Biomimicry in Architecture

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The inspiration for this class came to me while I was eating peanuts. I have always found nature inspiring in many ways. I was also familiar with the concept of biomimicry. That snack prompted me to make more research and to prepare this class. My hope is to guide you through the wonders of nature and the biomimetic process so that you too can feel inspired. At the end of the class I will tell you more about the peanuts too.

[1]Biomimicry (or Biomimetics) is the science of studying nature's models and taking inspiration from it to solve human problems. Rather than copying how nature looks, it is focused on how nature solves problems.

For example: how can we create wonderful colors without using toxic chemicals? Butterflies have the answer in the microstructure of their wings!

[2]Since the dawn of the industrial Revolution, manufacturers have been building things by a process that is now known as "heat, beat, and treat." The top biologists, engineers and scientists promoting biomimicry find fascinating (and instructive) how nature can do wonders at room temperature, with regular pressure, and by using only the energy of the sun.

Today we will start by:

1. Defining the basic vocabulary and terms that will be used in class
2. Learning about seminal case studies in the field of biomimicry
3. Exploring original ideas of biomimicry applied to architecture
4. Group discussion

We will first review a few keywords like Sustainability, Biophilia, Organic Architecture and finally Biomimicry.

Defining the basic vocabulary and terms that will be used in class

- ➔ Sustainability

[3]Biomimicry is often associated with sustainability. The claim is that emulating natural processes is the way to shift towards a more sustainable society. Sustainability refers generally to the capacity for the biosphere and human civilization to coexist. For many in the field, sustainability

[1] https://environment-review.yale.edu/does-nature-hold-answer-sustainability-biomimicry-ecological-innovation-0
[2] https://www.newsweek.com/biomimicry-turns-nature-factory-72815
[3] https://en.wikipedia.org/wiki/Sustainability

is defined through the BALANCE OF Environmental, economic and social realms. If a technology lacks one of the three, it is not sustainable in the long term.

The Western industrial revolution of the 18th to 19th centuries tapped into the vast growth potential of the energy in fossil fuels.
In the mid-20th century, a gathering environmental movement pointed out that there were environmental costs associated with the many material benefits that were now being enjoyed.
In the 1970s, the energy crisis demonstrated how the ecological footprint of humanity exceeded the carrying capacity of earth, therefore the mode of life of humanity became unsustainable.

In the 21st century, there is increasing global awareness of the threat posed by the human greenhouse effect, produced largely by forest clearing and the burning of fossil fuels. There are at least 3 letters from the scientific community about the growing threat to Sustainability and ways to remove the threat, in 1992, 2017 and 2019.
In the most recent, scientists have declared a "climate emergency" .

Pollution is another result of industrialization as we know it and we do it. While the idea of plastic “islands” bigger than Texas floating in the oceans is not scientifically correct, there is an incredible amount of plastic in the biosphere. It affects our ecosystems FOR SURE, at sea and on the land.

Biomimicry is seen as a sustainable approach to progress also because of its “circular economy” embedded in it. The Lion King movie made it popular: it is the circle of life. In the natural systems, resources are generated, consumed, and then naturally released in nature to start the cycle again, with minimal waste. A linear economy like ours mainly ends up in waste.

➔ Biophilia

The etymology of Biophilia literally means “love for nature”. This goes far beyond the idea that “diamonds are girls’ best friends” - but it captures the base idea.

[4]Cultures around the world have long brought nature into homes and public spaces. Classic examples include the garden courtyards of the Alhambra in Spain, frescos in Faraons’ graves, countless examples in the Asian civilizations, and frescos in Roman villas.

[5] Plinius the Eldest was the first to talk about *hortus,* as a way to domesticate nature into gardens, for leisure purposes. Before Romans, Etruscans loved parks and gardens so much that their cemeteries already included trees and flower beds. Even gardeners!
In Roman times, the best homes would have a courtyard in the center, like this one rebuilt in Pompei. At a public scale, big areas in Rome were destined to green areas for the people to enjoy.

