I, Joseph William McGovern, hereby submit this original work as part of the requirements for the degree of: Master of Architecture in School of Architecture and Interior Design.

It is entitled: Biomimicry: how learning from nature can restore sustainability in architecture.

Student Signature: Joseph McGovern

This work and its defense approved by:

Committee Chair: Jerry Larson
John Hancock

Approval of the electronic document:

I have reviewed the Thesis/Dissertation in its final electronic format and certify that it is an accurate copy of the document reviewed and approved by the committee.

Committee Chair signature: Jerry Larson
Biomimicry: how learning from nature can restore sustainability in architecture

A thesis submitted to the Graduate School of the University of Cincinnati in partial fulfillment of the requirements for the degree of Masters of Architecture in the School of Architecture and Interior Design of the College of Design, Architecture, Art, + Planning

Joseph W. McGovern
B.S. of Arch. U. of Cincinnati  |  June 2007

Prof. Jerry Larson  |  Thesis Chair
Prof. John Hancock  |  Second Chair

May 2009
Abstract
Building trends over the past half century have created spaces that don’t respond to the climate of the place and have deteriorated the quality of physiological conditions and the sustainability of our built environment. Every organism in nature is a product of the need to be sustainable and energy efficient, however, in the quest to create more sustainable buildings the wealth of solutions provided by nature is largely overlooked. This thesis studies how nature solves impediments to sustainability in architecture and applies those strategies to create a truly environmentally sustainable architectural project. Strategies used in nature for construction, thermal comfort, daylighting, and ventilation will be explored and applied while trying to reduce the embodied and operating energy of the built environment. This thesis outlines an applicable, repeatable process of architectural design that is rooted in scientifically researched natural solutions, or biomimicry. This process is applied from the start of the design process through design development of a sustainable, multi-family housing project in the Over-the-Rhine neighborhood of Cincinnati.

Thesis Keywords:
biomimicry,
sustainability,
live/work,
Cincinnati,
Over-the-Rhine
ACKNOWLEDGEMENTS

I would like to thank everyone that has contributed to this thesis specifically my first and second thesis chairs, Jerry Larson and John Hancock for pushing me to take this thesis as far as it went. I would also like to thank Nick Gray, Elizabeth Rajala, and all my peers for all of their contributions to the thesis. Their invaluable input took this thesis to a level, I could not have made it to on my own.

This thesis is dedicated to my wife and love of my life, Lisa, for putting up with me and the long hours throughout this extensive process.

CONTENTS

THESIS

1 - Introduction
2 - The problem in a nutshell
4 - How we can solve it
6 - What is already out there? - Literary
13 - What is already out there? - Architectural
20 - The Process

DESIGN

33 - Design Introduction
34 - Site Context/Analysis
41 - Building Type + Program
29 - Project Design
34 - Bibliography

Key Terms
Biomimicry - noun - an innovation method that seeks sustainable solutions by emulating nature's time-tested patterns and strategies

-From Biomimicry Guild
This thesis developed in direct response to the huge impact modern buildings have on our environment. The impact of buildings dwarfs the impacts of transportation and industry, and if we are to slow or stop global climate change and create a healthier world, architects need to lead the charge. By using nature as mentor and model, architects and designers can address impediments to sustainable design in new and innovative ways. This way of innovating is called biomimicry. Organisms in nature respond and adapt to their environment to solve issues of thermal comfort, resource transportation and utilization, and other physiological needs in a truly sustainable way. It is for this reason that nature is the perfect precedent for sustainable design.

Through the study of literary and architectural precedents, this thesis defines and outlines a process by which architectural designers can effectively integrate biomimetic thinking into their creative process. In this way, the thesis is meant to proliferate sustainable design solutions to energy intensive buildings through the use of low-tech principles in nature. This process is broken down into five parts: Identify, Order, Research, Apply, and Evaluate + Implement.

The thesis is then implemented through a specific architectural design project. The design of a six unit Live/Work project in the Over-the-Rhine neighborhood of Cincinnati. The goal of which is to create an innovative zero-energy development in which energy demand is dramatically reduced and then met with on-site renewable energy generation.
**The Problem in a Nutshell**

The building trends over the past half century have deteriorated the quality of physiological conditions and the sustainability of our built environment. Since the development of modern active heating and cooling systems, the competency of our buildings alone to protect us from the elements has slowly declined. Many buildings are no longer built to respond to the climate of its place. Buildings in cold climates are built with large expanses of single pane glass facing winter winds, tropical buildings are sealed up, disallowing cross ventilation and encouraging mold growth, and similar instances can be found all around the developed world. Our buildings are consuming more energy than ever before. Meanwhile, modern day building technologies have resulted in the sealing up of our buildings all year round. Many of these advancements in building technologies have actually resulted in health risks. Asbestos, lead paint, carpet, and fiberglass insulation are just a few modern building materials that have been proven to present health risks during installation and beyond. Many contemporary building materials off-gas volatile organic compounds. This in combination with the reduced ventilation of our buildings has resulted in the fact that the interiors of most of our buildings are actually more polluted than the exterior.\(^1\) Besides these physiological deficiencies our buildings are consuming vast amounts of fossil fuels both for construction and for operation. Building operations consume 78% of electricity produced and are responsible for 48% of greenhouse gas emissions annually in the United States, according to statistics from the US Energy Information Administration. This makes buildings by far the single greatest contributor to climate change. As our population and influence on the world increases the combined effect of our buildings is not only destructive to the biodiversity and health of our local environs, but to our global climate. Now that we are becoming aware of our collective impact on this earth, reducing this impact is one of the most pressing issues of our time. It is for these reasons that the thesis was formed.

---

\(^1\) A study by the California Air Resources Board estimated that indoor air pollutant levels are 25-62% greater than outside levels and can pose serious health problems.
**How we can solve it**

Organisms in nature are the product of billions of years of “research & development”, are models of sustainability, and are responsive to specific physiological needs. Nature provides a wealth of solutions to the challenges and needs that face the built environment, however, biomimicry in architecture is largely unexplored and an under utilized method of creating environmentally sustainable projects. This thesis specifically explores how the use of biomimicry in architectural design can address issues of sustainability and physiological needs, such as thermal comfort. As an example, the Macrotermes michaelensi of Zimbabwe regulate their termite mound’s temperature within 2 degrees while the diurnal temperatures outside fluctuates as much as 70 degrees Fahrenheit! All of this is done without external power. If insects can achieve this in one of the most challenging climates on earth why can’t humans? This thesis investigates this and other natural phenomena as inspiration for a truly sustainable architectural project.

Exploration into the diverse yet universal forms employed throughout nature provide an understanding of how nature solves specific problems, and creates a repertoire of design tools to employ in architectural projects. Historical precedents, both architectural and not, that employ biomimicry are presented to provide precedents and context to the thesis. The previous research on and architectural work in biomimicry will also be presented and built upon. The above combined with other research into sustainable indigenous, and animal architecture will draw out several strategies appropriate to the thesis.

The thesis culminates in the development of a repeatable, architectural design process that employs biomimicry in solving sustainable and physiological issues in the built environment. The process is carried through to produce an architectural project that exemplifies the use of biomimicry in creating an environmentally sustainable project. In investigating architectural issues, the project seeks other nature inspired solutions to provide a holistic approach to creating a project that excels in meeting sustainability benchmarks and the physiological needs of its users. The highest benchmark for the project would be a building that is not only zero-energy, but actually restores habitat. Physiologically, the goal of the thesis project is to provide optimal thermal comfort, daylighting, abundant fresh air, and a connection to the biology of the site (biophilia). This has been proven in many studies to increase morale, and work productivity, among other things. The use of biomimicry in a holistic approach makes the project a truly sustainable and nurturing project. Sustainability in the built environment is not just an issue for developed countries, it is a global problem that in reality effects those in poverty and in third world countries more than most. For this reason, the project will create a sustainable architecture without the use of advanced or expensive technology, but rather with low-tech, low cost solutions that will allow its proliferation and implementation around the world.

