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Biomimicry: Emulating the Closed-Loops Systems of the Oak Tree for Sustainable Architecture

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BIOMIMICRY: EMULATING THE CLOSED-LOOPS SYSTEMS OF THE OAK TREE FOR SUSTAINABLE ARCHITECTURE

A Thesis Presented

by

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DEDICATION

To David Dillon

ABSTRACT

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MAY 2011

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Biomimicry comes from *bios*, life, and *mimesis*, to imitate. Biomimicry is becoming an increasingly well-known topic in the field of architecture, imitating nature's designs and processes to solve human problems. This project uses the oak tree as a model, measure, and mentor to derive sustainable architecture. Biomimicry is examined as a holistic methodology with six steps: identify, interpret, discover, abstract, emulate, and evaluate. Using this methodology, this project investigates oak tree's closed-loop systems including water, oxygen, and food. The synergies that exist within these systems are emulated to develop a complex green infrastructure of building and landscape systems. This project provides an illustrated process using the biomimicry methodology to generate sustainable architecture.

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CHAPTER 1

INTRODUCTION

1.1 Trees as Teachers

I was not the first child ever to climb a tree, nor was I the last. One summer morning I found myself, again, in a tree. The branches began fairly low to the ground, making it easy to begin my climb. Branch after branch, I ascended towards the sky. Before I knew it, I was at the top taking in an incredible mountain view. I sat for a time, reaping the rewards of my curiosity.

Hoping to share this experience, I started calling to my father. *Dad!* I observed him make his way through the backyard, following my voice. *Dad, up here! Look how high I am!* I watched his eyes gradually climb the tree until he found me. He told me lunch was ready and to slowly climb down. Lunch? I suppose I'll descend. This tree is not going anywhere after all.

Walking back towards the house, my father told me never to climb that tree again. Years later, he refers to that as the day he had a heart attack. A lot surges through your mind when you see your six-year-old child one-hundred-feet in the air. This explained his lack of enthusiasm for my personal adventure.

Growing up amidst Mount Toby State Forest, my affinity and curiosity for nature began at a young age. Watching this complex ecosystem throughout my life, I developed a deep interest and love for forests. Trees were my teachers, and the lessons I learned beneath them were as infinite and memorable as the times I had climbed them.

1.2 Biomimicry

This environment sparked my interest in biomimicry, using nature as a teacher, similar to the way I had used trees as teachers all my life. Biomimicry comes from *bios*, life, and *mimesis*, to imitate. Biomimicry is becoming an increasingly well-known topic in the fields of design, engineering, architecture, and business, imitating nature's designs and processes to solve human problems. [1] When redesigning the very noisy Shinkansen Bullet Train of the West Japan Railway, the chief engineer imitated the Kingfisher. As described by the Biomimicry Institute: "Modeling the front-end of the train after the beak of kingfishers, which dive from the air into bodies of water with very little splash to catch fish, resulted not only in a quieter train, but 15% less electricity use even while the train travels 10% faster,"[2] shown in Figure 1.

Figure 1: The Kingfisher (The Biomimicry Institute)

[1] "What is Biomimicry?," Biomimicry Institute, 2010, 3 March 2010 <http://www. biomimicryinstitute.org/about-us/what-is-biomimicry.html>.

[2] "Transportation." Biomimicry Institute, 2010, 1 Dec 2010 <http://www.biomimicry institute.org/case-studies/case-studies/transportation.html>.

CHAPTER 2

THE BIOMIMICRY METHODOLOGY

2.1 Model, Measure Mentor

This research explores using biomimicry as a methodology to achieve sustainable architectural solutions looking to nature as a model, measure, and mentor. Entering into this exploration through the vantage point of my personal interests and background, my research into biomimicry looks to the oak tree—a native plant that operates with systems it has developed over millenniums to function flawlessly in our environment. I am using the oak tree as a model, measure, and mentor for the design of a sustainable building (Figure 2).

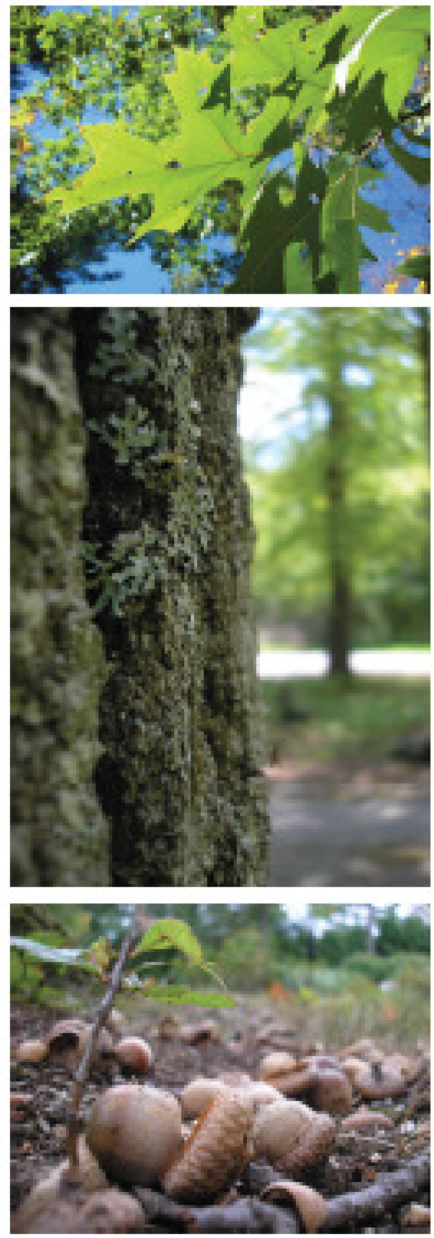

Figure 2: The Oak Tree

The oak tree as a model: From lone seedling to dense forest and root to canopy, studying the oak tree and emulating its forms, processes, and systems to sustainably solve architectural problems.

The oak tree as a measure: Using the oak tree as an ecological standard to judge the sustainability of our innovations. After 40 to 56 million years of evolution, oak trees have learned what works and what lasts.

The oak tree as a mentor: Finding new ways of viewing and valuing the oak tree, introducing an era based not on what we can physically extract from the oak tree, but what we can learn from it.

Using the oak tree as a model, measure, and mentor, there are six steps I follow that form the biomimicry methodology: identify, interpret, discover, abstract, emulate, and evaluate.[3] These steps are illustrated in the design spiral (Figure 3), reinforcing the cyclical process. Using this methodology, I will investigate the oak tree's closed-loop systems (i.e. water, oxygen, and food) and the synergies that exist within and between these systems to derive sustainable architecture.

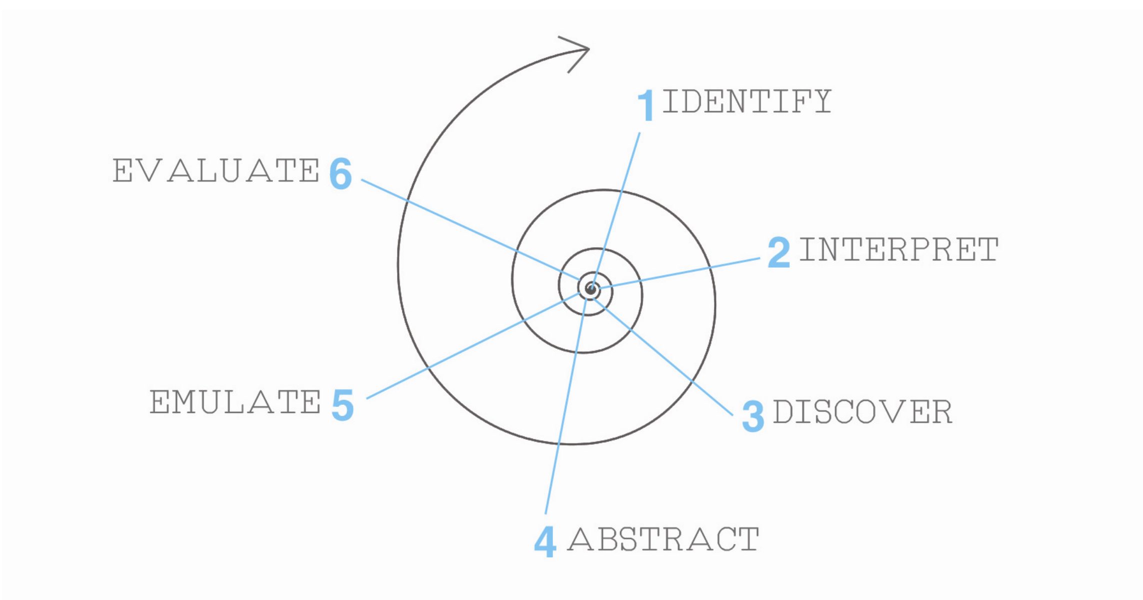

Figure 3: The Design Spiral

[3]"Biomimicry: A Tool for Innovation 2010," Biomimicry Institute, 1 Dec 2010 <http://www.biomimicryinstitute.org/about-us/biomimicry-a-tool-for-innovation.html>.