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[4] https://www.terrapinbrightgreen.com/reports/14-patterns/#biophilia-in-context
[5] https://www.capitolivm.it/societa-romana/gli-horti-i-giardini-nellantica-roma/

Biophilia at an urban scale makes lots of sense in dense cities like NYC.
Prior to and even after the Industrial Revolution, the vast majority of humans lived in nature. American landscape architect Frederick Law Olmsted (who designed central park) argued in 1865, that "…the enjoyment of scenery employs the mind without fatigue and yet exercises it, tranquilizes it and yet enlivens it; and gives the effect of refreshing rest and reinvigoration to the whole system".

The term 'biophilia' was popularized by biologist Edward Wilson (Biophilia, 1984). The translation of biophilia as a hypothesis into design of the built environment was the topic of a 2004 conference and subsequent book on biophilic design, edited by Stephen Kellert who is also considered an authority in the field.

Incorporating Biophilic Design in architecture is becoming more and more popular. Many designers are even trying to quantify the biophilia in projects and its benefits. Currently, the firm "Terrapin Bright Green" has been promoting biophilia in design like no others. They identified 14 patterns that architects can follow to include a biophilic approach in their projects. The patterns mainly define how to bring nature in a space, how to create natural analogues, and how to work with the nature of a space itself.

A Great example of biophilic design is right here in Pittsburgh: the Center for Sustainable Landscape behind the Phipps Conservatory. The architect was the local Design Associates, and the landscape was by the also local Andropogon Associates.

- ➔ Organic architecture

Organic architecture refers to designing and building structures and spaces that seem to blend with the landscape or rise from it. As early as 1908, Frank Lloyd Wright, while not the first to use the term 'organic architecture,' began expounding his philosophy of organic architecture. Falling Water is often considered a great example of organic architecture. It was built between 1936 and 1939.

(Principles of Organic Architecture)

1. Shelter: Buildings must serve to protect their inhabitants' safety and privacy.
2. Space: Spaces should flow naturally from one area to the next without formidable separation, yet no room or space should be completely visible from any angle. The use of alcoves and other elements will create a constant sense of discovery as one moves through the space.
3. Nature: Inspiration should be drawn from the natural surroundings, not in imitation of them, but as guides to selecting materials, textures, and colors.
4. Peacefulness: The design should avoid jarring contrasts with the landscape while providing inhabitants with a sense of openness free of clutter and offering a sense of tranquility.

5. Language: Wright saw the patterns and forms of a building's designs as elements of grammar in the building's language. When put together the design speaks, but each construction must have its own unique voice.
6. Ornamentation: If ornamentation is to be used on a building, it must not appear as if it was a decorative afterthought. Rather, it must be an integral part of the structure, seamlessly joining with the overall form.
7. Simplicity: Designs must be clear with a uniform scheme.

Kentuck Knob was built between 1953 and 1956. I really like this project, in particular how:

- It grows from its site, and is shaped as if it was itself created by nature for and from that landscape.
- The windows and the doors are treated as part of the ornamentation of a structure
- Color derives from fields and woods to fit with these natural forms.
- The nature of the materials from which a building is constructed is expressed freely.

[6]German Architect Hugo Haring contributed to Organic theory too. He expressed his belief that every place and task implies a form, and that it is the architect's job to discover it and let it unfold. Functional forms are the same throughout the world and history, while expressive forms are bound by blood and knowledge and thus dependent on time and place.

[7]Antoni Gaudi was also a supreme and passionate master of the organic, the straight line belonged to men and the curved line to God. Always at the bizarre and surrealist end of the organic spectrum, the early medieval, Islamic, and Catalan influences gave way, in his later work such as Casa Mila or Casa Battlo (1912), to extreme plasticity that superbly integrates structure, materials, and sculptural form. He closely observed natural forms, being inspired by the “latest” discoveries in the world of bacteria and viruses, made possible by increasingly potent microscopes.

