Exploring the Biomimetic Design Process

I. Introduction

The emerging biomimicry field fascinates me because it learns from nature, rather than extracts from it. In addition to imitating nature merely in aesthetic form, biomimicry imitates the efficient functions of nature as well – revealing a magnificent aesthetic and functional potential in architectural design. Nature has already solved many problems in the building industry such as energy production, ventilation, lighting, and waste and water management, and thus can serve as an insight to solving sustainability challenges today. For example, termite mounds have been replicated as an efficient means of natural ventilation; honeycombs, leaves, and nautilus shells have been studied as a way to increase a structure's strength to weight ratio; and the properties of soap bubbles have been used in the design of tensile structures. The applications of biomimicry to the field of architecture and structural engineering are endless.

A comprehensive study of current literature on the subject reveals research focusing on the outcome of projects utilizing biomimicry, while excluding the method of arriving at those solutions. In order for the application of architectural biomimicry to continue to expand, architects and engineers must become knowledgeable of the process of its implementation. Exploring the effectuation of biomimicry in current architectural designs and engineering projects would allow others to learn from these experiences and create sustainable, biomimetic designs of their own. Projects and firms implementing biomimicry have increased exponentially in the past few years, signaling that this is a significant direction in which the field is heading in the future. I travelled throughout Europe during the summer of 2016 meeting with different architects, engineers, professors, biomimetic experts, and researchers, as well as visiting various project sites to explore how biomimicry, both in product and process, can help buildings be beautiful, sustainable, and economically feasible.

II. Definition

Biomimicry is a recently emerging field, thus, there are a number of different definitions circling through the industry. Michael Weinstock, head of the Emergent Technologies program at the Architectural Association, defines biomimicry as the “embedding of engineering based on nature in material systems” (Weinstock). Julia Ratcliffe of Expedition Engineering defines biomimicry as “learning from nature, rather than mimicking it visually” (Ratcliffe). Biomimicry differs from biomorphism in the way that it examines natural organisms and processes in order to improve a building’s sustainability, function, and efficiency. This process also certainly generates aesthetically pleasing designs through the beauty and ingenuity of nature, but biomimicry is not employed solely for the purpose of making a building to visually resemble something in nature. This would be deemed as biomorphism.

III. Inspiration to Pursue Biomimetic Design
Inspiration to pursue biomimicry comes from a variety of places and is unique to each designer. This original inspiration often guides the course of designers’ following work. For example, in his early twenties, Michael Weinstock, now Director of the Emergent Technologies program at the Architectural Association in London, read the Voyage of Beagle, prompting him to spend ten years sailing and building ships (Weinstock). Through the experience, Weinstock felt an inherent connection to nature, the environment, and physical materials, cultivated through many years of tactile, hands-on building work on ships (Weinstock). At the age of 33, Weinstock went back to school for architecture, and found himself surprised at how architects then seemed to have no connection to the engineering of the materials they worked with (Weinstock). Weinstock desired to put humans back in touch with nature (Weinstock). This intrinsic draw to studying nature manifests itself in varied ways among professionals. Designers are often in awe of nature, its beauty, simplicity, and structure, desiring to make a connection with the natural world (Weinstock). On the other hand, mathematicians are often intrigued by the way mathematical models such as the Fibonacci Sequence and Logarithmic Spiral show up in nature (Weinstock).

IV. Exploring the Biomimetic Design Process

A number of design professionals involved in biomimicry were interviewed during the summer of 2016. Highlights and takeaways from several designers and firms are shared below for the source of inspiration and guidance when pursuing biomimetic design.

Every designer and firm is unique and will cultivate their own culture and design process. Similar to studying other buildings for inspiration in architectural design, studying other professionals’ design processes can serve as guidance and inspiration as well. There is not one single design process, but one can experiment, gathering ideas from others and molding them into one’s own personal design process and style.

a. Michael Weinstock, Architectural Association

Michael Weinstock first studies a range of species in the natural world, developing a wealth of knowledge in biology (Weinstock). Studying nature without directly thinking about its applications to architecture, Weinstock is then able to pull insight from across a range of species to then apply to his designs (Weinstock).

b. Julia Ratcliffe, Expedition Engineering

Expedition Engineering follows a design process that can be outlined as follows: Need, Brief, Conceive, Test, Judge, Make, Use, Learn (Ratcliffe). This outline is a cyclical process, often returning back to a previous stage and reiterating along the way (Ratcliffe). Before beginning the design of a project, the environmental focuses or goals must be determined – these must be realistic and be able to be measured (Ratcliffe). These optimal values are often on a spectrum, with some values fixed, and others allowed to vary within a given range (Ratcliffe). These values are then integrated into the construction of a genetic algorithm, a process which somewhat mimics the evolution of a species, reproducing then honing in on the strongest options, then reiterating those again (Ratcliffe). The genetic algorithm generates over three hundred random solutions to the given values and ranks.
them (Ratcliffe). The design team selects a few solutions, which are then used to regenerate new solutions focused on the optimal ones from the previous generation (Ratcliffe). Ratcliffe suggests iterating designs on paper and testing the selected parameters in order to figure out the true constraints of the project before inputting them into genetic algorithm processing (Ratcliffe).