2.2 Why Biomimicry?

Many variations of this practice have evolved, such as bionics, biomorphism, bioinspiration, bioinspired design, and the like. For my research, I specifically examine biomimicry for my exploration because of its advanced development as a holistic field of practice with sustainable goals. Janine Benyus coined the term *biomimicry* in 1997, when she released her book, *Biomimicry: Innovation Inspired by Nature*. The book examined this new science that analyzed some of nature's best ideas and adapted them for human use.

This book led to The Biomimicry Institute, a not-for-profit organization founded by Benyus, Dayna Baumeister, and Bryony Schwan in 2005. This organization promotes the study of nature and the bringing together of scientist, engineers, architects, and innovators to create sustainable technologies. The Institute offers workshops, courses, and other resources for all those interested in the field.[4] Benyus, in collaboration with this organization, has worked to develop Biomimicry into a holistic method with accessible resources.

This project has the potential to contribute to the resources available through the Biomimicry Institute. Careful documentation of this study will prove to be valuable in this recently emerging field. Expanding this network of research is vital to the growth of biomimicry. This is because the amount of biological research needed to make fruitful cases of biomimicry is extensive. A shallow understanding of the biology results in a similarly shallow example of biomimetic architecture, lacking sustainable solutions that

[4] "About Us," Biomimicry Institute, 2010, 3 March 2010 <http://www.biomimicry institute.org/about-us/>.

the biomimetic method can potentially yield. This outcome is determined initially by the nature and depth of this biological research.

2.3 Holism

With this considered, it is important to define the scope of my research. There are certain levels of depth to which one can become involved in biomimicry. The lowest level, as outlined by Julian Vincent, Director of the Centre for Biomimetics and Natural Technologies at the University of Bath, is the direct copying of biological objects.[5] It is not to say that examples of biomimetic design at this level are not of value, but they often lack a certain depth and research that keeps them from reaching their true biomimetic potential. This is because certain aspects of the biological model are usually extracted and torn from their context, diminishing other qualities that support or depend on that aspect.

If I were to design a building inspired by an oak tree at the low level described by Vincent, the building would most likely resemble an oak tree, but the shallow analogy that sparked resemblance would undoubtedly lack the sustainable attributes I am striving for. More thorough, holistic research of the oak tree would result in a more sustainable building. To achieve sustainability, I must mimic sustainability. The sustainability of the oak tree is a culmination of each characteristic of the tree and its contextual ecosystem. Since the goal of Biomimicry is to create sustainable and healthy human technologies and designs, biomimicry only reaches its full potential when a holistic approach is taken. This is how I intend to approach my research of the oak tree.

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[5] Julian Vincent, "Biomimetic Patterns in Architectural Design," Architectural Design 2009, 79: 76.

John Reap of the Systems Realization Laboratory at the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology explains what happens when biomimicry is not approached holistically:

> Scientists and engineers work diligently to mimic a few features or functions of particular organisms or biological processes. They focus on particular technologies or elements of technologies at particular scales…by narrowing the scope of inquiry, it threatens to limit biomimicry's applicability to sustainable design.[6]

Reap goes on to explain that biomimicry is not green by default, and requires this holistic strategy to reach sustainable outcomes. I argue that, given the definition and goals put forth by the Biomimicry Institute, such biological analogies are not examples of biomimicry because they do not fit its values of using to nature to derive sustainable solutions. Nonetheless, Reap does emphasize the depth at which the designer must study nature to achieve these sustainable goals.

2.4 Biomimetic Architecture

Architecture is one of the many fields that has benefitted from the concept of biomimicry. Seeking sustainable architectural solutions is important since buildings are one of the leading causes of global climate change. According to the Energy Information Administration, buildings in the United States account for 14% of potable water consumption, 30% of waste output, 38% of carbon dioxide emissions, 40% of raw

[6] John Reap, "Holism, Biomimicry, and Sustainable Engineering," Energy Conversion and Resources 2005, 424.

materials use, 24%-50% of energy use, and 72% of electricity consumption.[7] This raises many questions for architects regarding how to achieve more efficient buildings. Can the design of a building reduce cooling loads? Can it reduce structural materials?

Fortunately, architects are not alone when it comes to solving these problems. Employing biomimetic strategies, architects ask, "What would nature do?" Nature has already solved many of the problems that we, as humans, are dealing with. Having evolved over 3.8 billion years of research and development, nature has determined what works and sustains on Earth. By studying and imitating nature's designs and processes we are able to move towards sustainable solutions.

What might be the most successful example of this is the Eastgate Center in Harare, Zimbabwe. The steps that architect, Mick Pearce, took resemble those used in the biomimicry methodology. First, he identified the challenge: designing a building that passively cools and ventilates in an extreme climate. Second, he interpreted the challenge in terms of biology: what in nature, passively cools and ventilates in this extreme climate? Then he discovered a model that might inform the design of his building: the macrotermite termite mound. According to the Biomimicry Institute:

> "We generally think of termites as destroying buildings, not helping design them. But the Eastgate Building, an office complex in Harare, Zimbabwe, has an air conditioning system modeled on the self-cooling mounds of Macrotermes michaelseni, termites that maintain the temperature inside their nest to within one degree, day and night (while the temperatures outside swing from 42 °C to 3 °C).[8]

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[7] Energy Information Administration. 2005. EIA Annual Energy Review and Energy Information Administration. Emissions of Greenhouse Gases in the United States.

[8] "Architecture." Biomimicry Institute, 2010, 1 Dec 2010 <http://www.biomimicry institute.org/case-studies/case-studies/architecture.html>

Pearce studied these termite mounds extensively, abstracting and emulating their design into his design of the Eastgate Center. Figure 4 illustrates the sectional cooling and ventilation diagrams of the termite mounds (left) that Pearce emulated for the Eastgate Center (right).

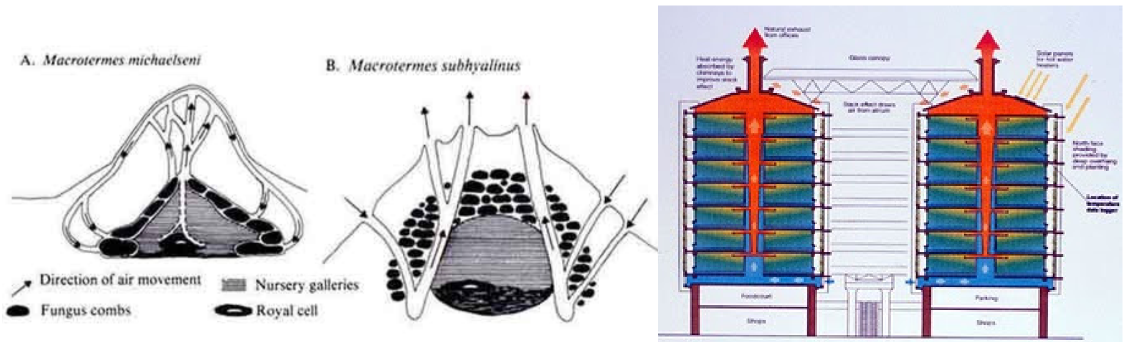

Figure 4: Termite Mound and Eastgate Center Sections (Inhabitat)

The result was a highly sustainable building that required no active air conditioning system in the hot Zimbabwean climate. The design saved the building owner over $3.5 million dollars in air conditioning costs during the first five years, using 90% less energy than conventional buildings of a similar scale.[9] The environmental benefits and cost savings of the Eastgate Center have made it an iconic case study of biomimetic architecture (Figure 5). Pearce's study of the termite mound has also inspired many to learn from the termite mound for other sustainable applications.