After F. L. Wright there were other “neo-organic architects” like [8]Reima and Raili Pietilä. They won the design competition for the Finnish Embassy to be located in New Delhi in 1963 with a beautiful and powerful competition entry called “Snow speaks on the mountains”. After a lengthy delay, the Embassy finally opened in 1986 with the large single expanse of the roof of the 1960’s design broken up into six separate lateral buildings around a central garden area. The sculptural roofs - the most significant architectural feature of the embassy compound - resemble the forms of the snowy Lake Kitkajärvi near Kuusamo, Northern Finland.

In more recent years, many architects have also been connecting with nature and the spirit of a place too. [9]This cemetery speaks to the dead and the people that remain. It is a cemetery and park, excavated in the land. In the mid 1990s, Miralles and Pinos conceptualized the poetic

[6] http://www.arch.mcgill.ca/prof/sijpkes/arch374/winter2002/pslizhou/history.htm
[7] http://www.arch.mcgill.ca/prof/sijpkes/arch374/winter2002/pslizhou/history.htm
[8] https://www.archdaily.com/926197/embassy-of-finland-in-new-delhi-renovation-ala-architects
[9] https://www.archdaily.com/103839/ad-classics-igualada-cemetery-enric-miralles

ideas of a cemetery for the visitors to begin to understand and accept the cycle of life as a link between the past, present, and future.

➔ Biomimicry (9:50 am)

As mentioned at the beginning, Biomimicry can generate solutions to many design challenges. It is also known as biomimetics and it is the design and production of materials, structures, processes, and systems that are modeled on biological entities and natural processes.

Janine Benyus wrote the highly readable book “Biomimicry: Innovation Inspired by Nature” in 1997. It is still intriguing today. She is biomimicry’s most famous advocate. [10]It was Otto Schmitt though, an American academic and inventor, to coin the term biomimetics in the 1950s, to describe the transfer of ideas from biology to technology.

*J*anine Banyus has done more than one TED talk explaining that “When we look at what is truly sustainable, the only real model that has worked over long periods of time is the natural world.” She is the co-founder of the Biomimicry 3.8 institute.

[11]The “3.8” in their name refers to the more than 3.8 billion years life has been adapting and evolving to changing conditions on the planet. They claim there are 3.8 billion years of R&D from which humankind can learn to innovate for a better world.

1. Nature runs on sunlight
2. Nature uses only the energy it needs
3. Nature fits form to function
4. Nature recycles everything
5. Nature rewards cooperation
6. Nature banks on diversity
7. Nature demands local expertise
8. Nature curbs excesses from within
9. Nature taps the power of limits (through the evolutive process)

Biomimicry, though, has been inspiring first of all in very literal ways, as in copying directly from nature. Leonardo da Vinci studied birds as he was trying to develop a flying machine.

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10 http://environment-ecology.com/biomimicry-bioneers/367-what-is-biomimicry.html#:~:text=Otto%20Schmitt%2C%20an%20American%20academic,ideas%20from%20biology%20to%20technology.&text=The%20term%20biomimicry%20appeared%20as,Biomimicry%3A%20Innovation%20Inspired%20by%20Nature.

11 https://biomimicry.net/faq/

Or, it can be “bioinspired” and take ideas from nature and modify them with engineering approach, imitating life in a less literal manner, like the case of velcro, developed in 1952 after George De Mestral noticed the curious behaviour of a plant.

- Organism Level: Mimicry of a specific organism
- Behaviour Level: Mimicry of how an organism behaves in a larger context.
- Ecosystem Level: Mimicry of an entire ecosystem.

