Biomimicry from Principles

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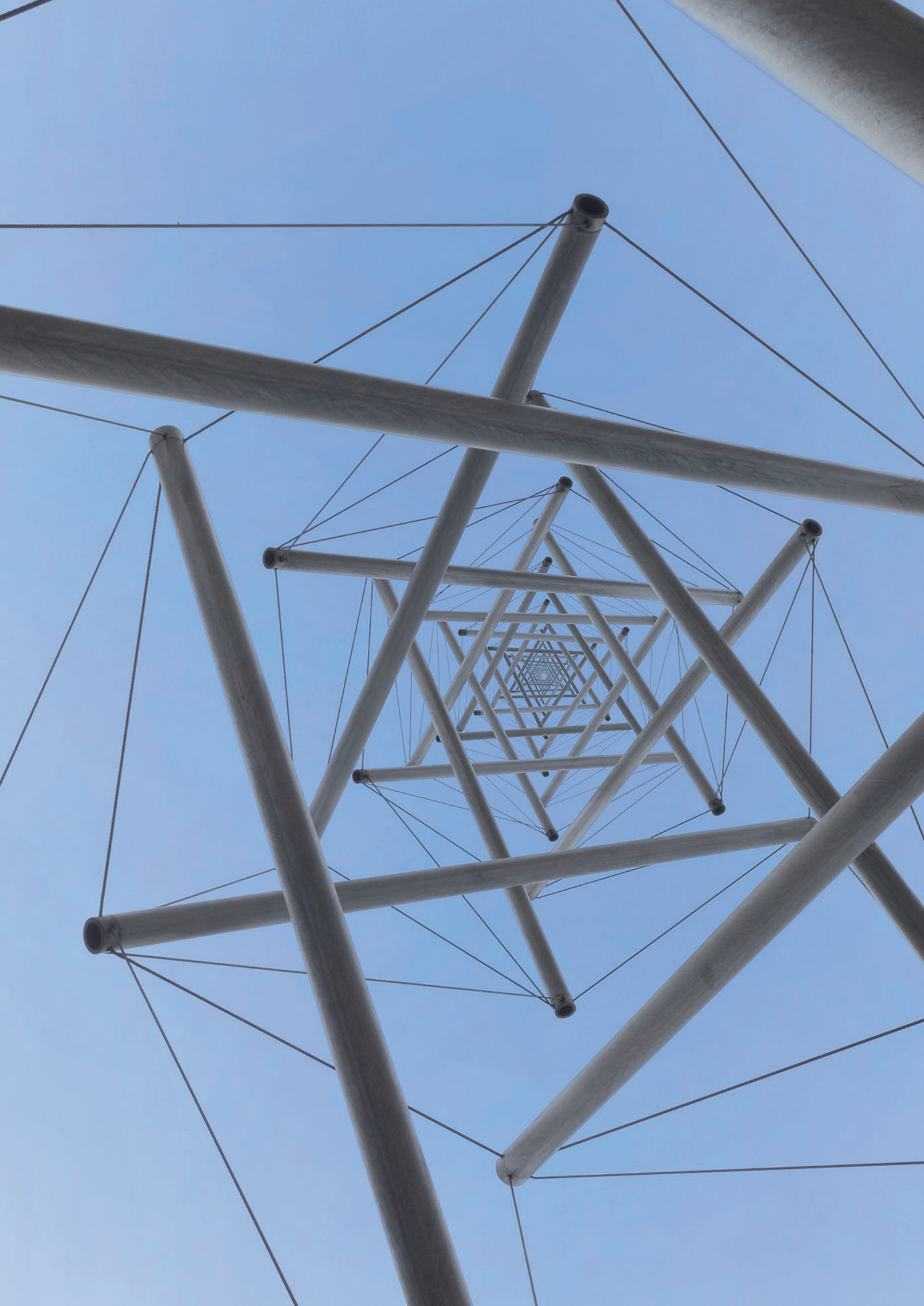

Source: Jeremy Faludi.

CHAPTER 24

Biomimicry from Principles

Jeremy Faludi

Goals

- Recognize principles of designing like nature
- Ideate sustainability solutions using inspiration from biomimetic principles

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Why It Matters

While biomimicry is a great source of inspiration and can help us reconnect with the natural world in professional practice, designing based on specific mentor organisms is often difficult and time-consuming, requiring much basic research. Designing by principles that other researchers have already identified is much faster and easier.