---

1. [http://www.asknature.org/strategy/8a16bdf027387cd2a3a995525ea0883#section](http://www.asknature.org/strategy/8a16bdf027387cd2a3a995525ea0883#section)

2. Studies completed by NASA, Washington State, and ongoing five year study by Yale University and the Rocky Mountain Institute.
Biomimicry has been around for ages. People have been imitating other organisms before written history. It is said that pottery was invented after humans observed potter wasps making their homes by taking up the wet clay near rivers and streams and molding it into their nest. The great Leonardo Da Vinci studied nature intimately in coordination with developing his many inventions. His biomimicry is especially prevalent in his many variations of a flying machine. In modern times Buckminster Fuller had as inspiration a pack of bubbles and the universal forms and patterns in nature to guide his design of the structurally efficient geodesic dome. In his writings, Buckminster Fuller explains how nature is often a source of inspiration for him. Fuller was also the first to suggest that nature’s teachings could be the perfect tool to sustainable design. These are really the first modern writings on biomimicry and architecture, though he doesn’t call it biomimicry by name. In fact, the term biomimetics wasn’t termed until the 1950’s by Otto Schmitt, an American inventor, engineer, and biophysicist. The term biomimicry was made popular by Janine Benyus in her 2002 book *Biomimicry: Innovation Inspired by Nature*. Although the use of biomimicry in modern science was in use well before that, but the Benyus’ breakthrough book gave it a name and a voice. Benyus’ book explains biomimicry as an innovation method that seeks sustainable solutions by emulating nature’s time-tested patterns and strategies. The application of this innovation method since *Biomimicry* was written has increased dramatically. It has even led to a second book by Benyus called *Nature’s 100 Best*, which focuses on 100 different innovations inspired by nature.

**Biomimicry: Innovation Inspired by Nature**

Nature has had billions of years of research and development, and has already solved many of the problems facing society today. Researchers and scientists around the world are now looking to this biological database for inspiration and know-how to solve the most pressing problems of the industrialized world, as we become aware of our effects and limits on this Earth, which is the basis of Janine Benyus’ 2002 book *Biomimicry: Innovation Inspired by Nature*. The book is a survey of the use of biomimicry in a variety of fields. In each case, the natural world is the inspiration for each innovation Benyus is exploring. Benyus interviews professionals who are developing new technologies and methods in agriculture, energy, materials engineering, health care, information technologies, and economics. The book is organized into “Questions”. These include: “How will we feed ourselves?”, “How will we harness energy?”, “How will we make things?”, “How will we heal ourselves?”, “How will we store what we learn?”, and “How will we conduct business?”. Each question is explored through multiple viewpoints by conducting interviews with leading biomimicry researchers on different projects from each question. Benyus interviews farmers who are growing food in fields that resemble prairie ecosystems and still producing high yields. She finds out that the study of leaves is leading to exponentially more efficient solar collectors, and computer processors are being made with organic single-cell organisms. These successful examples and case studies are inspiring and clearly illustrate that a more
sustainable future is possible through the development of technology and techniques that use nature as a model.

Janine Benyus is considered by many to be at the forefront of the biomimicry field. She is a trained biologist and co-founded the Biomimicry Guild and the Biomimicry Institute with Dayna Baumeister. The Biomimicry Guild is a consulting firm that works with firms in various fields to help them identify natural precedents and solutions to a wide variety of industry issues. They have worked with companies like Patagonia, General Electric, Herman Miller, and HOK Architects. The Biomimicry Guild works with these companies on design problems, and opens their eyes to how that problem is solved in nature and how the principles from that solution might be applied to the design problem at hand. In conjunction with the Biomimicry Guild, Janine Benyus set up the Biomimicry Institute, a non-profit organization that provides resources for learning more about biomimicry. They promote educational opportunities both formal and informal for people young and old. Perhaps the greatest achievement of the Institute is the development of the AskNature.org website. This website is a sort of wiki-type encyclopedia of design challenges and possible biological solutions, meant to act as a resource for designers in every field across the world. Janine Benyus and the Biomimicry Institute and Biomimicry Guild are truly at the forefront of biomimetic research. They have produced a general outline of the process of designing with biomimicry, created a directory of problems and solutions, and applied biomimicry to problems in the real world with companies across the globe.

Although Janine Benyus and the Biomimicry Institute and Guild made biomimicry as widespread as it is today, there are others in the field that are employing biomimicry outside of the Biomimicry Institute and Biomimicry Guild. Eugene Tsui of Tsui Design & Research, Inc. uses nature as the basis for design in a strikingly similar way as biomimicry. Tsui calls his work Evolutionary Architecture, and he explains his work in his book *Evolutionary Architecture: Nature as a Basis for Design*. In this book, Tsui explains how he investigates the natural world scientifically to solve problems in architectural design. The book explains Tsui’s design process and the research into specific natural phenomena that inspire his designs. An entire third of his book explores “Lessons From Nature.” This section talks about many different natural phenomenon, from termites to beavers, silkworms and potter wasp nests. Tsui explains what about these phenomenon are valuable to the built environment. Tsui has even preformed scientific tests such as wind tunnel tests and tension and compression tests on things like birds nests, and snail shells. Tsui also performs microscopic observations to better understand the makeup and arrangement of things like wasp nests, and bones. Eugene Tsui’s research is perhaps the most holistic and in-depth of biomimetics in architecture. His application of this research in natural phenomenon is applied to improving structural efficiency and resistance to disasters such as earthquakes and hurricanes. Tsui uses these lessons from nature to improve the construction methods and materials, ventilation, insulation, and solar access among other architectural
issues in his buildings. Although his architectural works are highly fantastical and mostly unrealized, the research and process of using biomimetics in architecture is a basis for this thesis and a valuable resource for the design field.

CRADLE-TO-CRADLE: REMAKING THE WAY WE MAKE THINGS

Cradle-to-Cradle: Remaking the Way We Make Things is written by William McDonough and Michael Braungart. The significance of this book to the thesis is in the process employed. The cradle-to-cradle concept is an over-arching concept that looks to increase sustainability in every field all over the world. It encourages holistic thinking and integrated processes to eliminate the concept of waste through process re-design. This outcome aligns with this thesis in that the ultimate goal is to increase sustainability across an array of professional fields. The book is a call to action to employ a design process that closes the loop on the cradle-to-grave manufacturing model. The book challenges the view that human industry must damage the natural world, and offers up nature’s model as the solution. In nature “waste” doesn’t exist; the by-products and outputs of one organism or system are “biological nutrients” for another organism or system. This closed loop system is the basis for the cradle-to-cradle system. The book not only walks through the kind of thinking that produces a cradle-to-cradle model, but it shares examples of how that model has been carried out by the authors. About ten examples of the process being carried through implementation are described in the book to illustrate how the process can be employed in seemingly very different circumstances.