Learning about seminal case studies in the field of biomimicry

These are some solution developed thanks to biomimicry:

- **Bullet train** and kingfisher
- Improved **Wind Turbines** inspired by Fins, Tails and Flippers
- Fluid Earth developed a **fin for surfing** that increases maneuverability and performance. It is called the Humpback Fin
- Improved **turbines**, that reduce friction and vibrations thx to maple seeds
- **Tidal power**, inspired by fish movement in water
- Mosquito-based **needle**: Japanese micro engineers created a minute needle just one millimetre long and with a diameter of 0.1 millimetres.
- **Self cleaning** surfaces: For the tokay gecko, when its foot detaches from a surface the animal is walking on, its toes have the ability to hyperextend: the toes peel off the surface starting at the tip, and curl up away from the surface (human fingers, for comparison, cannot voluntarily hyperextend, and are much more functional in flexion). When the setae at the tip of the toe are first pulled, they stretch a little and store elastic energy as the spatulae are still attached to the surface. As the toe continues to curl up, the setae suddenly detach from the substrate. Their stretchy nature and ability to spread out as the toe curls up and back results in a flinging motion that can dislodge particles caught on and between the spatulae.
- **Sharklet film** for medical devices

Biomimicry in architecture

- Natural Proportion (the golden proportion and fractals in facades)
- Natural Geometries (Frank Lloyd Wright)
- Natural Structure / Biomorphism design based on nature’s shapes and forms (Sagrada Familia)
- Natural Structure (Calatrava Oriente Station)
- Natural Patterns (anti-bird collision glass)
- Natural Systems (termites and jackrabbit)

- Natural Processes (self-healing concrete) [12]Self-healing concrete is a product that will biologically produce limestone to HEAL CRACKS that appear on the surface of concrete structures. Specially selected types of the bacteria genus Bacillus are added to the ingredients of the concrete when it is being mixed. When a concrete structure is damaged and water starts to seep through the cracks that appear in the concrete, the spores of the bacteria germinate on contact with the water and nutrients. Having been activated, the bacteria convert into insoluble limestone. The limestone solidifies on the cracked surface, thereby sealing it up. It mimics the process by which bone fractures in the human body are naturally healed by osteoblast cells that mineralise to re-form the bone.
- Natural Processes - BioMASON: Mimics the way shells harden to GROW BRICKS, kiln-free. Seashells are composed of calcium carbonate, commonly found in limestone. The inventor (a female architect!) wondered if biologically made calcium carbonate could replace cement and make concrete bricks. She now uses a Bacillus strain that's naturally occurring (no genetic modification) and it doesn't cause diseases. The organism creates a microenvironment that enables the formation of this calcium carbonate [limestone] crystal, by altering the pH balance of the surrounding aggregate material. This allows calcium carbonate to grow and bind the material together with little to no carbon emissions. "It's similar to what microorganisms do [to make] coral reefs. Bricks are ready in 72 hours.
- Natural Processes - BioRock Pavilion: The proposal is to grow a building through electro-deposition of minerals, using 'BioRock' - patented technology developed by Wolf Hilbertz and Tom Goreau. [13]You put a steel frame in the seawater, you pass a very low-level electric current through it, perfectly safe for wildlife, and you get fairly rapid deposition of minerals on that steel frame. After about a year, it can be 20-25 mm thick and it can be as strong as reinforced concrete. This would be the first time that a building had been grown from minerals, grown in the sea. They try to capture the excess carbon in the atmosphere, inspired by the coccolithophores and other marine microorganisms that have boomed during periods of higher atmospheric CO2 concentrations.

(10:15 am)

- Natural Structure - Birdsong Pavilion[14] by Exploration Architecture. The bones and the skulls of birds are light and strong. Built up of fine layers of bone connected by tiny struts, they combine dome and space-frame technologies. "Conventionally, it's been very difficult to mimic the complexity of biology without a huge cost penalty," he says. But now, with additive manufacturing processes placing material precisely and only where it's needed, there's no cost premium, says Pawlyn, "and there is actually the potential to save money by using less material. 'In biology materials are expensive and shape is cheap' (Professor

[12] https://www.ingenia.org.uk/getattachment/Ingenia/Issue-46/SelfHealing-Concrete/Arnold.pdf
[13] https://biomimicry.org/michael-pawlyn-biomimicry-climate-change/
[14] https://continuingeducation.bnpmedia.com/courses/multi-aia/biomimetic-materials/1/

Julian Vincent). A bird skull is made from extremely thin layers of bony material connected with struts so that it combines the efficiency benefits of a dome and space frame technology.