Summary

- Using design principles of nature is much faster and easier than researching mentor organisms, though it does not provide the deeper connection to nature.
- To ideate from principles, find a list of biological design principles, such as Biomimicry 3.8's "Life's Principles." Steven Vogel's list in *Cats' Paws and Catapults*, or this chapter. Select one or more relevant principle. Brainstorm buildable ideas from that principle. Repeat as necessary.
- Principles can also be used to assess how biomimetic a design idea is, though this is highly subjective.

24.1 How Nature Designs

As mentioned in Chapter 23, nature does not design, it evolves. But there are many commonalities in how organisms and ecosystems work. People interpret these as design strategies, so we can apply the ones we find relevant and helpful to our own designs. For example, Cradle to Cradle's "Waste = Food" is a fundamental principle of natural ecosystems, which is used as a design principle to eliminate the concept of waste: make all materials in one product recoverable for useful lives in other products.

When designing, it's more inspiring to look to specific mentor organisms, but it's faster and easier to brainstorm from biomimetic design strategies that other scientists, designers, and engineers have identified. Especially when brainstorming buildable ideas. This is doing biomimicry from principles.

24.2 Doing Biomimicry from Principles

To design based on natural principles, simply find a list of biological design principles, such as those listed below. Select one or more principle relevant to your design problem. Then brainstorm buildable ideas following that principle. Repeat as necessary.

Many people have made lists of nature's principles. The most famous is Biomimicry 3.8's "Life's Principles," in Figure 24.1. For more details on it and how Biomimicry 3.8 uses it in design, see Biomimicry 3.8 (2013). A few are explained below, as examples:

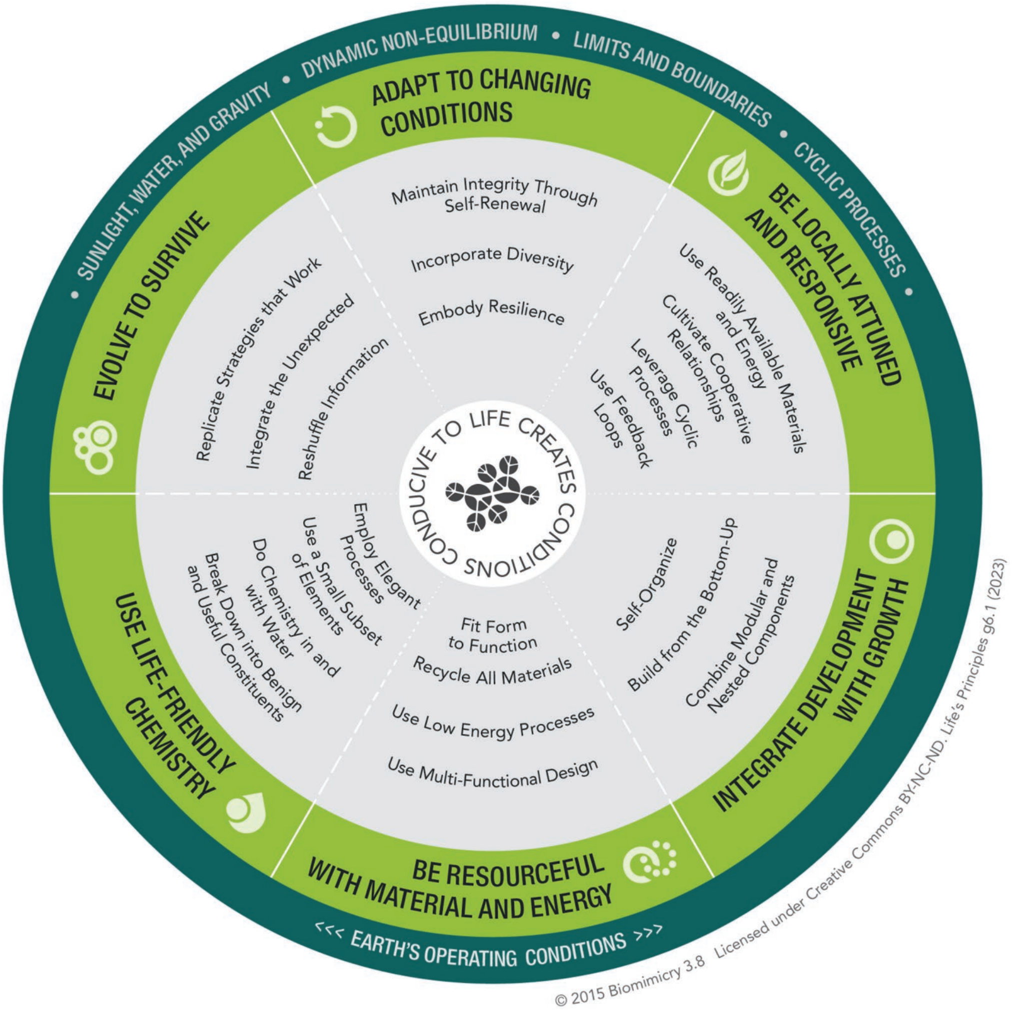

Figure 24.1 Biomimicry 3.8's "Life's Principles"

Source: Biomimicry 3.8 (2013).

Note: For explanations, see link in Resources for Further Study at the end of the chapter.

Evolve to survive: Biology does not design, as previously mentioned—it simply tries many random variants and the strategies that work best survive and propagate; repeating this countless times finds optimized solutions for the conditions at hand. Genetic algorithms imitate this in design—you feed parameters of variation and success criteria into a software optimization tool, and it simulates survival of the fittest for many variations across many virtual generations. The NASA spacecraft antenna in Figure 24.2 owes its odd shape to genetic algorithms, which optimized it in ways a human engineer would never have thought of. This means designers are no longer authors, but gardeners,

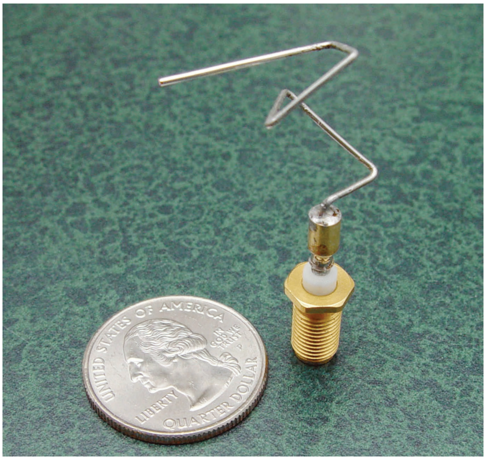

Figure 24.2 NASA antenna designed by evolutionary algorithms

Source: NASA.

creating the right conditions for great designs to emerge from. Kevin Kelly described it as "letting go, with dignity" (Kelly, 1995).

Do chemistry in water: Most industrial chemistry is petroleum-based (non-renewable), happens at high temperatures and/or pressures (energy-intensive), and frequently involves toxic solvents or other chemicals that must be carefully managed to avoid harm. Biological chemistry generally happens at ambient temperature and pressure, is water-based, using non-toxic renewable organic chemicals. However, it is also extremely complicated, and thus has been hard for industry to understand and use. Chemical and biotech industries are making headway, and design engineers can help invent new materials, such as Figure 24.3's Spintex fabric, which imitates spider silk. Producing it uses 1/1000th the energy of synthetic plastic fibers, uses no hazardous ingredients, and its only byproduct is water. In the long run, such biochemistry should also be cheaper than today's industrial chemistry because of the reduced energy and need for safety procedures, plus the plentiful (renewable) materials.

Be locally attuned and responsive: Trees change from summer to winter; many

Figure 24.3 Spintex Engineering's bio-based and biodegradable silk fibers are made at room temperature in non-toxic, water-based chemistry

Source: Spintex Engineering.

animals hibernate for the winter, or change color and behavior. Products can also adjust to their user or current circumstances. For example, Figure 24.4 shows a child's high chair that adjusts to grow as the child grows, thus greatly extending the product's life. For another example, many computers save power by having their CPUs and other chips selectively shut down areas not being used, constantly adapting to usage intensity as needed.

Figure 24.4 The Goodevas Growing Chair

Source: modernnursery.com

24.3 Other General Principles

Other principles of nature not included in the wheel above include the following.