[9] "Architecture," Biomimicry Institute, 2010, 3 March 2010 <http://www.biomimicry institute.org/case-studies/case-studies/architecture.html>.

Figure 5: The Eastgate Center (The Biomimicry Institute)

CHAPTER 3

APPLYING THE METHOD

3.1 Identify

I approached my research of the oak tree using the biomimicry methodology and Pearce's extensive study of the termite mound. These strategies helped me approach the design challenge holistically and ultimately led me to my goal of designing a sustainable building in New England. The first step of the biomimicry methodology is to identify the underlying challenge. My challenge is to design a building that meets the programmatic needs while functioning sustainably in the New England climate.

3.2 Interpret

The next step is to interpret the challenge in terms of biology. What in nature solves for that function? This involves defining the operating parameters—the conditions in which the design functions. The biological model must also live in similar conditions. In this case, the challenge in terms of biology is to determine what in nature functions sustainably in the New England climate?

3.3 Discover

The third step is to discover a biological model that performs the same function as my design needs to perform. Through my personal interests and experiences, I arrived at the oak tree. The oak tree is a native plant that operates with systems it has developed for this climate over thousands of years. The oak tree operates sustainably in the New

England climate. The oak tree will serve as the biological model for this project, focusing on the operations and processes of the tree's closed loop systems (water, oxygen, and food) to derive sustainable architecture.

CHAPTER 4

ABSTRACT

4.1 Abstract

After discovering the biological model that would inform the design of my building, abstracting means to identify the deep patterns and processes of the model that achieve success. This involves rigorous examination of the oak tree's closed-loop systems: water, oxygen, and food.

4.4.1 The Water Cycle

Trees are natural sponges—the most effective evapotranspirers of all plants. A large oak tree can transpire 40,000 gallons per year. That is over 100 gallons a day. They allow land areas far from the ocean to maintain the water cycle. When it rains, water filters through the canopy of leaves, decreasing the rate at which the water hits the ground below. This reduces soil erosion. In the summer when it is warm and dry, the thick canopy of leaves provides shade that cools the soil beneath, helping it to retain moisture. Forest waste matter slows evaporation from the soil, allowing it more time to be absorbed by the roots. The water is absorbed by the roots that extend far beyond the diameter of the canopy, anchoring the tree and acting as a super highway for water and nutrients. The roots of an oak are very efficient at pulling water out of the soil. Depending on the amount of evaporation of water off the leaves above, the oak adjusts its water intake accordingly. The water is under negative pressure, causing suction in the water column that moves the water up to the leaves for food and for photosynthesis. The water is then release through the stomata, tiny holes in the surface of the leaf, evaporating into the air and back into the water cycle.

4.4.2 The Oxygen Cycle

A system of limbs and branches present the leaves on the tree to the sun in a dense canopy. The leaves are positioned to gather the most sunlight, which is required for photosynthesis to occur. In photosynthesis, chloroplasts capture the sun's light and energy when carbon dioxide enters the leaf through the stomata and water enters the leaf through transpiration. The light triggers a chemical reaction that turns the carbon dioxide and water into glucose and oxygen. The glucose is carried to the trunk and roots where it is used and stored for energy. Oxygen is a waste product of photosynthesis and is released back into the atmosphere. The oxygen is then breathed in by humans, animals, and other organisms. Carbon dioxide, a waste product of our breathing, is let back out into the atmosphere to be absorbed by the tree again.

4.4.3 The Food Cycle

A mature oak tree drops about 75 pounds of organic material a year. Leaves, twigs, and acorns fall to ground where they begin to decompose. This ground material may also include animal pelts, bones, or fungus. Nitrogen in this decaying matter is converted into nutrients as part of the nitrogen cycle. The nutrients nourish microorganisms, insects, plants, animals, and soil. The tree grows and harvests its own food while nurturing the ecosystems around it.

William McDonough has explored similar concepts in his book, *Cradle to Cradle:*

> Consider the cherry tree: Thousands of blossoms create fruit for birds, humans, and other animals, in order that one pit might eventually fall onto the ground, take root, and grow. Who would look at the ground littered with cherry blossoms and complain, "How inefficient and wasteful!" [10]

Similar to the oak, these cherry blossoms fall to the ground, decompose and nourish the soil that then feeds the trees. Waste equals food.

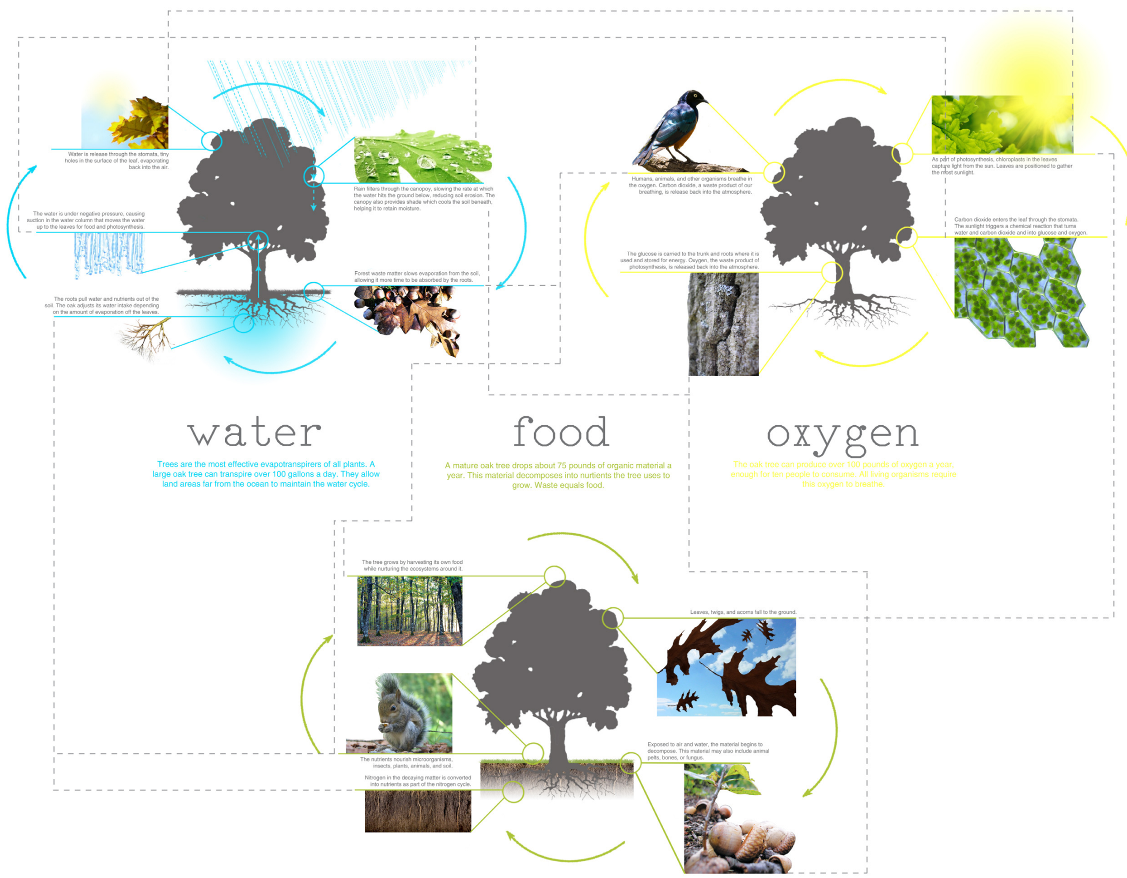

Figure 6: Closed-loop systems of the oak tree

[10] William McDonough and Michael Braungart, Cradle to Cradle (New York: North Point Press, 2002) 72-73.

4.4.4 Synergy

The water, oxygen, and food cycles are individual, closed-loop systems, but between each of them exists many synergies. These systems work together to create a sustaining oak tree. Maximizing these synergies allows the oak tree to grow and thrive. Figure 6 illustrates the three closed-loop cycles and the synergies between them.

For example, water is released into the air as part of the water cycle. The water is release through the stomata. The stomata are also where the carbon dioxide enters the leaves in the oxygen cycle. The oxygen cycle provides energy needed for the tree to complete the food and water cycle. The food cycle requires water and oxygen for the decomposition process. Without the other cycles, the closed-loop becomes open, and the system does not function efficiently. These cycles thrive on each other, and the oak tree is healthiest when they are all functioning together.

