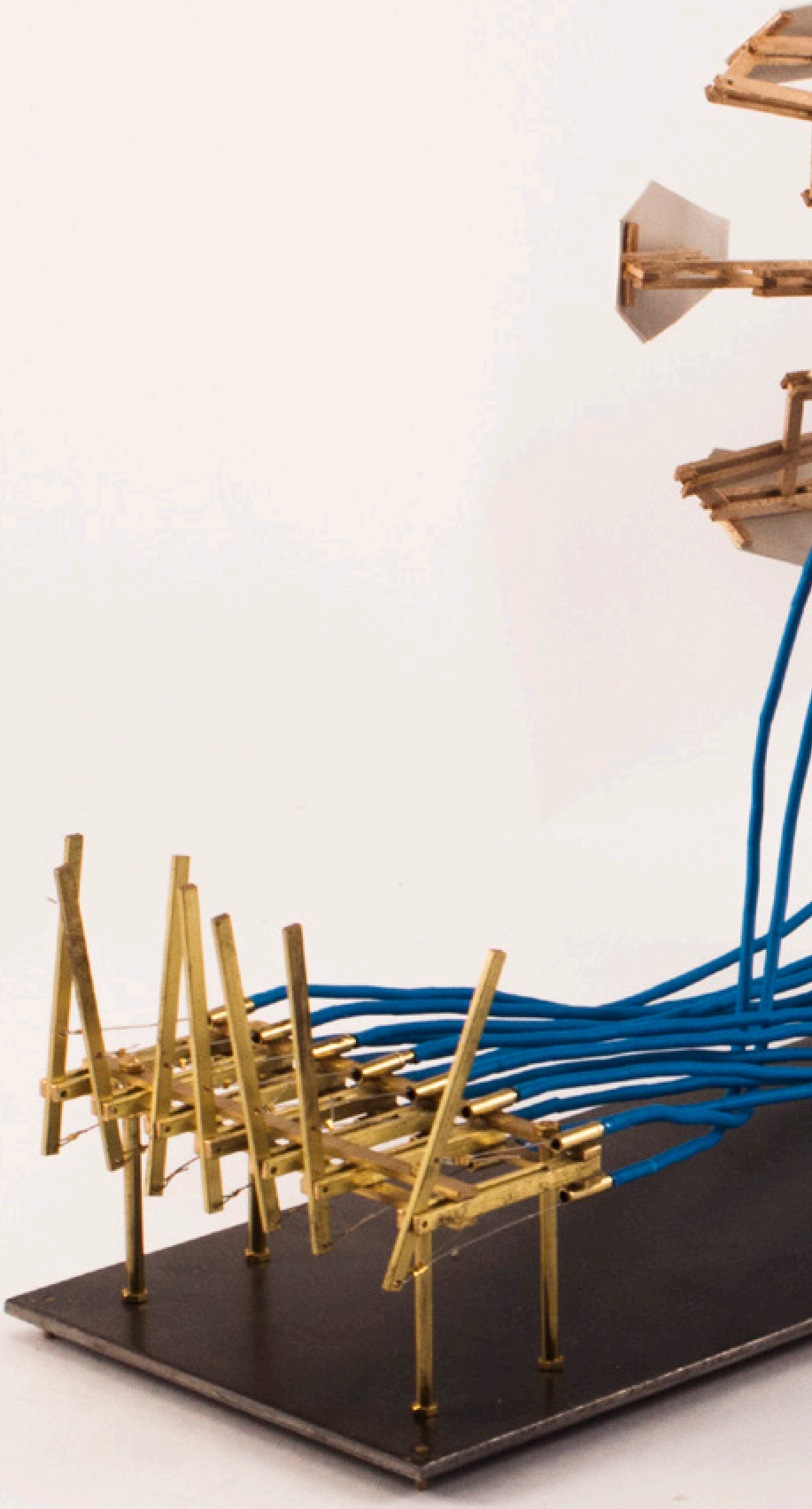
Anguilliform motion | Ritchie van Daal

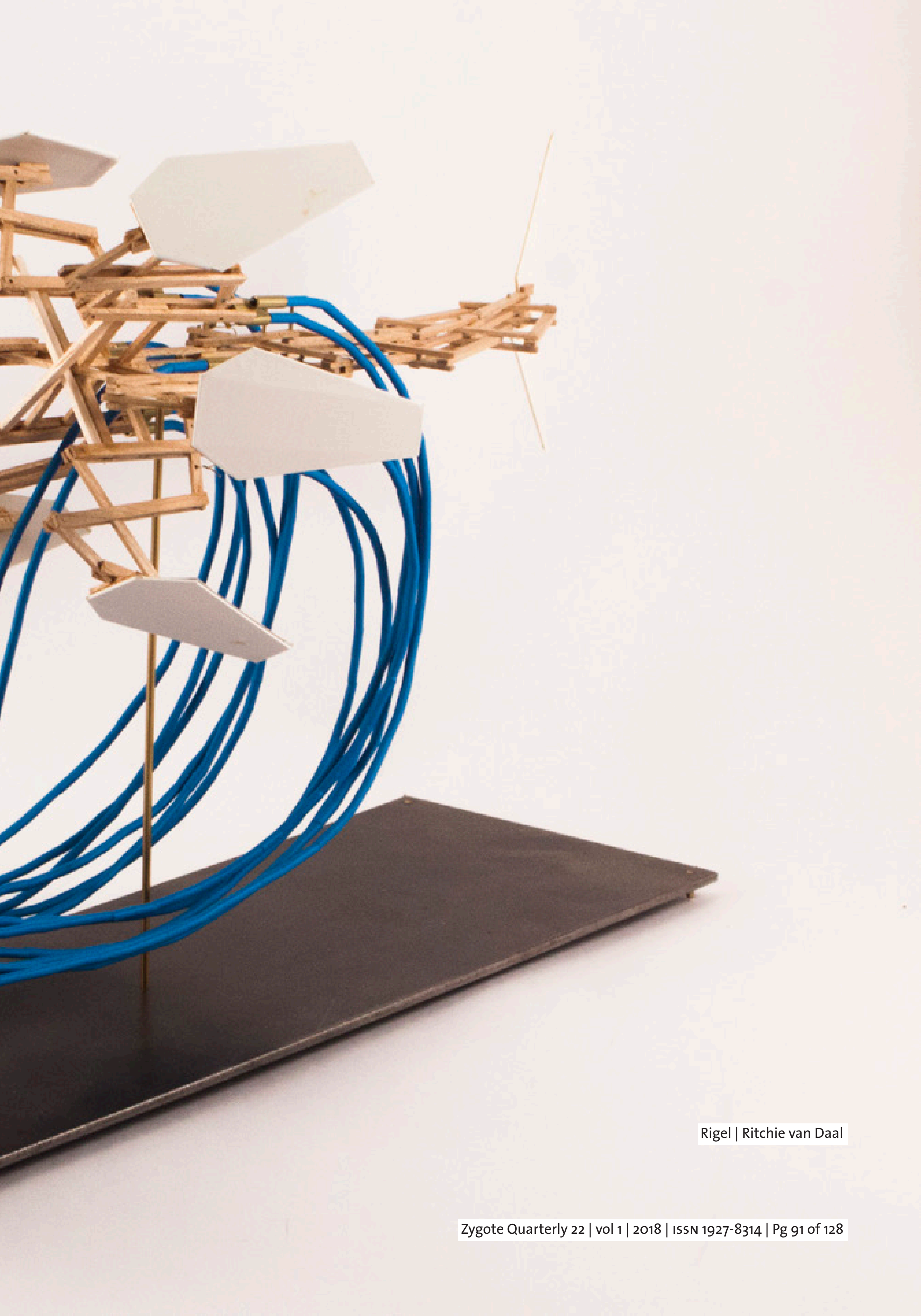
Eel model | Ritchie van Daal





Rigel model overview | Ritchie van Daal





Rigel | Ritchie van Daal

Northern Spotted Owl in Muir Woods
Photo: TJ Gehling, 2011 | Flickr cc

Science of Seeing

Hope and the Thing with Feathers

Adelheid Fischer

Hope And The Thing With Feathers
Adelheid Fischer

To see a northern spotted owl, you must travel a two-lane highway for many miles, then make a turn onto an unmarked road and drive until the gravel slowly disappears under a swish of overgrown grass. You creep along until the path narrows, and the branches of young Douglas fir begin to pluck at your truck antenna like mischievous kids lining a parade route. You stop just as your front bumper grazes the massive trunk of a toppled tree, blocking you from going any further. Then—and only then—do you kill the engine and step out of the car.

This is a typical workday commute for Rita Claremont, one of a small group of biologists who conduct surveys of northern spotted owls each summer in the Cascade Mountains some 45 miles east of Eugene, Oregon. On a sunny day in August 2017, I tagged along with her into the old-growth forests that are home to these birds. We were joined by two other writers who, like me, were participants in the Long-term Ecological Reflections program at the nearby H.J. Andrews Experimental Forest station. Established in 2003, the program pairs writers and scientists in the field where together they spend time “re-imagin[ing] our relation to the natural world.”

Arguably, in the Pacific Northwest, no other animal has caused a greater reassessment of our relationship to the natural world than the northern spotted owl. In the pitched timber wars of the 1990s, the bird was the cause célèbre of environmentalists who sought to use the owl’s plummeting numbers as a way to end tree harvesting in the dwindling old-growth forests on public lands. In response, plastic owls were hung in effigy by sawmill operators who viewed the lockdown of these commercially valuable forests as a threat to their livelihoods.

Despite securing protection under the Endangered Species Act in 1990, owl populations have continued to struggle. These days, only about 1,200 pairs are estimated to live in the entire State of Oregon, most of them confined to remnant old-growth stands, a mere two percent of the original forest.

Claremont knows these owl habitats well, having spent nearly a quarter century crashing through them in search of the birds. At 52 she says the field work has taken its toll on her shoulders, back and knees, but you’d never know it by the way this trim, energetic biologist scrambles down a steep ravine, negotiates the soggy bottom of a narrow stream, and then lopes up the opposite slope, leaping from rock to rock or traversing the length of a downed tree covered in slippery moss with the grace of an Olympic gymnast on a balance beam.

