Reston Site Redevelopment Project
(Technical Paper)

Morally Imagining Implications Induced on Forests by Mass Timber Construction
(STS Paper)

A Thesis Project Prospectus Submitted to the

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Reviews and Comments

Throughout the duration of this course and in preparation of my prospectus, I received helpful feedback from Professor Gorman and my peers. Without their input, I would have been unable to cultivate my research into an appropriate thesis topic. This section is dedicated to my gratitude for their assistance.

I failed to take advantage of a strong case study within my own technical topic, which Professor Gorman highlighted in his comments. This was my capstone group's use of the metaphor of biodiversity in designing a retrofittable garage for a development in Reston. Not only did the situation revolving around garage design consist of a barrier to adoption of biomimetic design (seen through the developers' lack of inclination towards the idea), but a resolution (seen through our advisor's role as a translator between different paradigms to create a trading zone). Professor Gorman also recommended that I address what my capstone group learned through the process. This was the acknowledgement that a trading zone needed to be developed because we, as students, had a different language towards building design than that of the developers. Additionally, Gorman made it clear that my representation of trading zones in building design during my presentation was hard to follow. I made a point of outlining trading zones in a more organized manner throughout the prospectus. I did this through analyzing the framework's application before using the framework on several case studies dealing with my technical topic. Professor Gorman also aided in the development of my framework discussion through his work with Matt Mehalik in *Ethical & Environmental Challenges to Engineering*.

Several of my peers, Stephen Shiao, Julian Nguyen, and Craig Doody recommended that I pursue research in daylighting in architecture or wood as a sustainable construction material as opposed to biomimicry in building design. They suggested that it would be difficult to find case studies and data regarding biomimicry in the built environment. I am thankful for their input, as it encouraged me to be more intentional and proactive in my research. They helped me realize that biomimicry was a topic I particularly enjoyed learning and writing about.

I owe special thanks to Brianna Biesecher, who through her own thesis topic helped me discover several cases of biomimicry that served as a foundation of which to build my research on.

I also owe special thanks to William McDonough, who Professor Gorman recommended I read. His ideas within sustainable design, such as cradle-to-cradle analysis, were vital in understanding the macroscopic utility of biomimetic practices.

Introduction

Nature is more frequently used as a source of inspiration for designers as means of improving the world around them. This extends beyond a societal turn to ecologically friendly practices in the residential, industrial, and commercial world that started in the Environmental Reform of the 1970s.[1] Instead of only asking how they can conserve the earth's health, designers are evaluating nature's capacity to engineer its own efficiencies. In what could be mistaken for an anthropocentric approach to design (elements of the environment are extracted for humankind's benefit), the method of modeling and recreating natural processes and systems in the manufactured world, called biomimicry, holds nature's integrity most valuable.

Biomimicry can be found in many different design practices. In particular, architects and engineers conclude that reaping the benefits of bio-inspired design can produce more sustainable buildings and construction procedures. There is cause for concern though. As a field, building design largely developed in opposition to the environment. Ever since the beginning of humankind, a structure's main utility was to separate and protect people from the natural environment, and this position eventually manifested in unsustainable design. Buildings alone are responsible for 41% of the world's energy use.[2] Up until the mid 20th century, architects created buildings that stood out from the natural environment. Frank Lloyd Wright coined the term "organic architecture" in the midst of his career. The idea of creating buildings that drew aesthetic parallels to the site they inhabited was foreign up until Wright, and this idea became a thematic trademark of his work.[3] Classical architecture strived to form perfect symmetry and

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1 "Environmental Reform," *US History*, http://www.ushistory.org/us/57e.asp.
2 "How Buildings Impact the Environment," *BOSS Controls*, https://bosscontrols.com/buildings-impact-environment/.
3 "When Buildings Blend with Nature," *Garden Collage Magazine*, https://gardencollage.com/change/sustainability/frank-lloyd-wright/.

order in a juxtaposition to the natural world. Engineers created buildings with mechanical systems that created artificial environments. The goal of building design might as well have been to create structures that encouraged people to ignore and discount the environment.

