Applying Nature's Solutions to Architectural Problems

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Abstract

Nature has inspired architecture for millennia and recent discoveries allow designers to understand the wealth of biological information further. The architectural profession is at a critical point in history with regards to reducing its impact on the environment. To truly minimize a building's impact it needs to interact more holistically with its surroundings. The lessons learned from natural systems can be applied to architecture to lessen its environmental impact, and this is a critical point to ask: Will architects utilize construction technology as well as advanced scientific knowledge to create an architecture that behaves like nature? Imagine a building that can convert carbon dioxide to oxygen and during the process efficiently converting sunlight into energy.

The Architecture + Biomimicry course was set up so students could specifically address this question and explore these possibilities. Research of literature and experts helped the students seek an answer to 'What would nature do?' This knowledge was then applied to an architectural solution that addressed the original challenge they selected. Work culminated in an exhibit and was attended by numerous faculty and students from cross-disciplinary fields (including engineering, interior design and sustainability). Discussions with these professors planted the seed for this course to expand and coordinate with their courses. This will lead to a new interdisciplinary approach to seeing and solving challenges in a new light.

Students will learn to look beyond the forms in nature and understand the principles behind them in order to create effective solutions to environmental issues; for example carbon dioxide emissions. Which will require the construction industry to look beyond itself and look to nature with its array of plentiful, creative appropriate designs. Since buildings account for thirty-nine percent of carbon dioxide emissions in the United States, these designs provide crucial for architects to learn from.

Keywords: Biomimicry, Biomimetic, Design, Carbon Dioxide, Building Envelope

Why Biomimicry and Architecture

Looking beyond architectural design to nature is not a new idea. Architect Petra Gruber states, "Researchers and scholars, who have used biological role models for their work, can be found very early in history."[1] DaVinci, Gaudi and Fuller showed how nature inspired their work. If these innovative historical designers looked to nature for inspiration shouldn't today's architects do the same? Especially with our knowledge of architecture's impact on the environment and advanced knowledge of how nature functions.

There are many terms to describe this process: biomimicry, biomimetic, bioinspired, bionik, and biogenesis. For simplicity, this course and paper used the term Biomimicry, the title of the book by Janine Benyus in 1997. In this, she says that "Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems…" [2]

Today we know more than past generations about nature's principles and also have better understanding of our impact on the environment. Therefore, it is important to teach architecture students to utilize this knowledge and learn how nature solves similar problems we are attempting to solve. Gruber agrees, “The study of the overlapping fields of biology and architecture shows innovative potential for architectural solutions. Approaches that have been taken to transfer nature's principles to architecture have provided successful developments.” [3] Furthermore, innovative architect Frei Otto declared, “Not only has biology become indispensable for building but building for biology.” [4]

This interest in the connection between building and biology was evident in being invited to present at the American Institute of Architects (AIA) National Convention in 2007. The theme that year was “Growing Beyond Green”. This led to more presentations on biomimicry to AIA chapters in Nashville and Denver.

Architects working on small scale projects up to urban scale design projects were seeing the viability of applying biomimetic principles in their projects. In Denver, the architects that taught at the University of Colorado Denver, also saw the importance of teaching students these principles and had them attend this presentation. The feedback from these students influenced the shift to focus on biomimicry and architecture research in the academic setting.

Academic Setting

In 2009, I introduced this biomimicry approach to students in an Urban Design studio. We applied nature's solutions to urban issues. One of the main lessons learned was how differently this type of thinking was from the standard design approaches taken in studios. Typically, the student comes up with a concept for the problem defined in the project description. They often create multiple options and then, with the help of the studio professor, select the best option to develop. After pin ups and critiques, this option is fine-tuned for the final project.

This pattern is repeated project after project and semester after semester. The building type will change as will the approach of how to conceptualize and develop the design. But the framework and mindset remains the same. Taking a biomimetic approach interrupts this process. A detailed description is given later in this paper, but the main interruption is how a student comes to their final project. Instead of coming up with a concept quickly, the biomimicry approach causes the students to spend a long time defining the problem before coming up with a concept. Consulting with scientists is another interruption that students have to adjust to doing.

Biomimetic Building Skins Masters Research

Being able to teach this process is a result of not only teaching it in a previous class, but also from lessons learned by completing my master's in architecture degree. The thesis was to look at how building skins could function similar to tree bark. It was a result of trying to solve two major problems in architecture: energy inefficiency and loss of place. Trees are literally rooted in place and their bark is a reflection of this place while also providing protection, thermoregulation and conduits for food and water. Buildings perform these functions, but we would do well to perform similar to these natural systems.