We head far upslope and settle under the immense trees that the owls favor.

Old growth | Photo: almostsummersky, 2017 | Flickr cc

Dusk | Photo: BLMOregon, 2013 | Flickr cc

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Scanning the canopy, Claremont lets fly a convincing imitation of the bird's syncopated, four-beat hoot. Then she reaches into her backpack and pulls out a live mouse, placing it on a log in plain view. During the breeding and nesting seasons, male owls will investigate these calls and drive potential interlopers out of their territories. Sure enough, within minutes, a male owl appears on a branch silent as smoke. The bird takes a few seconds to assess the situation. Then, without warning, he free-falls out of the tree, snaps open his wings like a giant umbrella just before snagging the mouse with his talons. In one elegant scooping motion, he heads back up into the canopy and begins to glide away from us through the trees. We grab our backpacks and follow in a mad dash, keeping one eye on the bird and another on the jumble of roots and rocks on the forest floor.

What the males do with the captive mice provides Claremont with critical clues about their breeding status. If a male lacks a nesting mate, he is likely to cache the prey or eat it on the spot. If he does have a mate, he may pass his catch on to the female which, in turn, feeds it to her offspring. Claremont points out that this behavior may be a continuation of an early courtship ritual that serves to reinforce pair bonding during the raising of chicks. The challenge for the census takers is keeping pace with the male owl as he flies home to deliver the groceries. Fortunately, we don't need to clamber very far. This male has a mate and two chicks nearby. We catch up to the owls and slowly drop to the ground under their watchful gaze. To our surprise, they stay put. I look around at our group. We are seated, as if at a casual family picnic, with spotted owls. *Spotted owls*! The expressions on our faces flit from disbelief to delight to wonder and finally to reverence.

This is exactly how Claremont felt decades ago when former colleague Tim Fox on the survey crew introduced her to her first owl. She followed Fox on a long foray into the woods and then suddenly stopped. Fox was smiling. He had spied an owl. "Just look around," he said. As Claremont recalls, "I started looking around and looking around. I just looked right at the owl and past it, because they sit perfectly still and blend in. When I finally locked on to it, I was dumbfounded. I could not believe that this beautiful creature was just watching us so calmly with those big, big black eyes. It was close and it wasn't afraid. I fell in love instantly with them."