- Natural processes - DO|SU InVert shading system: InVert is an insulated glazing unit, is now market-ready. Its integrated shading device consists of a matrix of small, leaf-like pieces of thermobimetal inserted as an interlayer between the panes. As the pieces heat up in the sun, they toggle on a little pivot to lie perpendicular to the sun angle, shading the inner pane; as the sun moves on and the pieces cool, they toggle back.
- This is “THE biomimetic office”, as designed by Michael Pawlyn (an institution in Biomimicry in Architecture) and his firm Exploration Architecture. It strives to achieve maximum sustainability and efficient use of resources (electricity for illumination but also less steel for the structure). It is inspired by the eyes of a fish and the way it captures light even if deep in the waters. The fish has mirror-shaped structures in its eyes. That led to the idea of this pair of reflective surfaces in the atrium that bounce light into the other parts of the building. It uses glass shaped like lenses and the wavy shape itself is optimized to refract light deep in the building.
- ➔ [15]The Eden Project is a popular attraction in Cornwall, England, and it is home to the world’s largest indoor rainforest. It was designed by Grimshaw Architects and opened in 2001. Inside the two biomes are plants that are collected from many diverse climates and environments. The project is located in a reclaimed china clay pit on a piece of land that is irregular and continually changing. Soap bubbles provided a model for generating a building form that would work regardless of final ground levels. Studying pollen grains, radiolaria, and carbon molecules helped the team devise the most efficient structural solution using hexagons and pentagons. [16]If you want to pack together cells that are identical in shape and size so that they fill all of a flat plane, only three regular shapes (with all sides and angles identical) will work: equilateral triangles, squares, and hexagons. Of these, hexagonal cells require the least total length of wall, compared with triangles or squares of the same area.

➔ Beyond Biomimicry

- **Natural Metabolism**: Philip Beesley is a visual artist, architect, professor and director for the Living Architecture Systems Group in Waterloo, Canada. His research focuses on the issues of reactive and interactive systems. His creations often have movements modelled on the behaviour of natural elements. They are

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15 https://www.fenner-esler.com/blog/biomimicry-nature-as-design-inspiration/#:~:text=The%20Eden%20Project%2C%20a%20popular,most%20fertile%20ground%20for%20Biomimicry.&text=By%20emulating%20nature's%20genius%2C%20the,gracefully%20provide%20these%20ecosystem%20services.

16 http://nautil.us/issue/35/boundaries/why-nature-prefers-hexagons

poetically high-tech. Architecture refers to bioscience usually in terms of biomimicry and symbolism, referring to natural organisms and how they evolve, but I think there are other sciences that can be matched with architecture speaking in terms of metabolism and information. Classical design teaches that the environment needs to be mastered. Instead we can move into a mutual relationship, so there will be a renewed sense of sharing on how a human being works in the world.

- **Artificial Intelligence**: ADA by Jenny Sabin and Microsoft [17]is a cyber-physical architecture that immerses visitors in an interactive glow of photoluminescence." Its lightweight, digitally knitted structure consists of responsive and data-driven tubular and cellular components. Sensors in the pavilion and throughout the building collect indications of emotion, such as facial patterns and voice tones, from visitors choosing to participate. "It's an interactive, human-centered project that celebrates AI," says Sabin, "an architecture that is happy to see you and smiles back at you."
- **Bio-Informed Design**: Neri Oxman is going beyond biomimicry and toward the realm of bio-informed design (put simply: the augmentation of objects and buildings with biological materials that can adapt, respond, and potentially interact with their surroundings). Imagine you buy flowers and put them in a vase that can fertilize them, change color according to their lifecycle, and help them biodegrade after they've withered. Oxman calls it "Material Ecology"[18]. She is an associate professor of media arts and sciences at the MIT Media Lab where she is 3D printing with biologically-derived polymers. Oxman and her team have explored how to apply chitin to an architectural scale. Chitin is the second-most abundant biopolymer on earth. Through millions of years of evolution, chitin was chemically composed to generate stiffer and softer areas, e.g. accommodating different functions around the crab's body.
- Neri Oxman's Silk pavilion explores the relationship between digital and biological fabrication on product and architectural scales. The primary structure was created of 26 polygonal panels made of silk threads laid down by a CNC (Computer-Numerically Controlled) machine.