This Thesis

Janine Benyus’ book clearly illustrates many examples of biomimicry in a variety of fields, however, biomimicry in architecture is not discussed. Biomimicry has been employed in advances in the systems of a building (specifically power generation, and materials). Benyus’ book explores biomimicry in engineering, but not architecture. There is no discussion of the creative design process and how it specifically employs biomimicry. To fill this void, this thesis describes how biomimicry is utilized in every step of the architectural design process. Cradle to Cradle explores the design of processes that use nature as a model. William McDonough’s examples are mostly manufacturing based, but in his architectural practice applies the biomimetic strategies in creating “ecosystem synergies” among processes. However, he does not use biomimicry holistically to create an architecture that is more sustainable. Cradle-to-Cradle outlines how the principles are applied to macro-scale production processes rather than the micro-scale needed in designing living spaces. Eugene Tsui’s Evolutionary Architecture is the most closely related literature to this thesis. Tsui applies biomimicry in a scientific sense to create spaces that are more structurally efficient, are better ventilated, and more environmentally friendly. However, Tsui only briefly describes his design process, and this process results in largely fantastical buildings that although visually powerful are impractical and in many cases unbuildable. The purpose of the thesis is to bridge the gap among these three pieces of literature, and to create a well-defined holistic design process to create architecture that uses nature as its model. By describing the
process in depth, it should enable other designers to begin to employ biomimicry in their own designs. The application of the thesis will also result in an architecture that is more practical and applicable in architectural design today.

What is already out there?: Placing the Thesis in a Precedent Context

To really craft a thesis that is relevant and valid it is necessary to look at how biomimicry has been employed in the past. Throughout history there have been many architectural works that have taken inspiration from nature or some natural element. A much less common occurrence is when a work mimics nature in an effort to solve an architectural problem that has already been solved in nature. Some of the first architecture to mimic nature were ancient indigenous dwellings. These buildings didn’t have modern day environmental technologies such as central heat, air-conditioning, or even lighting. To survive in harsher climates indigenous peoples had to learn from how other animals in the area lived. The Inuits and their igloos are a prime example of this kind of architecture. Studying these ancient dwellings was the first step in finding precedents of biomimicry in architecture. During research, there were many different projects that used a type of biomimicry in the design, but there are three in particular that serve as examples for how biomimicry has been applied to architectural projects. Michael Reynolds’ Earthships use nature in general, instead of a specific organism, as model for the holistic design of these dwellings. The Eden project uses an old biomimetic solution, Buckminster Fuller’s geodesic dome, and improves on the design with inspiration from the study of a specific organism. The third precedent is Mick Pierce’s Eastgate Center. In this project, the building integrated systems were developed by studying how termites thermoregulate their mounds in the same climate. These three precedents along with a couple of minor projects helped to shape the process developed in this thesis.
Michael Reynolds is a 1969 graduate of the University of Cincinnati’s Bachelor of Architecture program. After graduating he moved out to Taos, NM and started experimenting with building. This experimenting led to the founding of a firm called Earthship Biotecture. Michael’s thesis revolved around the idea of the Earthship. An earthship is an architecture, or as Reynold’s likes to call it “biotecture”, that is in a harmony with nature. It is an architecture built from materials indigenous to everywhere in the world; it captures and cleans its own water; grows its own food; heats and cools itself; and treats and disposes of its own waste. Earthships are designed from a whole systems approach. Each part or system is integral to each other and the whole, and all the systems join to create a closed loop system, a sort of Cradle-to-Cradle design long before McDonough published a book on it. This kind of holistic design has produced self-sustaining modern dwellings that are totally off the grid, from the high deserts of Northern New Mexico, to the rainy fields of England, to the Andaman Islands of India. There are many lessons that can be learned from studying these earthships.

The materials and construction of Earthships are revolutionary. Much of the earthship is built from materials that would otherwise be taking up room in landfills, or would require vast amounts of energy to recycle or downcycle. The thermal mass and structural support of the earthships come from old, thrown-away tires that are filled with compacted dirt. Used glass bottles and cans provide much of the aggregate for the other parts of the buildings. This kind of re-purposing of materials that would otherwise pollute the environment actually makes earthships a regenerative architecture.

The water system of the earthship allows the users to survive on rainfall alone, even in some of the driest climates in the world. All the rainwater that falls on the roof of the earthship is captured and used four times before it is leached back into the ground to irrigate plants and recharge aquifers. As the rainwater falls onto the roof, all water is collected in a cistern, often integrated as an architectural feature of the house. Then the water is used in sinks and showers. That water is then sent through interior irrigation pipes that run through the beds of the greenhouse that is inside the dwelling. This water not only allows food production, but the system uses the plants to actually clean and filter the water and make it suitable for its third use in the toilets. After flushing, the water is pumped through underground irrigation pipes, which allows plants to grow around the earthship, and then the water seeps down to recharge aquifers. This sort of system requires the user to interact and understand their water usage, and better understand how they are affected by changes in the local climate.

The form of earthships are in direct response to providing thermal comfort for the user. The plans include several intersecting circles that provide a large volume of space with the least amount of surface area while maximizing the amount of direct sunlight and solar gain the interior receives. On the south side, the earthship employs a double skin to minimize temperature fluctuations, with the space between the first and second skin acting as a greenhouse. The earthship uses the sun to its fullest. An earthship captures sunlight for direct heating, daylighting and food production. Standard equipment on an earthship
also includes photovoltaics, and evacuated tubes for hot water heating. Perhaps the most surprising thing about earthships is that with many of the construction materials being free, most custom designs cost less than $200 per square foot after all technology and building costs.

There are some significant deficiencies. In recent years the materials from which the earthships are built are not necessarily free. As raw material prices go up, the tires, cans, and bottles will become harder to gather and could eventually no longer be free. The other raw materials used to build the earthship require significant industrial processing and therefore have high-embodied energy. Another concern is that the earthship has been designed and executed exclusively in rural environments. Earthships have not been tested in urban environments, and may struggle to remain self-sufficient. In conjunction with this rural design aesthetic, the earthship has only been designed to appeal to one relatively specific user group, this doesn’t include young professionals, and urbanites. The last and perhaps most important issue is that even though the passive strategies used in the earthships are extremely well-developed, they may be improved upon by employing biomimicry, and more specifically looking at animal architecture.

**EDEN PROJECT + CORE BUILDING**

The Eden Project is an environmental education center located near Cornwall, England. It was designed by a collaboration among Arup, Exploration, and Grimshaw-Architects. The main attraction at the Eden Project are its interconnected biomes. These biomes are directly modeled from nature, to create the lightest structure that encloses the greatest volume with the least surface area. The structure of the biome is that of a geodesic dome, which Buckminster Fuller developed from nature. The structure is assembled in hexagons much like the structure of packing as seen in bubbles, and turtle shells. This extremely efficient form combined with a three layer transparent film, helped to make the biomes at Eden one of the lightest structures ever created. By doing everything to make the structure lighter, the amount of steel needed was significantly reduced. These measures combined to reduce the amount of embodied energy in the building by a factor of 100. In addition to reduced embodied energy the reduced amount of steel allowed more daylight in and allowed the biomes to be totally heated by direct sunlight on all but the coldest, cloudiest of days. Even the steel connections of the biomes were a product of biomimicry. The study of dragonfly wings and how they connect to the dragonfly’s body helped to solve the problem.

Another newer building on the site is a great example of biomorphism, forms that are inspired by living things. The “Core Building” is literally in the shape known as spiral phyllotaxis. Spiral phyllotaxis can be seen throughout botany, in growth patterns of trees and plants, most notably in the sunflower, in vine tendrils, etc. In the core building, the exposed timber framing, solar panels, roofing panels, and light monitors are all arranged in a spiral phyllotaxis pattern. As an educational tool, a huge granite sculpture of a pine cone inside the Core Building illustrates spiral phyllotaxis and the latent energy in a single pine cone seed.