Cooperate *and* compete simultaneously: For the first hundred years of biology, most people described Darwinism as a world of pitiless competition; today's biologists emphasize the cooperative interdependencies of creatures in their ecosystems. Both are true, and both are useful in their own ways. Dee Hock, the creator of the VISA credit card system, coined the word "chaordic" to describe a partly-chaotic, partly-ordered system where the relationships can be both cooperative and competitive at the same time, as they are in natural ecosystems. He structured the VISA system like this, so that many banks could cooperatively agree on ordered rules for the system in which they chaotically compete with each other. This is also how open hardware and software standards work: interested parties cooperate to structure the standard (such as the USB connector geometry, or the HTML programming language) and then compete within that arena. Their cooperation creates a larger total market, saves them money, gives them more robust supply chains, and reduces waste from incompatible systems. The EU recently legislated all mobile phones and some other electronics use USB-C chargers, shown in Figure 24.5, in order to reduce the proliferation of charging hardware.

Organize fractally: A fractal is a form or pattern that is similar to itself at multiple levels. Fractals can plan for growth from the bottom up, or for detail from the top down. The logarithmic spiral of a snail's

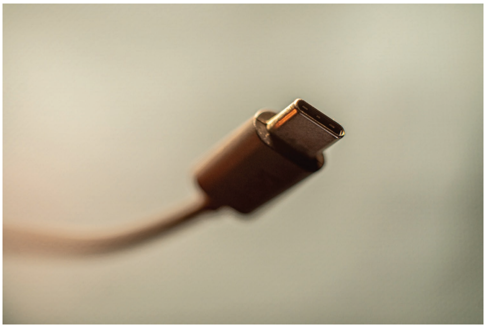

Figure 24.5 USB-C plugs, while not designed by biomimicry, are an open standard, letting manufacturers cooperate and compete simultaneously

Source: Marcus Urbenz on Unsplash.

shell did not evolve because it is pretty, but because it allows for perpetual growth without changing shape. When the snail grows to twice its original size, it does not need to tear down walls to expand its house, as most architects would; instead, it just keeps adding more shell in the same shape. Likewise, the detailed complex shape of a tree can be approximated by a simple branching algorithm. Fractals often don't look alike at different scales, but they still have self-similarity. They can be applied to design in many ways, for example, structural columns branching for efficient material use in Figure 24.6; or Barcelona's urban planning "superblocks" for walkable streets that build community (Salat et al., 2014); or multi-level organizational interventions driving companies toward sustainability strategy (O'Brien et al., 2023).

Design for emergence (swarm): Many small, simple things can work together to act like one large sophisticated thing. This results from "emergent properties," described in Chapter 6, making the whole greater than the

Figure 24.6 Tree-like fractal beams in Stuttgart airport reduce material use for the same strength

Source: CatalpaSpirit, Wikimedia Commons.

sum of its parts. As Kelly (1995) describes it, an individual bee has a small brain and simple behavior, but combining many bees into a swarm creates a super-organism with more intelligence and quite sophisticated behavior. Emergent phenomena are difficult (perhaps impossible) to predict analytically, but they can be simulated in virtual models.

Designing for emergent phenomena can do more with less. For instance, Encycle control systems reduce peak electricity use by scheduling heating, cooling, and other equipment to turn on and off at scheduled times (Figure 24.7). Many systems do that, but Encycle uses an algorithm inspired by bee swarms, where there is no central schedule, there is a distributed system of simple rules resulting in collective behavior. This has made it more effective while costing less money.

Designing for emergence can also help avoid unintended consequences, such as the suburban sprawl and traffic that unexpectedly came from the invention of the automobile. Most complex systems have emergent properties whether they are designed or not, and trying to predict them during design can help find and prevent problematic ones.