In their current state, building designers are not prepared to marry design and biomimicry. The two represent alternate perspectives of the field's standing within the scope of sustainability. Scientists must be involved in the process to not only accommodate the rift between building design and biomimicry, but also to ensure optimization of architecture and engineering. It is more likely that a biologist or chemist can procure knowledge connecting biomimicry and design than it is an architect or engineer, due to the fact that many of nature's most efficient systems require thorough study. Yet in the past, much like the relationship between building design and biomimicry, building designers and scientists have interacted very little. Therein lies a great issue. These two fields exist within separate paradigms but need to exist concurrently for a sustainable future.

Background

Not to be treated as a newfound practice, bio-inspired design is rooted in some of humankind's most groundbreaking inventions. An avid bird-watcher, Leonardo da Vinci used the anatomy and movements of birds' wings to prototype his flying machine.[4] Similarly, the Wright Brothers eventually succeeded in designing an airplane after observing pigeon flight. The process of using biologic features to produce more effective technological design became known as biomimetics by Otto Schmitt in 1974 and mainly referred to human technological adaptation

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[4] Rinaldi, Andrea. "Naturally Better. Science and Technology Are Looking to Nature's Successful Designs for Inspiration." *EMBO Reports* 8, no. 11 (November 2007): 995–99. https://doi.org/10.1038/sj.embor.7401107.

of natural materials and biological processes.[5] The term biomimicry became commonplace in academia in 1997 after the release of Janine Benyus' book *Biomimicry: Innovation Inspired by Nature*.[6] More accurately, biomimicry is a label placed on a process that humanity has carried out for many years. Unlike the past though, designers focus on the characterization and intentional pursuit of the process which can help lead to a more sustainable future. Therefore, it is vital that biomimicry is recognized and increasingly implemented in technological practice.

In relation to sustainability, the advantages in turning to biomimicry are many. Energy efficiency, energy generation, and the capture of carbon in the atmosphere are all qualities of naturally occurring technologies. Individually, these facets are vital in fighting the effects of climate change. Not only can designers limit the built environment's contribution to global warming, but by replicating natural mechanisms, manmade technology can promote the health of the natural environment. For example, buildings can be modeled after ecosystems and should be treated as such for the following reasons. Ecosystems are dependent on renewable, solar energy through photosynthesis. If buildings were designed to use active and passive solar technology, pollutant emission would greatly decrease and building energy efficiency would improve. Additionally, ecosystems are largely self-dependent. Using locally sourced materials in permaculture strengthens the local economy and decreases the need for transportation resources. Not only does this reduce pollutant emission, but it also encourages the use of "organic architecture", as construction materials that are sourced locally will more frequently resemble their environment.[7]

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[5] Maibritt Pedersen Zari (2010) "Biomimetic design for climate change adaptation and mitigation." *Architectural Science Review*, 53:2, 172-183

[6] Rinaldi, Andrea. "Naturally Better…"

[7] Maibritt Pedersen Zari (2010) "Biomimetic design for climate change…"

An increased sense of urgency regarding the health of the planet calls for an amplified use of biomimicry in building design. In a time where the benefits of the practice have proven advantageous, there may be no better step forward.

Framework Application

Biomimicry requires interdisciplinary interaction between extremely specialized fields that have historically shared little overlap. Werhane and Gorman's STS framework, Trading Zones, is ideal for analyzing the challenges within bio-inspired building design today.[8] As scientists and designers increasingly realize the importance of linking their fields, they discover that the "languages" they speak within the context of their respective technicalities are so different that they bar them from reaching common ground. An approach both parties could use to combat this disconnect is through moral imagination. In understanding that the rules drafted by one's own mental model determine one's perception of the goals behind design, designers and scientists begin to acknowledge that they work in different zones, using different languages.[9] It is then important for each party to contemplate other mental models that may exist in the context of design. At this stage, it is most probable that an architect or engineer will realize that they do not have the knowledge to perceive a scientist's paradigm and vice-versa. Recognizing an inability to communicate despite one's best effort reveals greater challenge.[10] A new mental model needs to be created by a third party who is able to speak both languages and translate between the two

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[8] Mehalik, Matthew M., and Michael E. Gorman. "A Framework for Strategic Network Design Assessment, Decision Making, and Moral Imagination." *Science, Technology, & Human Values* 31, no. 3 (May 2006): 289–308. https://doi.org/10.1177/0162243905285841. (Source obtained from comment from Professor Gorman's forum post.)