CHAPTER 5

EMULATE

5.1 Emulate

After identifying deep patterns and design principles of the oak tree's closed-loop systems, the next step is to emulate. This means developing ideas and solutions based on the model. This is where the systems of the oak tree begin to inform the design of a building.

5.2 The Site

The oak tree grows in a way that optimizes its system based on the conditions of the site. These include, but are not limited to, soil, terrain, wind, sun, and the nature of the surrounding conditions. The architecture must grow out of the site in the same way. Stimulating this growth involves detailed site analysis.

The anticipated site for this project is 500 and 502 Sunderland Road in Amherst, Massachusetts. On the northern border of Amherst, the site sits on Route 116 at the Amherst-Sunderland town line (Figure 7).

Though the two lots are currently being sold separately, this area of land is the former site of *Bioshelters*. Bioshelters was a hydroponics operation run by Waterfield Farms. Hydroponics is a closed-loop system that uses a symbiotic relationship between plants and animals to grow both. Fish waste creates nutrient-rich water for the plants to grow, while the plants clean the water for the fish to live in.[11] This operation closed in 2006.

Figure 7: Site Maps (Microsoft Bing Maps)

The first parcel, 500 Sunderland Road, is a 9.2 acre parcel that contains a 4,000 square foot residence, greenhouses, a garage, and seven man-made ponds. The second parcel, 502 Sunderland Road, is a 5.9 acre parcel that contains the 62,400 square foot Bioshelter. Aside from the residence, all facilities and equipment were abandoned and

[11] Bioshelters, 27 October 2010 < http://www.bioshelters.com/>.

have been left in a state of disrepair since the business closed (Figure 8).

Figure 8: Current state of the Bioshelter

5.2.1 Zoning

The properties are zoned as Low Density Residence and Outlying Residence. The Town of Amherst defines zoning districts as follows:

> R-LD, Low Density Residence- The purpose of the R-LD District is to provide for residential areas that allow limited development while providing protection for environmentally sensitive areas, agricultural resources, and other similar lands. To this end, this is the lowest density residential district.
>
> R-O, Outlying Residence- The purpose of the R-O District is to provide for lower density residential areas. In general, the R-O District is intended to be a transitional area between the low density R-LD District and medium density R-N District. [12]

[12] "Zoning Bylaw, Article 2: Zoning Districts," Amherst, Massachusetts, May 2010, 1 Oct 2010 <http://www.amherstma.gov/index.aspx?NID=476>.

In May 2008 a rezoning measure was denied that motioned to rezone the site to R-VC, Village Center Residence to develop residential and office buildings. According the Town of Amherst, "the purpose of the R-VC District is to provide residential neighborhoods, within and adjacent to village centers, that are of medium densities and that allow a limited mixed of residential and office uses."[13] The property was deemed inappropriate for this type of use because of the unique aquacultural features (Figure 9) of the site, as well as its lack of proximity to a village center and the un-walkable highway that the property sits on.[14]

Figure 9: On-site aquaculture

[13] "Zoning Bylaw, Article 2: Zoning Districts," Amherst, Massachusetts, May 2010, 1 Oct 2010 <http://www.amherstma.gov/index.aspx?NID=476>.

[14] Merzbach, Scott. "Rezoning measure denied," Amherst Bulletin, 23 May 2008, 26 October 2008 <http://www.amherstbulletin.com/story/id/94067/>.

5.2.2 Adjacencies

The aquacultural features on the site consist of not only of seven man-made ponds, but areas of wetland as well. Wetlands on the adjacent parcels north and west of the property flow over these edges of site. Wetland areas within the site exist on the western edge, between three of the man-made ponds (Figure 10). These areas require conversation.

Figure 10: The wetland area and lookout

The area to the south of the site is the Podick Cole Sanctuary. This conservation area encompasses 62 acres of local trails, the Noah Webster Trail, a connection to the

Katherine Cole Conservation Area, a stream, diverse forests, and community gardens.[15] Their close proximity to the site provides opportunities for linkages to this recreational area.

Though not directly adjacent to the site, prime farm land lies to the north, west, and south of the site. These agricultural centers are also important to the Amherst and neighboring town culture and economy.

Considering these current site conditions, this existing infrastructure is summarized in Figure 11. This illustrates the features of the site and the need to replace damaged and abandoned buildings with new structures and enhance existing wetlands and bodies of water.

Figure 11: Existing Infrastructure

15 "Amherst Conservation Areas," Amherst, Massachusetts, 1 Oct 2010 <http://www.amherstma.gov/index.aspx?NID=1291>.

5.2.3 Program

These unique conditions of the site make 500 and 502 Sunderland Road an ideal location for the Community Supported Agricultural Research Center. This facility will provide hands-on educational experiences that connect visitors with the surrounding landscape. These landscapes include ponds, streams, wetlands, woodlands, and farmland. This facility would enhance the existing landscape and promote education and awareness for surrounding landscapes. The overall goal is to create a green infrastructure that educates, integrates, and connects visitors to the site and beyond. This green infrastructure is illustrated in Figure 12.

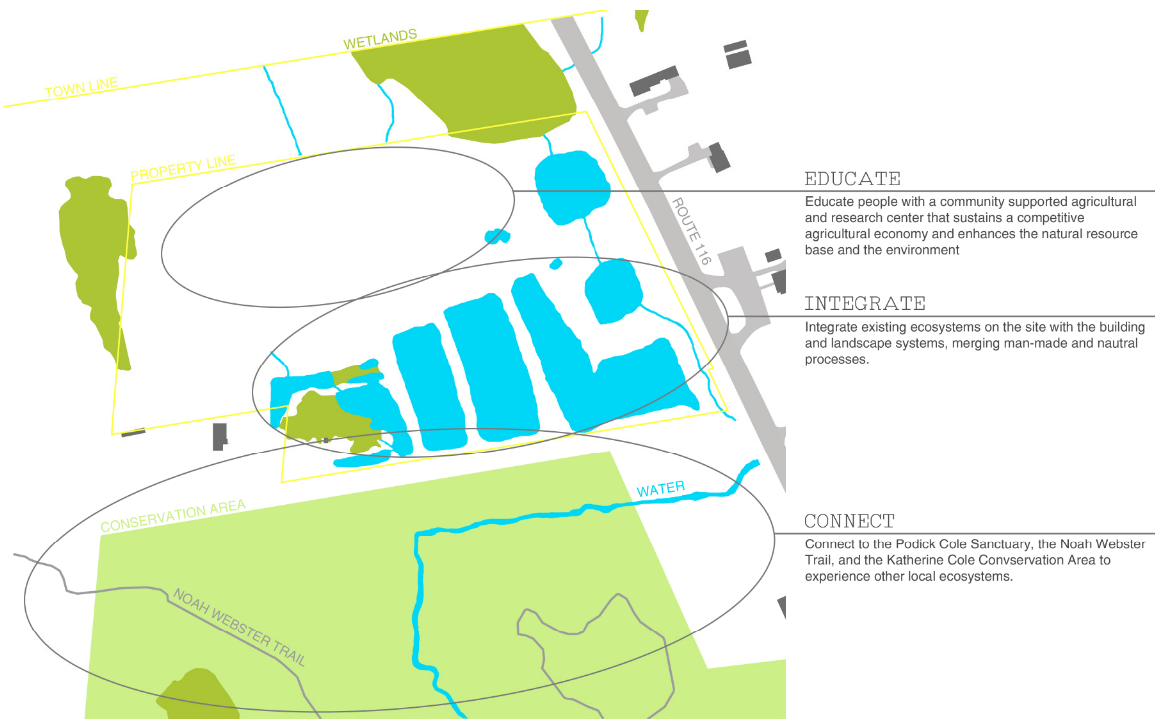

Figure 12: Green Infrastructure

The goals of this new infrastructure are to educate people with a Community Supported Agricultural Research Center that sustains a competitive agricultural economy, enhances the natural resource base, integrates existing ecosystems on the site with the building and landscape systems, merges man-made and natural processes, and connects to the Podick Cole Sanctuary, the Noah Webster Trail, and the Katherine Cole Conversation Area to experience other local ecosystems.

