Bioinspiration in Structures

"Functionality does not consist of using simple forms, traceable with compass and set square . . . but in taking those which the wisdom of nature generously offers." [1]

— *Juan Bassegoda Nonell*

Biomimicry

Humans have long looked to nature for inspiration in answering the challenges of the physical world. As the need for sustainability in the built environment becomes ever more evident, biomimetics has emerged as a compelling approach to building design. Biomimicry as an architectural philosophy strives for performance-based aesthetics by simulating the time-tested patterns and precedents exhibited in nature. [2] Rightly so—in few domains are form and function so inextricably linked as they are in structural design, and nowhere is the relationship between the two so elegantly balanced as in nature. The correlation between biological forms and mathematical transformations is well-documented, perhaps most notably by biologist D'arcy Wentworth Thompson in his work *On Growth and Form*.[3] It is this intersection of aesthetics and functionality to which biomimetic design aspires.

Figures 1 & 2. Fibonacci spirals in nature and architecture[4,5]

[1] Juan Bassegoda Nonell, Pere Vivas, and Ricard Pla, Gaudi: The Complete Works (Sant Lluis, Menorca: Triangle Postals, 2007), 5-6.
[2] Michael Pawlyn, *Biomimicry in Architecture* (London: RIBA Publishing, 2011), 1.
[3] D'arcy Wentworth Thompson, *On Growth and Form* (New York: Macmillan Company, 1945), 376-413.
[4] Photograph by Colin Warren

Constructability and Rationality

In the past, straight lines and right angles have equated to greater constructability and therefore lower costs, while the often complex shapes associated with translating biological concepts into structural design methodology have proven a stumbling block. Yet, it is a misconception that rationality and complexity are mutually exclusive and that the most logical forms are the most elementary, geometrically speaking.[6] Jan Molema, a Dutch structural engineering researcher and professor, presents this as a long-standing dilemma: "This is a decisive point in architecture. Should we apply the solution reached through the calculation, even if it leads to a form difficult to make given the materials available? Or should we apply the easiest constructive system?"[7] Fortunately, construction technology continues to evolve—particularly exciting are the advances in 3-D printing technology—and the realization of more sophisticated organic forms in structures becomes increasingly feasible as designers and builders look to the future. After all, structural art, as famously defined by Princeton University professor David Billington, must demonstrate excellence in economy as well as elegance and efficiency.[8]

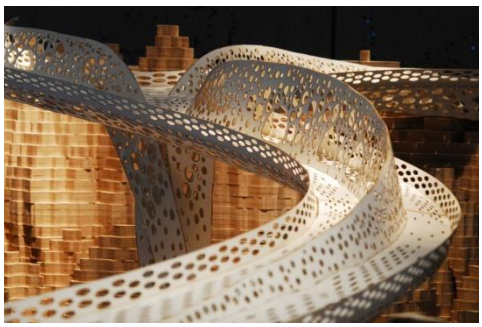


Figure 3. Shi Ling Bridge design by Tonkin Liu based on digital optimization[9]

[5] Photograph by author
[6] Juan Bassegoda Nonell et al., *Gaudi: The Complete Works* (Sant Lluis: Triangle Postals, 2007), 6.
[7] Jan Molema, *Gaudi: The Construction of Dreams* (Rotterdam: Episode, 2009), 10.
[8] David P. Billington, *The Tower and the Bridge: The New Art of Structural Design* (Princeton: Princeton University Press, 1985), 5.
[9] Image by Tonkin Liu

Form and Function

As bioinspiration gains traction as an innovative and meaningful design approach, the distinction between mere biomorphism (copying organic shapes for aesthetic purposes) and practical biomimicry (mimicking nature to draw on its efficiency) has proven a topic of debate regarding its application. For example, Frank Gehry's works, characterized by wild, sweeping curves, are often lauded as examples of biomimetic architecture. However, though visually striking, these geometries lack structural functionality. Adopting the form of nature does not necessarily equate to achieving a sustainable relationship with it. [10]

Figure 4. Guggenheim Museum Bilbao by Frank Gehry[11]

Case Study: La Sagrada Familia

An example of a structure that embodies both types of bioinspiration is the stunning Sagrada Familia in Barcelona. I had an unexpected opportunity to visit Antoni Gaudi's most acclaimed work several years ago and the experience remains a defining one in my development as a structural engineer. The cathedral incorporates both the beauty of nature in the biomorphic forms of the tree-like columns and canopy and the efficiency of nature in its catenary arches. The resulting spatial composition is breathtaking in its complexity and sheer verticality, a magnificent consummation of Gaudi's form-finding exercises with inverted string models. This was my first introduction to the concept of biomimetic architecture and sparked

[10] Michael J. Maglic, "Biomimicry: Using Nature as a Model for Design" (Master's thesis, University of Massachusetts—Amherst, 2014), 2-3.
[11] Photograph by David Heald

my interest in the possibilities for structural innovation drawn from the principles of the natural world.