[9] Gorman, Michael E. *Trading Zones and Interactional Expertise: Creating New Kinds of Collaboration*, 2010.

[10] Mehalik, Matthew M., and Michael E. Gorman. "A Framework…"

entities. A role fulfilling this duty, called a translator, is yet to exist in practice and is vital to biomimetic building design.

It is important to further analyze what is to blame for design's departure from biomimicry. Oguntona and Aigbavboa establish five barriers in interpreting biomimicry in building design and construction: barriers of environmental principles and policies, a language barrier, barriers due to ecosystem complexities, an integration barrier, and a conceptualization barrier.[11] Within these larger categories exist various factors that inhibit adoption. The survey study led by Oguntona and Aigbova finds that knowledge-based barriers exist because there is lack of education about biomimicry practices in the construction industry. Interestingly, the findings state that this is largely because construction firms do not consider the practice important enough to pursue.[12] This cyclical justification points to diverging value systems between design and science, an indication that paradigmatic differences prohibit the success of bio-inspired design.

Technical Section

My capstone project consists of the redevelopment of an urban parcel in Reston, Virginia. Situated next to a proposed stop on the Silver Line of the Washington Metro System, office and residential space on site is projected to be in great demand. As construction of this scale is a large capital investment, a developer strives to receive profit as quickly and consistently as

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[11] Oguntona, Olusegun A., and Clinton O. Aigbavboa. "Barriers Hindering Biomimicry Adoption and Application in the Construction Industry." *African Journal of Science, Technology, Innovation and Development* 11, no. 3 (April 16, 2019): 289–97. https://doi.org/10.1080/20421338.2018.1527968.

[12] Oguntona, Olusegun A., and Clinton O. Aigbavboa. "Barriers Hindering…"

possible during building operation. Biomimetic design is a tool that my team can use in building design to justify investment in the site given the long-term benefits.

Several biomimetic design studies indicate that they are not only innovative and sustainable technologies but that they are economically superior to traditional practices as well. A study from the University of Akron finds that structural beams modeled after the spines of hedgehogs could prove to be revolutionary in industry. Hollow cylindrical beams in structural applications typically cannot bear the loads required of a high-rise building. They are susceptible to buckling. While sharing the same shape, hedgehog spines possess both longitudinal stringers and transverse central support plates. Under loading conditions, 3D modeled beams resembling hedgehog spines can support three times the load of traditional hollow cylindrical beams before failure. The benefits of using beams like these in building truss systems are numerous. They are lightweight, strong, and impact resistant.[13] Foundation construction and maintenance costs would greatly decrease for a building on a site like the one in Reston if it were to utilize these beams.

Building energy efficiency can also be greatly improved with biomimicry. Cutting down on energy costs through passive ventilation in the Reston development can greatly decrease the cost of operation for the developer. Drawing inspiration from termite mounds, architects from University of Guelma and Biskra in Algeria find that incorporating central heat chimneys in the core of buildings can induce natural ventilation of the building. By drawing cold air into the first floor of the building, convection moves warm air up the core and expels it into the atmosphere.[14]

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[13] Drol, Christopher J., Emily B. Kennedy, Bor-Kai Hsiung, Nathan B. Swift, and Kwek-Tze Tan. "Bioinspirational Understanding of Flexural Performance in Hedgehog Spines." *Acta Biomaterialia* 94 (August 1, 2019): 553–64. https://doi.org/10.1016/j.actbio.2019.04.036.
[14] Khelil, S., and N. Zemmouri. "Biomimetic: A New Strategy for a Passive Sustainable Ventilation System Design in Hot and Arid Regions." *International Journal of Environmental Science and Technology* 16, no. 6 (June 1, 2019): 2821–30. https://doi.org/10.1007/s13762-018-2168-y.