One of the most sustainable parts of the Eden Project was its site. The Eden Project actually reused an
open pit mine. One of the most destructive activities on an environment is the open pit mine and by choosing to locate an environmental education center in one is memorable. The idea of using such a project to rehab and regenerate a site such as this and actually make it a safe haven for everything botanical is truly a 180 degree turnaround. The Eden Project is innovative in many ways and takes biomorphism to an entirely new level.

**Eastgate**

Eastgate building is a large office/retail building in Harare, Zimbabwe. It was designed by the architect Mick Pearce. This building is a great example of biomimicry rather than biomorphism. Mick Pearce studied large termite mounds throughout Zimbabwe. Termite mounds are huge cities housing millions of termites and are often over five or six feet tall. These millions of termites also grow fungi in these mounds, so the demand for fresh air within the tunnels of the mound is astronomical. In addition to this, the mounds regulate the temperature within 2 degrees while the diurnal temperatures outside fluctuate as much as 70 degrees Fahrenheit! Of course, all of this is done without external heating or cooling systems. To accomplish both temperature regulation and air exchanges, the termites are constantly opening and closing air tunnels throughout the mound. The stack effect is used very effectively within a termite mound. Mick Pearce took these principles from nature and applied them in his Eastgate building.

The building uses the stack effect by employing over forty roof vents that suck out heat by using the whole height of the building. The building uses a strategy known as night flush cooling. A controller system opens the roof vents at night pulling in cool air near the bottom of the building and exhausting the warmer air that had built up inside during the day. This opening and closing of vents provide ten air exchanges per hour for the entire building during the night and only two air exchanges per hour during the day to keep the cool night air in and the hot day air out.

This night flushing strategy is combined with other passive measures to make it more effective. The interior has a full-height atrium that allows for better ventilation while giving the warm air in the building a place to funnel without causing discomfort to the users. The building also has four large masonry towers that provide thermal mass for heat lag, so that the building doesn’t heat up as soon as the sun hits it in the morning. Deep overhangs and columns that have framework for vines to grow and spread protect the exterior from direct sunlight. Even the interior atrium has shading devices all around it so that the direct sun coming in through the skylight doesn’t directly hit the thermal mass, but still provides daylighting to the interior.

All of these strategies combined eliminated the need for air-conditioning in the building. This saved the owner from having to buy a $3.5 million air-conditioning system, which was equal to 10% of the construction cost. Due to the use of stack effect and not air-conditioning the air for required air exchanges, the ventilation cost is 1/10th that of an air-conditioned building. These strategies allow the building to use 35% less energy than a typical building in Harare. All these effects were gained by simply mimicking the architecture of an animal that has lived in this climate for millions of years.

**Other precedents**

There are many more buildings out there that have used biomimicry and/or biomorphism. Buckminster Fuller has often been called the first “sustainable” designer. Many of his inventions, including the geodesic dome and the
dymaxion designs, were innovations inspired by nature. The geodesic dome was first inspired by bubbles in the water, and was further developed by looking at beehive cells.

Tsui Design and Research is a firm in Berkeley and is one of the firms most closely aligned with this thesis. Tsui Design and Research studies animal architecture and the ways in which architecture deals with issues such as using material economically, creating forms that enhance air circulation, using local materials, and a long laundry list of other items. Very few of Tsui’s designs have been built mostly due to the fact that their construction is both difficult and labor intensive. His projects often turn out to be unbuildable which is why his literary research is included in this document, but not his architecture.

Exploration Architecture was one of the architecture firms involved in the Eden Project and many of their projects deal with biomorphism and biomimicry, specifically in exploring water and energy solutions inspired by nature and integrated into the architecture of the project. Again, many of Exploration Architecture’s projects are not yet built and the theories behind them tested. However, their conceptual designs have proved important in developing the process that follows.

Figure 4.19 - rendering for arctic gas pipeline research center. Fairbanks, Alaska. From http://www.tdrc.com/arctic.html.

Figure 4.20 - section rendering for Eco-Rainforest. From http://www.exploration-architecture.com/section.php?xSec=18.

Figure 4.21 - rendering of Eden Project Dry Tropics Biome From http://www.exploration-architecture.com/section.php?xSec=22
**The Process**

Most designers would agree that the single most important factor in the outcome of a design is the design process. The process shapes how the designer or design team creatively approaches the project. Therefore affecting the process is the best chance to affect the results. The Biomimicry Institute together with Carl Hestrich of the Ontario College of Art and Design developed a process to help implement the use of biomimicry in every design process. This “Design Spiral” shown below is a great tool to begin designing using Biomimicry. However, a design process that is more in tune with architectural design processes will make it a more effective tool in the field of architecture. The thesis will help to create a more in-depth process that will better serve architectural design professionals. There are as many different design processes as there are designers, and design processes can change and shift with each project. For that reason, this process is not meant as an end all be all, but rather as a detailed guideline from which to develop one’s own specific process. This process is meant to get the designer thinking critically about nature as teacher and mentor in creating environmentally sustainable projects that adequately provide for the physiological needs of its occupants.

**Identify**

In using biomimicry as a basis for architectural problem solving, it is important not to enter the design process with a preconceived notion of what you want the project aesthetics to be. A process such as this requires a performance based approach. It is essential that the real question be, what do you want your project to achieve? Therefore, the first step in this process is to IDENTIFY problems and opportunities for the specific project. This step is the most critical to the process because without the right questions there often cannot be the right solutions. What are the goals for the project? What are the impediments to sustainability? What are the most important aspects of providing for the physiological needs of the user in the given climate? This step is about brainstorming and problem seeking. It is essential to gather information from as many different perspectives as possible. The goal is to identify as many different problems or issues as possible.

These problems or issues can be numerous and varied, however, this thesis is centered around

---

**Figure 5.1** - Design Spiral developed by the Biomimicry Guild. From [http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html](http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html).
using biomimicry to solve architectural issues that are impediments to sustainability. Identifying impediments to sustainability can be difficult, and can be very different from region to region and project to project. Sustainability is a multi-faceted complicated concept. The most commonly acknowledged aspect is environmental sustainability. Over simplified, environmental sustainability is about using the Earth’s resources (wood, air, water, organisms, etc.) in a manner that doesn’t deplete them. A good place to start looking for impediments to sustainability in architecture is to look at the most energy consuming processes. This would include thermoregulation (heating, and cooling of space and water), lighting, and construction. For example, 47% of energy use in buildings is for thermoregulation of air and water, with ventilation consuming another 12.7%, according to the US Department of Energy. By looking at these energy intensive processes, one can make the most difference with the least effort. There are many resources that can help one identify the impediments to sustainability in these areas. One established resource for understanding the challenges to thermal comfort in climates throughout the United States is Norbert Lechner’s *Heating, Cooling, Lighting: Design Methods for Architects*. This book will help to identify the key concerns to thermal comfort for the climate where the project is located, as well as how some of those issues have been solved in the past. Identifying the impediments to thermal comfort is vitally important in setting the goals for the project and formulating the design questions. The *Green Studio Handbook* by Alison Kwok and Walter Grondzik is another notable resource. This book is a survey of “green” systems and strategies, and provides many strategies that address the issues identified using *Heating, Cooling, & Lighting*. The *Green Studio Handbook* explains in more technical depth into sustainable technologies and strategies than does *Heating, Cooling, & Lighting*.