This program is possible under the zoning district. Reservation, wildlife preserve, conservation, orchard, market garden, nursery, and agricultural production uses are permitted by right. With site plan review and special permit outdoor recreation, public park, sales of agriculture produce, surface water storage, flood retention ponds, reservoir, water supply use, commercial greenhouse, non-profit human service use, non-profit educational institution, non-profit library or museum uses are permitted.[16]

The functions of the Community Supported Agricultural Research Center fall under three programs: education, economy, and environment. Educational programs include conducting agricultural research to develop and apply solutions to problems, increasing and developing communication mechanisms between farmers, increasing public awareness of farming through community events, and developing educational programs for young people, farmers, and the community. Economic programs include promoting and sustaining a competitive agricultural economy, providing economic opportunities for rural citizens, communities, and society, developing partnerships with other organizations, and providing space for a year-round farmers' market. Finally, environmental program includes enhancing the natural resource base and the environment, promoting the preservation of farmland, and promoting sustainable agricultural practices.

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[16] "Zoning Bylaw, Article 3: Use Regulations," Amherst, Massachusetts, May 2010, 1 Oct 2010 <http://www.amherstma.gov/index.aspx?NID=476>.

5.3 Design Response

The site and programmatic functions derive the design of the building and landscape systems, much like the site and the functions of the oak tree derive its design. Emulating the synergies between the closed-loop systems of the oak tree, the building and landscapes are designed with a multi-functional green infrastructure. This infrastructure consists of the integration and interaction of different functions and activities on the same piece of land. The building and landscapes are designed for optimal system performance. They are climate responsive, support native species, maintain natural ecological processes, sustain air and water resources, and contribute to health and quality of life in the way that the oak tree does.

5.3.1 Plan Walkthrough

The building is oriented on the site with its long axis running east to west (Figure 13 and 14). Glazing is primarily oriented south towards the ponds, while parking is on the north side.

From the parking area, visitors enter the building through the main entrance to the multi-functional area. This is a flexible space where most of the programmatic functions take place (educational seminars, meetings, indoor farmers' market, etc.) The eastern most part of the building houses administrative functions including laboratories, offices, a conference room, and exhibit space. Rooms on the southern façade open to the deck while the rest open to the exhibit space. Visitors are able to observe research conducted in the facility.

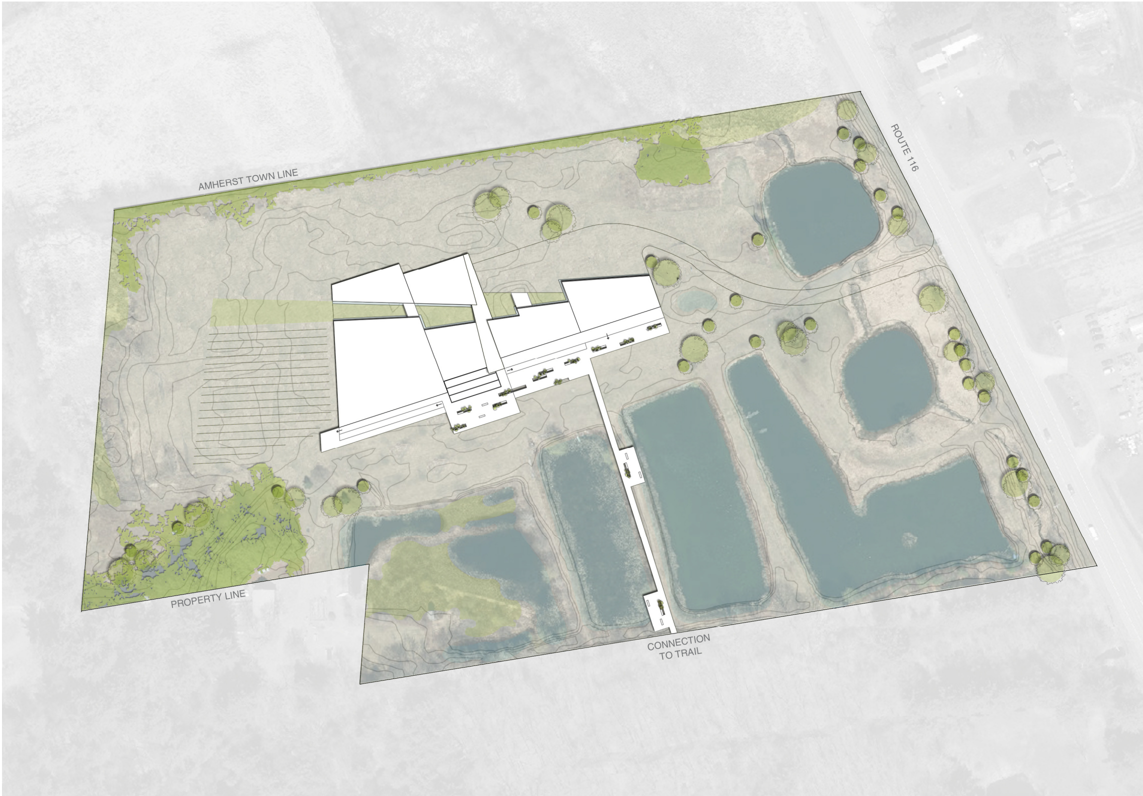


Figure 13: Site Plan. Not to scale.

To the west of the parking and the multi-functional area is the water reclamation system. The system starts on the north end of the site, below ground under the covered outdoor farmers' market. Visitors experience the water reclamation system as they move south, over the constructed wetlands, through the oxygenated cells, and out to the sand filter on the south deck. Visitors are able to see the process of cleansing wastewater. On the western most side of the building is the compost and hydroponic system. The compost area on the north allows visitors to bring in compostable items, learn how to make compost, and see the results. The heat from the composting process helps to offset the northern location of this system. The hydroponics system allows for the growth of plants and fish year-round, helping to support the indoor farmers' market during the winter months. These systems are later described in more detail.

On the west side of the site, wetland overflow contains excess water used for irrigation of the adjacent agricultural field. Off the south deck, visitors can walk to board walk to fish in the ponds or connect to the recreational areas south of the site.

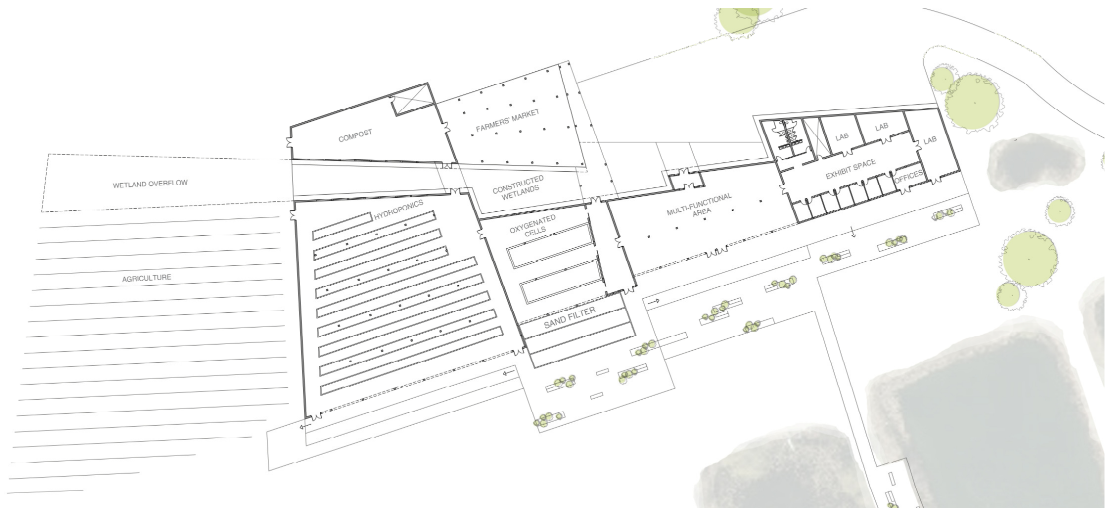


Figure 14: Floor Plan. Not to scale.

5.3.2. Building and Landscape Systems

Similarly to the way the oak tree was abstracted, the building and landscape features are organized into three main types of systems: active and passive, water, and vegetation (Figure 15). Each of these main systems consists of various smaller systems. Synergies exist between each of these systems throughout the site.