Specifically in regards to biomimicry, Julia Ratcliffe explained that the firm first asks the question, "how would nature design this? (Ratcliffe). Working with the biologist on the design team, the firm will outline to the biologist what they want their building to achieve or the challenge they wish to solve, and then ask the biologist for examples in nature that solve this problem. During the initial design, they cast their net wide, exploring many possibilities, organisms, and iterations. The entire design team should buy into the project at the earliest stage possible in order to cultivate genuine collaboration. The design drivers need to be fully understood, and the design team needs to be aware of which drivers have the most influence in the project (Ratcliffe). Collaboration is essential, as the team needs to understand and explicitly discuss everyone else’s drivers.

c. Denis Lacej, Grimshaw Architects

Denis Lacej explained a slightly different design process utilized by Grimshaw Architects. Grimshaw Architects constantly collaborates in the design process, holding design workshops where they share ideas, constraints, and upcoming opportunities. During the initial project brief, company aspirations of the firm and of the client provide added value on top of the original project description, making sure not to design anything outdated or unachievable, keeping budget in mind while working within a range of possibilities. Lacej emphasizes the importance of hiring a good team of consultants. The firm knows that they must rely on others’ expertise in order to do something ambitious, and thus seeks consultants that are like-minded to their firm. Grimshaw Architects will advise clients during the consultant selection process, but this process will vary from project to project. Consultants are usually directly employed by the client or hired by the design firm, where the architect serves as the lead designer. In smaller projects, the client will often ask for consultant suggestions from the architecture firm. However, if a project is driven by cost, firms are often forced to work with consultants desiring simpler, conventional solutions. In this case, the firm needs to find a way to encourage the consultants to support the firm’s innovative work. Lacej also stresses the importance of seeking manufacturer input during all stages of design in order to get cost details and check element development to ensure that the design is constructible. The initial concept and design is such a small part in the project, as it evolves so much along the way.

Sustainability drives architecture from the beginning (Lacej). As sustainability is such a strong focus in Grimshaw Architects’ agenda, it is easiest when the client desires to pursue innovative and sustainable solutions as well. Thus, Grimshaw delivers and does not need to impose sustainability aspirations on the client since it is already included in the design brief. Grimshaw Architects maintains an internal system to ensure they reach the pinnacle of innovative design and sustainability in every project (Lacej). Grimshaw has constructed a sustainability reviewing system, where a project goes through a review during each successive design phase (Lacej). The review is conducted by a panel of internal architects at Grimshaw, following a list covering the key elements to sustainable design (Lacej). After reviewing how the project has performed thus far, new sustainability targets
specific to each individual project are determined for the next design phase, which will be assessed at the following sustainability review (Lacej). As the duration of each design phase usually lasts between two and six months, Grimshaw Architects is continually analyzing their designs and striving for the pinnacle of sustainability and innovation (Lacej). The firm seeks innovation on multiple levels including structure, sustainability, and materials (Lacej). While innovative, Grimshaw aims to never be indulgent, always exhibiting a respect for the environment and an awareness of what is feasible (Lacej).

d. Michael Pawlyn, Exploration Architecture

Michael Pawlyn, head of Exploration Architecture in London, has worked closely with Expedition Engineering and provided insight to the design process from the role of the architect. Exploration Architecture utilizes a biological consultant on all projects, incorporating the biologist into the design team early on for optimal benefit (Pawlyn). While there are many knowledgeable biologists, those that have a broad knowledge and are able to problem solve and apply their biological knowledge to other fields are best for working with designers (Pawlyn).

Over the years, Pawlyn’s design process has become more systematic (Pawlyn). He describes his design process as a series of divergent and convergent phases (Pawlyn). The initial concept phase is as divergent as possible, followed by a convergent phase where possibilities are identified and narrowed down, described as analogous to a mass-extinction event (Pawlyn). The dynamics within the design team between the biological consultant and the architect is often very interesting, as each professional approaches the problem differently. Pawlyn explains that an architect or designer will often spot things in nature that are inspirational or intriguing, then figure out how it can be applied functionally to a building (Pawlyn). There is a sense of creativity and inquisitiveness in approaching nature with the question, “what can we do with that?” (Pawlyn). Comparatively, a biologist will often employ more of an engineering approach: starting with the problem that needs to be solved and then determining organisms that would be applicable (Pawlyn).

