



*Images sourced from (top to bottom): Wikipedia (http://en.wikipedia.org/wiki/Eastgate_Centre,_Harare); YouTube (<https://www.youtube.com/watch?v=HGOKof-ide4>); Energias Renovables (<http://www.energias-renovables.com/articulo/sahara-project-grows-cucumbers-using-seawater-and-20121217>)

Learning from Nature: Biological templates for adapting to climate change

Holly Jacobson | December 10, 2014

Abstract

Our built environment—complete with highly mechanized HVAC systems that engineer ‘habitable’ space—sits as a primary perpetrator of exponentially rising CO₂ concentrations, water scarcities, and growing desertification. A promising template for a ‘new approach’ seems to be nature itself. Designers, biologists, medical researchers, and engineers have been looking to nature for inspiration for centuries, yet in the past 30 years—driven by an urgency to find alternative, more sustainable methods for producing and consuming—there has been a surge of applications mimicking organism functions and ecological processes. The following study, investigates three cases that each employ nature’s prowess to address 21st century heat and water concerns: 1) the Eastgate Centre in Harare, Zimbabwe designed with natural ventilation based on termite mounds; 2) thermal bimetal that morph to regulate temperature, reminiscent of human skin; and 3) the Sahara Forest Project in Qatar which is developing a cluster of industrial laboratories that restore vegetation by mimicking how ecosystems encourage new growth. These three projects—ranging in scale from materials, to the building, to the urban system—suggest that biomimicry can provide a powerful model for not only

using resources more effectively and efficiently, but also for addressing thermal regulation, water provision, and the survival of temperate ecosystems in the face of climate change.

BIOMIMICRY: a source for inspiration

Can we find a sustainable energy source? Can we produce without that vicious byproduct? How can we maximize efficiency, and get the most “bang for our buck?”

Whether approaching these questions from business, manufacturing, agriculture, environmental engineering, construction, or urban and regional planning, these are 21st century questions we grapple with on a daily basis. Human ingenuity has brought us a long way—harnessing power and merging materials to service the needs of a growing and developing society over the past 50,000 years. Nature,¹ however, has had 3.8 billion years of “research and development” to tackle similar challenges, and it has not only resolved these challenges, but has resolved them well (Benyus, 1997; Pawlyn, 2011a). By looking to nature as a model for human-fabricated systems, processes, and products, we can recognize how much there remains to learn.

Mimicking nature is not a new concept—the first airplanes were modeled off avian biomechanics, for example—but in recognizing its vast, untapped potential, biologist Janine Benyus coined and popularized the field of “biomimicry” in the early 1980s. Biomimicry, she describes, is “the conscious emulation of life’s genius,” and “innovation inspired by nature” (Benyus, 1997). From examining nature’s processes, she argues, we can improve everything from product design to agricultural production to antibiotic development. And since Benyus’s inspirational wake up call, the application for biomimicry has grown. Michael Pawlyn applies it to the built environment in *Biomimicry in Architecture* (2011); Katherine Collins uses it as a lens for finance in *The Nature of Investing: Resilient Investment Strategies Through Biomimicry* (2014). The phrase “What would nature do?” now permeates design and innovation magazines and blogs.² A report by the Fermanian Business and Economic Institute predicts that by 2030, biomimicry research grants and patents could account for \$425 billion of US GDP and \$1.6 trillion of total global output (Ataide et al., 2013).

As the notion grows across popular culture, however, there is good reason to judge its use with a critical eye: *how effective is the mimicry?* When applied to architecture, for example, designers commonly perform the following thought process: “I need to build an office in the

¹ For the purpose of this paper, I refer to “nature” as all physical and biological elements and processes—anything that is not made by humans. Therefore, the human circulatory system would be included, whereas transportation infrastructure that humans construct would not.

² See Berg, 2013; Collins, 2014; Eberlein, 2013; and Nogrady, 2010 for a few of many examples.

desert. Cacti are also found in the desert; therefore this building is designed to look exactly like a cactus.” The downfall is the word *look*. All too often, designers mimic the form of nature without regard to how that form contributes to a particular biologically tailored function. Some call this bioformalism, others biomorphism; in either case, the use of mimicry or visual metaphor overlooks the much more robust learning potential when it fails to consider the function that the form provides.

What sort of functions would we want to gather from nature? This question zeros quickly into where biomimicry holds critical potential: sustainability and strategies for greater efficiency amidst increasingly resource-constrained environments (Pawlyn, 2011b). By mimicking nature, we can develop built environments that more effectively function collaboratively as opposed to adversely with nature. We can work within nature’s systems. Because of the toxic and extractive systems humans have historically relied on, we now face a global habitat with exponentially rising carbon dioxide levels, a changing climate, and food and water insecurities. Nature’s processes can model ‘best practices’ for energy regulation, climate responsiveness, and restorative growth.