Simply by modeling a building floorplan after the structure of a termite mound can reduce resource consumption, pollutant expulsion, and operating costs for the developer.

A study from the European Journal of Forest Research finds that biodiversity in forests helps the entire ecosystem adapt to climate change. By introducing non-native warm climate tree species to struggling forest systems, sapling mortality of all tree species decreases.[15] In light of bio-inspired design, if an entire ecosystem could be more successful from diversification, I established that a building would experience the same effect given similar design facets.

Per one of the advisors of my capstone project, more developed communities than Reston, such as Tyson's Corner, in the Northern Virginia region recently set lower parking per square foot requirements for office and residential buildings. Despite increased traffic counts nationally, vehicle counts in past years dropped in these areas due to improved public transportation and pedestrian friendly infrastructure. The site in Reston still maintains the older, larger parking requirements because developments in the area, being more recently constructed than those in Tyson's Corner, have not experienced a decline in vehicle counts. Taking into account this trend, I equated a change in parking requirements in Reston to that of climate change in European forests. Buildings, and more specifically their parking garages, must diversify to adapt to changing environments. In recognizing this analogy, I suggested to the team that we design the two uppermost parking garage levels in each building on site such that they could eventually be converted into ballrooms, exercise areas, and conference rooms. While

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[15] Frischbier, Nico, PS Nikolova, Peter Brang, Raphael Klummp, Gregor Aas, and Franz Binder. "Climate Change Adaptation with Non-Native Tree Species in Central European Forests: Early Tree Survival in a Multi-Site Field Trial." *European Journal of Forest Research* 138, no. 6 (December 2019): 1015–32. https://doi.org/10.1007/s10342-019-01222-1.

requiring a higher initial investment on the developer's part, the economic potential of implementing these spaces in office and residential buildings on site when vehicle counts will most likely decline in coming years justifies the application of the design.

Yet, a team-based student project such as this also suffers the same disadvantages biomimicry does in practice. In suggesting that our design include garage levels that can be converted to occupiable space to our industry mentors, my capstone team realized that trading zones had come into play. Wary of the unfamiliarity of the design recommendation, our industry mentors originally elected that we focus on more traditional forms of sustainable design and construction in our work. Their position most likely developed from a disparity between our languages within the greater idea of sustainable engineering. As students, we are surrounded by academic thought and research, which is oftentimes deemed idealistic in practice. They also live in a paradigm where biomimetic practices are not used in site design. Despite their advice, my capstone team felt that the analogy of biodiversity in our garage design would prove fruitful economically. Unfortunately, we did not share a trading zone oriented around biomimicry in building design. Without a translator, it was difficult for a developer to understand our team's focus on bio-inspired design and it was difficult for my team to understand a developer's opposition to it. For this reason, we consulted our project advisor, who in this case acted as our translator. He revealed that we framed our proposal of the garage design mainly around its association with biomimicry rather than the financial benefits of a retrofittable space. This error, a byproduct of our incongruous languages which was remediated by a translator, restricted us from eventually implementing the biomimetic garage design. We learned firsthand how paradigms can limit perspective for both designers and developers as well as the importance of a third party in aiding communication.

Steps Forward

The lack of a trading zone between designers and scientists can be attributed to insufficient education in biomimicry. In forming an ecologically-minded society, students and eventually leaders in science and building design would understand the urgent importance in imitating natural processes and design in artificial technologies.[16] Trading zones would serve vital between designers and scientists. Eventually the need for trading zones would diminish, as biomimicry becomes the lens in which many technical fields approach their studies. Paradigms would align under increased education in bio-inspired science and design.

Former Dean of the Architecture School at the University of Virginia, William McDonough, stresses the importance of bio-inspired design for the future in his book *Cradle to Cradle: Remaking the Way We Make Things*. In modeling materials and technological components after resources in their respective ecological systems, it becomes apparent that the life cycle of any component extends beyond its manufacture and operation.[17] Designing such that components can be reused or re-enter their ecosystems seamlessly is not only biomimetic but sustainable for the future.