Trained as an architect, this biomimicry process of design proved a difficult hurdle. To help, the first year was spent consulting with just scientists. Diagramming was a common communication method to help explain architectural skins (Figure 1) and for scientists to explain photosynthesis for example.

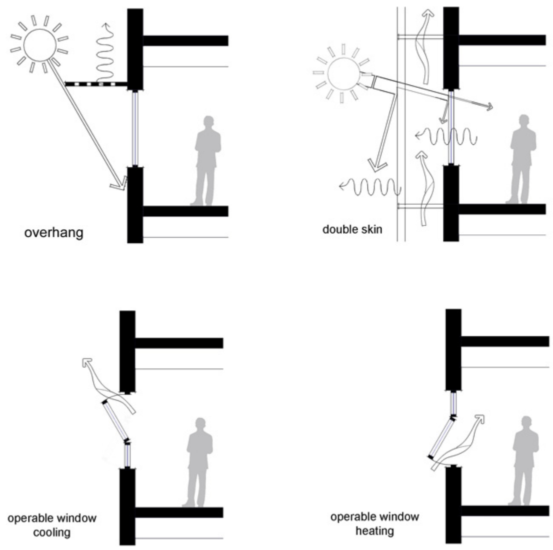

Fig. 1. Diagrams of existing building skin strategies.

The back and forth communication format proved helpful. Diagrammatic explanations eventually led to being able to understand tree bark and its direct comparison to building skins (Figure 2).

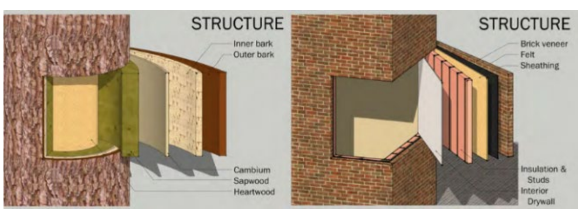

Fig. 2. Diagram of structure of building and tree skin.

Learning from their focused scientific approach and how they analyzed the organisms they studied proved to be a valuable methodology still applied to teaching today. Looking outside of the construction industry also led to being one of seven fellows at the Nature, Art & Habitat Residency (NAHR) program in Taleggio Valley, Italy during the summer of 2016.

Biomimicry and Architecture at Oklahoma State

Expanding upon this experience, a new course was created in the Architecture School at Oklahoma State University (OSU) in the spring of 2018. The focus of the course was to move beyond just form and copying how nature looks. A quote by architect Michael Pawlyn summarized the approach to the class, 'The intention is therefore to transcend the mimicking of natural forms and attempt to understand the principles that lie behind those forms and systems.' [5]

Biomimicry Design Spiral

With this mindset, the overall methodology framework was based upon the Biomimicry Design Spiral (Figure 3). The Biomimicry Institute says that it 'provides a succinct description of the essential elements of a design process that uses nature as a guide for creating solutions.' [6]

It breaks down the process in clear steps and format was used to layout the project assignments and steps to solving the design problems.

Fig. 3. Biomimicry Institute's Design Spiral

First Steps

Showing the students what has been and is currently being done laid the foundation for them to build upon. Specifically, investigating what other universities have a biology and architecture program. These schools included Georgia Tech, Arizona State, Minneapolis College of Art and Design, and the Architectural Association School of Architecture in London.

Additionally, the following literature was recommended to introduce biomimicry and architecture: 'Biomimicry' by Janine M. Benyus, 'Emergent Technologies and Design' by Hensel, Menges & Weinstock, 'On Growth and Form' by D'Arcy Thompson and 'The Gecko's Foot' by Peter Forbes.

Project 1 – Group Presentations

For the first week-long project, the twenty-three students gave group presentations on an innovative architect or engineer working with biomimicry (listed below).

Buckminster Fuller	Haresh Lalvani	Achim Menges
Frei Otto	Neri Oxman	Michael Pawlyn
Jenny Sabin	Doris Kim Sung	Julian Vincent
Michael Weinstock	Jeanette Yen	

Studying what these innovators have built, researched and written about their processes proved invaluable. It allowed them to see how to go deeper than just form when relating design to nature and also pushed them to go further with their ideas while seeing the historical context in what they are proposing for this class. For example, both Fuller and Otto were concerned with lightweight structures and minimal surface areas. Also, the students learned how each approached these concerns with different methods. Fuller explored the strength in geometric patterns of microscopic organisms while Otto studied soap bubbles as a form finding exercise. In these, the students saw that there are multiple ways to approach the same problem.