Pawlyn describes his design process as a sequence of mutations, utilizing a series of genetic algorithms (Pawlyn). Minimum and maximum constraints for certain aspects of the project are determined and inputted into a genetic algorithm, which then generates hundreds of solutions (Pawlyn). These solutions are then narrowed down and run through the genetic algorithm again, generating another set of further optimized solutions (Pawlyn). Pawlyn suggests using computer analysis early on in the design process as it can prevent architects from becoming stuck in intuitively derived dead ends since so many options are constantly regenerated (Pawlyn). Unlike an architect, the computer does not get fixated on a specific idea, nor does it have the capability of containing an ego, internal motives, or personal prejudices to certain designs (Pawlyn). Exploration Architecture primarily utilizes Grasshopper and additional plug-ins for genetic algorithms, and Rhino for the three-dimensional modeling (Pawlyn).

Michael Pawlyn shared an additional approach to the design process. Pawlyn suggests beginning with a focus on the sustainability challenges in a project, identifying the absolute ideal design solution without regard to practical constraints such as cost or constructability (Pawlyn). After understanding the optimal solution, work backwards to make the design more practical while keeping as closely aligned with the ideal as possible.
Pawlyn has found that the final design is more closely aligned to this ideal in larger projects or those with greater resources (Pawlyn).

e. Other
   The above excerpts and highlights comprise a small subset of all designers and firms considered in this research. A complete list of professionals, firms, and universities consulted in this research is as follows:

- Michael Weinstock, Architectural Association
- Architectural Association School of Architecture
- Expedition Engineering
- Gennaro Senatore
- Grimshaw Architects
- Michael Pawlyn
- University of Freiburg Students
- University of Stuttgart Students
- University of Tubingen Students
- Achim Menges, University of Stuttgart
- Jan Knippers, University of Stuttgart
- ITKE, University of Stuttgart
- ILEK, University of Stuttgart
- ICD, University of Stuttgart
- Werner Sobek

V. Biomimetic Design Process Outline

While there are a multitude of approaches to biomimetic design, no single rigid design process is better nor always results in a more sustainable building. As with all types of design, biomimetic design is a personal and creative process that differs between individuals and firms. The following design process outlines are given as suggestions, guidelines, and inspiration for those wanting to pursue biomimetic design. Feel free to pick, choose, and experiment with any methods that could be of benefit to your practice. This design process was constructed through a synthesis of best practices shared by various designers and firms across the United States and Europe currently implementing biomimicry.

Mindset –
Approach biomimetic design with the understanding that the design process will be a series of converging and diverging phases. Do not allow yourself to become fixated on your first idea and be prepared to examine a wide range of possibilities.

Educate –
At every possible moment, seek to educate yourself about the world around you. Study biology and keep note of organisms that interest you or could perhaps provide biomimetic inspiration.
Project Brief –
Before diving into the design of a new project, be sure to fully understand all components of the project requirements.

Study Building Site –
Study the given project site intensively, understanding the site context, connections to surrounding buildings, and environmental features of the land. Make note of any organisms living in the area, learning how they each specifically respond and adapt to the local climate and environment. These biological insights could be valuable for biomimetic inspiration further along in the design process.

Assemble Design Team –
Assemble an interdisciplinary design team consisting of architects, structural engineers, biologists, contractors, manufacturers, cultural scientists, and energy specialists, in addition to any specific consultants required for the individual function or purpose of the building. Team members should be excited about the project and willing to work with others from a wide-range of disciplines and backgrounds. Most importantly, team members should have a desire to learn and adapt along the way, as well as be committed to pursuing sustainability. Foster a collaborate environment that values open communication, listening, respect, and the sharing of information.

Define Functional Drivers –
As a design team, outline and define the goals of the project in terms of sustainability, cost, innovation, aesthetics, occupant health, and community integration, integrating these with the specifications given by the client. Determine ways to measure these functional drivers of the project, so that the team can assess the project’s progress and performance along the way.

Consult Biologist –
Share the main goals and challenges the project will need to address with the design team biologist. Working with the designers, the biologist should propose various organisms or natural processes that have similar processes that the building is trying to achieve. A wide range of organisms should be explored and presented, as inspiration, no matter how small, can be drawn from unexpected places.

Narrow Down –
Working as a holistic design team, narrow down the solutions by choosing those that best fit the project goals.

Genetic Algorithm Iteration –
Input the project parameters outlined in the design brief and decided on in previous steps to formulate a genetic algorithm that generates hundreds of solutions. Assess the solutions presented and narrow down based on the project’s functional drivers as well as the designers’ suggestions. Continue to iterate the algorithm to further narrow down these choices.
Select Design –
Select the design that best addresses the project needs. Be sure to assess the design for its function, aesthetics, comfort, feasibility, sustainability, cultural sensitivity, etc.