This tolerance of humans isn't unusual, Claremont says. Because the birds largely feed and nest high up in the canopy of old-growth forests, they have had relatively

Northern spotted owl | Photo: Forest Service USDA, 2009 | Flickr cc

Spotted Owl and Marbled Murrelet Habitat, Oregon Coastal Forest | Photo: David Patte/U.S. Fish and Wildlife Service/USFWS Pacific, 2010 | Flickr cc

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few interactions with humans over time. As a result, they tend to be less wary of people than many other species of owls.

The adults begin to call softly to each other in an ascending riff of Ooooooo-wee! Ooooooo-wee! The owlets join in with a kind of circular bobblehead motion atop bodies that are little more than puffs of wispy down. I look up at one of them and then squint my eyes, noting what a remarkable resemblance it bears to the big gray dust bunnies that accumulate on the floor under my bed. The male owl then begins nuzzling the face of one of the chicks which tips its head upward toward the parent in response and closes its eyes as if savoring the pleasure of the attention. In scientific circles, this is known as allopreening, or social grooming. The behavior helps with maintaining good hygiene, but it also serves to reinforce bonds among individuals in a family or social group.

Like Claremont in her first encounter with a spotted owl, I cannot get enough of looking at them. I marvel at the patterning on the birds' feathers—a stippling of whitish dots and short brown streaks that enable the birds to disappear into a background of tree bark and the forest's dappled light. Then there are the black outlines in

Threatened northern spotted owl (*Strix occidentalis caurina*) fledglings
Photo: Tom Kogut/USFS, 2010 | Wikimedia Commons

the shape of a heart that scribe the bird's face. I marvel at how some hidden antenna intercepts even the most subtle signals in the forest and how their heads swivel toward these sounds in what looks like a well-oiled machined movement. But most unforgettable are the owl's eyes. Most other owl species have yellowish eyes. Spotted owls have opaque, jet-black eyes that gleam like polished glass. I look up at the birds and repeat a silent message to them over and over in my mind with as much ardent good will as I can muster: You are so beautiful. May you live long and prosper.

But spotted owls in general are not prospering. More and more territories that once hosted breeding pairs are now empty of spotted owls. Fewer owlets are living to adulthood. According to a 2017 study published by the journal *Natural Resource Modeling*, "Less than 5% of historical Spotted Owl sites are projected to contain Spotted Owls by the year 2030."

A shortage of habitat continues to be a factor. There simply is not enough old-growth forest left for many young owls to disperse to. But the biggest threat comes from a newcomer to the forests of the Pacific Northwest: barred owls. A relative of spotted owls, barred owls are native to the forests of the eastern U.S. Prior to Euro-American settlement, the largely treeless grasslands of the Great Plains posed a natural barrier to the immigration of barred owls into western forests. But that changed as settlers suppressed the fires that killed trees, planted shelterbelts around their homesteads, and reduced populations of ungulates such as bison and elk that kept trees in check. Protected from predators in forested riparian corridors or woodland patches planted by humans, the birds hopscotched their way west.

The newcomers quickly made themselves at home in spotted owl territory, occupying the same old-growth habitats for nesting and consuming the same prey items

Barred Owl
Photo: Photo: Colleen Prieto, 2017 | Flickr cc

Red tree voles | Photo courtesy of Burt Gildart©

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of flying squirrels, tree voles and wood rats—with one critical difference. Spotted owls tend to be specialists; barred owls are generalists. When quarters become too cozy, for example, barred owls can switch to second growth or young stands. If rodent prey becomes scarce, they can supplement their diets with anything they can catch, from frogs and salamanders to crayfish and skunks. David Wiens, a biologist with the U.S. Geological Survey, even once observed a barred owl wading in a stream, vacuuming up snails. Finally, because barred owls also are bigger and more aggressive, they will feed on the offspring of spotted owls, harass and break up breeding pairs or drive adults from their nesting territories.

In 2015 sharpshooters from the U.S. Fish and Wildlife Service and U.S. Geological Survey began removing barred owls from select spotted owl population centers. In 2015-16 alone, 737 invasive owls were culled from parts of Washington, Oregon and northern California. This control process is costly and time-consuming, and the jury is still out on its long-term efficacy.

In the meantime, spotted owl surveyors like Claremont continue to head into the field each summer, walking the knife edge of hoping for the best and yet expecting the worst. The work is emotionally wrenching. Claremont recalls one episode several years ago in which a spotted owl pair fledged two chicks just before "a solid week of hard, hard cold, nasty weather with just buckets of rain coming down. I went back to check on them and gave the male a mouse and he took me down into the rhododendrons. He just kept sitting there calling and cooing. There in the rhododendrons I could see the two babies. The first one had died and fallen on the ground. The second one obviously had lived a little longer and then he too fell over and died and was laying on top of the first chick. I picked them up and put them in my backpack because they were perfect, and I knew the Burke Museum of Natural History would want them for museum study skins. So I offered the male another mouse to try to distract him while I tried to hide the chicks in my backpack. I went down a really steep slope to get to my truck. As I was standing at my tailgate taking out the babies to put in the back of the truck, I looked up over my shoulder and there was the male sitting in a tree nearby. He knew that those were his babies."

Since then, Claremont has not gone back to that site. "It's hard," she adds. "I definitely have had days where I've cried in the woods. I just keep telling myself that I can't give up because the owls aren't giving up." ×

Threatened northern spotted owl (*Strix occidentalis caurina*) | Photo: Shane Jeffries/USFWS Endangered Species, 2007 | Flickr cc

Bees
Photo: Keith Williamson, 2017 | Flickr cc


Article
The Blackout and the Bee
Margo Farnsworth

The Blackout And The Bee
Margo Farnsworth

You miss 100% of the shots you don't take.
Wayne Gretzky

In December, the fields of biomimicry and energy management lost an entrepreneurial pioneer, Mark Kerbel, who co-founded REGEN Energy (later renamed Encycle) with his friend and colleague Roman Kulyk. The company was among the first to tap into emergent behaviors of ants and bees for the purpose of managing energy.