Other ideas of biomimicry applied to architecture (10:25 am)

Biology to Design is most appropriate when your process initiates with an inspirational biological insight (including a Life's Principle) that you want to manifest as a design.

Challenge to Biology is a specific path through Biomimicry Thinking. This is useful for scenarios when a specific problem is at hand and you are seeking biological insights for the solution.

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[17] https://www.jennysabin.com/ada
[18] https://www.surfacemag.com/articles/neri-oxman-material-ecology/

A Biomimetic process: Biomimicry Learning Methodology according to the Biomimicry Institute "Design Lens" [19]

1 - DISCOVER Natural Models
2 - ABSTRACT Biological strategies
3 - IDENTIFY Function
4 - DEFINE Context
5 - BRAINSTORM bio-inspired ideas
6 - INTEGRATE life's principles into design solution
7- EMULATE Design Principles
(8 - MEASURE Using Life's Principles)

- Peanuts (Biology to design - Structure at a micro scale - Materials science)
- Bees Wings (Challenge to Biology - Shape at a macro scale - Architecture components)
- Moso Towers (Biology to design - Structure at a micro scale - Structural Engineering)
- Ecological Cities (Challenge to biology - Ecosystem scale - Urbanism)

Conclusion (10:45 am)

Biomimicry asks designers a better question: what do you want your design to DO? It also introduces a different approach to nature, which is no longer characterized by the domination and exploitation of nature, but by learning and exploration. Supporters of biomimicry claim that biomimetic technology is also ecosystem-friendly.

By 'doing it the natural way', our technological innovations can claim to be better embedded in, and in harmony with, the natural ecosystems of planet earth. An article titled: "Nature Does It Better", quotes Sigrid Adriaenssens, an engineering professor at Princeton, saying << [20]Biology offers lessons in hyper efficient resource stewardship and circular economies. Nature also practices a kind of "critical regionalism," the belief that architecture should reflect the geography and culture of its setting.>>

[21]A recent study, though, challenges this optimism, stating that the concept of biomimicry itself and its implications are philosophically underdeveloped (if not a way for scientists to feel more "sustainable"). Biomimicry does sit between two extremes: technology versus nature, discovery versus intervention, (technological) exploitation versus (ecological) exploration.
[22]The study distinguishes the concept of strong biomimicry, where nature is seen as a measure by which to judge the ethical rightness of our technological innovations that MIMIC nature, and

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[19] https://biomimicry.net/the-buzz/resources/designlens-biomimicry-thinking/

[20] https://www.autodesk.com/redshift/biomimicry-in-architecture/#:~:text=Biomimicry%20is%20the%20imitation%20of,processes%20that%20occur%20in%20nature.

[21] https://www.researchgate.net/publication/285805738_Innovation_inspired_by_nature_Biomimicry

[22] https://link.springer.com/article/10.1007/s10806-015-9596-1#:~:text=of%20planet%20earth.-,The%20strength%20of%20the%20strong%20concept%20of%20biomimicry%20is%20that,systems%20that%20already%20exist%E2%80%94natural

weak biomimicry, which recognize we are NOT duplicating nature, but rather being inspired by it.

I believe that [23]we cannot continue with our view of nature as something to be conquered and plundered. I also think that biomimicry is not necessarily sustainable: in fact, it can be quite energy consuming (in particular at the early stage of research and implementation).
This said, there is enormous potential for the future and a lot to learn from nature. For me, this is not the end of the journey, but an encouraging beginning. I hope you are feeling just as inspired as I am.

https://www.fastcompany.com/90423161/this-mushroom-building-cleans-our-air-as-it-grows

[23] https://www.dezeen.com/2019/10/07/michael-pawlyn-architects-declare-interview-regenerative-architecture-2/