The case studies

With this criterion in mind, I identified three projects—at three scales from material, to building, to urban/ecosystem—that employ biomimicry in a functional way and model climate adaptation strategies: 1) the Eastgate Centre in Harare, Zimbabwe; 2) thermal bimaterials employed in an installation in Los Angeles, US; and 3) the Sahara Forest Project in Masaiied Industrial City, Qatar. The following sections examine the ability of these three cases to harness the power of biomimicry towards new and successful climate adaptation approaches.

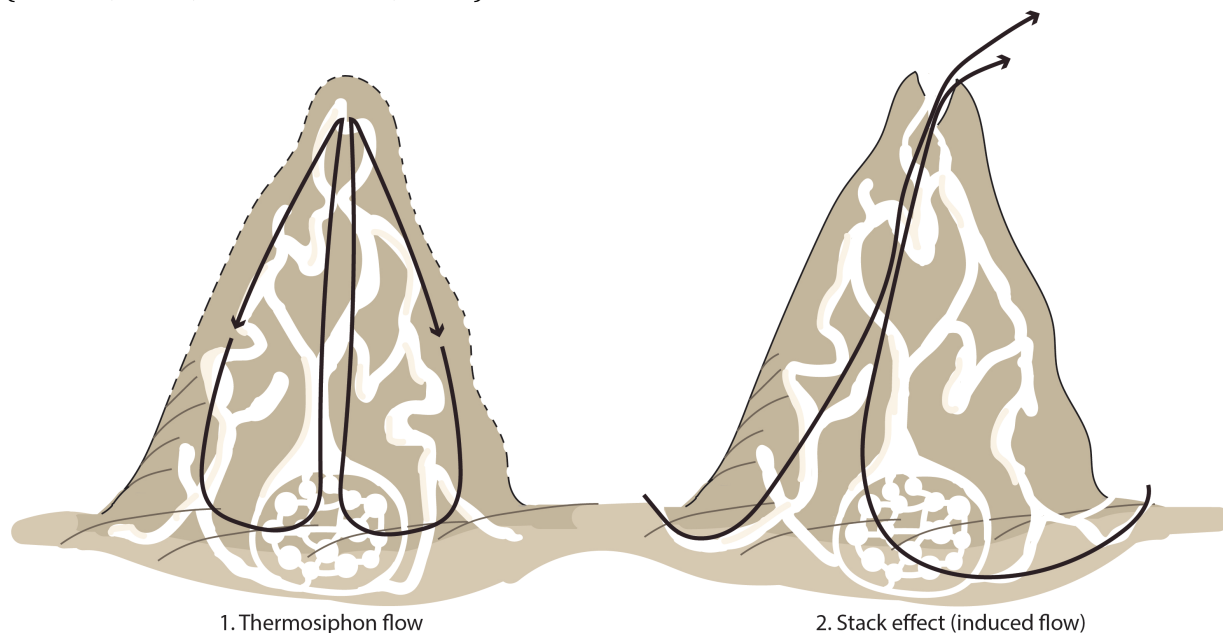
EASTGATE CENTRE: inspired by termite mounds

The Eastgate Centre, opened in 1996, is a 55,000 square meter office and shopping complex located downtown in Zimbabwe’s capital, Harare (Cotesia, 2013; M. Pearce, n.d.; Turner & Soar, 2008). It was commissioned by the property company of Old Mutual, the largest pension fund in Zimbabwe, in 1991, who requested that the building be “appropriate for the climate” and exhibit “appropriate” maintenance requirements and operating costs (“Eastgate, Harare,” 1997). Modern office buildings in southern Africa are usually air-conditioned—a cost that tends to be volatile, can account for 15-20% of the construction budget, and adds significant expense in operating the building over time. Furthermore, HVAC systems are difficult to repair or replace because parts are difficult to source (“Eastgate: Mick Pearce,” 2006). Knowing that Harare’s climate was tropical, with an eight-month dry season with cool nights and hot days, the client suggested using passive ventilation (“Eastgate, Harare,” 1997).

Mick Pearce of Pearce Partnership was chosen as the project's architect—an appropriate choice as Pearce frames his work on the notion that buildings in tropical climates too frequently are based on temperate climate designs and that instead a building should “draw inspiration from local nature” (Turner & Soar, 2008). For inspiration, he turned to African termite mounds. Termites, specifically from the genus *M. Michaelseni*, cultivate fungi in their subterranean nests in order to turn wood into digestible nutrients (Ball, 2010; Cotesia, 2013; Maglic, 2014). In order to do so, it was understood that the nest had to be kept at a constant temperature (87 degrees Fahrenheit), achieved by an elaborate ventilation system of air ducts in the self-cooling, climate-controlled mound (Cortes, 2014; Cotesia, 2013; Maglic, 2014).