TRIZ for biology: A method of classifying problem-solving principles, called TRIZ, claims there are just 40 methods ever used by any people to innovate new products, buildings, and systems (Russo & Spreafico, 2020). However, evolution works very differently from human minds. Researchers at the University of Bath extended TRIZ to biology, cataloging and analyzing many more than 40 methods that nature has used to "invent" new solutions in countless organisms around the world (Vincent et al., 2006). They

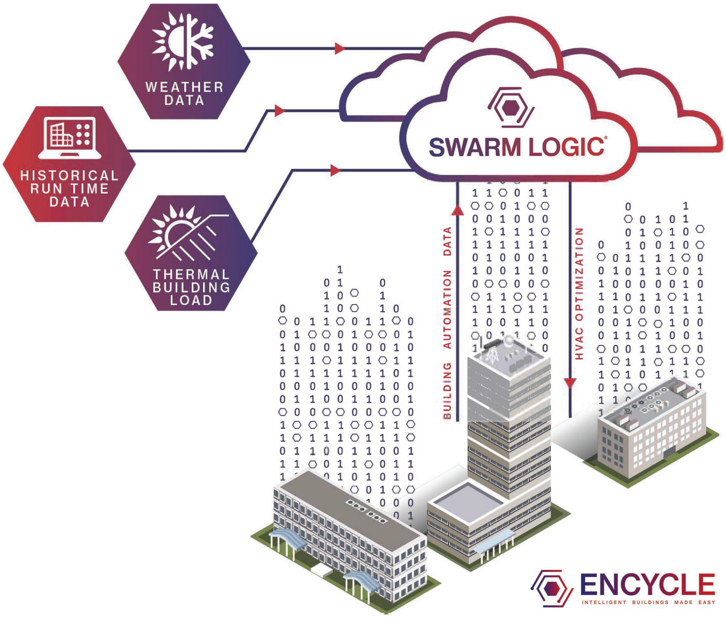

Figure 24.7 Encycle HVAC controllers use "swarm logic" algorithms to improve efficiency with decentralized control.

Source: encycle.com

found that “while technology solves problems largely by manipulating usage of energy, biology uses information and structure, two factors largely ignored by technology.”

24.4 Mechanical Principles

Steven Vogel’s (2000) book *Cats’ Paws and Catapults* lists almost 20 nature-based design principles that can be extremely useful for mechanical engineers. Here are some highlights, quoted or paraphrased from the book:

“Nature uses fewer flat and more curved surfaces than we do.” Natural forms round corners and taper shapes to avoid stress concentrations, thus using less material for the same strength and toughness, as with the tree in Figure 24.8.

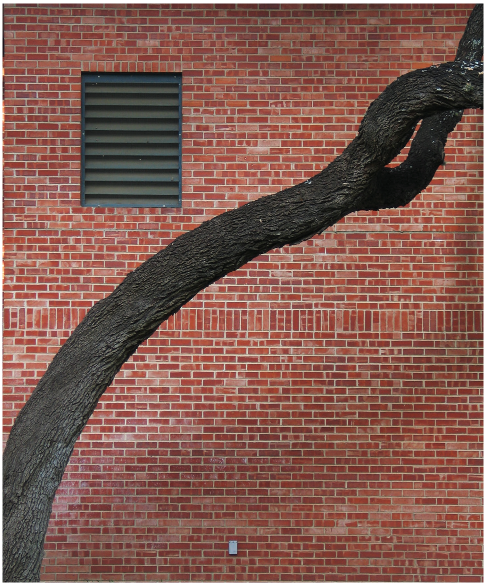

Figure 24.8 A tree’s curved surfaces and rounded corners versus bricks’ flat planes and right angles

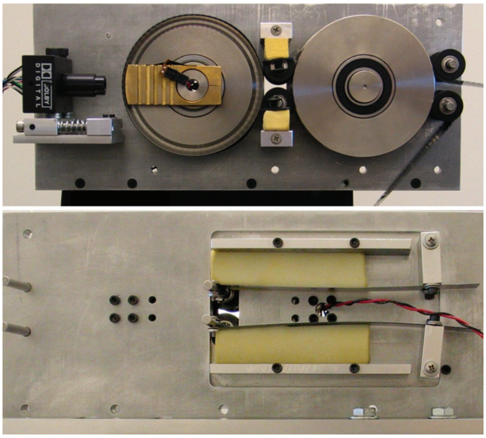

Figure 24.9 A biomimetic vibration damper for film soundtrack readers

“Nature’s objects bend, twist, or stretch at predetermined places” while industrial mechanisms have rigid parts moving on sliding contacts. Figure 24.9 shows a vibration damper for film projectors that used this principle to replace $50 of machined arms, high-precision bearings, springs, and air piston with roughly $1.50 of spring steel and viscoelastic foam, which would also last longer and be more easily repairable.