In 2015, Mark was kind enough to share his story for my upcoming book, *Biomimicry: Business of the Wild (How Five Companies Copied Nature to Win)*. This chapter highlights his journey and how he and his partner made biomimicry a reality in their business. Here you will read, not the technical details of their work, but a narrative of their route - as many times deciphering where to deploy innovations in a solution pathway and exhibiting the sheer persistence to make it happen are more than half the battle. Mark was both brilliant and generous. We wish there was one more battle he could have won. He will be missed. – MF

Margo Farnsworth
Image courtesy Biomimicry Institute

If there is one question common to all businessmen and women, it is probably, "What will make my business successful?" Of course, the answer is – it depends.

Mark Kerbel and Roman Kulyk were a couple of wickedly astute guys with backgrounds in computer science and computer engineering along with an ample dose of energy knowledge stirred into their technological stew. When they began working together they didn't know much biology, much less anything about the tool of biomimicry. They did know a fair bit about ant and bee societies because they had read Steven Johnson's book *Emergence*, which details the sources, history of, and uses for emergent system principles. These principles, loosely explained, are the processes and resulting outcomes of individuals or individual units completing simple directives which, in combination, form larger more complex results. The result itself could be resources gathered, as with bees

Little Bee | Photo: Hamish Irvine, 2011 | Flickr cc

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gathering nectar and pollen; a structure like an ant hill; a process of moving from one place to another, as with a flock of birds – or all of the above.

They found these premises both engaging and interesting relative to business possibilities they were considering. Even so, the principles related to emergent systems hadn't applied to the first company they had started, a software company, even after working late nights and weekends to see how they could fit. So they parked the idea. The two men were looking for real world problems to solve – particularly challenges presented in the use and management of energy – and effective tools to make any resulting business they might create successful.

Then came the blackout of 2003 in the Northeastern United States and Ontario, Canada. Over the next two days, 50 million people around parts of eight U.S. states and Southeastern Canada could imagine life before the assault of machines when, even in the Northeast, skies were starry by night and crystalline by day. But in our modern era, when machines have replaced tasks once done by hand (or not even yet imagined), the blackout meant everything in the entire region ground to a halt. Lights remained dark. Drinking water slowed to a standstill in its pipes. Cash registers ceased their blue-lit ciphering. As Mark considered the jarring change that August night, he suddenly felt a kind of buzz - their course was clear. They needed to improve resilience in cities by improving the energy grid or at least energy efficiency. The stars seemed to shine down in accord.

But both men were adamant that resilience and sustainability shouldn't, and in fact couldn't be the driver of what the

Out Of Sight Out Of Mind - Rooftop Wasteland
Photo: StephenNakatani, 2010 | Flickr cc

ultimate product or service was. Although Mark was personally attracted to the concepts, neither felt they should espouse sustainability principles to their customer base. It was the customer's responsibility to seek those values. What they did want to do was make sustainability financially beneficial to clients by managing energy usage – a kind of détente among the head, heart and gut. They and their customers would do well by doing good.

The two began examining various energy challenges facing companies around the globe. As each new idea popped up they would research it and ultimately discard it or find themselves moving into a space where they found the challenge connected to something else needing additional research. After a short while, they realized they could spend their lives researching with not much to show for it. Shaking their heads, they printed up what they had and threw the five main ideas which had materialized onto the table to mull and hopefully birth their next venture.

As they studied those five ideas they realized the elements of real world energy problems were all related to energy usage, energy savings, and energy generation or cost. It was as if a lightbulb of evidence kept illuminating the three concepts. Further focus was needed to break down an energy problem into the smaller pieces of energy control, or at least energy management – the latter of which seemed to be an ideal fit.

As Mark recounted, that's when they thought, "Wait a minute! If we go back to those emergent principles of bees and ants we read about a few years ago, could we use those emergent behaviors to address these problems?"

Emergence and the swarm-based algorithms they observed in bees and ants might actually work as the vehicle for their business. They had unknowingly moved through the back of the wardrobe and into the realm of biomimicry. But, they thought, either this was a crazy idea someone had already disproved or surely someone was already doing it. After doing further research into the matter, they realized no one had and no one was. Their company, REGEN, was born.

At this point in the story it behooves us to gain a better understanding of how emergence works. Emergent behavior is rooted in nature and a look there can yield the most logical snapshot of how emergent systems actually function. Emergent behavior is a blend of order and anarchy which achieves a goal or set of goals through self-organizing systems based on a feedback and pattern detection process. Social insects such as bees and ants are the most frequent species referred to in discussions about this

Ants Kew Gardens | Photo: Colin Redgriff, 2013 | Flickr cc practice. Organisms like these display emergent behaviors in an elegant, ever-evolving community building dance.

In bee or ant societies a large number of individuals have a few, very simple commands programmed into their biological systems. Any particular bee or ant might be heeding a biochemical directive to "collect food". In the course of doing so, the individual also communicates something about the instruction through behavior or in a biochemically-based fashion to other individuals upon randomly meeting them during the work day. As more individuals carrying the same directive meet and begin the same behavior, the signal is strengthened. (This is what you see when you notice a chorus line of ants promenading down your window ledge.)

All these signals are translatable to mathematics at their core. Bees, for example are innately aware of the sun and its location, gravity and in the case of food gathering, distance to the source. Even elements like wind have an effect on their communication. The research Mark and Roman had read suggested that upon finding food and returning to the hive, bees communicate by performing a dance; the direction, speed and length of which can be translated into exact algorithmic maps for other bees to follow.

When food supplies reach an acceptable level, individuals recognize this and begin conveying a different message – that the larder is full – at which point each individual sets off to satisfy an equally simple set of directions to start afresh on a different task. As each does, its biochemical communication feedback loop transfers this new message to subsequent hive or hillmates it meets – resulting in a greater number of individuals addressing the work, resulting in the subsequent completion of this brand new task.

These commands don't come from a central ruling party like a queen. Internal biological programming blends with biochemical communication among random individuals and combines with the uncanny ability to form larger patterns. As these organisms progress, they experience and in fact depend on those random encounters with fellow hive or colony members which collectively begin to create such patterns. The greater the number of individuals performing a task, the stronger the pattern becomes, until it reaches the required levels for project completion. These processes result in filled food banks, waste carried elsewhere, and living quarters constructed all in optimized forms and patterns.