Two ventilation models

Mound ventilation was thought to operate through two distinct processes. For mounds that are capped, or closed at the top, the air moves cyclically in what is known as the Martin Luscher model of thermosiphon flow. Heat generated by the nest causes the air to rise to the top of the mound, where it is supplemented by water vapor entering through the porous mound walls. Now denser, the air descends to the nest again where the process is repeated (Cotesia, 2013; Turner & Soar, 2008). If the mounds are open at the top, air travels unidirectionally, driven by the stack effect. It was commonly understood that the top of the mounds—which have been recorded to be up to thirty feet tall—break the surface boundary layer and are exposed to greater wind speeds. The wind current induces air flow, pulling air into channels near the bottom of the mound, and out the top of the mound like a chimney (Cotesia, 2013; Turner & Soar, 2008).



Two models of termite mound air flow. Diagrams redrawn based on illustrations by (Turner & Soar, 2008).

The Eastgate's design

The building is composed of two massive but narrow office blocks nine stories tall, running from east to west. The city street runs down the middle of the two buildings, as does a second story concourse “skywalk,” and a glass umbrella roof bridges the gap across the top (“Eastgate, Harare,” 1997). The building’s concrete frame is clad in brick and precast concrete, which has a high capacity to store heat within its thermal mass (“Eastgate, Harare,” 1997; Maglic, 2014).³

Impressively, Pearce in collaboration with Arup engineers incorporated both models—which in some cases have the potential to work against each other—simultaneously into the Eastgate Centre’s design (Cotesia, 2013; Turner & Soar, 2008). The buildings incorporate thirty-two vertical air ducts that open into voluminous air spaces, which permeate the building. Heat generated within the building, from the occupants, machinery, and lighting, as well as the heat stored in the building’s thermal mass drives the thermosiphon-effect from the interior offices up to the roof. Large chimney stacks on the roof release the hot air, creating the induced flow that drives the stack effect (Cotesia, 2013; “Eastgate, Harare,” 1997; Turner & Soar, 2008).

Was the biomimetic building successful?

The public was puzzled at first by the nontraditional building design; some shop tenants had to be persuaded not to install local air-conditioning units (“Eastgate, Harare,” 1997). Yet very quickly, the building became accepted, respected, and embraced as a central element of Harare’s urban fabric (Cotesia, 2013; “Eastgate, Harare,” 1997). With respect to the effectiveness of the ventilation strategy, the passive ventilation alone was not powerful enough to prevent air stagnation. Low and high capacity fans are run during the day and night, respectively, in order to help flush the hot air stored during the day with cool air during the night. In doing so, the design breaches from biomimicry—termites do not need fans to ventilate their mounds.

Nevertheless, in terms of calibrating the building’s temperature, the Eastgate Centre’s ventilation system works extremely well. The temperature on any given floor only swings two degrees between day and night, whereas outside temperatures fluctuate up to ten degrees (“Eastgate, Harare,” 1997). Furthermore, the ventilation system costs one tenth of standard air-conditioning systems and uses 35% less energy than comparable buildings (Parr, 2012; M. Pearce, n.d.; “Termite-Inspired Air Conditioning,” 2014). Due to the energy savings, the design saved over \$3.5 million within its first five years, not to mention its lower environmental impact as well (“Eastgate: Mick Pearce,” 2006, “Termite-Inspired Air Conditioning,” 2014; Parr, 2012).

³ For images of the building visit Mick Pearce’s website at: <http://www.mickpearce.com/works/office-public-buildings/eastgate-development-harare/>

The irony, however, is that termite mounds are not actually ventilated by thermosiphon or induced airflows (Turner & Soar, 2008). In fact, besides a dampening effect, there is no evidence that a termite mound even regulates temperatures. New studies published by Turner and Soar in 2008 illustrate that the temperature of the nest instead tracks closely with the temperature of the soil, fluctuating fifteen degrees depending on the time of the year. Furthermore, most termite mounds are not tall enough⁴ for induced airflow to be in effect; the boundary layer gradient between the bottom and the top of the mound is not large enough (Turner & Soar, 2008). Lastly, injecting a tracer gas into the mound elucidated that air in the mound never circulates into the nest; thus ventilation cannot facilitate the nest's respiratory gas exchange (Ball, 2010; Turner & Soar, 2008).

If the biology is wrong, is it still good biomimicry?

At one level, the fact that the science behind the natural system was misconstrued indicates a large failure in the practice of biomimicry. "If biomimicry and/or bioinspiration want to be considered legitimate fields of study," one critic protested, "and not just a feel-good endeavor, then the science that the field is based on has to be solid" (Cotesia, 2013). That being said, the attempt to mimic natural processes—despite being false—resulted in engineering innovation and a ventilation model with great implications for energy conservation. With such pro-environmental outcomes that seemingly adapt to the natural environment, it becomes less straightforward to discredit the mimicry. *If the outcome is good, does the source of inspiration matter?*