We usually load materials in compression, nature very often loads in tension. Buckminster Fuller called this “tensegrity.” Long thin objects usually fail by buckling long before reaching their ultimate strength limit, so tensegrity can enable radical reduction in material use, sometimes 10x or 100x in the case of the spokes on a bicycle wheel in Figure 24.10. Vogel also says, “Structures with tensile sheaths outside and pressurized fluid inside are both more common and more diverse in nature’s designs than in ours.” Figure 24.10’s inflated bicycle tire is an example of pressurized fluid tensegrity.

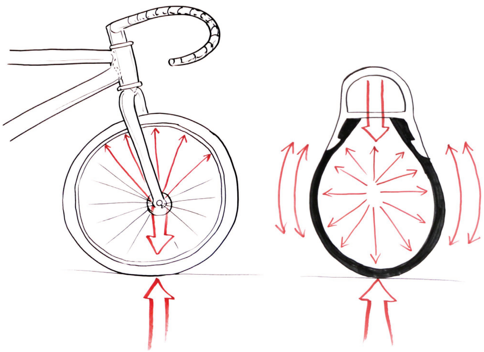

Figure 24.10 A bicycle wheel uses tensegrity both for the spokes (the axle hangs from the top of the wheel) and the tire (air inflates the rubber tube for strength with flexibility)

Source: Autodesk Sustainability Workshop, 2011.

Nature's factories are not size-limited. Unlike industry, nature's factories often produce things larger, not smaller, than themselves. Industrial engineering takes for granted that factories are buildings within which materials and components are processed into products. However, many natural organisms produce things larger than themselves. This happens through growth, such as seeds growing into trees or mothers bearing children that outgrow them. It also happens through mobile construction, such as single spiders spinning webs or swarms of bees building hives. Researchers are already investigating how small robots can build architecture (Tibbits, 2018), such as Figure 24.11's filament structure manufacturer.

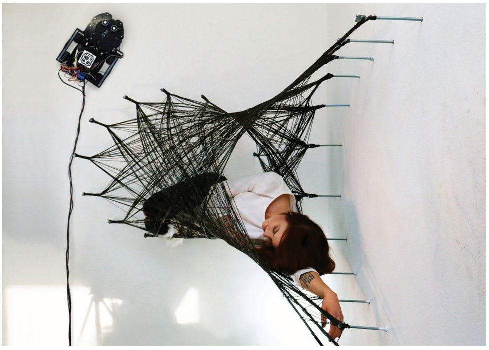

Figure 24.11 Maria Yablonina's mobile robotic fabrication system for filament structures

Source: mariayablonina.com

Resources and References

Resources for further study

- *Cats' Paws and Catapu*lts, by Steven Vogel (an excellent list of biomimicry design principles for mechanical engineering)
- *On Growth and Form*, by D'arcy Thompson (listing several physical and geometric principles)
- *Out of Control*, by Kevin Kelly (listing biomimetic systems design principles)
- *The Way Nature Works*, edited by Robin Rees (a picture book for ideas)
- Biomimicry 3.8. (2013). Biomimicry DesignLens: A toolkit of best practices. Biomimicry 3.8. Available at: https://biomimicry.net/the-buzz/resources/biomimicry-designlens/