Simple instructions plus random meetings with feedback, create evolving

Ants Marching | Photo: Clicksy, 2009 | Flickr cc

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connected patterns also recognized and managed in a kind of self-organizing system – the result of a nearly perfect communication-action blend of many creatures acting in concert. Such are the governances of many social insects as well as schooling fish and even slime molds. The relatively simple interactions of these organisms create larger and more complex operating systems which support entire species. Mark and Roman recognized that nature's algorithms for these behaviors can be mimicked and adapted by humans by transforming them into mathematical formulas for purposes such as – managing energy.

Commercial electrical customers with larger buildings are generally charged for not only what they consume, but also for their peak demand. This means that often the highest 15 minute burst of usage the meter displays in a month, or variations on that theme, drives the cost of electrical bills. Knowing large buildings require multiple heating and cooling units, Mark and Roman asked themselves, "Could we use an emergent, swarm-based algorithm here?"

As they worked, the concept evolved. Though the pair had little biological background, they both had a great general scientific curiosity and lest we forget, their knowledge of emergence. Originally, they looked at using the algorithm for pumps and motors, heating, ventilation and air conditioning (HVAC) systems and other types of energy loads, but the more they kept narrowing it down, the more logical individual HVAC sensors became as an innovation target.

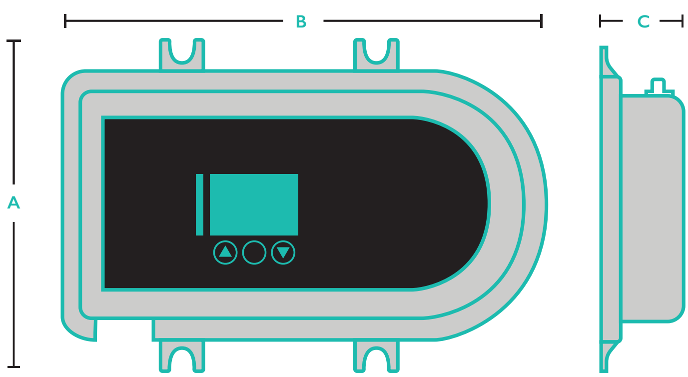
Each ant or bee is "aware" of its job at any given moment. Over time their entire system modulates to accommodate what the entire population experiences. Of course, there were still a number of questions, but Mark and Roman began designing and building a small electronic apparatus with a wireless transmitter. With one of these on each HVAC unit, the combined "swarm" could electronically spread out the equivalent of a bee's chemical pheromone trail to the rest of the colony. According to Mark, if each unit could "hear" all the other unit's "trails", then by modifying a swarming algorithm, individual nodes would register how they fit into the grand electrical scheme, thereby controlling energy at any point in time in relation to all the other building's units. Just like ants and bees, each REGEN electrical unit modulated its behavior a little bit here and a little bit there – depending on what the other units around the building communicated - to achieve the goal of coordinating to save energy.

There were, they knew, thousands and thousands of HVAC systems in every city ready, in their minds, to communicate and reduce energy loads. They now had a problem and a potential solution that seemed like it could work; but they were in for a shock as they sought support for their new way of problem-solving.

Mark approached researchers in academia well-versed and often quoted in the realm of emergent behavior for a little reassurance, possible subsidiary thoughts on commercial applications for comparison or even a little inspiration. When he contacted the first academic he was told he didn't understand; this concept just wasn't ready for commercial or industrial use yet. More study was needed.

He was taken aback, but he and Roman had tested the algorithm on simple cases at the white-boarded proving ground in their offices. It was true they had run through a number of iterations and stumbled. But each time they did, they dissected their work and found a miscalculation was their foil – not a fault in the algorithm. Each time it looked like the algorithm wasn't going to work, they found it was their "stupid human tricks," as they took to calling them, taking them south. The algorithm worked.

When Mark went to a second scholar and encountered the same thing, he and Roman were somewhat amused thinking, "What? What do you mean?" They couldn't imagine why the scholars weren't more interested in their breakthrough.



DIMENSIONS
(cm/inches)

A: 10.85/4.27
B: 15.89/6.25
C: 2.98/1.17

Encycle's patented controller

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With the third academic voicing a similar objection Mark thought, “You know, OK, thank you for your comments and I appreciate your thoughts.”

But he and his partner knew it had to be doable. It was just a matter of understanding the application. Although they didn’t know it at the time, this was where they took another step in a typical biomimetic process. They began to examine the context and parameters needed for their industrial “organism” to survive. Did heat matter? Did cold matter? How could they protect the unit from rain and snow? “Let’s just prove them wrong. Go ahead, you guys study it and we’ll do it. And we’ll tell you when we’re done.”

It wound up being an intellectual challenge as much as anything else, to prove to the supposed experts that, at least with what they knew so far, they didn’t have to just keep studying it. There was enough information already available for REGEN to make something useful.

However, there was another challenge they had to surmount. When considering biomimicry and how nature works, it’s a matter of doing what’s needed with the least amount of materials and energy as possible. This is often at odds with how a pre-biomimetic business world worked. To reap competitive advantage, designers and engineers had, and in many places still are required to add features to products with little regard for the long-term benefits or costs of those additions promoting these features as “upgrades” and “new models”. Mark and Roman were innovating counter to that pattern, with REGEN HVAC compact sensors having a very specific utility without a lot of add-ons.

Also, even if their product was materially and energy efficient, they also had to make their device fit easily into the existing HVAC work environment. They couldn’t approach manufacturers and ask them to change *their* underlying engineering of a system even if manufacturers could then attach a sexy “new model” label to their product. That cost of time and money from outside vendors just wouldn’t sell. If there was something they could drop into the system to have a specific positive effect on energy use and a financial return – then they’d have a chance.

The next group of naysayers was the bevy of technical, practical application energy experts who said, “No, it can’t be done. That’s not the way you manage energy loads.”

To be fair to them, maybe this wasn’t the typical way humans have evolved to solve problems, but we are a young species with much to learn from other species around us having leagues more experience than we do. Nature knows a better way; and now the guys were fervently following the paths of emergent, swarming behaviors of bees to move buildings toward energy efficiency. It took a lot of explaining but ultimately, it all came down to results. That's the only way people would believe it.