Through Turner and Soar's research, a new analogy has since emerged: termite mounds seem to behave like lungs with several "layers of subsidiary function." The subterranean nest employs diffusion (analogous to the alveolar ducts in the lung); the reticulum of the mound employs mixed forced convection and natural convection (as do the bronchi); and strong wind-driven convection ventilates the egress tunnels (compare to the trachea) (Turner & Soar, 2008). Although this has little to do with the Eastgate Centre, it is interesting to consider; our process for uncovering further biological understanding may provide a methodological analog for encouraging us to continue to push the boundaries of new design. *Could we design a lung-based ventilation system?*

Thus we are inspired to ask, *what next?* The Eastgate Centre regulated internal temperatures quite effectively, but can we make something that's more adaptive? ***Can we make a building physically respond to external conditions?***

⁴ The average termite mound is only around six feet tall (Cotesia, 2013)

THERMAL BIMETALS: inspired by skin

Human skin is a membrane capable of material, energy, and information exchanges—and a prime biological model of an entity that can change based on the exterior climate (Velikov & Thun, 2013). On a hot day, our blood vessels dilate to circulate more blood near the skin in order to cool us off; on cool days the blood vessels constrict to keep blood closer to the interior. In other words, skin can regulate interior temperatures—like the Eastgate Centre—but can also actively *respond* based on changes in the exterior climate. As we face rising temperatures due to climate change, *is there a way that we can fabricate building skins to be more climate-responsive?*

This question inspired Doris Kim Sung, principal of DO|SU Studio Architecture and architecture professor at the University of Southern California, to explore the use of “smart metals” in building skins (Furuto, 2012; Kimberley Mok, 2012; Velikov & Thun, 2013). These materials are deemed “smart” because of their ability to transform their physical properties without requiring an external power source (Velikov & Thun, 2013). More specifically, Sung is working with thermal bimetals—metal alloys made from two metals laminated together, each with a different coefficient of thermal expansion (Caulfield, 2012; “Kanthal Thermostatic Bimetal Handbook,” n.d.; Velikov & Thun, 2013). As the temperature rises, one metal expands more rapidly than the other, causing the alloy to curl.

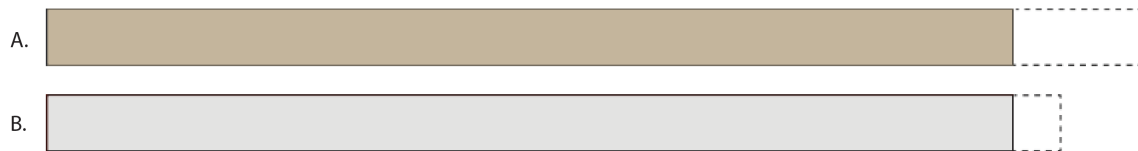


Figure 1.

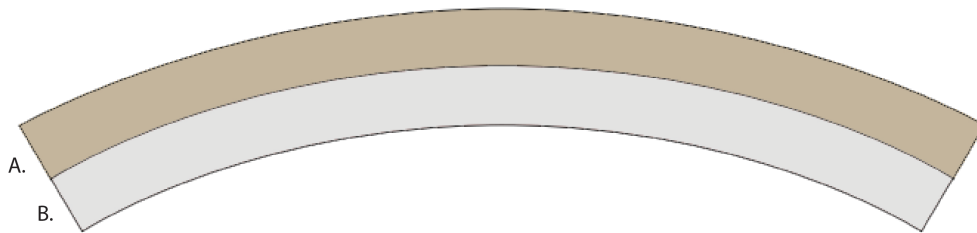


Figure 2.

Thermal bimetals. Two metals (figure 1) with different coefficients of thermal expansion. The metals expand to different extents when heat is applied. When laminated (figure 2), the metal alloy or thermal bimetal, curls due to the different rates of expansion. Diagrams redrawn based on illustrations by (“Kanthal Thermostatic Bimetal Handbook,” n.d.).

Although new to building materials, thermal bimetals have commonly been used in thermostats. With an application not all too dissimilar, Sung uses thermal bimetals as a form of self-activated temperature regulation, creating skins that are able to “open [and close] their pores” to control a building’s ventilation or interior sunlight (Cath, 2012; Velikov & Thun, 2013). To demonstrate the principles behind this new research and development, Sung assembled a 20-foot tall canopy installation, “Bloom,” at the Materials & Application Gallery in Los Angeles, CA that opened in November of 2011 (Cath, 2012; Furuto, 2012; Kimberley Mok, 2012; Lander, 2014).⁵ A manganese-nickel alloy was used to produce approximately 14,000 laser cut pieces, each designed to curl differently depending on its location on the structure in relation to the sun in order to control ventilation and shading (Caulfield, 2012; Furuto, 2012; Kimberley Mok, 2012). Although Bloom stood onsite for a year, the installation was calibrated for optimal effect on spring equinox, March 20, 2012 (Furuto, 2012).

Is the biomimetic material successful?