To better address the problems and issues identified, it is important to understand the cause of the problem. The designer must keep asking why this is a problem or what causes this problem until they get to the root of it. During this research it will be important to note the interrelationships between problems and issues. This process could be illustrated simply in a graphical web. One simple example follows. Once the majority of issues and their causes and interrelationships have been identified and mapped, one can truly understand the issues facing the project. Documenting the design issues and formulating specific questions that address the cause of each problem is essential to the research phase of the process. These specific questions will allow for a productive interaction with biologists and other design professionals. With this comprehensive understanding, the designer can move on to the next step in the process.

The identification process cannot be simply completed at the beginning of the process. Other issues and impediments will be discovered as the design process progresses. Some solutions will require addressing other issues that were not previously considered. It is important to keep an attentive eye to catch impediments to sustainability that may affect the project as it continues to develop.
Once a list of issues and problems has been compiled the next step is to rate the problems in order of importance. Which of the architectural issues are most critical to sustainability? There are many ways to do this, but it is critical to consider which are the most troubling or limiting problems. For example, in sub-tropical to tropical climates heat and humidity can make living there in the summer almost unbearable. Air conditioning is extremely energy intensive and is relied on for much of the year in many contemporary buildings in that region. The most important issue could also be the one that is connected to the most secondary issues in your graphical web. In the case of sustainability addressing the most energy intensive issues can yield the most powerful results. As shown by the stat that 47% and 12.7% of energy in a building is used for thermoregulation of air and water and for ventilation respectively, these issues should be right near the top. Ordering issues into most important to least important to solve will give one a road map to design. In this way the most pertinent solutions will be integral to the project, rather than an afterthought, making it more likely not to be “value engineered out” during the latter stages of the project.

Now that there is an ordered list of design issues complete with the causes of the problem, one can start from the top of the list and ask how does nature solve this problem. Armed with specific questions and problems the designer can now question how nature addresses similar issues. In this step, it can be helpful to engage someone intimately
knowledgeable with the natural world. A biologist, ecologist, or naturalist can enlighten the designer to what organisms already cope with the issues at hand, and how they cope with them. Fully understanding how organisms solve the design problems is crucial to adapting and applying the solutions to the issues of sustainability in architecture. In addition to being a resource on how the natural world deals with these issues, a biologist, ecologist, or naturalist can be a great asset in the dialogue of the design process. He or she can be instrumental in applying the principles or strategies of the natural world to the architectural project. If working with a natural scientist is outside the budget or otherwise not possible the process can be done with the designer only, but will require extensive amounts of research and scientific reading. In either case the following is a rough outline of the steps needed to maximize the chances in finding the most effective strategies in the natural world.

In looking for problem solvers in the natural world, it is important to look for those that solve the problem most effectively, or “champion adapters.” Below is a list of important considerations in seeking natural solutions to the given issues.

- Go outside and observe the natural world, considering how nature solves these issues everyday.
- Ask “what organisms’ survival depends on solving this problem?”
- Ask “In what extreme climates is this problem prolific?” and “Who or what lives there with ease?”
- Familiarize yourself with the key scientific terms associated with your problems and solutions.
- Use keywords to search through scientific literature; follow citations to other works
- Think of the problem from various perspectives; turn it upside down and inside out
- Look for multiple organisms and strategies
- Ask “Do all organisms discovered solve the problem in the same way?”
- Ask “What about this organism allows it to deal with this issue more effectively?”
- Converse with experts in the field

This research should be thorough and exhausting, and provide several possible solutions for each of the major impediments to architectural sustainability. Some of the solutions may come from behavioral adaptations, such as how termites open and close vent stacks to regulate heat loss. Others may come from formal adaptations, like how burrs have curled hooks to stick to the fur of passing animals. The solutions are innumerable. With each solution one must understand HOW the organism solves or addresses the issue. To move forward from the list of strategies, the next step is to create a taxonomy of solutions, that is to categorize and organize the solutions for each problem along with their interrelationships. This will help in the analysis and visualization of all the solutions and will be instrumental in choosing which solutions to develop and apply to the project. While creating a taxonomy of solutions, note any patterns or repeating successful principles. This will narrow the solutions to those that are the most dynamic or promising. Once a taxonomy is created the designer, with or without the natural scientist, can chose the strategies that
are most relevant to the given project or design problem.

**APPLY**

Applying the lessons from nature is the most creative and ill-defined step. It requires inventiveness and outside-the-box thinking. The process is fluid and individual. Here are some steps that could help in the process:

- **Brainstorm and create a list of a variety of applications for each principle or strategy.**
- **Develop each concept or idea to either confirm or deny its viability.**
- **Can multiple solutions work together to solve the same problem?**
- **Consider how the principle or strategy can be applied to multiple levels of the design: the form, the structure, the function, the process, the active and passive systems, etc.**
- **Continue to go back to and adjust your graphic map as you identify more problems and better understand the importance and connectedness of each of your issues.**
- **How does the solution affect the rest of the building and systems?**

Once the designer has gone through the creative process of using lessons from nature to develop architectural solutions to issues of sustainability, it is essential to understand how the various solutions will work together. Can the multiple strategies be implemented in harmony to address several impediments to sustainable design at the same time? Successfully integrating the solutions so that they complement each other will produce the most powerful results. Now that the solutions are clear and developed they can be successfully incorporated into the design of the project.

**EVALUATE & IMPLEMENT**

Once the design is fully developed, the next step is to evaluate the performance of the design prior to its execution. The testing of the solution can vary widely from case to case. Some testing will be less accurate than others. Some designs will not be able to be tested except on paper. Other solutions will be able to be very accurately tested. There are numerous ways to test designs. A small scale model of the project or a piece of the project may need to be produced. Digital models can be used for energy modelling. A full size construction of a detail may be required to test.

*figure 5.5 - life principles diagram developed by the Biomimicry Guild. From http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html.*
designs. With an architectural design that is scientifically produced it is important that its performance be tested by some scientific means, otherwise the projects success will be compromised. After testing the design by appropriate means, the designer must evaluate its successfulness. Is it more or less successful than he or she had expected? There are very few things that work the first time they are tried. This juncture allows for an evaluation of the success of the design and a chance to iterate and make the design more effective. The Biomimicry Guild has an effective evaluation tool that illustrates “Life’s Principles”. This tool can be used to evaluate the design as a whole and can help identify shortcomings in parts of the project that have not been identified. A project that meets life’s principles will not just be sustainable, but will actually be regenerative. Following any redesigns the project can be tested again. Often this iteration and retest process can be done quickly and repeated to significantly increase the performance of the design. After the retests and iterations, a successful biomimetic design that addresses issues of sustainability can be implemented. Often times architects execute a design and move onto the next project without pausing to actually learn from his or her own work. Post-occupancy evaluations are an under-utilized learning tool. They can provide valuable lessons that allow the designer to better implement his or her ideas in future projects. Learning the actual effectiveness of thermal comfort controls, which spaces are utilized versus those that are wasted, and how the everyday users feel about the project they have come to know intimately are all valuable lessons that can be taken away from post-occupancy evaluations. These evaluations can only shorten the learning curve for designers and help to improve our understanding of sustainable projects and how to create more effective designs in the future.

**WHAT THIS PROCESS CAN DO**

No matter how the above process is tweaked and executed the most important part is to look to nature as a design mentor. Most of the problems that architects face in regards to the built environment have already been resolved in nature. Through more than 3.5 billion years of development nature has not only resolved these issues but has done it in an absolutely sustainable way. This process provides a model for a more scientific, but low-tech approach to sustainable architectural design. By modeling our built environment after the most sustainable model we know, we can significantly reduce the huge environmental impact of our buildings.