In addition to looking at historical precedents, students researched current academic work. Achim Menges's investigation of shell structures at the University of Stuttgart and USC's Doris Kim Sung taking inspiration from human skin pores revealed the variety of similar biomimetic research. Pioneers in their respective fields, architect Michael Pawlyn and engineering professor Julian Vincent, showed the students they needed to take their ideas to a more thorough functional level and not be satisfied with simply mimicking shapes.

Project 2 – Distill

With this foundation, the students spent a week and identified current problems with the built environment. Categories created were: building interiors (i.e. indoor air quality), building systems (i.e. wind power), construction, urban design and materials. Each student then selected a single problem to develop based on their specific interest. Problems they researched ranged from lighting, efficiency, and insulation to material improvements (preventing wood rot, self-healing and non-toxic) to adaptable parking, road construction and safer road intersections for bicyclists.

The standard architectural studio approach would be to jump in to creating concepts on how to solve this problem. However, working with the biomimicry design spiral, the students spent two weeks defining the problem by investigating why it was a problem, what essential issues were, and what attempts had been made to solve it.

Project 3 – Translate

With the problem clearly defined, the next step was to translate it to biology. To seek out how nature solves the problem, an important question to ask is, "What would nature do here?" Simply using the original design to answer that question, it would be difficult to research. For example by asking. "How does nature make cycling at night safer?" It is better to biologize it and ask "How does nature enhance visibility in low light?" Seeking answers will lead one to identify the functions of the problem, reframe the questions and translate design parameters. Class presentations were also given to give insight into this process.

For two weeks, the class studied how nature uses feedback loops, how it operates with its diversity and design, symbiosis and nature's patterns. Nature repeats certain forms that conserve resources using the least amount of energy. Understanding how nature utilizes these patterns is invaluable for architects designing energy and resource efficient buildings.

One example presented was the 120 degree pattern. Seen in the honeycomb cells of bees, this pattern lets the bees minimize the amount of wax they use, while providing a strong structure to store honey. Approximately thirty percent less material is used with this pattern when compared to using a 90 degree grid. Scaling, fractals, symmetry, and spirals were other patterns discussed. Effective transportation flows were seen in the pattern of branching. Rivers transport water efficiently, lighting dissipates electricity efficiently, and plants and blood vessels move water and nutrients efficiently all with the pattern of branching. Discovering these repeated patterns in nature's design helped the students make a connection to the next phase.

Project 4 – Discover

After weeks of investigating, asking questions, reading and presenting, the students were ready to design. But it still wasn't time yet; students spent two more weeks discovering natural models. There was some frustration at this point in the semester since it was different than their standard process in a studio. Discovering natural models was the last step before they could begin what they consider 'designing'.

To help and find the strongest examples, it was good to consider the so called champions in nature that specifically solve their problem. These champions are typically found in extreme environments. For example, the desert or the arctic. It was also a beneficial exercise to utilize proper terms for natural systems and use terminology used by researchers being studied. For example, when looking for how design relates to its local environment, architects often use the term 'regionalism'. Scientists, however, use the term 'speciation' to describe the development of species in a region.

Project 5 – Emulate

With the knowledge of these natural strategies, the students could finally begin to seek design solutions to the problems they had clearly defined. For four weeks, they created multiple concepts based on work in projects three and four in addition to the literature, professionals presented on, and the work in other universities.

Final Project - Communicate

The semester culminated in an exhibition of the students' work. Standard final presentations just show the finished design and presentation boards. For this exhibit, however, in addition to their final design, process work and research was also included.

Specific Student Examples

Two student projects below show this process in detail.

Victoria R. – Macro Stomata

The problem Victoria was proposing to solve dealt with light in buildings. The question she asked was "How can we control the quality and quantity of light inside buildings through sustainable materials and structure?" She saw that many glazing and façade designs function like units of separate systems. Which leads to a disconnect of controlling the light on the interior leading to glare, heat gain on one end and no connection to the outdoors on the other end. Both extremes create an uncomfortable interior for users. Environments that have the proper amount and quality of daylight increase occupant productivity and comfort. Controlled, it also helps with the heating and cooling loads on the building.