So, they began to hone the application for what was becoming a small wireless device with the ability to communicate among fellow sensors to shave peak energy loads. They found the original device they designed wouldn't necessarily work for tall, thin buildings or small individual or individually connected buildings like strip malls. They would solve these problems with later iterations of the device. The original device *did* work well for low, wide buildings with multiple air conditioners sitting on rooftops. Theaters, big box retail, and other types of office or warehouse spaces with good-sized footprints to heat or cool; and fairly big zones for each to cover would work well under "swarming" assistance. The heating and cooling in these buildings was a larger chunk of overall costs and their devices could yield a mighty bang for the buck.

The two kept heads bent toward managing energy consumption and perfected sensors that would talk to each other first to coordinate and shave loads – and later, to go further, turning off devices not needed at specific times of day or under certain conditions.

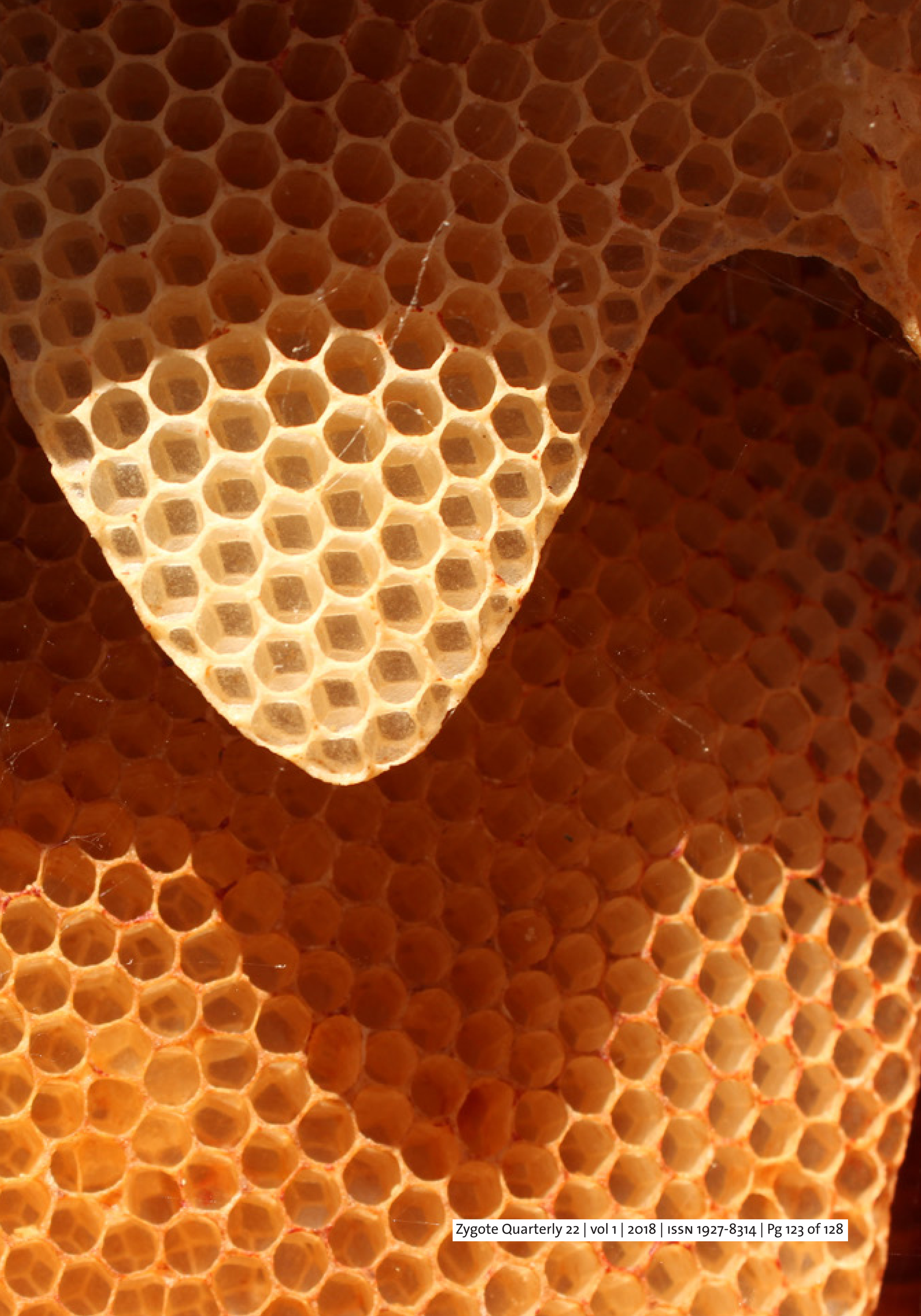
Among their first customers was a family-owned theater chain in New Mexico. With the Southwest's challenge of managing extraordinary energy loads, especially in summer months, the company first elected to try the sensors at three facilities.

The sensors were easily installed and turned on with Mark and Roman quietly monitoring the theater's energy use behind the scenes to understand the base load. After a couple of weeks of learning the heating and cooling rhythms of the buildings, the two flipped the switches and began a savings course which ended up yielding $35,361 in energy savings for the first year. The owners of the company have since almost tripled their number of buildings with sensors guiding their energy use.

Next, they applied the technology to Sage Hill School, a high school with a wish to save energy while teaching students about energy management and an attendant dividend of investing funds saved into their environmental stewardship programs. The school shaved 28% off their consumption and reinvested that erstwhile expense into those student programs.

This success was followed by a contract with CCI, a pioneering valve production company known for its transformational

Natural Honeycomb | Photo: Danna & Curious Tangles, 2015 | Flickr cc



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technologies across 16 countries on five continents and counting. After applying REGEN's swarm-based units for demand, they amassed $28K in savings over just six months.

As time moved on, the pair moved forward gaining hundreds of companies as customers. Household names like Pier 1, Petco and BMW became believers. Michaels, Sports Authority and Sears joined in as the company sold thousands of units. Roman later moved on to other business pursuits while remaining friendly with Mark, who ended up serving as Chief Technical Officer for REGEN, newly branded as Encycle.

As for biomimicry, a core group of people keep it always in their minds as a design base. The business and sales people at Encycle are also well-versed in the core principles which carried the company to where it is today. They know the swarm algorithm and know how to articulate how this is different from those used on conventional buildings. They continue to grow the company globally in places like Japan, for instance, where a food and beverage production and distribution company noted early demand energy savings of between 20-30%. Mark noted the additional value of biomimicry to his customers' corporate sustainability reports and added, "The whole biomimetic angle is what makes us uniquely successful."