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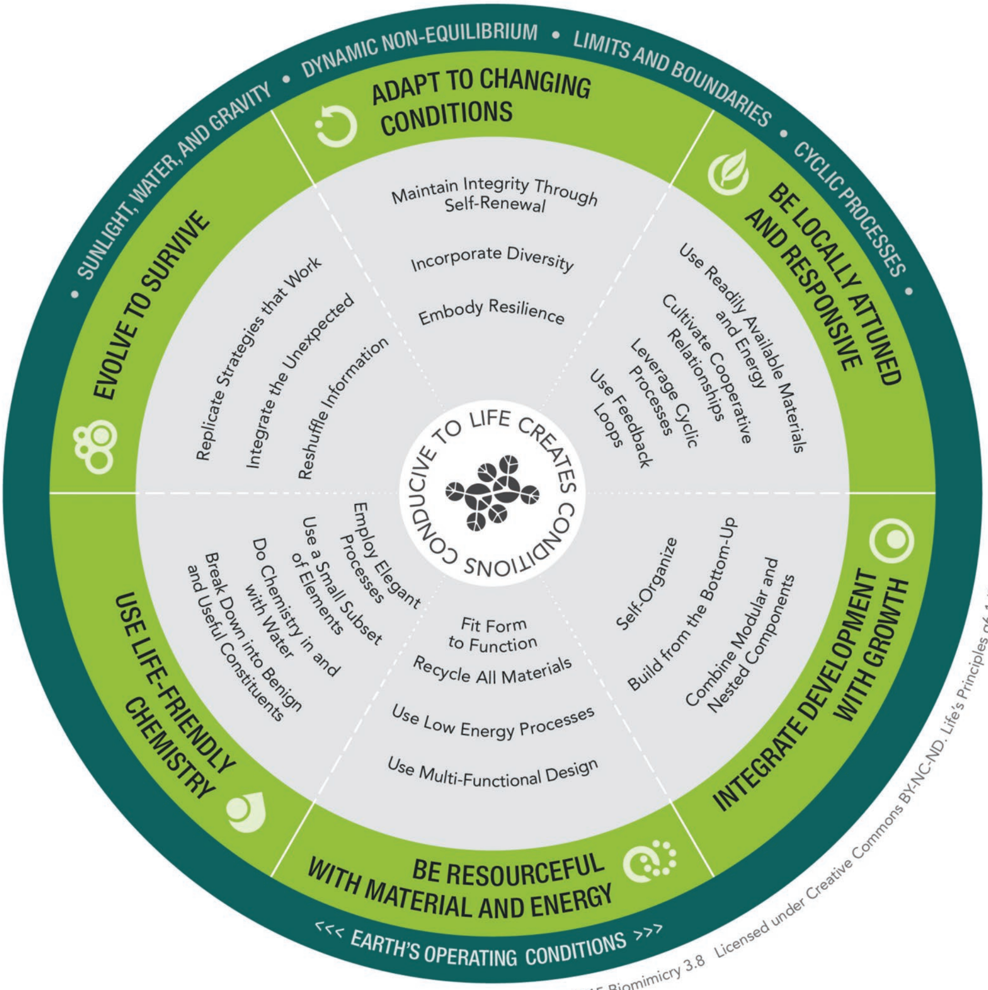

How to Apply #24: Biomimicry from Principles

Time Estimate: 30–120 Minutes

Goal: Generate new ideas to improve your product (or service) using a list of biomimicry principles.

This is the indirect method of biomimicry, brainstorming from general principles of nature that are listed by experts. Not as inspiring or personal as finding a specific design hero in nature, but faster and easier to apply.

STEP 1: Understand and Select Natural Principles

Time Estimate: 10–40 Minutes

Many scientists, designers, and engineers have already identified common ways in which nature designs differently from industry. Three good lists are the Biomimicry 3.8's "Life's Principles" list (see Figure 24.1), Steven Vogel's (2000) list of mechanical engineering principles in the book *Cats' Paws and Catapults*, and the list of other biological principles in this chapter.

Read through one or more of these lists, and pick a principle (or a few) that you think would be most fruitful for improving your product or system's sustainability.

STEP 2: Brainstorm from Natural Principles

Time Estimate: 10–40 Minutes

Now that you've chosen a natural principle, you can use them as design inspiration. Brainstorm how you could improve your product's design based on the principle you chose. Have at least 20+ ideas (50+ is better), and write or sketch them in whatever format you want.

If you chose more than one natural principle, have a separate brainstorm for each one.

STEP 3: Choose Solution and Illustrate

Time Estimate: 10–40 Minutes

After the brainstorm, choose a winning idea (or a couple) that you might want to further pursue. Illustrate it in a sketch, rendering, physical model, or other means to communicate both how it works and why it's a valuable idea.

Optional: to choose intelligently, we recommend using a Whole System Mapping decision matrix, LCA, or other sustainability measurements based on estimated impacts.

Checklist for Self-Assessment

To score your success on this exercise, see if you…

☐ *Clearly identified what principle(s) you brainstormed on.*

☐ *Brainstormed at least 20+ ideas.*

☐ *Chose and clearly described the winning design.*

☐ ***Illustrated the winning design.***