This process is meant to make biomimicry as a design process more pervasive in the field of architecture. By outlining the process and how it can be effectively utilized in the field of architecture, more and more designers and architects will implement it to create a more sustainable built environment. This holistic design approach promotes a multi-disciplinary design process that requires the architect to interact with professionals in the natural sciences. This new perspective for designers can help them to create environments that are comfortable all year round, boost well-being by exceeding the physiological needs of its users, and above all, is sustainable.
Design

The execution of the design process

This design project closely follows the process laid out previously in the document. In this way, the reader has an example of how the process is carried out throughout the entire design process. This will highlight its strengths and weaknesses and test its overall successfulness in developing a truly environmentally sustainable architectural project.

The first step in the design process was to select a site. The region of the nation that I am particularly interested in is the “Rust Belt”, specifically parts of Ohio, Michigan, Pennsylvania, Kentucky, New York, Illinois, and Wisconsin. This region offers diverse opportunities and challenges both ecologically and socially. The “Rust Belt” has a shortage of clean energy solutions, an abundance of water, mild to harsh winters and hot and humid summers. The vegetation and wildlife studied in this area reflect the broad variations in environments. Societal attitudes toward sustainability in the “Rust Belt” are also a challenge. It is the heart of coal country, and home to many of the most polluting and energy intensive manufacturing industries in the country. These factors along with the balance between rural and urban lifestyles in this region would provide interesting and challenging solutions.

More specifically the site is located in the Ohio River Valley in the basin of Cincinnati. The site is just under a mile from the Ohio River, far enough to be well out of the 100 year flood plain, but close enough to downtown to be easily accessible by foot, bike or public transportation. It was important to pick a site that was local and easily accessible throughout the thesis process. Visiting and experiencing the site and

figure 6.1 - the “rust belt” of the upper midwest

becoming intimately knowledgeable with it is essential in producing a sustainable project based on lessons learned from local flora and fauna. All decisions that led to the choice of the more specific site of the northeast corner of 12th and Vine Streets in the Over-the-Rhine were centered around creating a project that encouraged a sustainable lifestyle. Locating the project with nearby services, and access to major employment centers and public transportation was of utmost importance. In coordination with those criteria, it was important to pick a previously developed site in the center of the city, in a neighborhood that is under-utilized, and within reach of lower income aspiring homeowners. Another important criteria was choosing a site in an area that had good vehicular traffic, and was on the border between a residential area and commercial or industrial area. All of these criteria are met by the site on Vine Street. Before any design work can begin it is important to understand the site and its context.

**Site/Context and Analysis**

The site for the thesis is located at the northeast corner of 12th and Vine Streets in the Over-the-Rhine (OTR) neighborhood of Cincinnati. The site is in the south of the neighborhood and just north of Central Parkway and Downtown. Currently, the site is a newly renovated surface parking lot. The site is a conglomeration of six lots that make up approximately .4 acres. These combined lots make an irregular site with three street frontages and only one corner. There is a 130’ of frontage on Vine Street and a 140’ of frontage on 12th Street. There is also a 40’ frontage along Jackson Street, which is a short north-south street bordering the east side of the site. Like the majority of the basin of Cincinnati, the site is essentially flat with less than two feet of relief over the entire site. Surrounding the site are mostly three, four, and five-story historic masonry buildings built in the 1880’s and 1890’s. The building that borders the north side of the site is a tall four-story renovated mixed-use building. This building is comprised of condos located over retail. The buildings that face the site across Vine Street are similar in that they are also renovated mixed-use with condos over various retail. On the southeast corner of the site stands a five-story mixed-use building with apartments above ground floor retail bordering 12th and Jackson Streets. There are two buildings bordering the site on the northeast. The southern most building is a four-story apartments over retail, and the northern most building is a two-story commercial building both of which face Jackson Street. Across 12th Street to the south is a building built in 2004. The eastern half of the building is a five-story parking structure largely meant for employees of the Kroger building located just south across Central Parkway. The western half of the building is another mixed-use building with retail over condos. Diagonally from the site on the southwest corner of 12th and Vine is a three-story building that houses the sales office for the area with apartments above.

Zooming out and looking at the wider context of the neighborhood, one realizes its dynamic and important position in the Cincinnati basin. Vine Street is a vibrant, neighborhood street that is eclectic and starting to see new life. A slow intimate two lane street which is always alive with pedestrians, Vine Street is a cultural center of Over-The Rhine. Vine Street at 12th is at the center of the
redevelopment of the neighborhood. The site is currently a parking lot used primarily during the week for patrons of the newer retail developments. The area around the site has seen significant redevelopment over the last five years. The site is a part of the 3CDC’s (Cincinnati Center City Development Corporation) Gateway Quarter development. 3CDC has renovated these historic buildings and has provided over 100 new housing units, and several new retail spaces. In addition to these developments in the lower Over-the-Rhine area, bars, restaurants, cafes, retail stores, and two schools have moved to the the lower OTR area. The Art Academy of Cincinnati is on 12th Street one block east of the site. The School for Creative and Performing Arts is constructing a new home on 12th Street two blocks west of the site. Despite all of this development, there are still a large number of parking garages and surface lots in Downtown and Over-the-Rhine. This includes a new large parking garage built on the south side of 12th Street across from the site. This is why a surface parking lot was chosen, and as OTR becomes more densely redeveloped and more walkable community these types of lots will become unnecessary and uneconomical.