VI. Additional Implications of Biomimicry

Biomimicry has the ability to influence the aesthetics, sustainability, and economics of building projects. However, there is the danger that some may see biomimicry as a fad and want designs to literally resemble nature, rather than also capitalizing on the functional benefits nature has to offer (Ratcliffe). Nature can certainly provide inspiration for beautiful designs, however, in order for biomimicry to truly be beneficial, it cannot stop with merely aesthetics. Michael Pawlyn explains that he has yet to find a building type that biomimicry cannot be applied to; however, it is easier to integrate biomimicry to new builds rather than refurbished designs (Pawlyn). Biomimicry is never a complete design philosophy, as it still needs to be integrated with cultural knowledge, psychological impacts, feasibility, historical context, and the creative touch of humanity (Pawlyn). For example, during Exploration Architecture’s design for the Biomimetic Office, the genetic algorithm produced an optimal design with three atrium spaces, however, the project architects determined that space would be unpleasantly claustrophobic and rejected the idea (Pawlyn).

Biomimetic design can certainly reduce building costs through material efficiency and sustainability; however, some biomimetic projects can be more expensive than traditional designs due to heightened technology, and innovative building or manufacturing techniques. The concept of economics and cost is a human construct and not directly found in nature (Weinstock). Nature’s equivalent of human economics would probably be its flow of energy; the most cost effective or cheapest option would be that which uses less material or energy (Weinstock).

Biomimicry can also be applied on a larger scale to organizational processes and communities rather than just physical design, as discussed thus far; however, the design process and implementation is slightly different. Instead of using inspiration from specific organisms, as is typical for individual buildings, ecosystem models can be applied (Pawlyn). These ecosystem models help to outline a process or exhibit a closed-loop system, which can be used as guidance in the construction of larger entities – everything from communities, companies, cities, networks, and more. Characteristics of complete ecosystems rather than specific organisms are utilized, and biology is implemented more as a metaphor (Pawlyn). There are some areas where this logic breaks down, as society does not have anything analogous to bacteria that break materials down (Pawlyn). Whether this capability will be seen in new technology to come, or remains a break in attempting closed looped systems in society, biomimetic design can still provide insight and guidance in many other components of organizational processes.

VII. Challenges to Biomimicry

Across the board, the main challenges to the implementation of biomimicry expressed were clients and societal mentality in regards to sustainability. Often times,
society is simply not concerned with a sustainable future and will only take action in immediate peril (Weinstock). While many designers, biologists, architects, artists, and more across a variety of disciplines are fascinated with bionics, the majority of the world does not share that same intrigue (Weinstock).

It is often difficult to keep sustainability as the most important driver in a biomimetic project, as clients usually never invest in a building only to make a statement on sustainability, there is always another reason, motivation, or purpose for the building – as it should be (Lacej). However, the main challenge presents itself when clients do not share the same sustainable agenda as the firm in a project (Lacej). Often times, local authorities will implement certain sustainability standards that need to be met, but if no local standards are imposed, it is up to the architect to pursue a heightened level of sustainability (Lacej). Most private clients or developments ignore environmental issues, as they are driven by cost and money, while limited by their own lack of education on the topic (Lacej). In order to mitigate this challenge and improve sustainability across all building projects, policies could be implemented that ease the granting of planning commission if buildings hit certain sustainability marks, allowing for growth and development but with a sustainable agenda (Lacej). Also, when accreditation for certain sustainability standards are bestowed upon offices, it helps the firm win more work (Lacej). Encouraging clients to look at cost more holistically, understanding the benefits of sustainability and certain payback periods, can also help persuade clients to pursue a biomimetic approach (Pawlyn).

BREEAM in the UK, and LEED in the US, similarly reward projects for achieving certain benchmarks in sustainability. While these indicators encourage certain parts of sustainable design, some firms are often shortsighted, focusing on fitting their design to the BREEAM or LEED specifications rather than pursuing innovative design, such as biomimicry (Lacej). Additionally, BREEAM does not credit for efficiency, nor are many credits given for structural ingenuity – both of which can drastically increase the sustainability of a project (Ratcliff).

Current manufacturing capabilities and technologies also challenges the future of biomimicry. While there are many innovative materials that can be utilized, designers cannot create the same structures found in nature with their complicated hierarchical structures (Pawlyn). The industry also currently lacks living materials that can create out of elements and regenerate themselves (Pawlyn).

VIII. Conclusion

Meeting with the above design firms and professionals has made it increasingly apparent that biomimetic design processes are almost as varied as their applications. While there is not one single best practice for biomimetic design, as each project and designer varies in their style, the discussed methods can serve as guidance and inspiration in the pursuit of biomimetic design. The applications of biomimetic design are endless and provide countless ways to optimize sustainability, aesthetics, and cost efficiency.
Bibliography