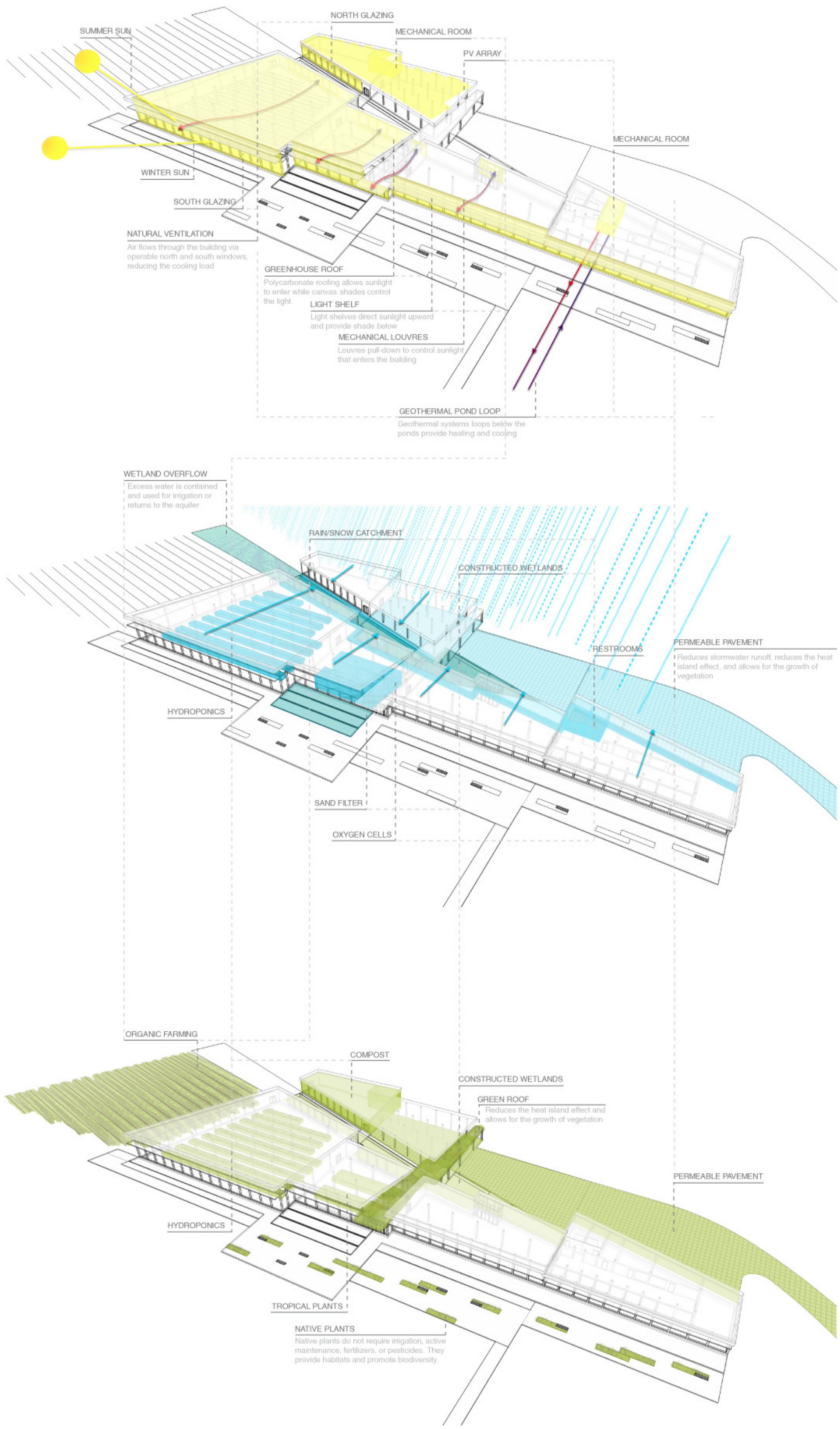


Figure 15: Active, Passive, Water, and Vegetation Systems Diagram

The Active and passive systems include a south-facing photovoltaic array to turn energy from the sun into electricity. A geothermal loop below the ponds collect the earth's natural heat in the winter and draw excess heat from the building back to the earth in the summer. Above ground, permeable pavement and other material selections help to reduce the heat island effect, reducing the cooling load of the building. The building also uses passive ventilation strategies. North and south windows allow outside air to flow through the building, also reducing the cooling load. These south and north windows are sized and positioned for passive solar strategies. To control the sunlight, light shelves help to soften glare and disperse light deep into the building. The light shelves provide shade from the high summer sun, while allowing the lower winter sun to penetrate into the building. Similarly, mechanical louvers control the amount of sunlight that enters the building by descending from the ceiling and rotating according to the position of the sun. Polycarbonate roofing allows sunlight to enter the greenhouses, while interior canvases shade the interior as needed. These active and passive systems help to reduce the amount of energy used by the building.

The water systems primarily consist of the gray and wastewater reclamation cycles. Visible portions of the wastewater reclamation system include constructed wetlands, oxygenated cells, and the sand filter. This system reclaims waste water for non-potable uses. Butterfly roofs channel rain and snow into catchment areas for where graywater is stored and recycled for potable uses. Water is also cycled through the hydroponic system as needed. Wetland overflow contains excess water from these systems and is used for irrigation or returned to the aquifer. Permeable pavement reduces the amount of stormwater runoff and contaminated water that enters these systems. These systems are later explained in more detail.

The vegetation on site includes both indoor and outdoor vegetation systems. Native plants grow around the site, in the constructed wetlands, up through the deck, on the green roof, and through the permeable pavement. These plants do not require irrigation, active maintenance, fertilizers, or pesticides. The site also includes an agricultural field for organic farming, supported by on site composting. Indoors, various types of plants rotate in the hydroponic system while tropical plants inhabit the oxygenated cells as part of the wastewater reclamation system. These systems are later explained in more detail.

The active, passive, water, and vegetative systems consist of many individual components, but between each of them exists many synergies. This is similar to the water, oxygen, and food cycles of the oak tree. For example, the permeable pavement reduces the heat island effect, reduces stormwater runoff, and allows for the growth of vegetation. The photovoltaic system harvests energy from the sun to run many of the active and water systems on the site. Reclaimed water is used for organic farming, the hydroponics systems, and other potable and non-potable uses. Composting provides soil for organic farming and food for the fish in the hydroponic system. Passive heating and cooling strategies reduce the load of the active systems. Optimizing each of these individual systems by maximizing the positive synergies that they create together, yields a more sustainable building than if they were to operate independently.

5.3.3 Connecting to the Systems

The interaction between visitors and the site is important for the Community Supported Agricultural Research Center to satisfy the aforementioned goals of the educational, economic, and environment programs. To connect visitors to the site, all systems are in some way visible and revealed as they navigate the site. Visual signage adjacent to each site feature explains to the visitors how the system works and how it connects to other systems. Some of the systems and signage are illustrated in Figure 16.