One of the main reasons the site was picked was for its location to services and amenities. The site is a five to ten minute walk to the employment center of downtown. This also means that all of the services provided in downtown are also within walking distance. Several small grocers, and a chain grocer within a quarter mile of the site. In addition to these, the vibrant Findlay Market is within walking distance (.5 miles). The large urban park, Washington Park, is two blocks west of the site. Next to Washington Park is a huge entertainment draw in the historic Music Hall, and two theatres, the Know and Ensemble Theatres are also located nearby. Schools, bars, restaurants, and retail stores are all moving to locate in Lower OTR. There are several hardware stores, auto repair shops, and convenience stores in the immediate area around 12th and Vine. The accompanying figure illustrates the comfortable walking radii and some of the amenities located within them. In addition to these immediate amenities, two bus stops are located on the sidewalk in front of the site and nearly every Metro route in Greater Cincinnati stops within a half mile of the site. This makes the site highly accessible to the metropolitan area without the use of a vehicle. It is due to this central location, where all the daily needs of residents can be met within a ten minute walk that makes this site a very sustainable place to put a project.
In a national historic district like OTR, it is important to understand its historical and cultural context, before designing a project there. The lower Over-the-Rhine neighborhood was started in the late 1700s and incorporated into the city of Cincinnati in 1803. After the completion of the Miami and Erie canal, bordering the neighborhood on the west and south, in 1820, many industries and people moved into the neighborhood. OTR continued to grow and was a dense, diverse, and established neighborhood by the 1850s with an estimated 43,000 people in 3,625 acres or 5.7 square miles. This made it one of the most densely populated areas in the country. As its name suggests the neighborhood was primarily inhabited by German immigrants. The area got its name because some local residents likened crossing north over the Miami-Erie Canal was like crossing the Rhine River into Germany. At this time more than half of all residents of OTR were German immigrants, with much of the rest of the population being Irish immigrants. The area developed a wide-variety and vast number of industries. Iron-making, meat packing, cloth manufacturing and most importantly brewing. Over-the-Rhine was often considered the brewing capital of the United States, as at one time it was home to 17 breweries. Many churches were built in this area, and the oldest standing church in Cincinnati is located here, Old St. Mary’s Church. This church still has a mass every Sunday in German. Over-the-Rhine is home to Music Hall and hosted people from all over the world during the Cincinnati Industrial Expositions from 1870 to 1888. Music Hall stands across Elm Street from Washington Park. This six acre park was established in 1860, and still serves as one of the community centers today. In the late 1850s, Findlay Market was completed and became the retail center of OTR. The beer gardens located throughout the neighborhood were one of the daily pleasures for families living in Over-the-Rhine. Much of the Italinate masonry buildings found in OTR today were built between 1880 and 1900. This is after the rows of small wood structures and homes built in the 1830s and 40’s could not house the population. The majority of the architecture in OTR is Italinate row houses and mixed-use buildings. There are also examples of Queen Anne, and Muted Greek Revival buildings. By the turn of the century, OTR was home to nearly 45,000 people, most of which were German, but there were also many immigrants from Ireland, and southern states. Many large institutions started to move into OTR in the early 1900s. The YMCA and Cincinnati Public Schools built large buildings in Over-the-Rhine. The Ohio Mechanics Institute built their new building including the Emery Auditorium. Hamilton County built Memorial Hall next to Music Hall in honor of Cincinnati and Hamilton County veterans. These landmarks along with the dense, diverse makeup of the neighborhood, made Over-the-Rhine into a cultural center of the City of Cincinnati. This heyday of Over-the-Rhine lasted until the early 1920s. OTR saw a slow decline from the early 1900s until the 1960s. The anti-German sentiment from the United States involvement in WWI combined with better transportation in inclines and street cars caused many of the German immigrants to move out into the suburbs on the hills surrounding OTR. This in combination with prohibition, the now obsolete canal system and the failure of the subway forced many industries to close or move out of the area. Slowly people started to move from
OTR out into the first and second suburbs of Cincinnati. The exodus consisted of the more affluent residents of Over-the-Rhine. From the 1920s until the 1960s Over-the-Rhine’s demographics changed considerably. During this time, there was a steady influx of Appalachians into the area. This population was mostly transient, staying in OTR for a short time, before moving onto greater opportunities. By the 1960s OTR’s population was down to 30,000. During the 1960s, “White flight” and deindustrialization reduced OTR's population by nearly half. During this same time, the community saw a doubling in its African-American population, as low income residents were forced out of the West End due to the construction of I-75. Since then the decline of the number of people living in Over-the-Rhine and the rise in dilapidated buildings has been constant. In 2000, OTR had about 7,500 residents, only one sixth of its 1900 population. In 2006, Over-the-Rhine was placed on the National Trust for Historic Preservation’s list of “Eleven Most Endangered Historic Places”, highlighting the deterioration of the 983 contributing historic structures that make up this special neighborhood in Cincinnati’s Basin.

**Developing a Building Type + Program**

A single family detached home is the epitome of the “American Dream.” The pursuit for a house and a piece of nature to call one’s own has made this type of dwelling unit the most prolific over the last half century. This migration out of the cities is the engine that drives urban sprawl, and has, ironically, dramatically endangered the health of the local ecology. In addition, this model was built on fast, cheap private transportation. In a new era where that fast is not so fast, and the cheap is not so cheap, a new model most dominate the 21st century. This model will increase density and locate everyday needs in a much tighter radius accommodating slower, more accessible transportation (biking, walking, etc.); all this while including natural landscape to enable each user to provide for themselves. In this light, the program and typology of the project was chosen; a multi-family mixed-use development that is at least six times the current density of the City of Cincinnati, or about as dense as New York City. The dwelling units have corresponding work spaces either for their use or as an income producing rental space. In addition, the project provides natural landscape for both energy production and pure enjoyment. This kind of live/work is becoming a typical typology for “sustainable” communities throughout the United States. Working to improve the sustainable qualities of this typology through investigation and application of formal strategies would help create a more comprehensive, more sustainable development model. To apply biomimicry to this specific

---

kind of architecture could generate the greatest change in today's developed nations, while helping users to live in closer harmony with the nature they so desperately seek.

The building type for this project is a six unit multi-family dwelling with integral workplaces. The project consists of semi-detached live/work buildings. The project includes more than ample common outdoor space for food production, and activities. This building type was developed to encourage local interdependence, by including amenities that make it easier for the inhabitants to provide for themselves. The building type is also meant to encourage community engagement within the project and immediate neighborhood. The project is home to between 15 and 21 people in six units, small enough to feel like extended family and large enough to ensure that everyone can connect with someone. The project accommodates the new American “family” consisting of one and two children traditional families, small groups of close friends living together, and young professionals. The live/work units encourage the development of smaller “cottage” industries that do business locally. All of the decisions made to define the building type were made to promote a more sustainable lifestyle.

The spatial requirements of the program are set to not only meet the needs of this new American “family”, but also help foster a more sustainable lifestyle. One of the most stringent spatial requirements is the reduced size of the units. There will be a mix of two and three bedroom units with office space ranging between 1000 and 1300 square feet. Economy of space will be of upmost concern. Having spaces that serve dual purposes and are somewhat flexible makes these small dwellings feel larger than they actually are. The units maximize common areas by having bedrooms that are much smaller than those seen in “McMansions” to encourage family togetherness. An abundance of shared outdoor space and the intertwining of interior and exterior space will not only make the units feel larger, but should also encourage engagement among the other inhabitants of the project. The outdoor space has both active and passive roles. This exterior space will need to accommodate energy generation, food production, and recreational space, while serving to rehabilitate the brownfield site into some resemblance of its former ecosystem. These criteria help to guide the project to becoming more sustainable, but are flexible enough not to impede the development of a building based on an ever-developing biomimetic approach.

The program is not limited to the spatial, and in this thesis the spatial is really secondary to the performance criteria. The real goal of the thesis is to study nature and use the lessons learned to improve the sustainability and physiological conditions of the built environment. Of course those conditions are not only broad, but can be achieved many different ways. Although the design approach is holistic, there are some very specific aspects in modern building where there is a lot of room for improvement. The thesis looks to nature to learn how to use local materials economically, and in a truly sustainable way, and to create energy-efficient, well-insulated, comfortable environments without external power. In striving to achieve these lofty performance goals, the project will also have to be regenerative, actually healing the site and context in which it is situated.
**Programming Precedents**

**Sabin Green**

Sabin Green is a housing project which consists of four separate homes all built on one lot in Portland, Oregon. The four homes combined are a mere 3,874 sq. ft. A retired couple, two young professionals, a young family with two children, and a single woman with a dog, each have their own separate dwelling, but make many decisions for the community together. Outside each of their dwellings the open space is shared by all. The project, designed by Communitecture of Portland, renovates a single bungalow and garage into two dwellings. The project also built two new dwellings to significantly increase the density of the lot while allowing the owners to have a home to call their own. The small size of these buildings are perhaps their greenest feature. Other green features include solar hot water, photovoltaics for electricity, on-site stormwater management, reused and natural (cob, straw bale) building materials. The smaller size and the sub-division of the lot made each of these dwellings affordable to those who would not otherwise be able to own their own home. By mutually sharing not only a lot but, other resources such as stormwater management, energy generation, and even smaller things such as internet access, and gardening tools make this model even more economical.

6 “Green Like Us.” *Sunset Magazine.* From http://www.sunset.com/sunset/travel/article/0,20633,1709818,00.html
7 According to Communitecture. From http://www.communitecture.net/communitecture/projects.php

The sustainability of a program and model such as this is evident in a quote from one of the project designers.