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[16] Pankina, Marina, and Svetlana Zakharova. "The Need for Ecologization of Design-Education." *Procedia - Social and Behavioral Sciences*, Worldwide trends in the development of education and academic research, Sofia, Bulgaria, 15-18 June, 2015., 214 (December 5, 2015): 338–43. https://doi.org/10.1016/j.sbspro.2015.11.656.
[17] McDonough, William, and Michael Braungart. *Cradle to Cradle: Remaking the Way We Make Things*. North Point Press, 2002. (Source obtained after reading Prof. Gorman's forum comments. Really applicable commentary on biomimicry and sustainable design.)

References

1. “Environmental Reform,” *US History*, http://www.ushistory.org/us/57e.asp.
2. “How Buildings Impact the Environment,” *BOSS Controls*, https://bosscontrols.com/buildings-impact-environment/.
3. “When Buildings Blend with Nature,” *Garden Collage Magazine*, https://gardencollage.com/change/sustainability/frank-lloyd-wright/.
4. Rinaldi, Andrea. “Naturally Better. Science and Technology Are Looking to Nature’s Successful Designs for Inspiration.” *EMBO Reports* 8, no. 11 (November 2007): 995–99. https://doi.org/10.1038/sj.embor.7401107.
5. Maibritt Pedersen Zari (2010) “Biomimetic design for climate change adaptation and mitigation.” *Architectural Science Review*, 53:2, 172-183
6. Rinaldi, Andrea. “Naturally Better…”
7. Maibritt Pedersen Zari (2010) “Biomimetic design for climate change…”
8. Mehalik, Matthew M., and Michael E. Gorman. “A Framework for Strategic Network Design Assessment, Decision Making, and Moral Imagination.” *Science, Technology, & Human Values* 31, no. 3 (May 2006): 289–308. https://doi.org/10.1177/0162243905285841.
9. Gorman, Michael E. *Trading Zones and Interactional Expertise: Creating New Kinds of Collaboration*, 2010.
10. Mehalik, Matthew M., and Michael E. Gorman. “A Framework…”
11. Oguntona, Olusegun A., and Clinton O. Aigbavboa. “Barriers Hindering Biomimicry Adoption and Application in the Construction Industry.” *African Journal of Science, Technology, Innovation and Development* 11, no. 3 (April 16, 2019): 289–97. https://doi.org/10.1080/20421338.2018.1527968.
12. Oguntona, Olusegun A., and Clinton O. Aigbavboa. “Barriers Hindering…”
13. Drol, Christopher J., Emily B. Kennedy, Bor-Kai Hsiung, Nathan B. Swift, and Kwek-Tze Tan. “Bioinspirational Understanding of Flexural Performance in Hedgehog Spines.” *Acta Biomaterialia* 94 (August 1, 2019): 553–64. https://doi.org/10.1016/j.actbio.2019.04.036.
14. Khelil, S., and N. Zemmouri. “Biomimetic: A New Strategy for a Passive Sustainable Ventilation System Design in Hot and Arid Regions.” *International Journal of Environmental Science and Technology* 16, no. 6 (June 1, 2019): 2821–30. https://doi.org/10.1007/s13762-018-2168-y.
15. Frischbier, Nico, PS Nikolova, Peter Brang, Raphael Klummp, Gregor Aas, and Franz Binder. “Climate Change Adaptation with Non-Native Tree Species in Central European Forests: Early Tree Survival in a Multi-Site Field Trial.” *European Journal of Forest Research* 138, no. 6 (December 2019): 1015–32. https://doi.org/10.1007/s10342-019-01222-1.
16. Pankina, Marina, and Svetlana Zakharova. “The Need for Ecologization of Design-Education.” *Procedia - Social and Behavioral Sciences*, Worldwide trends in the development of education and academic research, Sofia, Bulgaria, 15-18 June, 2015., 214 (December 5, 2015): 338–43. https://doi.org/10.1016/j.sbspro.2015.11.656.
17. McDonough, William, and Michael Braungart. *Cradle to Cradle: Remaking the Way We Make Things*. North Point Press, 2002.