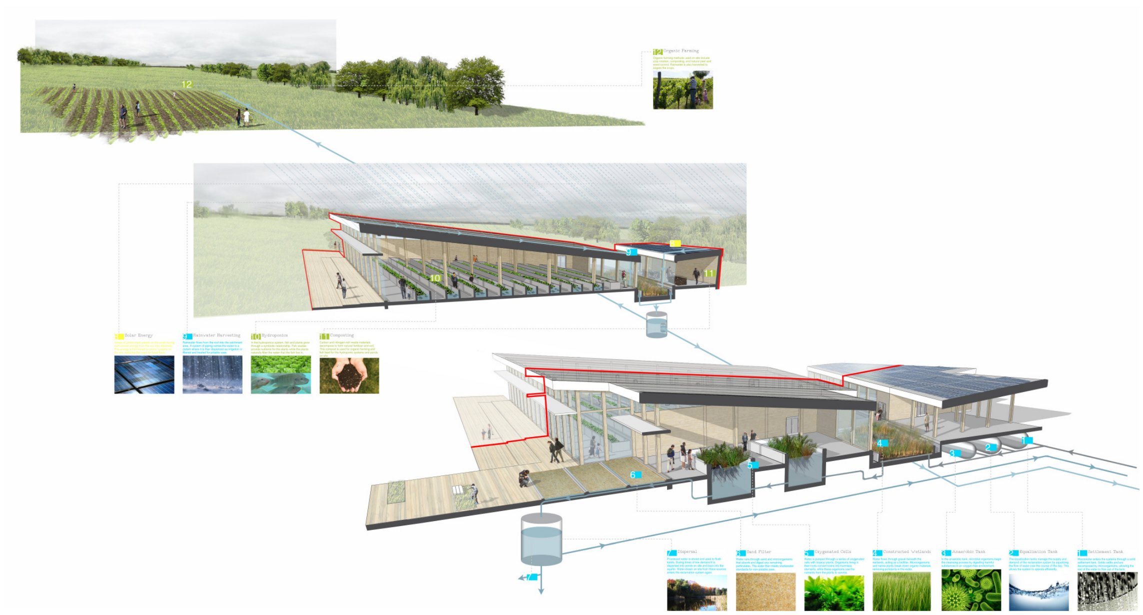


Figure 16: Sectional Perspective

The wastewater reclamation cycle (bottom in Figure 16) begins when wastewater enters the system through a settlement tank. Solids settle and are decomposed by microorganisms, allowing the rest of the water to flow out of the tank to the equalization tank. The equalization tank manages the supply and demand of the reclamation system by equalizing the flow of water over the course of the day. This allows the system to operate efficiently. Next, the water enters the anaerobic tank. In the anaerobic tank, microbial organisms begin cleansing the waste water by digesting harmful substances in an oxygen-free environment. The water leaves the tanks and enters the constructed wetlands. Water flows through gravel beneath the wetlands. Acting as a biofilter, microorganisms and native plants break down organic materials, removing pollutants in the water. The water is then pumped through a series of oxygenated cells with tropical plants. Organisms living in their roots convert toxins into harmless elements, while these organisms use the nutrients from the plants to survive. At this stage of the wastewater reclamation system, the water appears and smells clean. As the final stage of the cleansing process, the water enters the sand filter. Water runs through sand and microorganisms that absorb and digest any remaining particulates. After the sand filter, the water meets wastewater standards for non-portable uses. This processed water is stored and used to flush toilets on site or dispersed into ponds on site and back into the aquifer. Water is drawn from the aquifer, used on site, and enters the wastewater reclamation system again. Though part of this system is outdoors, the system is able to operate in winter months. Microorganisms generate enough heat to keep the system from freezing.

The center image of Figure 16 illustrates the rain and snow catchment systems. As mentioned previously, butterfly roofs channel rain and snow into catchment areas. The catchment area features subsurface warming to aid in the melting of snow for its entrance into the system. This graywater is then stored in a cistern and used for agricultural irrigation or filtered and returned to the building for potable-uses. The hydroponic system, mentioned earlier, may also utilize reclaimed water. The hydroponic system is a greenhouse environment where plants grown in water. The system functions similarly to the Bioshelter that previously existed, except it is tied to other systems on the site. Also featured in this image are the photovoltaic panels and composting center, both previously discussed in the active systems and vegetation systems, respectively.

The top image of Figure 16 illustrates the organic farming field. Organic farming methods use are site include, but are not limited to, crop rotation, composting, and natural pest and weed control. New methods are researched and implemented on-site. The connection to the rainwater harvesting system used for irrigation is also shown.

5.3.4 The Final Walkthrough

The Entrance to the Community Supported Agricultural Research Center instantly showcases permeable pavement, rain and snow catchment areas, constructed wetlands, the green roof, native vegetation, and space for an outdoor farmers market. Visitors are immediately exposed to site systems, as shown in Figure 17.

Figure 17: Main Entrance

The South deck, shown in Figure 18, provides views of the ponds and adjacent recreational areas to the south. Native plants penetrate areas of the deck, integrating elements of the landscape with the built structure. Benches provide places for visitors to sit and gather. Southern glazing can open to the deck. By providing a seamless indoor/outdoor connection, this allows the program to expand outside, connecting visitors with the landscape.

Figure 18: South Deck

The boardwalk leads from the South Deck to two smaller decks as shown in Figure 19. These provide places for visitors to sit, fish, and enjoy the aquaculture. The boardwalk connects to a new extension to the Noah Webster Trail on the southern edge of the site. Connecting to these destinations extends the path of the visitor, allowing them to experience other unique ecosystems in close proximity to the site.

Figure 19: Recreation

CHAPTER 6

EVALUATE

6.1 Evaluate

The final step of the biomimicry methodology is to evaluate: evaluate the success of the design based on whether or not it adheres to life's principles, shown in Figure 20. Does the Community Supported Agricultural Research Center create conditions conducive to life? Does it adapt and evolve?

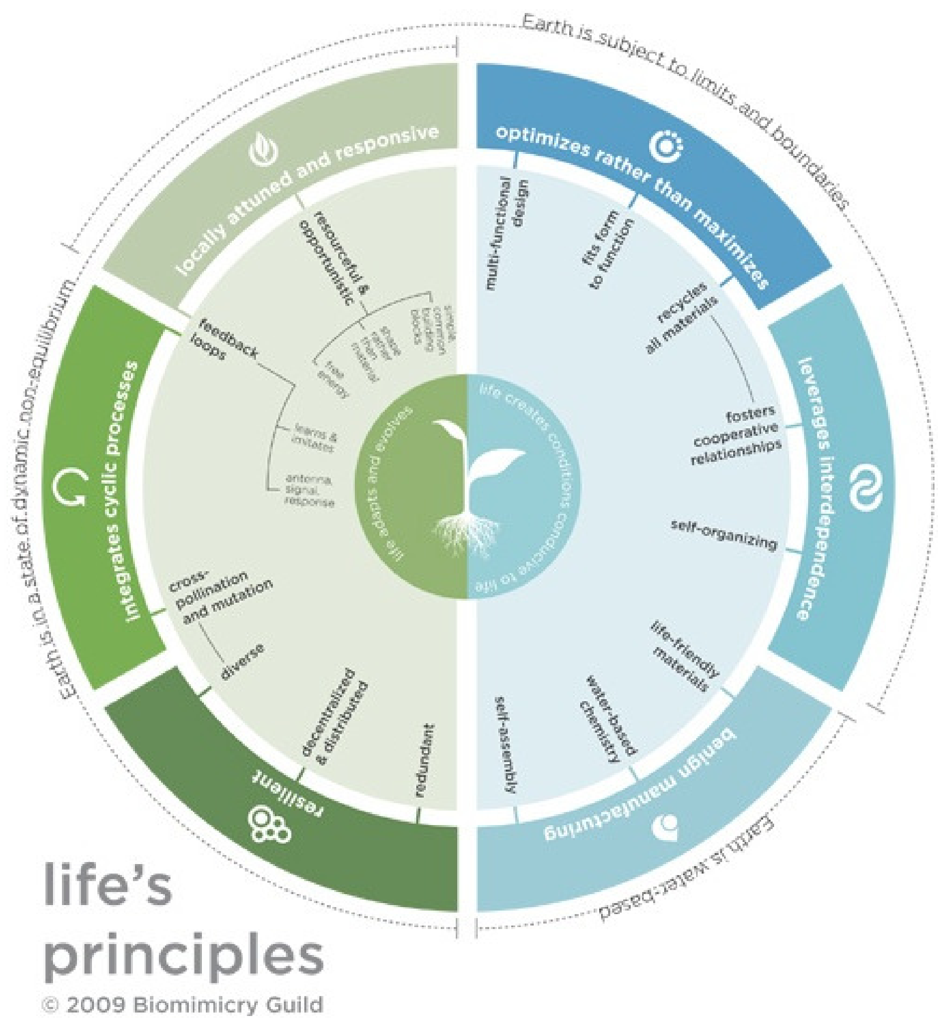


Figure 20: Life's Principles (The Biomimicry Guild)

Optimizing rather than maximizing: The Community Supported Agricultural Research Center has a multi-functional design that moves beyond a single resolution to satisfy the programmatic needs. The design of the building was determined by the needs of the systems (active, passive, water, and vegetation), fitting form to function. Optimization is achieved by the synergies between the systems, whose closed-loop nature recycles resources on site. When these systems are optimized, waste does not exist.

Leveraging interdependence: The design finds value through interactions. It is organized so that the individual components of the system interact to create a green infrastructure. The building and landscape systems were designed to create cooperative relationships with one another. This principle is personified by the concept of synergy.

Using benign manufacturing: Though components of this principle are outside the scope of this project, the design has the potential to satisfy this principle by exercising strategies used in the rest of the design. As a result, the design could cause no harm in its creation, use materials that do not harm life, use water-based chemistry, and utilize self assembly.

Locally attuned and responsive: This building was designed for this site and is able to adapt based on the day to day and seasonal changes. The building continuously adapts to its surroundings. The design is resourceful and opportunistic, taking advantage of unique features of the climate, site, and surrounding area. As users occupy the building over time, the building could learn and imitate from evolving conditions using feedback loops to relay information and enhance its performance throughout its life.