Victoria began to biologize the issue and explored how it was possible to create a symbiotic relationship between the building's structure and skin. She sought to discover natural models where material functions as the structure and the system.

For the Discovery phase, she focused on two organisms: cactus and the glass sponge (Figure 4). The cacti, because it is designed to survive in the most extreme hot conditions. She found that they embody self-shading and self-harvesting properties that could translate to a building's façade. Chemical and structural compositions were explored in the glass sponge.

Victoria formulated questions to further her knowledge of these two natural systems. How does the structure of cacti allow them to develop variable heights? How do glass sponges filter light so deep below sea level? How does materiality in glass sponges have an effect on how light is processed?

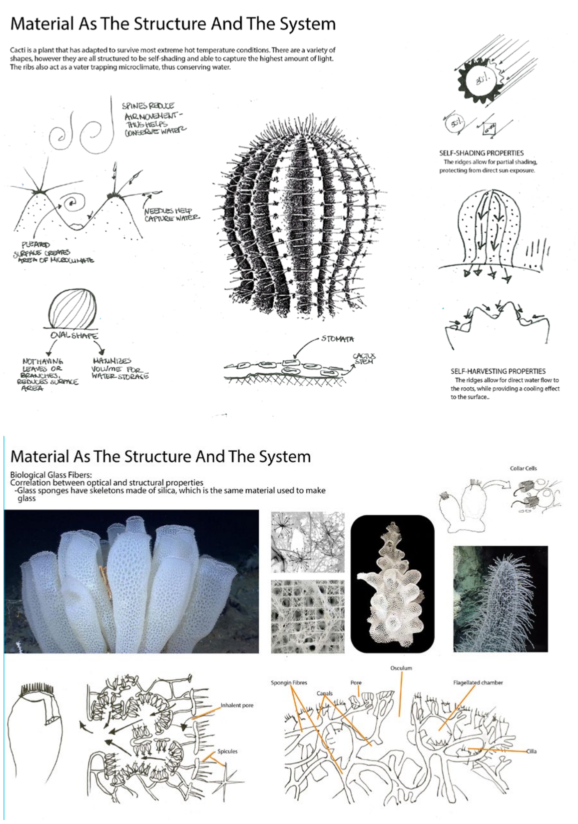

Fig. 4. Victoria's Discovery of Cactus and Glass Sponge

In answering these questions, she focused on cactus for the inspiration organism. She researched numerous cactus pecies and analyzed which best addressed her defined problems. Through further research into literature and scientific work, she concluded that the Saguro Cactus encompassed the two fundamental goals of her project: light control and material as structure.

First, the plant is adaptable and uniform. It is able to survive in this harsh environment up to two hundred years. Second, the Saguro cactus is the largest cactus in the United States, growing up to thirty to forty feet tall. [7]

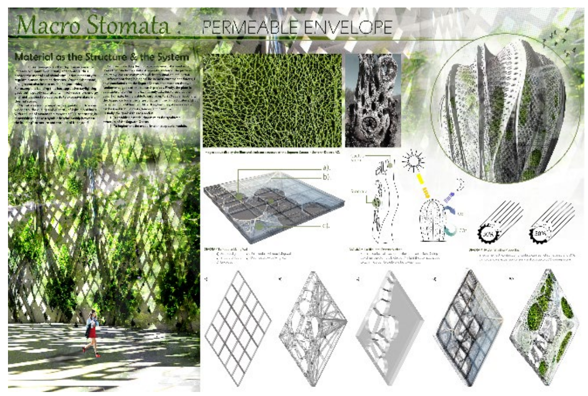

Fig. 5. Macro Stomata Final Board

Creating a building skin based on the fiber and skeleton structure of the Saguaro Cactus was completed for the Emulate phase (Figure 5). She designed a modular living wall composing of structural fibers woven in a structural skin creating a stomatic surface allowing contraction and expansion. Similar to the natural system, this skin can filter carbon dioxide and oxygen through this movement.

In addition to the skin filtering, it was designed to have self-shading properties. In extreme heat, contraction of the surface can restrict sun exposure and in cold temperatures, its expansion allows sun exposure.