Sung’s application of thermal bimetals has demonstrated new innovation for energy efficiency. It has also contributed to a shift in how architects think of building design, adding emphasis on performance rather than form (Velikov & Thun, 2013). Walls are no longer only a barrier between interior and exterior, but rather a “living system” or “adaptive interfaces, where fluxes of matter and energy are not blocked but managed by the wall itself” (Turner & Soar, 2008). Based on this premise, Sung is exploring future applications, including how the bimetals could be inserted between glass panes to create sun-regulating drapes, or between bricks to create temperature-regulated ventilation (Cath, 2012; Kimberley Mok, 2012).

Despite this forward thinking, however, the thermal bimetals’ effectiveness in this application still raises questions. Bimetals’ have a specific range of motion and their performance is often bracketed within a narrow temperature range and climatic conditions (Velikov & Thun, 2013). Because they need to respond to temperature changes over the course of the day, I question whether the material would have any applicability in a region with distinct seasons; for example, in northern New England, the metals would have to cater to temperature swings in the high 80s as well as just below zero. Also, as the material stands currently, its raw costs are prohibitively high for mainstream projects (roughly \$100 for a 4x8’ sheet), although this is likely to come down with mass production (Caulfield, 2012).

In terms of its execution, the biomimetic merits are just as unclear. The title of the installation, “Bloom,” as well as the voluminous shape of the canopy seemed to confuse the direct biomimetic comparison; some related its appearance to an orchid, others to women’s bloomers (Furuto, 2012). Few grasped the *functional* biomimicry behind the design. One commenter even described: “Although the transformation is unrelated to biology, the result is reminiscent of natural phenomena such as breathing or peeling skin” (Brownell, 2013). While

⁵ For images and a video of the installation visit the DO|SU Studio website at: <http://dosu-arch.com/bloom.html>

the reference to breathing may have identified a functional biological analog, the comparison to peeling skin again missed the deeper point of biomimicry. The building only *looks* like peeling skin, but skin does not *peel* in order to regulate internal temperature.

Does it matter if the public understands the biological reference?

Or, as we saw in the Eastgate case, *does it matter what form of nature inspired the design?* Sung compared Bloom's response to sunlight to skin. From a thermoregulation standpoint, this holds true. However, based on the mechanism itself—the physical transformation of the metals—I would argue that the bimetals more closely mimic heliotropism. This form of plant movement allows plants to rotate their leaves into a more vertical position to avoid damage by overheating. Like the bimetals, this process is directed by the angle of the sun.

However, whether the bimetals mimic nature in such a way that can effectively function within nature is perhaps a more vital critique to the use of biomimicry. *Are these materials 'nature-friendly'?* They hold potential to lower energy costs, but before this stage, they are fabricated in a high frequency (induction) furnace ("Kanthal Thermostatic Bimetal Handbook," n.d.). Janine Benyus calls our manufacturing process "heat, beat, and treat"—a process with high temperatures, high pressure, and many chemicals (Benyus, 1997). As a biomimetic alternative, she suggests we should instead strive for "life-friendly" manufacturing conditions: "in water, at room temperature, without harsh chemicals or pressure." The gap between bimetal fabrication and "what nature would do" draws skepticism in the biomimetic execution. However, there seems to be little precedent of "life-friendly manufacturing" currently, suggesting it is a tough standard to hold against. Furthermore, high frequency furnaces are known for being a "clean, energy efficient, and well-controllable melting process compared to most other means of melting" ("Induction Furnace," n.d.).

This case suggests that to understand the true effectiveness of biomimicry, it is necessary to put it in context within its full lifecycle. *What are the externalities? Is it possible to create a biomimetic ecosystem?* In other words, thermal bimetals responded to the exterior climate. ***But can we make a built environment that restores our ecosystems?***

THE SAHARA FOREST PROJECT: inspired by ecosystem restorative growth

At a global scale, communities are facing food, water, and energy insecurity, which will only increase with the coupled impact of climate change and desertification. These complex, intertwined, and growing hazards provided the motivation for the Sahara Forest Project (SFP), a Norwegian-based research and development project launched in 2011 that has taken on the challenge of catalyzing restorative ecosystem growth in arid regions ("Restorative Growth," n.d.).

The Sahara Forest Project is piloted in Qatar and was built in collaboration with Norwegian-based Yara, the world's largest fertilizer supplier, and the Qatari company Qafco, the largest single site producer of urea and ammonia (Parkinson, 2012; Whitlock, 2012). Located in Masaieed Industrial City, forty kilometers south of the capital Doha, the one hectare pilot site runs adjacent to the Qafco facilities and leverages the pipelines that Qafco has built to transport seawater to the site (Friedman, 2014; F. Pearce, 2013).⁶ An arid climate blankets the barren landscape; average temperatures for the country linger between 90 to 104 degrees Fahrenheit. With little rain and minimal arable land,⁷ Qatar relies on imports for 90% of its food supply (Friedman, 2014; Gonda, Al-Albi, & Fekete-Farkas, n.d.). Consequently, the Qatar National Vision 2030 has identified sustainability as a key national concern, and—despite the harsh growing climate—the nation aims to become “the food hub of the Gulf region” (Gonda et al., n.d.).