“The most important cultural feature of the project is the shared communal space and amenities. In today’s society the status quo is that everyone owns their own lawnmower, their own lawn tools, and their own shop-vac in their own garage, on a lot delineated from the neighbor’s by a fence. An actual community is a social group of organisms with shared interests and goals. The sharing of resources is important to reducing consumption and the drain on our natural resources.”

- Christine Yun, Project Designer

Although this project does not have workspace, it proves that increased density, combined lot ownership, and smaller homes are not only possible, but are more economical, and have a laundry list of positive outcomes. This project guided the definition of the program and provided a wealth of information to the thesis.

**Diva**

Diva is a live/work project in Seattle by Place Architects. When working at Place Architects the author became intimately familiar with this project. Diva is a three story building with a loft type office space on the top floor, a drive-in public ground floor and a private living floor below that opens on the other side on the sloping site. The space seamlessly functions as both a commercial and residential space. The gracious and transparent garage door entrance provides an accessible and welcoming facade for both residential and commercial visitor. The open plan and loft provide for a variety of programs and activities, making

![Figure 7.4](http://www.communitecture.net) - four small homes on a single site with community space and cob teahouse in the center.

![Figure 7.5](http://www.communitecture.net) - communal space with teahouse on the left and a residence on the right.

![Figure 7.6](http://www.placearchitects.com) - porch opening on to common area, made of reused windows.

![Figure 7.7](http://www.placearchitects.com) - view of diva from street.
the space adaptable for many different living and work arrangements. The demarcation of functions happens through vertical separation. The severity of vertical separation differs based on function. The public ground floor and office space above have little separation. This allows for the functions to flow together. Business and entertainment can happen seamlessly. The lower floor is concealed and tucked away from the public spaces of this live/work project. This gives it more security and privacy than the rest of the home. The project contains several types of work and living spaces. This allows for a variety of configurations, and spaces where work can be done in close private quarters, and other spaces where larger works can be spread about. It blends a warehouse type office space with a cozy home. This treatment makes the Diva live/work project a dynamic interaction of residential and commercial spaces while still serving the domestic needs of its three residents.

The organization and treatment of the variety of spaces has informed the way the thesis was programmed and the formal arrangement of the spaces within the project. The project includes a variety of working and living spaces and arrangements with an open plan, and levels that are more or less demarcated from other spaces/levels. The way in which Diva blends working and living space in an open plan has significantly informed the thesis.
Four energy intensive impediments to sustainability were identified:

**High humidity**
**High heat**
**Cold winters**
**Lighting**

What are the goals for the project?
- to be mostly self-sufficient (water, power, food, etc.)
- building operation be carbon neutral
- use no external power
- building to be constructed with least embodied energy
- to be regenerative
  - increase biodiversity of the site
  - improve air quality of the site
  - improve water quality of the site
  - improve soil quality of the site
- be thermally comfortable for all
  - easily adjustable thermal comfort
- sufficient daylighting to negate artificial lighting during the day
- foster a close community among residents
- foster holistic sustainable living
- provide near sustenance farming
- using local materials in a truly economical way

What are the impediments to sustainability?
- contemporary high-embodied energy construction materials and methods
- high humidity and heat in late June, July, August, and September
- long, cold, and dry winters (November, December, January, February, and March)
- quickly changing weather patterns (from heating to cooling)
- dependence of power grid on fossil fuels
- air-tightness (super insulation) traps indoor air pollution
- negative effect of modern materials on air quality (carpet, VOC’s, OSB, etc.)
- dependence on artificial lighting due to insufficient daylighting (esp. winter)

What are the most important aspects of providing for the physiological needs of the user?
- thermal comfort; not precisely regulated but within limits (thermal delight in architecture)
  - humidity, heat, + cold
- fresh air (air exchanges)
- daylighting
- views
- biophilia

Figure 8.1 - Early exercise setting goals and identifying issues, by asking questions.
figure 8.2 - Diagram illustrating human turbinates and their ability to cool and dehumidify exhaled air.

figure 8.3 - Diagram and image comparing the surface area of scroll shaped human turbinates at left, versus the brain like pattern of the more effective bear turbinates at right. Left image from http://getbodysmart.com. Right image from Evolutionary Architecture: Nature as a Basis for Design by Eugene Tsui.

figure 8.4 - Images comparing the direct surface area contact in a singular cylindrical tube, versus more and smaller fin tubes.

figure 8.5 - Current installations of inefficient earth tubes, maximum volume and minimum surface area for heat transfer.

figure 8.6 - By using tubes that have greater surface area for heat transfer, earth tube runs can be shorter and more effective and efficient.

figure 8.7 - Employment of fin tubes in an earth tube system below a watered garden to make the heat transfer twice as efficient by utilizing conduction in combination with convection. By running the air through 65 degree soil and lowering the temperature humidity condenses out of the air.
Figure 8.8 - Air speed and direction measured during the cooling city. Majority of wind comes from the Southwest more than 45% of the time.

Figure 8.9 - The extensive ventilation scheme is inspired by termite mounds. It utilizes earth tubes, the stack effect, many smaller operable windows, and Bernoulli’s principle to draw air through the building, to provide comfort ventilation.

Figure 8.10 - Anotermes (termite mounds) in Australia with channeled faces to increase diffusion by increasing wind speed along the face.

Figure 8.11 - Wind flow and speed diagram showing how the chevron facade speeds up wind and channels it to increase wind speed and comfort ventilation in the sometimes stagnant air of the Cincinnati Basin.

Figure 8.12 - Iterative process showing development of chevron based on wind and wind shadows and, winter and summer solar gain. In the compromise the wind speed is increased and the building self shades in the morning and evenings of the hottest months.
Cincinnati’s Cold Winters

Figure 8.13 - Diagram and images of Jean Pain’s 1970’s compost water heater used to heat his home during the winter in France.

Figure 8.14 - Series of drawings illustrating the concept and technical aspects of the compost heater proposed for the project. The calculations for volume and heating capacity are at right, and the schedule of operation is explained at bottom.

Figure 8.15 - Walkability to everyday necessities reduces dependence on private and public transit.

Figure 8.16 - The building has a long east-west orientation and shallow north-south floor plate to maximize daylighting and winter solar gain.

Figure 8.17 - The building captures rainwater that falls on site to meet the reduced water demand of the residents.

Figure 8.18 - Compact spaces decrease requirements for heating and cooling.

Figure 8.19 - Green roof helps to reduce cooling load by shading roof and adding insulation.

Figure 8.20 - Shading louvers keep the summer sun from directly hitting the wall and interior of the building, reducing cooling needs.

Figure 8.21 - By providing land for farming the residents can grow a large amount of their food, reducing dependence on non-local food.
Figure 8.22 - Series of shadow studies that dictated site massing based on solar access.

April 15th

June 21st

October 1st

December 21st

Figure 8.23 - Site model illustrating massing in response to shadow, solar orientation, and ventilation factors.
Figure 8.24 - This page and facing: Floor plans for main building on the north side of the lot. Four units are included in this building. Three typical three bedroom units, an ADA two bedroom unit, and a work space facing Vine Street. Scale: 1/32" = 1'-0"
Figure 8.25 - Street perspective from Vine Street looking north at north building with shuttered produce stands at right.

Figure 8.26 - Perspective of south facade looking over communal garden courtyard space.
BIBLIOGRAPHY


Huntley, A. C.; Costa, D. P.; Rubin, R. D. 1984. The contribution of nasal countercurrent heat exchange to water balance in the northern elephant seal, Mirounga angustirostris. 447-454