Holly S. – Algal Energy

Reducing the urban heat island effect was the problem Holly proposed to solve with her design solution. The materials, dark surfaces and lack of vegetation in urban spaces absorb heat and raise the temperature in these areas. These structures and surfaces also radiate heat when the sun goes down. Energy efficiency is greatly reduced in structures as a result. In her research, she found that some attempts have been made to combat the urban heat island effect by adding vegetation and light colored roofs.

She sought to discover how plants help combat the urban heat island effect. [8] They lower air temperature through evapotranspiration, which is the process where they evaporate water through their leaves. In the Discover Phase, she focused on algae and how it covers a body of water and lowers the water's temperature. As it spreads out on the surface, it speeds up the efficiency of photosynthesis, rapidly spreading out more and making shade for the environment below. Additionally, she found that this algae converts sunlight and carbon dioxide into an oil it uses for energy. Other systems Holly explored were how whales regulate their temperature and into electric eels that are able to produce a sizable amount of electricity.

She focused on algae mainly because of its temperature reducing qualities, but also because of its ability to produce large amounts of energy. Plus, it has been used in a similar manner in buildings. In an article about Arup's Bio Intelligent Quotient building in Hamburg, Mark Hay states, "Producing about five times as much biomass per square foot as soil grown plants, and thriving on carbon dioxide, algae have the potential to grow almost limitlessly and produce oily lipids and gases that can be transformed into relatively clean energy." [9]

To emulate this, she proposed to create a skin with algae that shades the building while the film still allows for evapotranspiration, cooling the air around it. The panels tilt away from the building, following the movement of the sun to maximize photosynthesis and shading. The waste water and carbon dioxide waste from the building can be converted into usable nutrients for the algae.

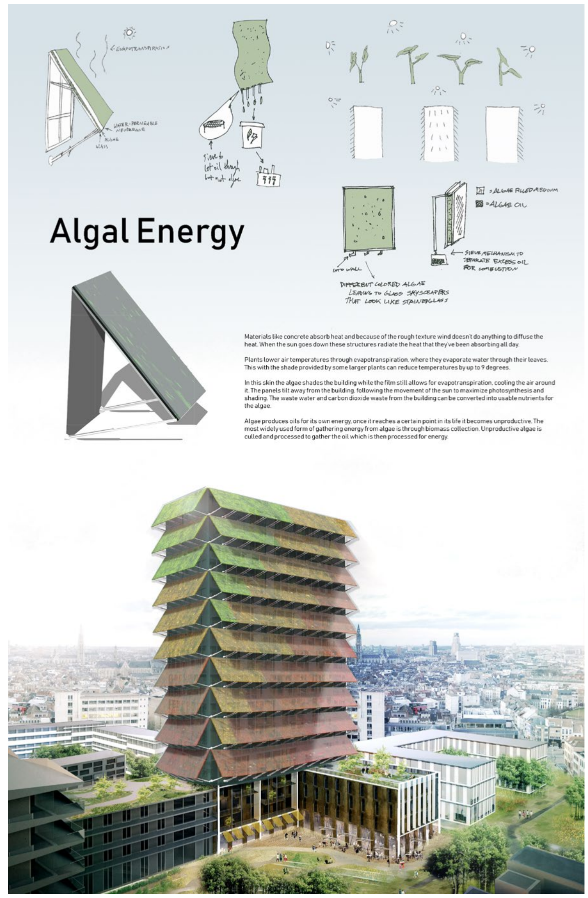

Fig. 6. Algal Energy Final Board

The panel is comprised of a layer of glass, a framework with algae covered in a water-permeable membrane and has a sieve at the base that lets oil through but not the algae. This excess oil can be used for fuel. These panels can be used in new buildings or retrofitted to older buildings. Holly also proposed to use different colored algae and in this framework, thus causing the glass skyscraper appear to be clad in contemporary stained glass (Figure 6).

Pedagogical Innovation

These two examples represent similar work done by all twenty-three students in the Biomimicry and Architecture class. The process was not only distinct from other studio classes, but also from typical biomimicry class currently being taught. It is becoming common for architecture students to look at natural organisms to apply to their design. This course looked deeper into the problem being defined and then explored principles of natural systems that applied to these detailed, defined problems. Each of the twenty-three architecture students spent most of the semester reworking how they approach the design training they had received thus far in their academic training. As described, the Biomimicry Spiral provided the overall framework to design a solution to the problem each student defined. To help with this innovative process required a series of detailed assignments to push the students to think differently.

It is typical to have a problem to solve in design studio. Here, however, the students had to ask: Why this was a problem? What were the elements of the problem? How are others trying to solve this problem?