Figures 5 & 6. La Sagrada Familia[12]

Proposal

The central theme I wish to explore is this: Where do biomimicry of form and biomorphism diverge in structural design? How can the aesthetic elegance of biomorphism be achieved by first seeking the functionality of biomimicry? What are the qualities of a structural form that truly functions cohesively with nature?

The proposed study will include travel to a number of biologically inspired structures across the globe, including both bridges and buildings. This survey will provide the opportunity to experience firsthand the distinction between biomorphism and biomimicry as it applies to the built environment. The final report will document my observations on the relationship between aesthetic expression (form) and structural efficiency (function) in bioinspiration with the goal of contributing to the structural design profession's understanding of how one can beget or obstruct the other.

[12] Photographs by author

Proposed Itinerary

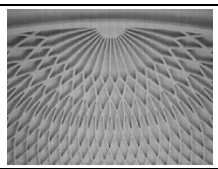
Criteria for Selection

The objective is to perform a study of bioinspiration in the built environment; to achieve this, I developed an itinerary of selected structures which exhibit biological influences in form, function, or ideally, both. Preference was given to functionally innovative examples. Sites were chosen to represent a maximum variety of structural systems, architectural styles, and construction techniques. Buildings, bridges, and smaller installations are all considered, and highly recognizable works (such as those by Santiago Calatrava and Zaha Hadid) are featured alongside more obscure projects. Aesthetics, structural efficiency, economic practicality, and environmental sustainability will be assessed for each to determine a) whether the structure demonstrates biomorphism, biomimicry, or a combination thereof and b) how these characteristics contribute to creating a design that functions cohesively with nature. The final report will document the resulting conclusions.

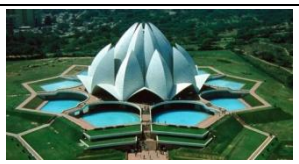
Itinerary

Europe

HSB Turning Torso Malmo, Sweden Santiago Calatrava		Design based on the human spine
3D Print Canal House* Amsterdam, Netherlands DUS Architects		3D printing construction technique using bioplastics
Hungerburg Funicular Station Innsbruck, Austria Zaha Hadid		Inspired by study of natural ice formations
Building Academy Salzburg Extension Salzburg, Austria Soma Architecture		Roof structure based on particle flow simulation

ICD-ITKE Research Pavilion Stuttgart, Germany ICD-ITKE		Structure based on lobster exoskeleton
Munich Olympic Stadium Munich, Germany Frei Otto		Tensile structure based on soap bubbles
TGV Exupery Train Station Lyon, France Santiago Calatrava		Skeletal morphology of bird wings
HygroScope at Centre Pompidou Paris Paris, France Achim Menges		Environment-responsive wooden structure
L'Oceanografic Valencia, Spain Felix Candela		Hyperboloid shell structure
Metropol Parasol Seville, Spain Jurgen Mayer H		Honeycomb structure, mushroom morphology, world's largest wooden structure
Palazzetto dello Sport Rome, Italy Pier Luigi Nervi		Ribbed roof structure based on lilypad
Swiss Re Building London, UK Foster and Partners		Based on form of the glass sea sponge
Times Eureka Pavilion London, UK NEX Architecture		Modular structure mimics leaf
Eden Project Cornwall, UK Grimshaw Architects		Geodesic biodomes

Asia

Lotus Temple		Lotus-like architecture
New Delhi, India		
Fariborz Sahba		
Esplanade Theater		Durian fruit inspired exterior, responsive roof and envelope
Singapore		
Michael Wilford and Partners		
PARKROYAL		Vertical garden incorporated into building envelope
Singapore		
WOHA		
SUTD Library Pavilion		Timber shell based on hanging chain model
Singapore		
City Form Lab		
Helix Bridge		DNA-inspired double helix structure
Singapore		
COX Group, Architects 61		
Spanish Pavilion at 2010 World Expo		Tubular structure, wicker-woven façade
Shanghai, China		
Benedetta Tagliabue		
Beijing Olympic Stadium		Bird's nest structure
Beijing, China		
Herzog & de Mueron		
Beijing National Aquatics Center		Exterior structure based on natural pattern of bubbles
Beijing, China		
Arup		
New Beijing Poly Plaza		Seismic mechanism inspired by human arm, flexible envelope inspired by spiderweb
Beijing, China		
SOM		
Sendai Mediatheque		Seaweed-like tubular structural system
Sendai, Miyago Prefecture, Japan		
Toyo Ito		

New Songdo City Central Park I and II		Honeycomb-based structure
Incheon, South Korea		
HOK		

Australia & New Zealand

Sydney Opera House		Shell-like sails
Sydney, NSW, Australia		
Jorn Utzon		
Kurilpa Bridge		World's largest tensegrity structure, spiderweb inspiration
Brisbane, Australia		
Arup Group		
Redwood Treehouse		Inspired by seed pod
Auckland, NZ		
Pacific Environment Architects		

** Indicates a project still under construction*

Conclusion

In closing, thank you for considering my application for the SOM Foundation Structural Engineering Traveling Fellowship. I am thrilled at the prospect of undertaking the proposed study and look forward to hearing the final decision.