Integrates cyclic processes: The design systems follow a cyclical path. The building and landscape systems were designed based on synergies between the closed-loop systems of the oak tree, so many closed-loop systems operate on the site. These systems are either closed-loop systems independently, or create closed-loops when combined with other systems.

Resilient: The design is able to maintain function following disturbance by incorporating multiple systems to meet the programmatic needs of the building. Some forms and processes are redundant, incorporate into multiple systems, and distributed across the site.

By satisfying life's principles, the Community Supported Agricultural Resource Center creates conditions that are conducive to life and adapts and evolves.

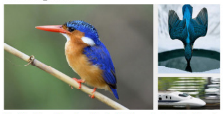
6.2 Outlook

The Community Supported Agricultural Research Center demonstrates the process of using biomimicry as a tool for sustainable architecture (Figure 21). By moving through the six steps of the biomimicry methodology (identify, interpret, discover, abstract, and emulate), this project moves from a design problem to a design solution—from oak tree to green infrastructure. The intent is that this will serve as a model for biomimetic applications in future architecture. In its entirety, I hope that this project will act as the ultimate illustrated case study of the biomimicry methodology and inspire architects to use biomimicry as a tool for sustainable design.

biomimicry emulating the closed-loop systems of the oak tree

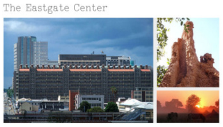
Biomimicry comes from *bios*, life, and *mimesis*, to imitate. Biomimicry is becoming an increasingly well-known topic in the field of architecture and design, imitating nature's designs and processes to solve human problems.

The Kingfisher



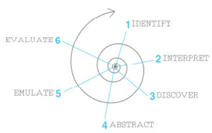
The Kingfisher dives from the air into the water to catch fish, with minimal splash. Modeling the bullet train after the beak of a Kingfisher produced a quieter train that uses 15% less electricity and travels 10% faster.

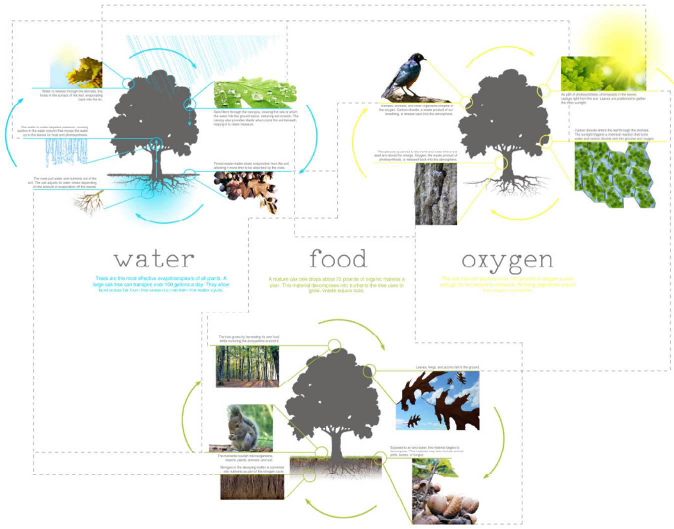
The Eastgate Center



Zimbabwe is a climate with extreme day-to-night temperature fluctuations. Architect Mick Pearce wanted to design a building that could passively cool. Termite mounds are able to maintain the temperature inside their nests to within one degree from day to night, despite temperatures outside that fluctuate from just above freezing to over 100 degrees. Modeled after termind mounds, the Eastgate Center uses 90% less energy than conventional buildings of a similar scale.

The Biomimicry Methodology





1. Identify
Identify the underlying challenge. Design a building that meets the programmatic needs while functioning sustainably in the New England climate.

2. Interpret
Interpret the challenge in terms of biology. What in nature functions sustainably in the New England climate? What organism is locally attuned and responsive, resilient, integrates cyclic processes, and *optimizes* rather than *maximizes* in this climatic?

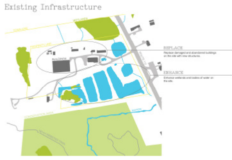
3. Discover
Discover a biological model that performs the same function that the design needs to perform. The oak tree operates sustainably in the New England climate. It is a native plant that operates with systems it has developed for this climate over thousands of years.

4. Abstract
Find deep patterns and processes of the model that achieve success. The oak tree's closed loop systems (water, food, and oxygen) use synergy to function optimally.

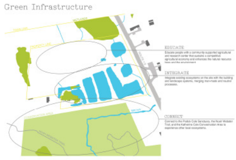
for sustainable architecture

Site Conditions

Existing Infrastructure



Green Infrastructure



Program

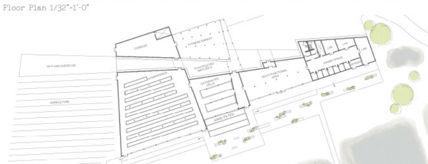
Education
+Conduct agricultural research to develop and apply solutions to problems
+Increase and develop communication mechanisms between farmers
+Increase public awareness of farming through community events
+Develop educational programs for young people, farmers, and the community

Economy
+Promote and sustain a competitive agricultural economy
+Provide economic opportunities for rural citizens, communities, and society
+Develop partnerships with other organizations
+Provide space for a year-round farmers' market

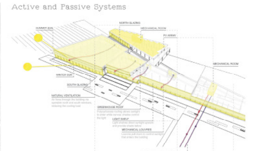
Environment
+Enhance the natural resource base and the environment
+Promote the preservation of farmland
+Promote sustainable agricultural practices

Site Plan 1/64"=1'-0"

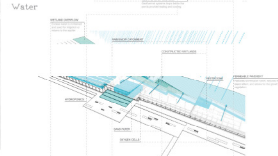
Floor Plan 1/32"=1'-0"



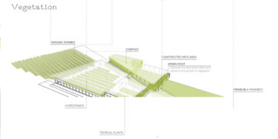
Active and Passive Systems



Water



Vegetation



5. Emulate
Develop ideas and solutions based on the model. Emulating the synergies between the closed-loop systems of the oak tree, the building and landscape will be designed with a multi-functional green infrastructure. This infrastructure consists of the integration and interaction of different functions and activities on the same piece of land. The building and landscapes must be climate/responsive, support native species, maintain natural ecological processes, sustain air and water resources, and contribute to health and quality of life, in the way that the oak tree does.

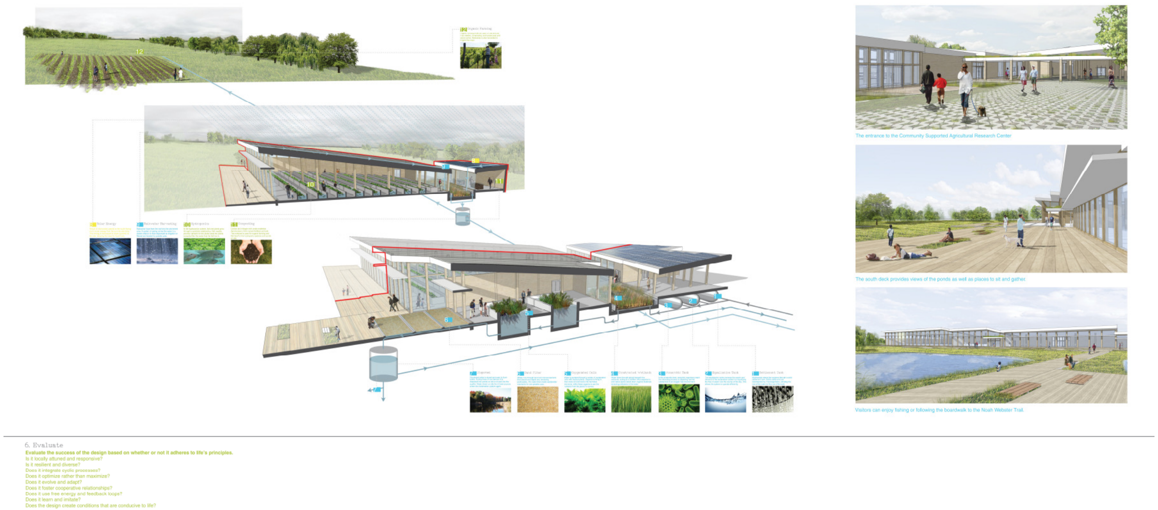


Figure 21: Final Presentation

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