The Sahara Forest Project is aligned in that mission, piloting a model for growing food in a desert—a model that takes Qatar's abundant resources: sunlight, saltwater, and carbon dioxide, and generates more of what is scarce and needed: food, clean energy, and fresh water (Carrington, 2013; Pawlyn, 2011b; “Restorative Growth,” n.d.). This process is developed as a synergy between already proven environmental technologies, including saltwater greenhouses and concentrated solar power (CSP) technology (“Restorative Growth,” n.d.; Yeang & Pawlyn, 2009). The CSP plant uses parabolic mirrors to amplify the sun's rays; the solar heat generates steam, which powers turbines and generators to generate electricity. This power 1) runs a desalination process to produce fresh water, and 2) pumps seawater to the greenhouses (Carrington, 2013; Clery, 2013; Friedman, 2014; F. Pearce, 2013; Whitlock, 2012). The seawater is trickled down through “evaporative hedges” made from honeycombed cardboard pads that are stationed along the walls of the greenhouses. Hot desert air, as it blows through the cardboard, becomes cooler and more humid, creating a microclimate more conducive to growing (Clery, 2013; Friedman, 2014; F. Pearce, 2013). As a result, the facility is able to cultivate three crops per year, even in the sweltering summer months (Clery, 2013).

Mimicking two of nature's principles

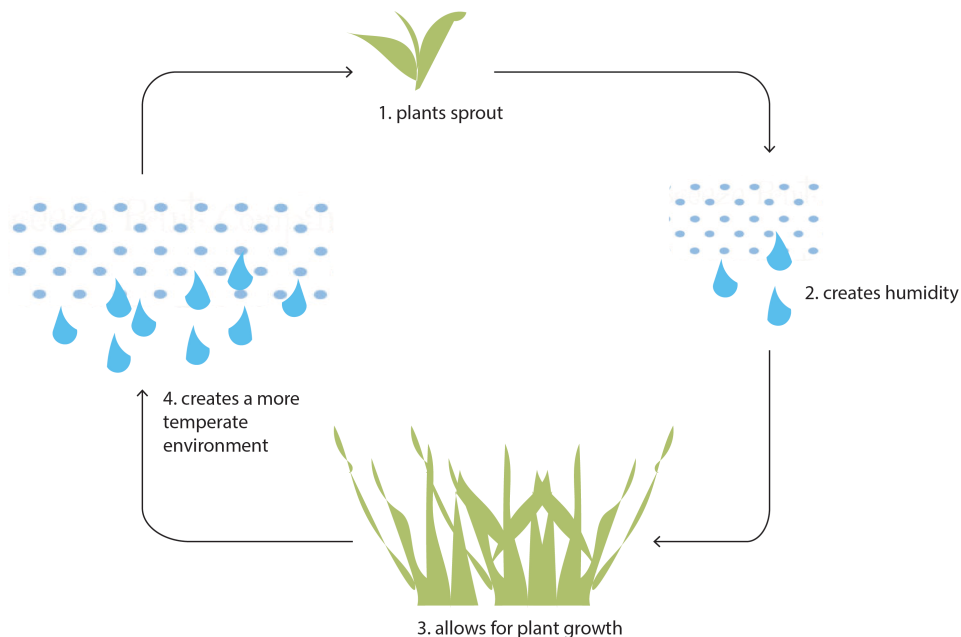
This synergy between the concentrated solar power and saltwater greenhouse technologies allows for freshwater, clean energy, and food production. However, the system takes advantage of two key ecological principles that in the long run beget a multitude of further beneficial impacts. As a first principle, nature maintains composite, closed-loop resource cycles, where waste from one process becomes used as a resource in another (Benyus, 1997;

⁶ For images of the project visit Business Insider at: <http://www.businessinsider.sg/sahara-forest-project-growing-food-in-qatar-2014-7/-VHHoo77XdUR>

⁷ Deforestation has led to high salinity and a loss of minerals in the soil. Consequently, only 5.61% of Qatari land can be used for agriculture (Gonda et al., n.d.; “Restorative Growth,” n.d.).

Pawlyn, 2011a; Yeang & Pawlyn, 2009). In the same sense, the Sahara Forest Project facilities generate symbiotic relationships between processes' byproducts. Condensation (freshwater) builds up on the pipes transporting cold seawater, which is collected and used to irrigate the greenhouses (Clery, 2013; F. Pearce, 2013). Meanwhile, the water trickling through the cardboard hedges concentrates the saltwater, increasing the salinity from 3.5% to 30%. The freshwater that filters out is distilled in the desalination plant for irrigation, while the highly concentrated saltwater is deposited in shallow ponds; as the water evaporates, pure sea salt can be harvested and sold (Friedman, 2014; Pawlyn, 2011b; F. Pearce, 2013). Extra saltwater has also been used to grow algae, an additional byproduct to be eventually used as biodiesel fuel (Carrington, 2013; Friedman, 2014; Parkinson, 2012; F. Pearce, 2013). As Yeang and Pawlyn describe, the project has encouraged the team "to consider anything that is under-utilised as an opportunity for adding elements to the system to achieve greater resource efficiency" (Yeang & Pawlyn, 2009).