When asked about the future, Mark kicked back and looked up at the sky; cloudy that day. "I try to convince people more and more they should look at this (biomimicry) as part of a standard approach – part of their everyday toolkit. Actually, it bothers me that it's not part of the standard control system course in engineering. It should be." It's good for the earth which is good for people and in the end makes good dollars and sense and ultimately – yields success. ×

Acknowledgements
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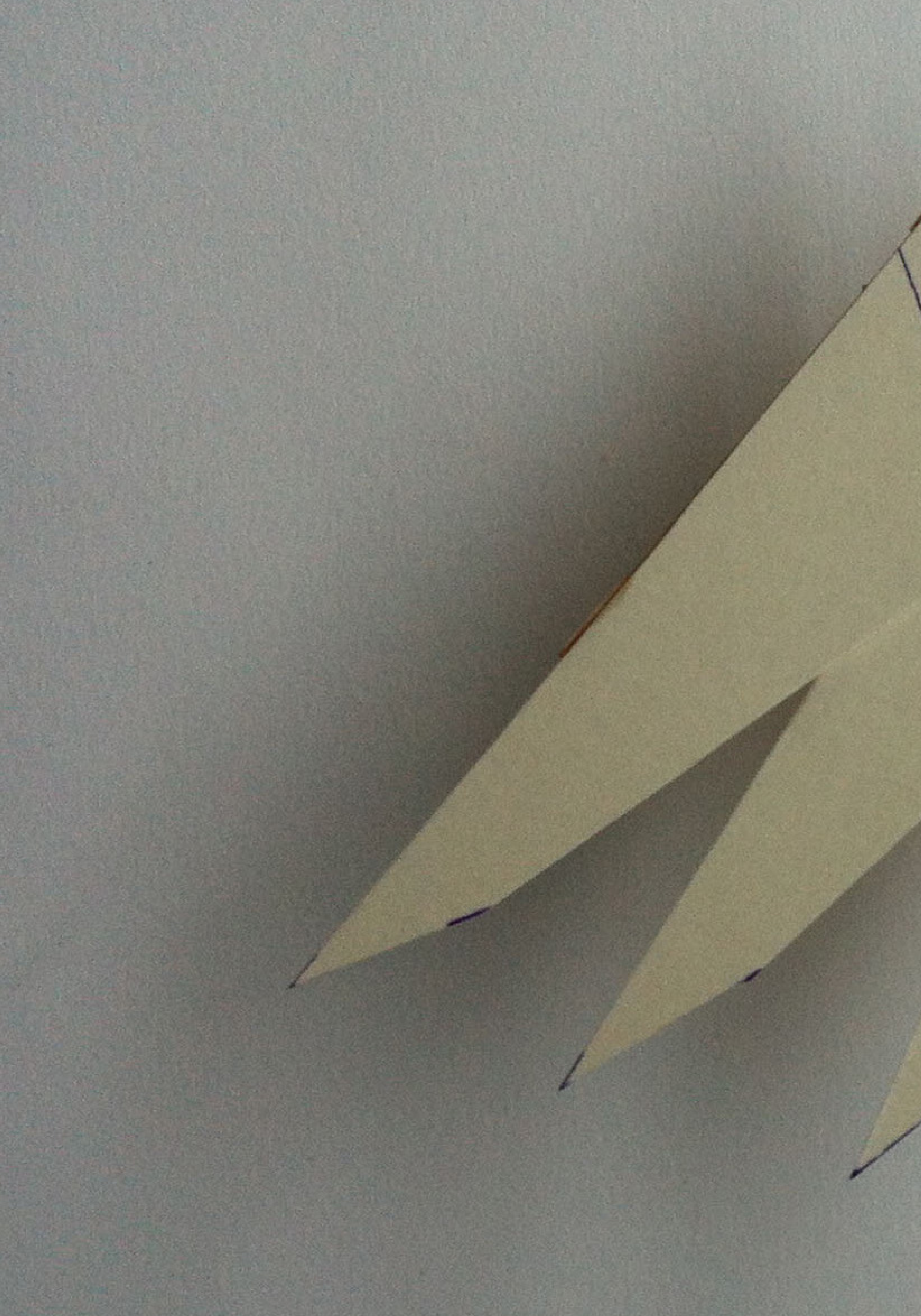
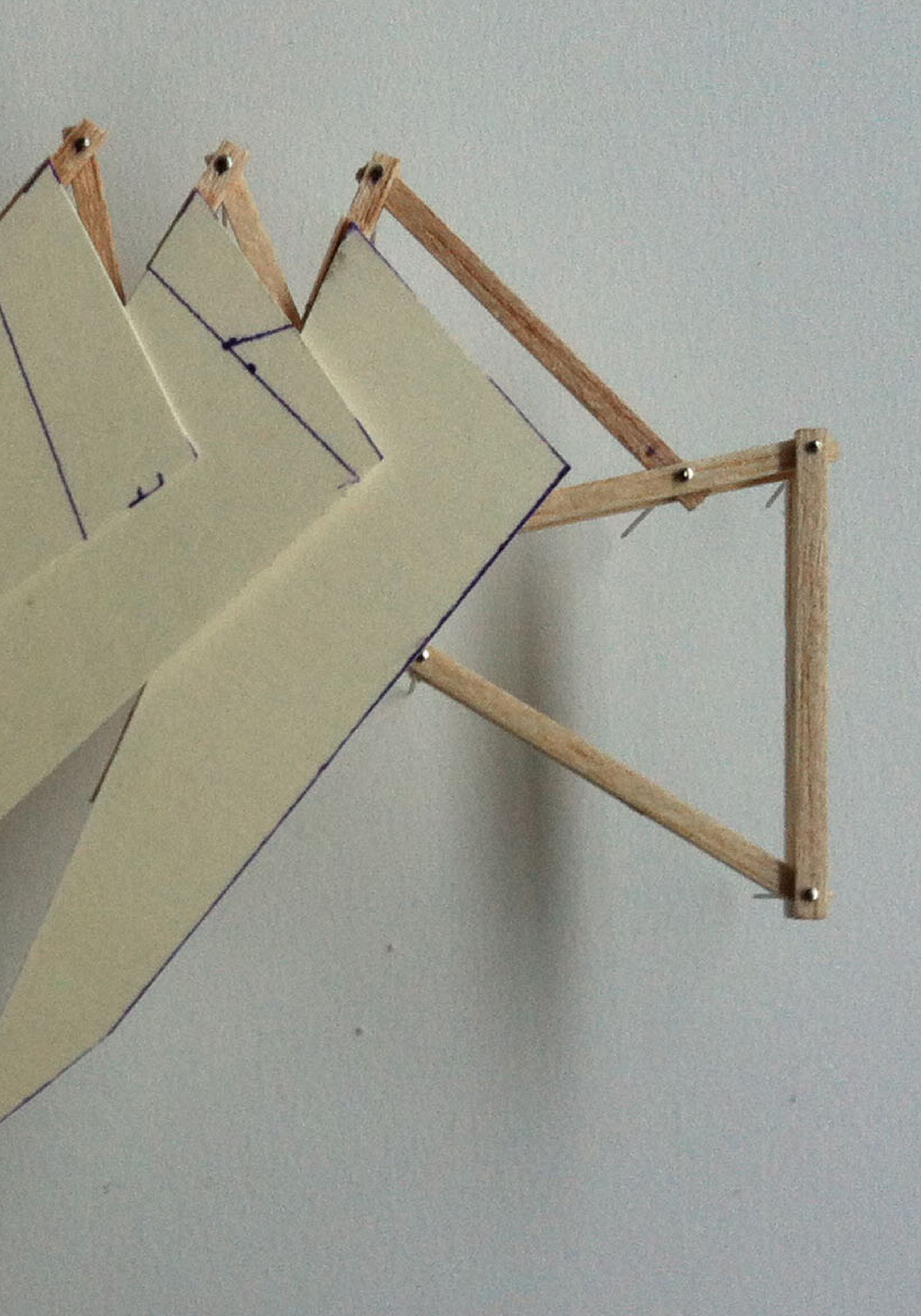
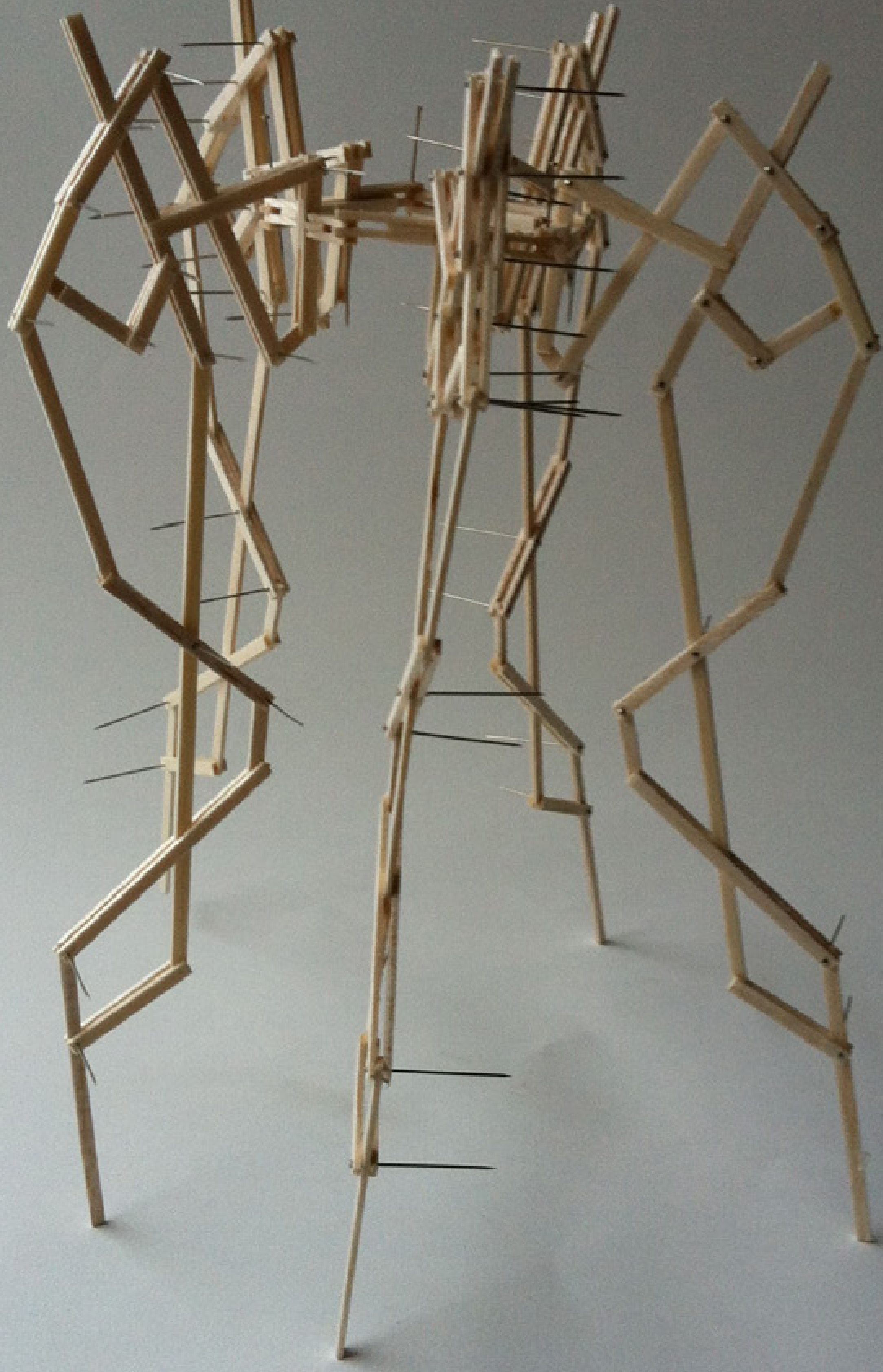
References
Johnson, Steven. *Emergence – The Connected Lives of Ants, Brains, Cities and Software.* New York, New York: Scribner, 2001

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

Bee peeking | Photo: Gordon, 2012 | Flickr cc







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