Translating the problem was the most irregular, and therefore difficult, step for the students. One assignment had them breakdown the functions and context of the design question they posed. Not looking for answers yet, just posing questions. Following this, assignments had them think critically about the functions at the heart of the outcome their design question is trying to solve. Also, to consider including relevant opposites or tangential functions that may be worth exploring.

After this step, each were assigned to define relevant contextual factors and use biologically-relevant terms to describe the context in which their design must function. What terms do scientist use to describe the functions studied? Using these terms helped them look at the problem in a new language and see the biological strategies nature used to solve a problem. Taking this approach was another area that made this class unique from standard architecture and biomimicry courses.

When students went to Discover their natural models, the students researched the literature. To explore further, they had to list a variety of organisms and in addition to the literature, study research by scientists and look for patterns these natural systems had that addressed their problem. The class also had to write why they chose these particular organisms.

Students then rewrote the strategies previously defined using architectural terms but staying true to the science. Their assignment for this stated that the design strategy should clearly address the function they want to meet within the context it will be used. It was not to be a statement about the design or solution; it was a launching pad for brainstorming possible solutions. Repeating this step proved necessary since designers almost immediately begin making design statements.

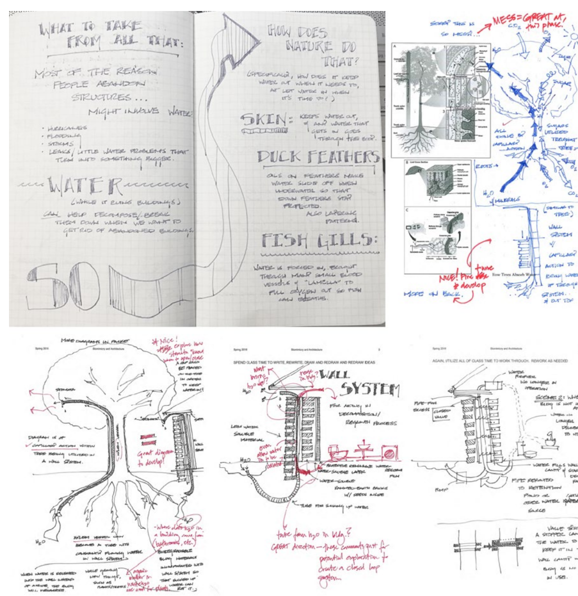

Fig. 7. Various in depth assignments

After much writing, the students created multiple diagrams based on these strategies while they began the Emulate Phase of the project. These drawings were to depict the design strategy based on their thorough research not simply a copy of the biological strategy. It was meant to focus on the functional elements in the natural system. A step to help with this was to have them imagine the strategy like a mechanical system or process diagram in order to draw it without depicting biological parts. Next, students reviewed and refined these diagrams to see if they gained any new insights or confirmed existing design approaches (Figure 7).

Conclusions

While this process proved beneficial, reflections on the class reveal steps to improve. Mainly to bring in scientists early in the process as collaborators. Architects already use the expertise of consultants in specific areas like structural and mechanical systems. Consulting with experts in scientific fields can benefit designers in the same manner. Their knowledge of the natural world and the applicable technology will continue to advance how architecture can create more energy efficient buildings. Doing so will require us to change our thinking and to not keep repeating the same approaches. Improving how our buildings work with nature will require a deeper understanding of how nature works.

The methodology for this class gave students a unique approach to create innovative design solutions. Applying nature's principles, clearly defining the problem at multiple levels, and exploring appropriate scientific research all made for an original course. Dealing with carbon dioxide, water, transportation, energy and structure can all be improved by emulating nature's time-tested strategies. It can lead to more environmentally efficient buildings but this process also provides an innovative design process since the students make a thorough investigation into the problem. Unexpected solutions were created by taking this innovative design approach which benefits the students in future design courses. It will help them to look beyond the construction industry, but more importantly to explore the essence of the problems they want to solve. Which will also create a heightened awareness of the world around them, architecturally and naturally.

Our understanding of this natural world and the problems like increased carbon dioxide levels is higher than it has ever been. How the architecture community, starting at the academic level, utilizes this knowledge is at a critical point. Looking at the problem they are trying to solve and using the current scientific knowledge available will cause the student to build on the shoulders of giants; DaVinci, Gaudi, Fuller and Otto for example, who took their inspiration from the natural world.

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