A second guiding principle, has been the notion of restorative growth, or in other words, life creates an environment hospitable for more life (Benyus, 1997). In the case of the Sahara Forest Project, cool, humid air from inside the greenhouses leaks out and provides a more conducive climate on the surrounding site. Vegetation has begun to sprout naturally and the SFP team now grows other crops, including barley, arugula, as well as local desert vegetation on the surrounding land (Clery, 2013; Friedman, 2014). Additional evaporative cardboard hedges are installed along the peripheries to assist cultivation, although CEO Joakim Hauge suggests that it does not take much to spur new growth (Clery, 2013). The plants themselves help to make the air cooler and moister, which in turn encourages more growth.



Restorative growth. The plants that are able to sprout around the greenhouses spur a positive feedback cycle that fosters further growth. Beyond influencing the climate, the plants also drive desert revegetation by fertilizing the desert land.

Is the biomimetic cultivation strategy successful?

When the strategy was first shared in 2009 with the delegates at the Copenhagen Climate Change Conference (COP 15), the general consensus was that it sounded “too good to be true” (Parkinson, 2012). Within its first year of operation, however, the facility was growing three crops annually with a productivity of 75 kilograms of vegetables per square meter—a quantity comparable to commercial farms in Europe (Clery, 2013). The Sahara Forest Project team predicts that by scaling up the facility to 50 megawatts of concentrated solar power and 50 hectares⁸ of saltwater greenhouses, the Sahara Forest Project will be able to produce 34,000 tons of vegetables, export 155 gigawatt hours of electricity, employ over 800 people, and sequester over 8,250 tons of carbon dioxide (“The Sahara Forest Project in 10 Sentences,” n.d.). By creating a hospitable environmental, as well as jobs and economic growth, the project is generating ‘restorative growth’ in an additional metaphorical sense, bringing people into the barren industrial region.

The initial success of the Sahara Forest Project—particularly in one of the most challenging climates in the world—has shown promise for replication (Carrington, 2013). The SFP has conducted a feasibility study in Amman, Jordan and will start construction on a demonstration center by the end of 2014. This next stage is seen as a second step to proving the viability of the combined system as a large-scale component of urban infrastructure and a necessary element for future eco-cities (Yeang & Pawlyn, 2009). The team has intentions of creating interconnected stations in low lying desert areas around the world—particularly in North Africa where there are plans for solar power facilities currently underway (F. Pearce, 2013; “Restorative Growth,” n.d.). Because of global concerns over farming productivity, rising food prices, and decreasing food supplies, the Sahara Forest Project has wide applicability; southern Spain is facing freshwater shortages and thus the SFP technology has the potential to save 20,000 hectares of fruit and vegetable greenhouses (Pearce, 2013).

Yet the project does not come without challenges. The project cost nearly \$6 million to build, and some experts question whether it’s the best use of resources. The money could arguably go a lot further by supporting community-based natural resource management programs (Carrington, 2013). Others worry it is only “an expensive publicity exercise” (Pearce, 2013). Based on the costs, the average price for a cucumber given the anticipated harvest, would be nearly a dollar per cucumber without factoring in overhead. This price—although seemingly normal in the US—would be about five times the average price in Doha (F. Pearce, 2013). Lastly, others argue that “greening” small patches of a desert will not necessarily boost natural vegetation in all deserts, and in fact may make no difference at all. Because of climate change, which is predicted to make arid areas even dryer, this may be a losing battle (F. Pearce, 2013). Nevertheless, proponents argue that as they bring the technology to scale, costs will pay off, and that there are still many places with similar climates to Masaieed

⁸ For a comparable reference, it is estimated that 60 hectares of greenhouse growing space could supply all the eggplants, peppers, cucumbers, and tomatoes that Qatar imports currently (Clery, 2013).

Industrial City where the project could gain traction (Clery, 2013). Furthermore, as food and water prices continue to increase due to shortages, the project is only going to become more viable.

IMPLICATIONS FOR BIOIMIMICRY: prerequisites for success

Is biomimicry useful? On one scale, biomimicry has vast potential for engineering and product innovation, driving “new” and more resource-efficient ways for generating products and processes. From a sustainability standpoint, however, the implications are more convoluted. Biomimicry can be a means for environmental solutions, but can also enhance a level of “techno-optimism”—a notion that humans can and continually will engineer their way out of problems. The practice does not insinuate the need for behavior change, nor does it necessarily ensure an effort to live by what Janine Benyus calls nature’s key principals:⁹

1. Run on sunlight
2. Use only the energy needed
3. Fit form to function
4. Recycle everything
5. Reward cooperation
6. Bank on diversity
7. Demand local expertise
8. Curb excesses from within
9. Tap the power of limits

Considering this list helps to provide a frame of reference for considering several key questions generated from the three cases:

1. Does the project need to mimic biology accurately to be successful?

An understanding of biology is a prerequisite to the practice, but science is not finite! The Eastgate Centre case confirmed this. Because our knowledge of biology and ecology is constantly changing, it is perhaps impossible to know at any given time the complete system of elements and processes that make it function. By rather living by nature’s principles, I would argue that it matters less if the biology is an exact replication of a singular model.

⁹ Since the publication of *Biomimicry: Innovation Inspired by Nature* in 1997, Benyus has reworked the list of “Life’s Principles,” pairing the list of nine down to the following six: 1. Adapt to changing conditions, 2. Be locally attuned and responsive, 3. Use life-friendly chemistry, 4. Be resource efficient (material and energy), 5. Integrate development with growth, 6. Evolve to survive. I have mixed feelings about the changes. The difference between 1. *Adapt to changing conditions* and 6. *Evolve to survive* is not entirely clear. Meanwhile, the new list loses 5. *Reward cooperation*, which in its trueness to nature holds a powerful message for society—particularly in the US where the notion of the “self-made man” prevails.

Biomimicry can perform successfully if the building, material, or built environment replicates principally “what nature would do.”

2. Does the project need to foster sustainability to be successful?

Sustainability is not a prerequisite to innovative biomimetic thinking. But as we look towards a future where compatibility with the environment is critical to our very survival, we overlook an enormous set of tools that biomimicry offers if the application fails to advance sustainable practices. Both the Eastgate Centre and the thermal bimetals rethink tactics for energy efficiency, but arguably only abide by a few¹⁰ of Benyus’s nine principles. Although implicitly doing so, LEED certification could better gauge its merits against these nine “natural codes,” providing a new lens to how we think about green infrastructure and building design.

As a comparison, the Sahara Forest Project displays evidence of all nine principles—most notably 4. *Recycle everything*, 5. *Reward cooperation*, and 9. *Tap the power of limits*. The project models synergistic closed-loop processes that demonstrate how to use the limited resources available locally to live within a finite, global carrying capacity.

3. Does the project need to be integrated into a biomimetic ecosystem to be successful?

In other words, *does the entire lifecycle need to be biomimetic?* This question flows directly from question two. If the project seeks to mimic nature’s prowess in a way that works sustainably within nature, then it is necessary to consider where the material and energy flows come from and where they end up. Ideally the project would mimic not only a single facet of nature—a physical property that performs in a particular way—but would also work within the surrounding natural environment just as nature integrates within its local biome. By doing so, we can create environments that are not only sustainable, but also restorative—fostering healthy local regrowth. *Is it possible to create biomimetic ecosystems?* Living by nature’s principles suggests a solid way to start.

What are our next steps?

When considering replication of biomimetic design, financial feasibility comes to question. The three cases examined were each backed by prominent institutions or sizable funding streams. *Is the discipline applicable to the general populace?* To be at the forefront of biomimetic research, projects undergo significant research and development phases—a cost-heavy endeavor. Yet, the products and processes themselves do not correlate exclusively with high costs. Passive ventilation, for example, drastically undercuts market HVAC systems simply by rethinking how to leverage natural airflow.

¹⁰ Both the Eastgate Centre’s ventilation scheme and the thermal bimetal installation embrace 2. *Use only the energy needed*, and 3. *Fit form to function*. Thermal bimetals also to a certain degree employ 1. *Run on sunlight*, and 6. *Bank on diversity* by catering each bimetal panel to act in a very specific way. The Eastgate Centre, on the other hand uses 7. *Demand local expertise* as it draws inspiration from the local fauna. The other principles are largely uninvolved—particularly 4. *Recycle everything* which insinuates a closed-loop material cycle.

Likewise, although I focus on the built environment, biomimicry is not only relegated to what can be physically manufactured. Sociologists employ notions of succession and renewal to the processes that change urban communities, and companies have begun using principles drawn from nature—from “be locally attuned” to “evolve to survive”—to defend altering their business models. I would argue that the way of thinking, reflecting on and modeling nature’s principles more generally, is the most critical asset to biomimicry. *But how do we cultivate this thinking?* It is clear that more interdisciplinary teaching models are needed; there should be a biologist at every design table. Shifting education—at a primary to a graduate school level—to place sociologists, designers, and biologists on the same team will notably advance the biomimicry profession as well as the advancement of new environmental strategies. Will this prepare all our infrastructure for climate change? Likely not. But thinking in such a way that mimics how nature would solve the same problem gives us a decent start.

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